Environment Waikato Technical Series 2007/09

Environmental Costs of Electricity Generation

www.ew.govt.nz
ISSN 1172-4005

Environment Waikato
REGIONAL COUNCIL

Prepared by:
Tim Denne
Covec Limited

For:
Environment Waikato
PO Box 4010
HAMILTON EAST

October 2006

ISSN: 1174-7234

Document #: 1161186v2

Peer reviewed by:
Annabelle Giorgetti Date Mar 2007

Approved for release by:
Paul Chantrill Date Mar 2007

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Executive Summary

Scope

This report examines the social[1] costs of electricity generation. This includes the private costs of generation and the wider costs falling on society because of the environmental impacts of energy use. The results do not reflect a comprehensive analysis of all external effects, ie those not currently included in market prices; rather the analysis has been limited to the most significant impact categories. International studies have shown that the external effects are dominated by those associated with air emissions from generation. Other effects include amenity impacts of plants; these are highly site-specific, are taken into account in the consent process and are not considered here.

The report explores the potential use of monetary valuation of damage costs as an input to the development of policies relating to energy and analysis of the implications of proposals for new plants. It also provides some context for the consideration of national versus local impacts in electricity supply. There are considerable data gaps, particularly an absence of relevant New Zealand studies. The report has thus relied on published information, including from international literature; these have been modified to take account of New Zealand conditions where possible. This is a limitation to the study, and potentially to the wider use of the techniques. However, the analysis provides an understanding of the relative magnitude of the different effects which is likely to be consistent across countries.

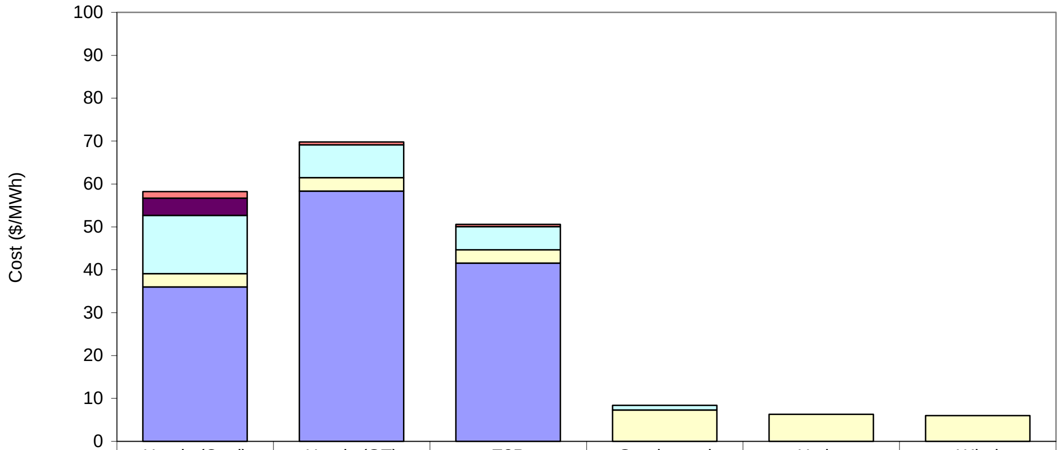
The report is limited to the implications of electricity generation; it does not consider the impacts of transmission which are the subject of analyses in other fora. Nor does it assess the impacts of the same pollutants from industrial or other sources.

Results

Total costs for the different pollutants, in comparison with the other costs of generation, are shown in Figures a to d below. Figures a and b are concerned with the impacts of environmental costs on the variable costs of generation. In the current electricity market, variable costs determine the order in which plants operate relative to other plants and the hours for which they operate during the year. Figures c and d represent the impacts of environmental costs on the average costs of generation; this represents the costs of new plant entry. For both variable and average costs analyses, two figures are produced representing low and high cost estimates of environmental damage costs.

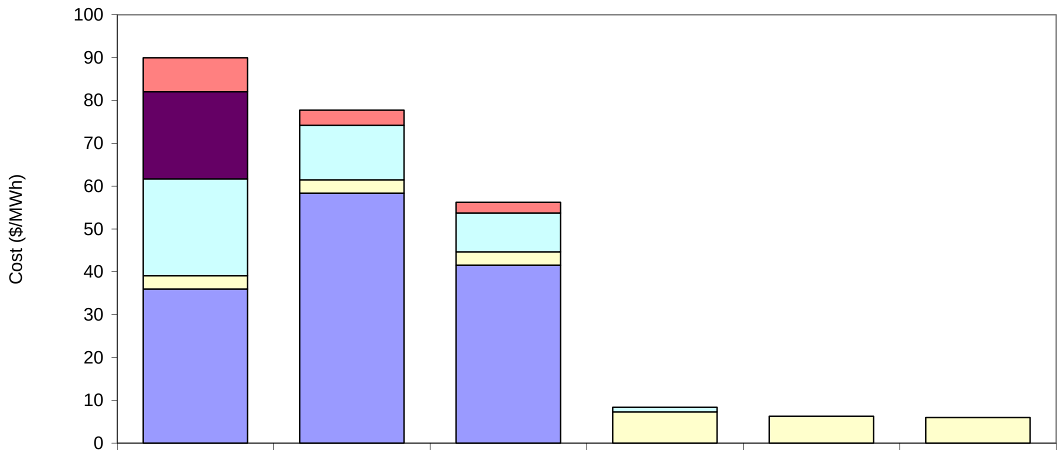
The results suggest that environmental costs that are borne by society are a significant additional element of the social costs of electricity generation; they are dominated by carbon costs. Amongst the different plant types, carbon costs are most significant for coal plants, including Huntly, because of the high carbon content of this fuel. Of current plants, the open cycle gas turbine plant (OCGT) at Huntly also has significant carbon costs. SO_2 is emitted by coal plants and, under the low cost assumptions, the costs of sulphur are equal to approximately 10% of the initial private variable costs of generation (fuel + O&M costs), and 5% of new coal plant costs; this compares with the percentage additions attributable to CO_2 of 35% of initial variable costs for coal plant and 16% of new entry costs.

[1] Social here refers to the full costs to society. It includes the private costs reflected in market prices and the environmental costs that currently are not expressed in market prices.



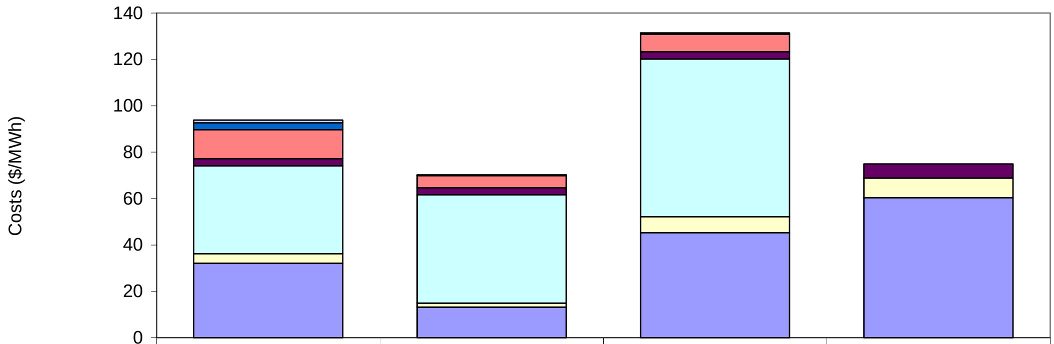
	Huntly (Coal)	Huntly (GT)	E3P	Geothermal	Hydro	Wind
NOx	1.57	0.70	0.50	0	0	0
SO2	4.03	0	0	0	0	0
Carbon	13.55	7.63	5.43	1.10	0	0
O&M	3.1	3.1	3.1	7.3	6.3	6.0
Fuel	36.00	58.38	41.54	0	0	0
Total	58.25	69.81	50.57	8.40	6.30	6.00

Figure a Components of Variable Costs (Low Costs)



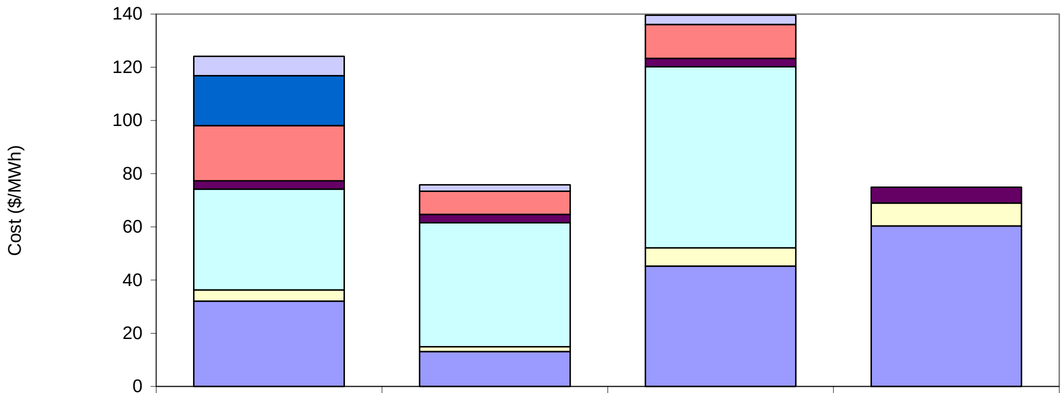
	Huntly (Coal)	Huntly (GT)	E3P	Geothermal	Hydro	Wind
NOx	7.91	3.54	2.52	0	0	0
SO2	20.36	0	0	0	0	0
Carbon	22.58	12.72	9.05	1.10	0	0
O&M	3.1	3.1	3.1	7.3	6.3	6.0
Fuel	36.00	58.38	41.54	0	0	0
Total	89.95	77.74	56.21	8.40	6.30	6.00

Figure b: Components of Variable Costs (High Costs)



	Coal	CCGT	OCGT	Wind turbine
NOx	1.13	0.38	0.55	0
SO2	2.91	0	0	0
Carbon	12.48	5.23	7.63	0
O&M	3.1	3.1	3.1	6
Fuel	37.89	46.67	68.11	0.00
Annual fixed	4.16	1.78	6.85	8.56
Capital	32.11	13.14	45.27	60.34
Total	93.79	70.28	131.52	74.90

Figure c: Components of Average Costs of New Plant (Low Costs)



	Coal	CCGT	OCGT	Wind turbine
NOx	7.29	2.43	3.54	0
SO2	18.75	0	0	0
Carbon	20.80	8.72	12.72	0
O&M	3.10	3.10	3.10	6
Fuel	37.89	46.67	68.11	0
Annual fixed	4.16	1.78	6.85	8.56
Capital	32.11	13.14	45.27	60.34
Total	124.10	75.82	139.60	74.90

Figure d: Components of Average Costs of New Plant (High Costs)

Geothermal electricity generation has low carbon emissions and there is some debate over the extent to which they are anthropogenic, ie attributable to human causes. The steam and CO_2 would be released anyway but electricity generation from geothermal resources may increase the rate at which it is released. Attributing the emissions to human causes is thus dependent on time frames of analysis. These issues have not been clearly resolved and are beyond the scope of this report.

Wind has no CO_2 emissions in generation.

For new plants, capital costs are an additional element of total costs, and because of this, environmental costs are relatively less important.

Under assumptions of high environmental costs, which we regard as a significant over-estimate of costs for SO_2, SO_2 costs are equal to approximately 52% of initial variable costs for coal plant and 24% of new plant costs. Taking account of SO_2 costs, under the high cost assumptions, would mean that burning gas, rather than coal, became the better option for Huntly (up to a gas price of $6.70/GJ).

Other pollutants are less significant contributors to total costs. Although, under the high cost assumptions NOx costs can be substantive—equal to 21% of the initial estimate of variable costs for coal plant or 9% for the costs of new coal plant entry.

Policy Responses

CO_2 and other greenhouse gases are being addressed nationally and the government is developing a policy package to tackle emissions during the first commitment period under the Kyoto Protocol. This might include a tax on emissions from electricity generators. The government has made it clear that it expects to take the policy lead on developing a climate change policy package; it is appropriate that policy on CO_2 and other greenhouse gases is developed nationally rather than regionally.

Currently the costs of the main local pollutants, SO_2 and NOx, are not priced but are addressed via the consent process under the Resource Management Act. The analysis presented in this report suggests that there are residual effects of SO_2 emissions that are not currently avoided, remedied or mitigated. These are attributable to sulphur's contribution to concentrations of small particulates, for which there are unlikely to be impact thresholds. In other words, every emission has a potential effect. There is an improvement in economic efficiency if emitters face the costs of these residual emissions in the form of a charge equal to the damage cost per tonne of emissions, whether implemented as a national or a regional instrument.[2] Such a charge would provide incentives for additional emission reduction where this could be achieved for less than the charge level.

[2] Practical issues to do with a charge on pollutants implemented at a regional level are addressed in Covec (2005) Economic Instruments for the Environment. Final Report to Environment Waikato. TR 2006/23, available at: www.ew.govt.nz/publications/technicalreports/tr0623.htm

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1 Introduction

This report examines the social[3] costs of electricity generation. This includes the private costs of generation and the wider costs falling on society because of the environmental impacts. Electricity consumption has social benefits also, but these benefits can be expressed in a market currently; they result in existing levels of demand. In contrast some of the environmental costs of electricity production are not currently priced but are an externality of generation.

The results in this report do not reflect a comprehensive analysis of all external effects; rather the analysis has been limited to the most significant impact categories. International studies of the full life cycle impacts of generation have suggested that the effects are dominated by those associated with air emissions from generation.[4]

The report aims to provide technical information both to assist Environment Waikato in its development of policies relating to energy and its local communities in considering the implications of proposals for new plants. It also provides some context for the consideration of national versus local interest in electricity supply.

The report is limited to the implications of electricity generation; it does not consider the impacts of transmission which are the subject of analyses in other fora.

Environment Waikato is charged under the Local Government Act 2002 with making decisions that improve the well-being of regional communities. This requires that account is taken of the full costs and benefits of decisions over which it has influence.[5] Decisions regarding investment in electricity generation are made currently on the basis of private costs and benefits, ie the financial costs and revenues that accrue to private sector and state-owned enterprise (SOE) generators. There are requirements on these generators to limit the environmental effects of operation and these result in increased costs of generation. However, there are additional costs (and benefits) of generation that fall more widely on society, particularly the emissions associated with combustion of fossil fuels. This report compiles information on these residual environmental damages, ie those that remain after the consent conditions have been met.

The report is divided into two main sections. The first (Section 2) compiles data on the costs to private developers of operating existing plants and of commissioning new plants. This will include some costs of environmental controls required by legislation. The next section (Section 3) reports on the environmental damage associated with electricity generation and provides estimates of the monetary valuation of this damage. The combination of these two elements of costs can be used to estimate the costs falling more widely on the community.

2 Private Costs of Electricity Generation

2.1 Electricity Costs and Pricing

This section reviews the private costs of electricity generation. It starts with a review of approaches to price setting and the types of costs that are relevant to different generation decisions, and specifically:

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[3] Social here refers to the full costs to society. It includes the private costs reflected in market prices and the environmental costs that currently are not expressed in market prices.

[4] We rely particularly on the comprehensive analyses undertaken for the European Commission's ExternE study (www.externe.info/). These studies used a full life cycle approach to analysis but identified that air emissions during generation dominated the full effects.

[5] That is the impacts with respect to social, economic, environmental and cultural well-being.

- generation (or dispatch), ie the costs that determine the decision to run a plant once it has been built and is operational; and
- market entry, ie the costs of building a new plant to generate electricity.

As with other industries organised along competitive lines, the wholesale electricity price setting mechanism is designed to reflect short run marginal costs of production (SRMC). Once capital has been committed and operational fixed costs incurred, a generator is willing to produce electricity if it can cover its variable costs of generation. These are largely fuel costs and some other operational and maintenance costs.

Plants enter the market if they estimate that they can cover their variable costs and full fixed costs, including a return on capital employed.

Thus the costs in **Error! Reference source not found.** are relevant in estimating the costs of electricity generation.

Table 1: Categories of Cost

Cost Type	Description
Variable costs	Costs that change with each additional unit of electrical output. Variable costs are dominated by fuel costs (for thermal plants). They also include some minor operational and maintenance (O&M) costs
Fixed costs	Fixed costs include those that are avoidable through closing down a plant, such as the annual costs of labour and some O&M costs, and some that are not. Unavoidable fixed costs include capital costs
Capital costs	The costs of plant construction—plant and machinery

2.2 Variable Costs of Generation

The variable or short run marginal costs (SRMC) of a plant determine the way in which it is dispatched in a competitive market.[6] Plants compete on the basis of their short run marginal costs as this is the basis on which they are willing to price in the short run.

Estimates of the variable costs of generation for different plant types are provided in Table 2 on the basis of published data on generation costs. Geothermal, wind and hydro plants have no fuel costs; their variable costs of generation are made up of small operational and maintenance (O&M) costs.

Within the Waikato region, there are currently two thermal plants at Huntly—a 1000MW pulverised coal plant and a 40MW open cycle gas turbine (OCGT) plant. A third plant, a combined cycle gas turbine (CCGT) plant named E3P, is under construction. The coal plant has considerably lower variable costs than the OCGT, because of the higher costs of gas, relative to coal. E3P's higher efficiency of fuel use reduces its costs to less than the estimated costs of the Huntly coal plant.

Table 2 Variable Costs of Generation

	Gross Efficiency (Net)	Efficiency	Fuel cost	Fuel cost	O&M	Total Variable
Plant	%	GJ/MWh	$/GJ	$/MWh	$/MWh	$/MWh
Huntly (Coal)	35 (36)	10.29	3.5	36	3.1	39.10
Huntly (Gas Turbine)	37 (41)	9.73	6	58.38	3.1	61.48
E3P	52 (57)	6.92	6	41.54	3.1	44.64
Geothermal	15	24.00	0	0	7.3	7.30
Hydro	-	-			6.3	6.30
Wind	-	-			6	6.00

Source: www. genesisenergy.co.nz; East Harbour Management Services (2004) Fossil Fuel Electricity Generating Costs. Prepared for MED; East Harbour Management Services (2005) Availabilities and Costs

[6] For peaking plant, start-up and ramp-down costs are also an important part of generation decisions.

of Renewable Sources of Energy for Generating Electricity and Heat. 2005 Edition. Prepared for MED; Marsden A, Poskitt R and Small J (2004) Investment in New Zealand Electricity Industry. An examination of comparative financial performance, pricing, and new entry conditions; and a discussion of the principles of new investment. Auckland Uniservices Limited

The government has recently decided not to implement a carbon tax, previously scheduled to be introduced from 2007. However, the government has obligations to meet targets for greenhouse gas emissions during the first commitment period under the Kyoto Protocol (2008-12). Emissions from power plants will impose costs on New Zealand because of the requirement to limit total emissions. It is not clear, at this stage, whether these costs will be passed on directly to electricity generators in proportion to their emissions, particularly because, in deciding not to continue with the carbon tax, the government has not precluded putting in place a more narrowly based tax on large emitters, which would include electricity generators. The costs of carbon might be realised as a private costs for generators or as costs falling more widely on the community because of the need to reduce emissions (or purchase international allowances) to meet targets.

2.3 Costs of New Plants

The decision to build a new plant is based on a comparison of expected revenues at market prices with the full costs of entry. These full costs will include the short run variable costs, plus fixed costs of operation (eg labour costs) and capital costs. This set of costs, divided by the quantity generated produces an average cost of generation for a new plant.

An estimate of the costs of entry for a number of different plant types is given in Table 3. This includes conventional (super-critical) coal plant, combined cycle gas turbines (CCGT), open cycle gas turbines (OCGT) and wind. Other technologies, including biomass-based generation, have not been assessed. A 10% discount rate is used in analysis.

Table 3 Costs of Plant Entry (10% Discount Rate)

Plant type	Efficiency	Plant life (years)	Load Factor	Capital Cost			Fixed Costs		Fuel cost		Variable O&M Cost[4]	Average Cost
				$/kW	$/kW/yr	$/MWh	$/kW/yr	$/MWh	$/GJ	$/MWh	$/MWh	$/MWh
Conventional Coal	38%	25	85%	2170[1]	$239	32.11	31	4.16	4	37.89	3.1	77
CCGT	52%	25	90%	940[2]	$104	13.14	14	1.78	7	46.67	3.1	65
OCGT	33%	25	20%	720[2]	$79	45.27	12	6.85	7	68.11	3.1	123
Wind	-	20	40%	1800[3]	$211	60.34	30	8.56			6	75
Hydro	-	25	55%	3000[3]	$331	68.60	15	3.11			6	78
Geo-thermal	15%	25	90%	3000[3]	$331	41.92	30	3.81			6	52

[1]Supercritical plant. Source: PB Power (2004) Coal Fired Power Stations. Generic Costing and Technical Information.
[2] East Harbour Management Services (2004) Fossil Fuel Electricity Generating Costs. Prepared for MED
[3] East Harbour Management Services (2005) Availabilities and Costs of Renewable Sources of Energy for Generating Electricity and Heat 2005 Edition. Prepared for the Ministry of Economic Development.
[4] Marsden A, Poskitt R and Small J (2004) Investment in the New Zealand Electricity Industry. An examination of comparative financial performance, pricing and new entry conditions; and a discussion of the principles of new investment. Auckland Uniservices

A higher gas price has been used in this table than used above. This reflects the longer run expectation of rising gas prices as the Maui field is depleted and production shifts to higher cost fields. In the long run, gas prices may be set by the costs of imported liquefied natural gas (LNG). The plant lives are based on an assumed economic life.

For thermal plant this assumes some time after which new technologies displace them, eg because of higher efficiency. For wind this reflects a technical life, ie the time before major parts replacement is required or plant reconstruction.

OCGT plants have low capital costs but typically have very low load factors, because of their low efficiencies—they have a high fuel cost per unit of output. It means that capital and other fixed costs are recovered over a much smaller quantity of output. CCGTs are a low cost new plant type. Coal, despite the lower fuel cost, has higher costs than CCGTs because of the lower efficiency. Renewable plants, including wind, hydro and geothermal, have high capital costs but little in the way of other costs.

The analysis above uses a 10% discount rate or cost of capital. Adopting a lower social discount rate[7] (5%) results in a different set of cost estimates (Table 4).

Table 4 Costs of Plant Entry (5% Discount Rate)

Plant type	Capital Costs ($/MWh)	Fixed Costs ($/MWh)	Fuel cost ($/MWh)	Variable O&M Cost ($/MWh)	Average Costs ($/MWh)
Conventional Coal	20.68	4.16	37.89	3.1	66
CCGT	8.46	1.78	46.67	3.1	60
OCGT	29.16	6.85	68.11	3.1	107
Wind	41.22	8.56	0.00	6	56
Hydro	44.18	3.11	0.00	6	53
Geothermal	27.00	3.81	0.00	6	37

These costs give a slightly misleading picture because costs are provided as point estimates; in practice there are numerous site specific factors that determine both the plant type that is chosen and the costs (eg site specific connection costs). To demonstrate this, the entry costs data are presented in Figure 1 with costs grouped under broad categories of plants. It shows that the renewable options can be low cost but within the range of possible costs for hydro and wind plants, in particular, are costs for thermal plants, both gas (combined cycle gas turbine or CCGT) and coal.

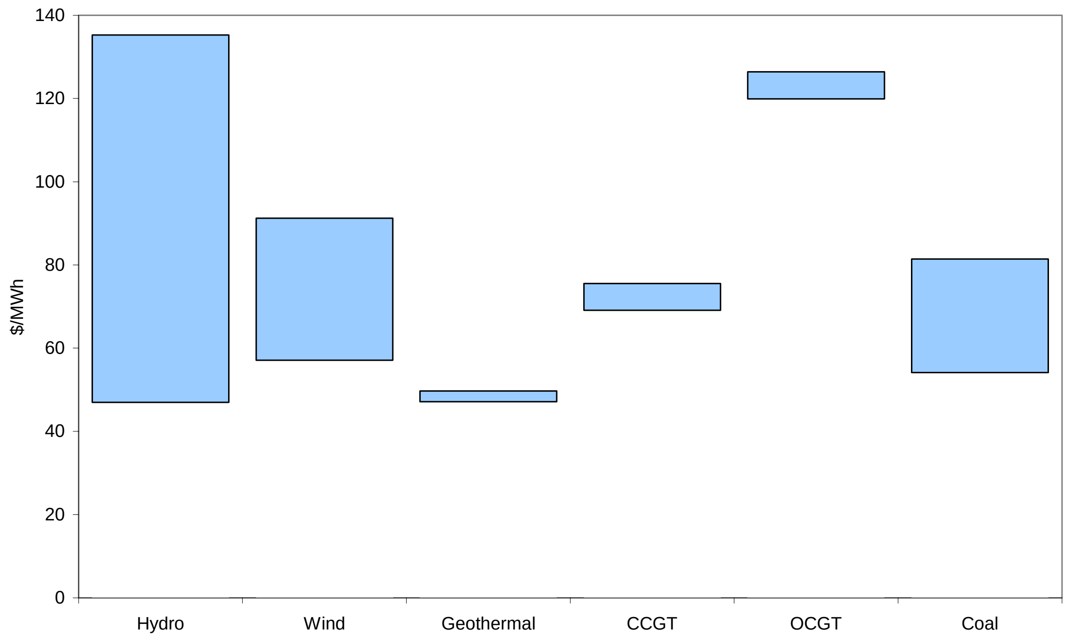

Figure 1 Cost Ranges for New Entrants

[7] The social rate of time preference, used as the basis for estimating discount rates for public policy purposes, is generally lower than private sector costs of capital. Private sector discount rates include a significant risk element that applies to individual companies and investments, but when making decisions at the community level, risks are more widely shared across the community.

3 Environmental Costs

The social costs of electricity are estimated from the private costs plus additional costs that are external to the current estimates of generation costs. Other studies demonstrate that these are dominated by the costs associated with air emissions from generation [8] and these are the only costs assessed in this report. There are environmental amenity effects associated with the development of plants but these are highly site specific and would need to be considered for any individual development. The analysis does not attempt to be a full life cycle assessment because of the dominant importance of emissions in generation.

There is no central source of information on the environmental costs of electricity generation in New Zealand. Some data have been compiled on the environmental costs of specific pollutants, particularly particulates from transport emissions. However, mostly these have established total costs of emissions, and cannot readily be used to assess the marginal costs of electricity generation.

The most comprehensive analysis to date of the full environmental costs of different energy sources has been the ExternE project[9], started by the European Commission with the US EPA in the early 1990s and latterly managed solely by the European Commission. It set out to define the environmental costs of different generation types, using a full life cycle approach. More recently, this work has been advanced under other programmes managed by the European Commission, particularly Clean Air for Europe (CAFE).[10] These European data can be converted to New Zealand conditions to some extent, but there are important differences, as discussed below.

A separate body of work from ExternE is used to examine the costs of greenhouse gas emissions, including those that assess damage costs and those that assess the costs of reducing emissions.

The major pollutants that are considered in this report are:

- Carbon dioxide (CO_2);
- Methane (CH_4)
- Sulphur dioxide (SO_2); and
- Nitrous oxides (NOx).

3.1 Carbon Dioxide (CO_2)

The Resource Management Act restricts the extent to which local government can take CO_2 and other greenhouse gases into account in decision making. Section 70(A) states:

> … when making a rule to control the discharge into air of greenhouse gases … a regional council must not have regard to the effects of such a discharge on climate change, except to the extent that the use and development of renewable energy enables a reduction in the discharge into air of greenhouse gases …

Greenhouse gases are controlled under a national programme of action and it is likely that additional measures will be introduced over the next two years, including a possible carbon tax on electricity generators and other large emitters. From 2008 and for the duration of the first (2008-12) and subsequent commitment periods under the Kyoto Protocol, the New Zealand government is required to limit net emissions of greenhouse gases, or to purchase emission allowances in the form of products of the

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[8] European Commission DG Science, Research and Development. ExternE Externalities of Energy.

[9] www.externe.info/

[10] http://europa.eu.int/comm/environment/air/cafe/

Kyoto mechanisms;[11] these allow New Zealand to emit more than its target on the basis of additional reductions in other countries.[12]

3.1.1 CO_2 Emission Rates

CO_2 is released when carbon-based (thermal) fuels are combusted in the presence of oxygen. In addition, CO_2 is combined naturally with other gases and is released when they are extracted. This includes CO_2 mixed with natural gas and with steam that is an input to geothermal plants.

Coal
Coal types differ in their energy content and therefore the CO_2 emissions that result. The national inventory document[13] estimates an emissions factor for sub-bituminous coal combustion as 91.2kt CO_2/PJ. However, this is an average for coal use across a range of sectors. Analysis of data for electricity generation, using the most recent year's (2005) data, suggests a slightly different emissions factor of 91.14kt CO_2/PJ.[14] This is used in analysis.

Coal is combusted at Huntly. To convert this input-based emissions factor[15] into an output-based factor[16] requires an estimate of the conversion efficiency. We assume a gross efficiency rate of 35%.[17] The resulting emissions factor for Huntly coal plant on an output basis is thus 0.937t CO_2/MWh.[18]

Natural Gas
Gas fields differ in their energy and CO_2 content. The CO_2 emissions factor for natural gas will thus change over time as gas production shifts from Maui to other fields.

The current weighted average estimated emissions factor for gas is 52.3kt CO_2/PJ.[19]

Wood Waste
The CO_2 emission factor for wood combustion is 104.2 kt CO_2/PJ.[20] Wood waste is used at Kinleith as an energy source in the production of heat and electricity. However, the CO_2 emitted from combustion of wood waste is not counted for the purposes of estimating New Zealand's national emissions of greenhouse gases. This is because the emissions associated with felling trees are counted at the point of felling; they are assumed to be emitted regardless of whether they are burnt or allowed to decompose on the forest floor. Thus burning wood waste is regarded as a carbon-free fuel.

Geothermal
CO_2 is emitted with steam from geothermal resources. Some of this is naturally occurring and therefore is not included in the national greenhouse gas inventory for the purposes of measuring emissions against commitments under the Kyoto Protocol. However, there is a question mark over the extent to which geothermal electricity generation forces steam at a greater rate than otherwise it would be extracted and therefore if these emissions count as anthropogenic. Emission rates differ by field. We

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[11] international emissions trading, joint implementation and the clean development mechanism

[12] These can either be reductions below targets in countries that have targets under the Kyoto Protocol or reductions below business as usual emissions in countries that do not have targets.

[13] Ministry for the Environment (2005) New Zealand's Greenhouse Gas Inventory 1990-2003

[14] 4,693kt of CO_2 from 51.49PJ of coal taken from Ministry of Economic Development (2006) New Zealand Energy Greenhouse Gas Emissions 1990-2005

[15] emissions per unit of fuel input

[16] emissions per unit of electrical output

[17] Marsden A, Poskitt R and Small J (2004) Investment in the New Zealand Electricity Industry. An examination of comparative financial performance, pricing and new entry conditions; and a discussion of the principles of new investment. Auckland Uniservices.

[18] An efficiency of 35% is equivalent to 10.29GJ/MWh; note this is based on gross calorific values.

[19] Ministry of Economic Development (2006) New Zealand Energy Greenhouse Gas Emissions 1990-2005

[20] MED (op cit)

have used a weighted average emission factor of 73g CO_2/kWh (Table 5). This is equivalent to 3.04t CO_2/TJ at an assumed 15% efficiency.

Table 5 CO_2 Emission Rates from Geothermal Fields

Geothermal Field	GWh	CO_2 Emission Rates (g/kWh)
Ohaaki	343	249
Wairakei	1,384	32
Poihipi Road	212	35
Rotokawa	210	105
Mokai	430	66
Weighted Average		**73[1]**

Source: East Harbour Management Services Ltd (2005) Availabilities and Costs of Renewable Sources of Energy for Generating Electricity and Heat. Report to the Ministry of Economic Development. and Covec calculations.
[1] Weighted average using GWh of generation for each station as reported by East Harbour

3.1.2 CO_2 Costs

CO_2 is a greenhouse gas and has no local effects at the concentrations emitted. And as a global pollutant, the impacts of greenhouse gas emissions from the Waikato, on communities in the Waikato region, will be very small. CO_2, and other greenhouse gases, have global effects. CO_2 is very long lasting in the atmosphere, mixes thoroughly and thus its impacts are felt worldwide. The impacts that an individual molecule will have are shared with the rest of the world.

Estimates have been made of the damage costs of greenhouse gases—the social costs of carbon (see Annex A). These estimates are highly uncertain and are the subject of ongoing work, including a component of a major review of the economics of climate change—the Stern Review,[21] the results of which are expected later this year. The most recent literature was brought together for a UK government workshop.[22] From this work a best estimate of approximately US$25/t carbon, equivalent to approximately NZ$12/t CO_2 [23] can be derived, and a maximum likely figure of US$50/t (NZ$25/t CO_2). These values are surprisingly low, given levels of international concern over the climate change issue and the possibly high levels of damage that could result, but are the best published estimates. The output from the more comprehensive Stern review will thus be of considerable interest.

The other way to examine this issue is with respect to the policy costs.

The government had announced the introduction of a carbon tax from April 2007.[24] It would have been set at a level of $15/tonne of CO_2 equivalent and retained at that level until 2012 (unless the price diverged significantly and on a sustained basis from the international price). Subsequently it decided not to continue with this broad tax, but has retained the option to introduce a tax on a narrower group of industries, including electricity generators.[25]

Alternatively, under the Kyoto Protocol, if New Zealand expects to fail to meet its target, it can purchase emission rights from other countries that allow it to increase its emissions.[26] Similarly, if New Zealand expects to emit less than the target it can sell surplus emission allowances. Because of this market in emission allowances, every emission has a cost to the nation—either because of the requirement to purchase one more allowance or because of the lost opportunity to sell an allowance. The expected

[21] The Stern Review of the Economics of Climate Change. (see http://www.hm-treasury.gov.uk)

[22] http://www.defra.gov.uk/environment/climatechange/carboncost/proceedings.htm

[23] 1 tonne of carbon = 3.67 tonnes of CO_2; assumes exchange rate of US$0.55:NZ$1

[24] Implementing the Carbon Tax. A government consultation paper. May 2005. Policy Advice Division, Inland Revenue Department.

[25] Cabinet Minute CBC Min (05) 20/10: Climate Change: Review of Policy and Next Steps. (www.climatechange.govt.nz/resources/cabinet/cbc-min-05-20-10.html)

[26] government to government or entity (firm) to entity or some combination

international price of emission allowances is thus an estimate of the cost to New Zealand of emitting greenhouse gases.

The most significant existing market for emission allowances is the EU emissions trading scheme. In that market, which is providing one early indication of future international prices of allowances, CO_2 allowances had been trading at a price of more than €25/t CO_2 [27] (NZ$43/t CO_2), however prices have fallen to below €20/t recently because of over-supply of allowances to obligated sectors. There is also a market in the Kyoto mechanisms outside of the EU and specifically credits from the clean development mechanism (CDM) and joint implementation (JI). These have been selling at prices significantly below the EU trading price.[28]

The appropriate cost of CO_2 is thus highly uncertain. Previously, the New Zealand government, when outlining the details of the carbon tax, set a maximum price of $25/tonne of CO_2, which is also the estimated maximum likely damage cost. We have used this as our maximum in this work. For analysis we use two price scenarios, a low price of NZ$15/t CO_2 and a high price of $25/t. The low price is slightly above the estimated damage costs but is the level that the government had originally set for the introduction of a carbon tax and might be used for any sectoral carbon tax.

Table 6 Impact of Carbon Tax on Fuel Costs

Fuel	Carbon content t CO_2/TJ	$/GJ (@$15/t)	$/GJ (@$25/t)	Basic fuel cost ($/GJ)	Total cost ($/GJ) (@$15/t)	Total cost ($/GJ) (@$25/t)
Coal	91.1	1.37	2.28	3.5	4.87	5.78
Natural Gas	52.3	0.78	1.31	6	6.78	7.31
Geo-thermal	3.04	0.05	0.08	0	0.05	0.08

Source: See Section 3.1

Table 7 Variable Costs of Generation including carbon costs ($/MWh)

Plant	No CO_2 cost	$15/t CO_2	$25/t CO_2
Huntly (Coal)	39.10	53.16	62.54
Huntly (GT)	61.48	69.11	74.20
E3P	44.64	50.07	53.69
Geothermal	7.30	8.40	9.13
Hydro	6.30	6.30	6.30
Wind	6.00	6.00	6.00

The most significant impact is on coal plants as coal has a very high carbon content—considerably higher than for gas. Geothermal plants have CO_2 mixed with the steam. There are some questions over whether these are naturally occurring or not, ie whether this steam and CO_2 would be released anyway—in which case the emissions do not count under the Kyoto Protocol. In addition, levels of CO_2 content vary widely. The data here are based on MED averages.

3.2 Methane (CH_4) and Nitrous Oxide (N_2O)

3.2.1 Emission Rates

CH_4 is emitted as a fugitive emission during coal mining, but there is considerable doubt over whether this is appropriately measured as a marginal effect as coal that is not consumed in New Zealand is exported.

For fugitive emissions of gas, levels are extremely low for the transmission network and are ignored in the national greenhouse gas inventory. This applies to consumption by electricity generation and other major industrial loads that take gas directly from the transmission network.

[27] http://www.europeanclimateexchange.com
[28] Point Carbon (see www.pointcarbon.com)

There are additional methane and nitrous oxide emissions from fuel combustion. These are shown in Table 8 and are extremely small; they make an insignificant difference to total emissions and the effects are ignored in analysis.

Table 8 CH_4 and N_2O Emission Factors - Combustion

	t/PJ	kg/GJ
Natural gas - methane	2.7	0.0027
Natural gas – N_2O	0.09	0.00009
Coal – methane	0.67	0.00067
Coal - N_2O	1.5	0.0015

3.2.2 Costs

CH_4 and N_2O are greenhouse gases and have a global warming potential (GWP), ie they are long-lived in the atmosphere in a similar way to CO_2. The effects are estimated by converting gases with a GWP into CO_2 equivalents. The warming attributable to CH_4 and N_2O is greater than for CO_2 per molecule but the relative effect depends on the timeframe over which the estimate is made, because they have different expected atmospheric half-lives.

It has been agreed for reporting under the UN Framework Convention on Climate Change to use 100-year GWPs for conversions to CO_2-equivalents; these are 21 for CH_4 and 310 for N_2O. Thus 1 tonne of CH_4 is equivalent in effect to 21 tonnes of CO_2.

In cost terms, and using a CO_2 emissions cost of $15/t and the 100-year GWPs, the costs are:

- $315/t CH_4 (or $525/t CH_4 @ $25/t)
- $4,650/t N_2O (or $7,750/t N_2O @ $25/t)

The other costs are insignificant additional costs and are ignored in analysis. At a carbon tax rate of $15/t, including the costs of methane emissions from coal mining would result in a coal price increase of approximately $0.19/GJ,[29] about a 5% increase on the fuel costs; these costs would not apply to imported coals.

We have ignored these costs in analysis but note their potential impact here.

3.3 Sulphur Dioxide (SO_2)

3.3.1 Emission Rates

Sulphur oxides including SO_2 and, to a lesser extent, SO_3 are formed when sulphur-containing fuel is combusted in oxygen.

The sulphur content of natural gas is effectively zero. That for wood waste and for sub-bituminous coal is taken from the national greenhouse gas inventory (Table 9).

Table 9 SO_2 Emission Factors

	t SO2/PJ	kg/GJ
Coal - sub-bituminous	387.2	0.387
Wood	331.1	0.331

3.3.2 Emission Costs

SO_2 can have direct health effects on breathing, respiratory illness, alterations in pulmonary defences, and aggravation of existing cardiovascular disease[30]; however it is not clear that this effect is measurable. In addition SO_2 has secondary effects as it combines with other molecules to form sulphate aerosols (a small particulate) and

29 This is equivalent to an additional cost at Huntly of $1.95/MWh.

30 http://www.enviropedia.org.uk/Acid_Rain/Sulphur_Dioxide.php

sulphuric acid (acid rain). The epidemiological literature suggests that there are no thresholds in the effects, ie no levels below which there is no appreciable damage.[31] It means that all emissions will have some damage.

There has been no primary research into the costs of SO_2 emissions in New Zealand. Analysis of the direct health impacts, both here and internationally, have noted the difficulties in separating out the effects of SO_2 from those of other pollutants, particularly noting the close relationship between emissions of SO_2 and particulates. The ExternE study initially concluded that the evidence for SO_2 damaging health directly was too weak for this effect to be included in the analysis of costs; specifically there was no evidence of causality because of the strong relationship between SO_2 emissions and that of other pollutants. More recent outputs suggested that there was evidence of a direct effect.[32] However, the latest studies are ignoring these effects because of the lack of clear evidence of causality[33].

There is no evidence of acidification effects in New Zealand and we ignore these effects.

In this study the direct impacts of SO_2 are not assessed; however we do assess the impacts of SO_2 as an aerosol (small particulate). There has been little work to analyse the component parts of particulate concentrations in New Zealand. The limited work that has been undertaken[34] notes the presence of sulphates; citing this work, Fisher and King[35] suggest that the fraction of particulates due to sulphates might be 10-30% of the total, depending on the atmospheric conditions.

The European work under ExternE and the more recent work for CAFE quantifies the sulphate aerosol effects and some of the acidification impacts. More recently, questions are being asked about the extent of the sulphate impact. As AEA Technology notes[36]:

> *Evidence is coalescing that, with fine particles from combustion sources, toxicity resides especially in the primary particles, as opposed to the secondary particles (sulphates, nitrates)…. In general, toxicologists are more sceptical than epidemiologists about the adverse effects of secondary particles. This reflects differences in toxicological evidence.*
>
> - *There is substantial epidemiological evidence of associations between health and sulphates. In these studies sulphates may of course be a marker for other aspects of the mixture, rather than a direct causal agent. They do suggest however that if sulphates are reduced, as part of the reduction of a mixture, then there will be real benefits to health.*
> - *There are many fewer epidemiological studies showing relationships between nitrates and health. This may be due at least in part to difficulties in measuring nitrates.*

However, this has not, to date, led to changes to the quantification of sulphate impacts, ie they are measured as though they were fine particles.

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[31] AEA Technology Environment (2005). Methodology for the Cost-Benefit Analysis for CAFE: Volume 2: Health Impact Assessment. Service Contract for Carrying out Cost-Benefit Analysis of Air Quality Related Issues, in particular in the Clean Air for Europe (CAFE) Programme. Methodology for the Cost-Benefit Analysis for CAFE: Volume 2: Health Impact Assessment.

[32] European Commission (1998) ExternE Externalities of Energy Methodology 1998 Update

[33] Paul Watkiss, AEA Technology, personal communication

[34] Fisher GW, Thompson A and Kuschel GI (1998) An Overview of the Elemental Analysis of Ambient Particulates in New Zealand. NIWA Report AK98029 (www.smf.govt.nz/results/5006_ak98029.pdf)

[35] Fisher GW and King D (2002) Cleaning Our Air: Implications for Air Quality from Reductions in the Sulphur Content of Diesel Fuel. NIWA Report AK02007.

[36] AEA Technology Environment (2005) Methodology for the Cost-Benefit Analysis for CAFE: Volume 2: Health Impact Assessment. Service Contract for Carrying out Cost-Benefit Analysis of Air Quality Related Issues, in particular in the Clean Air for Europe (CAFE) Programme. p 14

In this report we measure the impacts of SO_2 via its effect as a small particulate. The detailed analysis is provided in Annex B. The work has considerable uncertainties and Annex B raises questions about approaches currently used to value the damage costs of emissions.

The costs for SO_2 range from $1,012-5,113/t. This is used with the emission factors above to find a cost per GJ of coal use (Table 10).

Table 10 Costs of SO_2 Emissions

Fuel	t SO2/PJ	kg/GJ	$/GJ (low)	$/GJ (high)
Coal - sub-bituminous	387.2	0.387	0.39	1.98
Wood	331.1	0.331	0.34	1.69

3.4 Nitrogen Oxides (NOx)

3.4.1 Emission Rates

Nitrogen oxides is a collective term used to refer to two species of oxides of nitrogen: nitric oxide (NO) and nitrogen dioxide (NO_2). They are formed during fuel combustion. At high concentrations, NO_2 can be highly toxic causing direct health effects. Nitrogen dioxide reacts in the atmosphere to form nitric acid and nitrate aerosols.

NOx emission rates are taken from the greenhouse gas inventory and summarised in Table 11.

Table 11 NOx Emission Factors

	t NOx/PJ	kg NOx/GJ
Coal	361	0.361
Natural gas	171	0.171
Wood	62	0.062

Source: MED (op cit)

3.4.2 Emission Costs

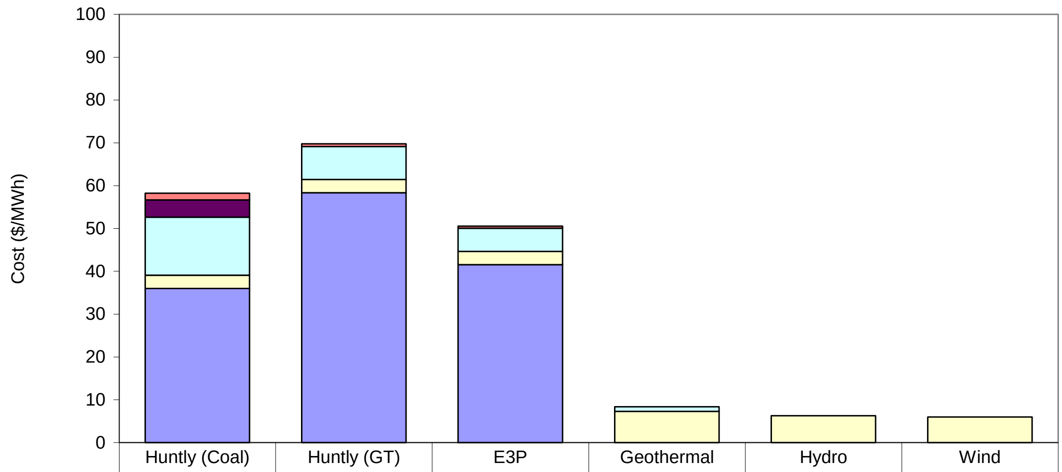
The discussion of the effects of NOx and the way that they have been measured is similar to that for SO_2. We do not provide a detailed discussion here. For analysis, as for SO_2, costs are dominated by the fine particulate effect. As for the discussion of SO_2 above, we use modified estimates of the recent EU CAFE programme values. The range is $422-662/t and the effect on fuel costs is shown in Table 12.

Table 12 Costs of NOx Emissions

	t NOx/PJ	kg NOx/GJ	$/GJ (low)	$/GJ (high)
Coal	361	0.361	0.15	0.77
Natural gas	171	0.171	0.07	0.36
Wood	62	0.062	0.03	0.13

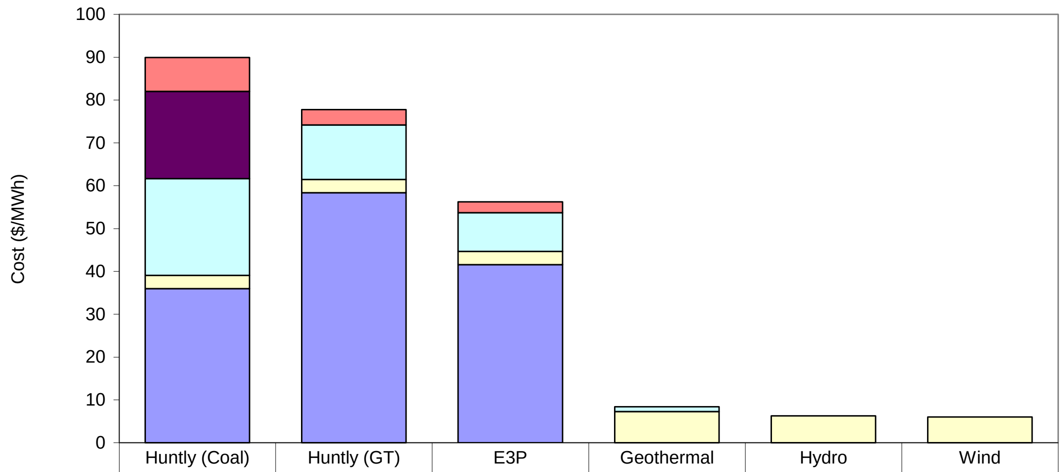
3.5 Total Costs

Total costs for the different pollutants, in comparison with the other costs of generation, are shown in Figure 2 to Figure 5 below.



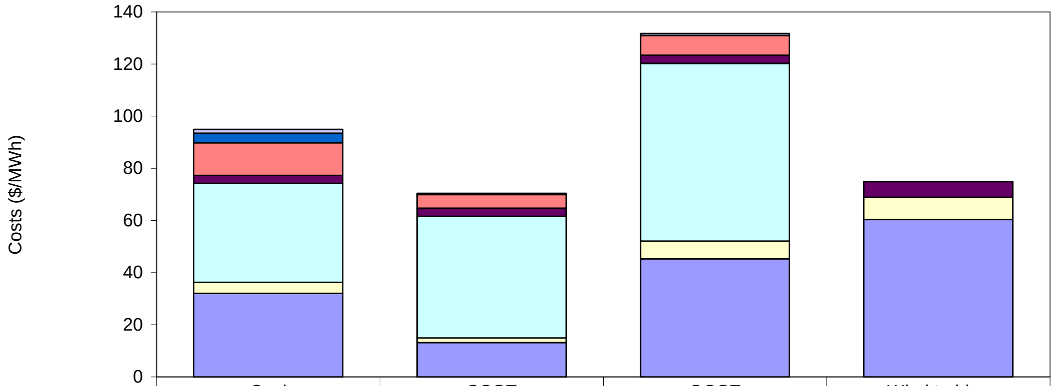
	Huntly (Coal)	Huntly (GT)	E3P	Geothermal	Hydro	Wind
NOx	1.57	0.70	0.50	0	0	0
SO2	4.03	0	0	0	0	0
Carbon	13.55	7.63	5.43	1.10	0	0
O&M	3.1	3.1	3.1	7.3	6.3	6.0
Fuel	36.00	58.38	41.54	0	0	0
Total	58.25	69.81	50.57	8.40	6.30	6.00

Figure 2 Components of Variable Costs (Low Costs)



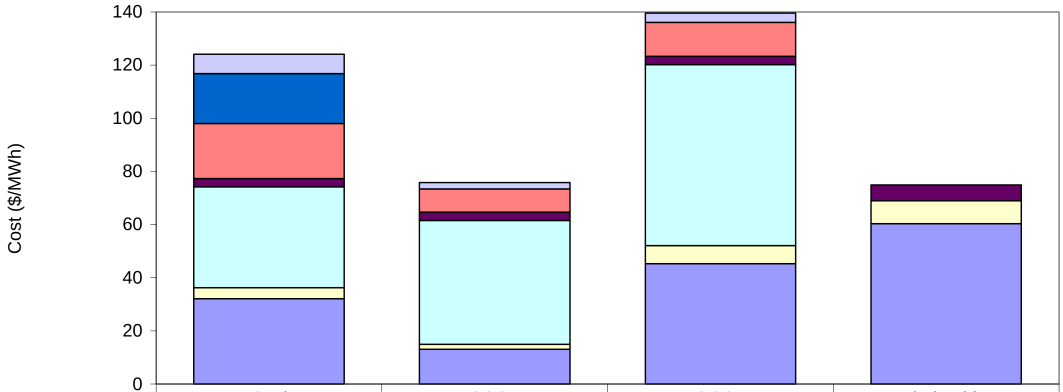
	Huntly (Coal)	Huntly (GT)	E3P	Geothermal	Hydro	Wind
NOx	7.91	3.54	2.52	0	0	0
SO2	20.36	0	0	0	0	0
Carbon	22.58	12.72	9.05	1.10	0	0
O&M	3.1	3.1	3.1	7.3	6.3	6.0
Fuel	36.00	58.38	41.54	0	0	0
Total	89.95	77.74	56.21	8.40	6.30	6.00

Figure 3 **Components of Variable Costs (High Costs)**



	Coal	CCGT	OCGT	Wind turbine
NOx	1.44	0.48	0.70	0
SO2	3.71	0	0	0
Carbon	12.48	5.23	7.63	0
O&M	3.1	3.1	3.1	6
Fuel	37.89	46.67	68.11	0.00
Annual fixed	4.16	1.78	6.85	8.56
Capital	32.11	13.14	45.27	60.34
Total	94.90	70.39	131.67	74.90

Figure 4 **Components of Average Costs of New Plant (Low Costs)**



	Coal	CCGT	OCGT	Wind turbine
NOx	7.29	2.43	3.54	0
SO2	18.75	0	0	0
Carbon	20.80	8.72	12.72	0
O&M	3.10	3.10	3.10	6
Fuel	37.89	46.67	68.11	0
Annual fixed	4.16	1.78	6.85	8.56
Capital	32.11	13.14	45.27	60.34
Total	124.10	75.82	139.60	74.90

Figure 5 Components of Average Costs of New Plant (High Costs)

Figure 6 shows the impacts of the environmental costs on the range of costs for new entrants. The range and maximum costs for coal plants is considerably increased relative to the costs presented in Figure 1. It means that renewable plants are lower cost options over a wider range of input assumptions.

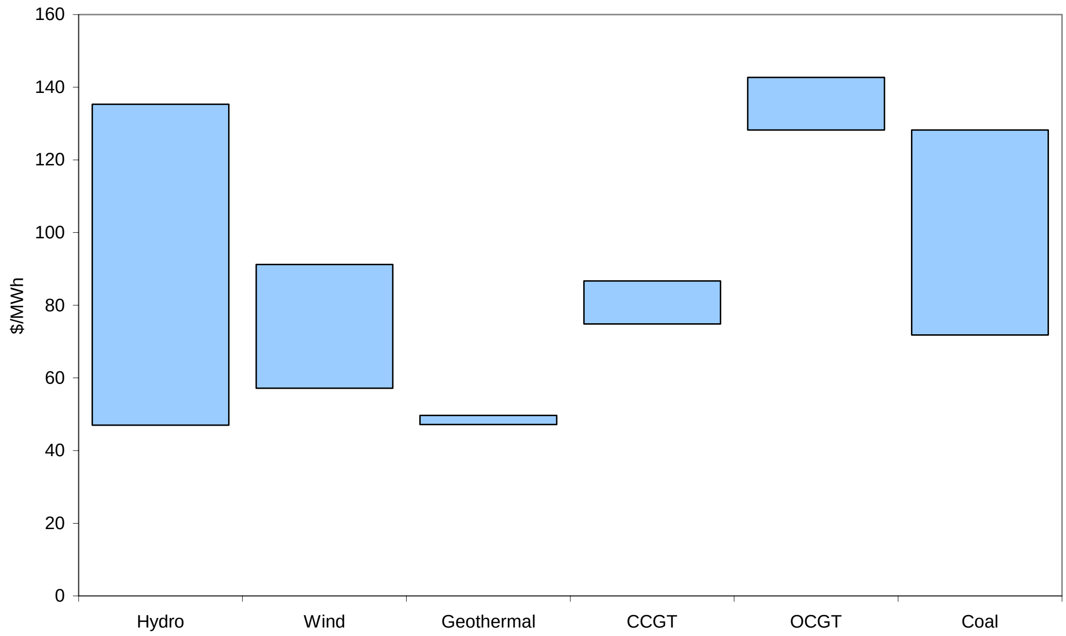


Figure 6 Cost Ranges for New Entrants including Environmental Costs

3.6 Conclusions

3.6.1 Cost Estimates

This report has used New Zealand and international data to attribute costs to the environmental effects of electricity generation.

Environmental costs that are borne by society are a significant additional element of the full social costs of electricity generation. The analysis above categorises the different environmental costs; they are dominated by carbon costs under the low cost options (Figure 2 and Figure 4). Amongst the different plant types, carbon costs are most significant for coal plants, including Huntly, because of the high carbon content of this fuel. Of current plants, the open cycle gas turbine plant at Huntly also has significant carbon costs, because of the relatively low efficiency of this plant. SO_2 is emitted by coal plants and, under the low cost assumptions, the costs of sulphur are equal to approximately 10% of the initial private variable costs of generation, and 5% of new coal plant costs; this compares with the percentage additions attributable to CO_2 of 35% of initial variable costs for coal plant and 16% of new entry costs.

Geothermal electricity generation has low carbon emissions and there is some debate over the extent to which they are anthropogenic, ie attributable to human causes. The steam and CO_2 would be released anyway, but electricity generation from geothermal resources may increase the rate at which it is released. Attributing the emissions to human causes is thus dependent on time frames of analysis. These issues have not been clearly resolved and are beyond the scope of this report.

Wind has no CO_2 emissions in generation.

For new plants, capital costs are an additional element of total costs, and because of this, environmental costs are relatively less important.

Under assumptions of high environmental costs, which we regard as a significant over-estimate of costs for SO_2, SO_2 costs are equal to approximately 52% of initial variable costs for coal plant and 24% of new plant costs. Taking account of SO_2 costs, under the high cost assumptions, would mean that burning gas, rather than coal, became the better option for Huntly (up to a gas price of $6.70/GJ).

Other pollutants are less significant contributors to total costs. Although, under the high cost assumptions NOx costs can be substantive—equal to 21% of the initial estimate of variable costs for coal plant or 9% for the costs of new coal plant entry.

3.6.2 Policy Responses

CO_2 and other greenhouse gases are being addressed nationally and the government is developing a policy package to tackle emissions during the first commitment period under the Kyoto Protocol. This might include a tax on emissions from electricity generators. The government has made it clear that it expects to take the policy lead on developing a climate change policy package; it is appropriate that policy on CO_2 and other greenhouse gases is developed nationally rather than regionally.

Currently the costs of the main local pollutants, SO_2 and NOx, are not priced but are addressed via the consent process under the Resource Management Act. The analysis presented in this report suggests that there are residual effects of SO_2 emissions that are not currently avoided, remedied or mitigated. These are attributable to sulphur's contribution to concentrations of small particulates, for which there are unlikely to be impact thresholds. In other words, every emission has a potential effect. There is an improvement in economic efficiency if emitters face the costs of these residual emissions in the form of a charge equal to the damage cost per tonne of emissions, whether implemented as a national or a regional instrument.[37] Such a charge would provide incentives for additional emission reduction where this could be achieved for less than the charge level.

[37] Practical issues to do with a charge on pollutants implemented at a regional level are addressed in Covec (2005) Economic Instruments for the Environment. Final Report to Environment Waikato. TR 2006/23, available at: www.ew.govt.nz/publications/technicalreports/tr0623.htm

Annex A — Carbon Costs

There are two main ways of estimating the costs of greenhouse gas emissions in monetary terms. One is to estimate the future expected prices of international permits; the other is to estimate damage costs.

International permits for greenhouse gases are tradable commodities made up of parts of national targets. Prices are set by the market and depend on levels of supply and demand. There are significant uncertainties.

- The level of supply is established through international target-setting, with the current set for industrialised economies having been finalised in the Kyoto Protocol for the period 2008-12. The future price of carbon emissions would be determined by the level of international targets in future years. This is by no means certain; some countries have called for much more stringent targets, and for their extension to developing countries; others have suggested that targets are established on a different basis, eg by emissions intensity.

- Levels of demand will depend on the costs of reducing emissions reflecting technological development.

It would be rational for countries to set targets on the basis of some understanding of the costs of control and of damage costs. For this reason, an assessment of damage costs is likely to be a better way to estimate future expected prices of carbon emissions. This assumes that the global community, via the UN Framework Convention on Climate Change, would examine the costs and benefits of emission reductions and establish targets (or other means of influencing domestic policy) in such a way that the international price effect of emitting greenhouse gases approached the damage cost estimates.

Estimates of Damage Costs
The science of climate change is characterised by uncertainty. There is a high degree of certainty surrounding the existence of an enhanced greenhouse effect and increasing certainty of anthropogenic causes. There is a high level of confidence in estimates of the impacts on global mean temperatures. However, the impacts will depend on local and regional changes in climate combined with current distribution of ecosystems, populations and land uses. Regional and local impacts are much less certain.

Comprehensive assessments of the social costs of CO_2 have been undertaken in the UK. In January 2002, a Government Economic Service working paper[38] suggested £70/tC (NZ$62/t CO_2)[39] (within a range of £35 to £140/tC or NZ$31-124/t CO_2) as an illustrative estimate for the global damage cost of carbon emissions. The GES paper recommended periodic reviews of the illustrative figures as new evidence became available.
In this context, Defra organised an International Seminar on the Social Costs of Carbon (SCC) on the 7th July 2003.

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.

[38] Clarkson R and Deyes K (2002) Estimating the Social Cost of Carbon Emissions. HM Treasury & DEFRA. www.hm-treasury.gov.uk/media/209/60/SCC.pdf
[39] Converted using £1:NZ$3.24 and 3.67t CO_2/t carbon

There have been a number of reviews of the damage cost estimates resulting from IAMs, and recently a useful review of reviews[40] for a UK government-sponsored international seminar on the social costs of carbon (SCC)[41] that provided the following summary[42]:

- In 1996, the Intergovernmental Panel on Climate Change (IPCC's) Working Group III published a range of $5 - $125 per tonne of carbon (in 1990 prices, or $6 - $160/tC in 2000 prices) based on a review of existing studies and relating to carbon emissions in the period 1991-2000. For the period 2001-2010, the representative range was estimated to increase to $7 - $154/tC (in 1990 prices, or $9-$197/tC in 2000 prices);
- On the basis of a review of 8 major studies, the UK Government Economic Service[43] suggested $101.5/tC (within a range of $51 to $203/tC) as an illustrative estimate for the global damage cost of carbon emissions. It also suggested that these figures should be raised in real terms by $1.45/tC per year as the costs of climate change are likely to increase over time.
- Pearce (2003)[44] lists 24 estimates from 12 studies in his review, some of which have been published or peer-reviewed following the publication of the GES paper. Pearce's survey of the SCC literature leads him to conclude that a more appropriate range would be $6 to $39/tC.
- In a recent working paper that probably constitutes the most complete survey of the literature to date, Tol (2003)[45] counts 88 estimates from 22 published studies. The mode of these estimates is $5/tC, the mean $104/tC and the 95th percentile $446/tC, the right skewed distribution reflecting the presence of a few estimates that place the SCC at a few hundred of dollars (and in one case more than a thousand of dollars) under pessimistic scenarios. After weighting the estimates, Tol concludes that "[…] for all practical purposes, climate change impacts may be very uncertain but is unlikely that the marginal costs of carbon dioxide emissions exceed $50/tC and are likely to be substantially smaller than that."

There are a number of key parameters that affect the results including[46] 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[47]; time varying discount rates could roughly double damage estimates.

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

[41] http://www.defra.gov.uk/environment/climatechange/carbonseminar/index.htm

[42] Note these estimates are for CO_2 measured as carbon. To convert to CO_2, they need to be divided by 3.67, so $50/t C becomes $13.6/t CO_2.

[43] Clarkson R and Deyes K (2002) Estimating the Social Cost of Carbon Emissions. Government Economic Service Working Paper 140. HM Treasury, Department for Environment, Food and Rural Affairs.

[44] Now published as: David Pearce (2003) The Social Costs of Carbon and its Policy Implications. Oxford Review of Economic Policy, 19(3): 362-384

[45] 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

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

[47] 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.

Taking account of Tol's recent analysis, we have chosen a figure of US$25/t of carbon (US$6.81/t CO_2) as the best current estimate of the global damage costs of greenhouse gas emissions.

Annex B—Costs of Particulates

There is a very considerable literature on the costs of particulates, including studies in New Zealand.

The impacts are dominated by the effects on morbidity (respiratory illness) and mortality (premature death).

Epidemiological studies have correlated numbers of deaths and hospital admissions for a range of symptoms to pollutant concentrations, while accounting for factors such as season, temperature and day of the week. The results have been highly consistent and have withstood criticism.[48]

The studies have resulted in a series of risk estimates that correlate changes in pollutant concentration to impacts including asthma attacks, restricted activity days, bronchitis episodes, respiratory hospital admissions and total mortality. An example is given in Table 13.

Table 13 Impacts of 10μg/m^3 increase in concentration of PM_{10}

Health outcome	Relative risk	(±95% confidence interval)
Total mortality (adults ≥30 years)	1.043	(1.026-1.061)
Respiratory hospital admissions (all ages)	1.0131	(1.001-1.025)
Cardiovascular hospital admissions (all ages)	1.0125	(1.007-1.019)
Chronic bronchitis incidence (Adults ≥25)	1.098	(1.009-1.194)
Bronchitis (children <15)	1.306	(1.135-1.502)
Restricted activity days (adults ≥20)	1.094	(1.079-1.102)
Asthma attacks (children <15)	1.044	(1.027-1.062)
Asthma attacks (adults ≥15)	1.039	(1.019-1.059)

Source: Künzli N, Kaiser R, Medina S, Studnicka M, Chanel O, Filliger P, Herry M, Horak F jr, Puybonnieux-Texier V, Quénel P, Schneider J, Seethaler R, Vergnaud J-C and Sommer H (2000) Public-health impact of outdoor traffic-related air pollution: a European assessment. *The Lancet*: 356: 795-801

In New Zealand studies have been undertaken in Christchurch. These have shown an association between 24-hour concentrations of fine particulates (PM_{10}) and mortality and hospital admissions; the results are consistent with overseas studies.

A 2002 report for the Ministry of Transport[49] notes the lack of data but uses what is available making "realistic assumptions … to arrive at the current best estimate for public health effects". It used the exposure data to estimate the expected mortality impacts of elevated PM_{10} concentrations. The authors describe the methodology as being published in the well-respected medical science journal, the Lancet (see Table 13), and derived from long term studies. It used a 4.3% increase in background mortality rate for each 10μg/m^3 annual average increase in PM_{10} concentrations above a 7.5 μg/m^3 threshold as a chronic mortality impact. Others have assumed no health effect threshold, including the US EPA[50] and the recent studies coordinated by the European Commission.[51] The World Health Organisation[52] examines a number of

48 Samet et al, 1996 in: Fisher GW, Rolfe KA, Kjellstrom T, Woodward A, Hales S, Sturman AP, Kingham S, Petersen J, Shrestha R and King D (2002) Health effects due to motor vehicle air pollution in New Zealand. Report to the Ministry of Transport

49 Fisher et al (op cit)

50 Hubbell BJ, Koman T, Fox TJ, Possiel MS, Stella G and Timin B. Health benefits of reducing particulate air pollution from heavy duty vehicles. USEPA (www.epa.gov/ttn/ecas/workingpapers/hddben.pdf)

51 AEA Technology Environment (2005) Methodology for the Cost-Benefit Analysis for CAFE: Volume 2: Health Impact Assessment. Service Contract for Carrying out Cost-Benefit Analysis of Air Quality Related Issues, in particular in the Clean Air for Europe (CAFE) Programme. Methodology for the Cost-Benefit Analysis for CAFE: Volume 2: Health Impact Assessment

studies that report a range of chronic impacts from 3-18% increase per 10µg/m^3 increase in PM_{10} concentrations, with a mid value of 10%. The most recent work coming out from the European Commission[53] uses an approach described by Arden Pope and others[54] that recommends a total mortality impact of a 6% increase in death rates per 10µg/m^3 increase in $PM_{2.5}$.

There are two main approaches used to measure the impacts of air pollution on mortality.

- the time series method which can identify only acute effects—deaths attributable to short term exposures;
- cohort studies, which can measure the total mortality impact due to chronic exposure.

The chronic effects are regarded as the most important.

There are two significant issues involved in taking these through to estimate damage costs:

- The delay in the mortality impact;
- The quantification of the value of lives lost.

Delay in Impact
The mortality studies include[55]:
- Time series studies of acute exposure, ie the impacts of short term spikes in concentrations; and
- Cohort studies of chronic (long term) exposure that result in changes to age-specific death rates.

The impacts across a wide range of studies are dominated by the chronic effects. These studies show the impact on death rates, or more correctly life expectancy, of long term exposure to elevated levels of pollution. However, the results need to be interpreted with some caution.

The long and short term impacts can be explained using a two by two matrix (Table 14). Susceptibility to death may be increased because of air pollution or some other cause, eg illness, and the event of death may be triggered by air pollution or another cause. The long term studies that demonstrate a linkage between rates of death and long run exposure to pollution do not separate out causes A, B and C.

Table 14 Long-term Frailty and Trigger of Death

Long-term frailty	Event of death	
	Related to air pollution	Not related to air pollution
Related to air pollution	A	B
Not related to air pollution	C	D

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[52] World Health Organisation (2000) Air Quality Guidelines for Europe (www.euro.who.int/document/e71922.pdf)

[53] AEA Technology (op cit)

[54] Pope CA III, Burnett RT, Thun MJ, Calle EE, Krewski D, Ito K, Thurston GD (2002). Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution. Journal of the American medical association, 287: 1132 - 1141. In: AEA Technology (op cit)

[55] AEA Technology Environment (2005). Methodology for the Cost-Benefit Analysis for CAFE: Volume 2: Health Impact Assessment .Service Contract for Carrying out Cost-Benefit Analysis of Air Quality Related Issues, in particular in the Clean Air for Europe (CAFE) Programme. Methodology for the Cost-Benefit Analysis for CAFE: Volume 2: Health Impact Assessment.

Source: Seethaler, RK, Künzli N, Sommer H, Chanel O, Herry M, Masson, S, Vergnaud J-C, Filliger P, Horak F Jr, Kaiser R, Medina S, Puybonnieux-Texier V, Quénel P, Schneider J, Studnicka M and Heldstab, J (2003) Economic Costs of Air Pollution Related Health Impacts: An Impact Assessment Project of Austria, France and Switzerland. Clean Air and Environmental Quality, 37/1: 35-43

While a reduction in emissions may reduce the number of deaths immediately related to air pollution (A and C), average levels of long term frailty in the population will change slowly over time.

However, despite this, the results of studies used to estimate current premature mortality owing to air pollution have been used to estimate marginal effects of reducing pollution levels. This approach is consistent with numerous overseas studies but misleading as a measure of the expected effect, principally because it assumes that reductions in emissions or concentrations will have an immediate and proportional reduction in the number of premature deaths, but also because of the approach used to measure damage (as discussed in the next section).

The cohort studies used to establish the chronic effect suggest that people are frail as a result of a lifetime living in air pollution. Given this, even if air pollution is cut to zero tomorrow, these people will still be frail and many will die prematurely because of this frailty. The reduction in pollution stops additional frailty and allows some repair, however even if all pollution is cut, it will take many years and probably decades for the full effect to be realised.

This is recognized by a number of authors. For example, Nino Künzli notes that emission reduction will bring about the total benefit as suggested by the studies, but that the full mortality benefit will not result next year; he suggests that the answer to when it results is not known.[56] Arden Pope suggests that the pollution damage effects will persist for years or even decades.[57]

These effects are beginning to be taken into account as they are vital for an understanding of the marginal effects of reductions in pollution.

A recent report published by the US EPA and including advice by a Health Effects Subcommittee (HES) notes the importance of this issue and that, to date, a weighted 5-year time course of benefits has been assumed in which 25% of the PM-related mortality benefits were assumed to occur in the first and second year, and 16.7% were assumed to occur in each of the remaining 3 years.[58] The EPA noted that it was considering use of a range of lag structures from 0 to 20-30 years, with 10 or 15 years selected as the mid-point value until more definitive information becomes available. The HES endorsed the consideration of these alternative approaches that took account of long lags.

In response to this cumulative advice, the EPA has stated that it intends to further analyse the cessation lag question, but in the interim, it intends to use an alternative lag structure, which assumes 20% of the incidence reduction occurs in the first year of a reduction in PM exposure, another 50% is evenly spread among years 2 through 5 (ie 12.5% each year), and the remaining 30 percent of the incidence reduction is evenly spread out among years 6 through 20 (ie 2% each year)[59].

[56] Nino Künzli, personal communication

[57] Arden Pope, personal communication.

[58] US EPA (2004) Advisory on Plans for Health Effects Analysis in the Analytical Plan for EPA's Second Prospective Analysis—Benefits and Costs of the Clean Air Act, 1990-2020. Advisory by the Health Effects Subcommittee of the Advisory Council on Clean Air Compliance Analysis. (www.epa.gov/sab/pdf/council_adv_04002.pdf)

[59] www.epa.gov/sab/pdf/comments_on_council_adv_04001.pdf

In contrast, the work for the European Commission continues to assume no lags[60], although as sensitivity analysis researchers have examined the effects associated with a 1-year pulse change, ie a sudden reduction in pollution for one year. Here, in contrast to a 6% increase in mortality for a 10µg/m^3 increase in $PM_{2.5}$ concentrations, they assumed a 2.4% increase in year 1, followed by 0.36% increases in years 2 to 11, followed by reversion to the original mortality rate.

The need for new research is clear when we think through the impacts as marginal effects. If there is a reduction in emissions of a single tonne (or even a single tonne per annum), there is a lesser risk of an acute effect but the chronic effect involves a very slight delay in the build up of frailty.

All of the researchers that are starting to take account of these effects are using assumptions in the absence of studies that have truly examined a marginal effect. However, they demonstrate that the assumptions of an instantaneous response greatly over-estimate the measured impact.

Quantification of Value

Many studies have sought to quantify the damage attributable to air pollution in monetary terms. They are dominated by the health effects and the impacts on life expectancy.

The morbidity effects are typically estimated using the costs of treatment and there is little controversy about these.

There are a number of issues that are not fully resolved related to the measurement of the valuation of mortality impacts.

Recent work to examine the impact of pollution in New Zealand has used a simple approach to analysis involving the following calculation:

annual death rate x population size x %increase per µg/m^3 PM_{10} x change in PM_{10}

This results in an estimated number of attributable deaths. Using a 4.3% increase in death rate, as discussed above, Fisher and others[61] estimated 970 additional deaths per annum attributable to PM_{10}, 399 of which were attributable to transport emissions. These have then been multiplied by an estimate of the value of a statistical life (VSL), eg to estimate the costs of damage due to air pollution from traffic.[62]

This simple approach is described by the recent European team as “easy to do and … easy to understand and to communicate … The main weakness is that strictly speaking it is wrong”[63] There are a number of issues of concern. The European team notes the simplifications involved relative to an approach that uses life tables in which the impacts of extra deaths in one year affect the structure of the population in future years.

Other issues relate to the nature of delay and the characterisation of the deaths.

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[60] AEA Technology Environment (2005) Methodology for the Cost-Benefit Analysis for CAFE: Volume 2: Health Impact Assessment. .Service Contract for Carrying out Cost-Benefit Analysis of Air Quality Related Issues, in particular in the Clean Air for Europe (CAFE) Programme. Methodology for the Cost-Benefit Analysis for CAFE: Volume 2: Health Impact Assessment.

[61] Fisher GW, Rolfe KA, Kjellstrom T, Woodward A, Hales S, Sturman AP, Kingham S, Petersen J, Shrestha R and King D (2002) Health effects due to motor vehicle air pollution in New Zealand. Report to the Ministry of Transport

[62] Fisher G (2002) The cost of PM_{10} air pollution in Auckland: a preliminary assessment. NIWA Discussion Paper.

[63] AEA Technology Environment (2005) Methodology for the Cost-Benefit Analysis for CAFE: Volume 2: Health Impact Assessment. Service Contract for Carrying out Cost-Benefit Analysis of Air Quality Related Issues, in particular in the Clean Air for Europe (CAFE) Programme. p41

Firstly, taking the New Zealand example above, the results do not mean the premature deaths of 970 (or 399) distinct individuals. The research on which this work is based shows only that the death rate increases under pollution; it might be caused by the measured increase as discrete deaths, but it is more likely that it is an outcome of the reduced lifespans of thousands of individuals so that deaths are squeezed into fewer years and the total annual death rate changes by this amount.

AEA Technology notes[64]:

> *…in the long run everybody dies, and dies once only, the aggregate number of deaths in a birth cohort … or in the currently-alive population … will be exactly everybody in that birth cohort or population, irrespective of the effects of pollution on mortality. This highlights the possibly obvious fact that information about pollution and mortality does not reside in the fact of death — this is taken as being certain but rather in its timing: how soon will death occur?*

Aggregate deaths will always be the same. What differs is lifespan.

It is increasingly being recognized that reporting the effect as a number of premature deaths is not an appropriate metric for total mortality.[65, 66] Rather, the appropriate metric is the loss of life expectancy (LE).

And the lifespan impact might only be felt in the long run. For example, if the impact of pollution reduction is as described in the previous section—a reduction in frailty—the result might be seen as life extended at its end. For some individuals this may be many years in the future.

For valuing the mortality effects there are two main approaches that are used in the literature:

- Estimating the number of premature deaths and multiplying by a value of statistical life (VOSL or VSL). This is the approach described above as used in New Zealand. The VSL is typically measured using willingness to pay studies, eg through observing the behaviour of individuals and the amount that they are willing to pay to reduce the risk of death, eg through safer cars or wage rates in risky jobs; and

- Reductions in life expectancy, combined with a value of life years lost (VOLL) or values of life years (VOLY). VOLLs/VOLYs have been measured either as a proportion of VSL or through studies which ascertain the willingness to pay for changes in life expectancy.

Given that the impact is better typified as changes in life expectancy rather than “additional deaths”, a VOLY based approach appears to be a better approach. However, the VSL approach has been widely used because it is simple, and because VOLYs are often derived from VSLs anyway. As no empirical data on VOLYs were

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[64] AEA Technology Environment (2005) Methodology for the Cost-Benefit Analysis for CAFE: Volume 2: Health Impact Assessment. Service Contract for Carrying out Cost-Benefit Analysis of Air Quality Related Issues, in particular in the Clean Air for Europe (CAFE) Programme.

[65] Desaigues B, Rabl A, Ami D, Boun My K, Masson S, Salomon M-A and Santoni L (2004) Monetary Valuation of Air Pollution Mortality: Current Practice, Research Needs and Lessons from a Contingent Valuation (www.arirabl.com/papers/MortalVal-Desaigues%20et%20al04.pdf)

[66] Rabl A 2003. "Interpretation of Air Pollution Mortality: Number of Deaths or Years of Life Lost?" *J Air and Waste Management*, Vol.53 (1), 41-50 (2003).

available, the ExternE team calculated the VOLY on theoretical grounds by assuming that VSL is the sum of discounted annual VOLY over 30 to 40 years. [67]

To illustrate the difference in result, AEAT provides the results using VSLs and VOLYs. Because they estimate that each premature death represents a loss of one life year on average, ie people die one year earlier as a result of air pollution, the results are comparable. They note that the saving in life years is approximately 1 year per death. The results are shown in Table 15 converted to New Zealand dollars.

Table 15 Values of Lives Lost from Air Pollution (NZ$)

	VSL	VOLY
Median	$1,781,818	$90,909
Mean	$3,636,364	$218,182

Source: AEA Technology Environment (2005) Service Contract for Carrying out Cost-Benefit Analysis of Air Quality Related Issues, in particular in the Clean Air for Europe (CAFE) Programme. Methodology for the Cost-Benefit Analysis for CAFE: Volume 2: Health Impact Assessment
Converted to NZ$ at NZ$1:€0.55

The recent cost benefit analysis for the air quality strategy used a VSL approach and a value of $1.88million, very close to the median value above. This was derived from work by Transfund on the value of life for accidents, adjusted to reflect the older population likely to die from air pollution.[68]

However, even the VOLY approach is likely to be an over-estimate for the marginal effects because there is an assumption of divisibility of effect. For example, we might assume that as a result of baseline levels of air pollution, those that die prematurely do so one year earlier than otherwise they would. Using a full VOLY value to estimate the effects of a small reduction in pollution and thus an extension in life of a few days or months assumes that the value of an extra day is worth one 365th of a VOLY. However, the studies that exist do not suggest this.

The first survey, to our knowledge, that asked explicitly about the valuation of a gain in life expectancy was by Swedish researchers Johannesson & Johansson. They administered a telephone survey and asked the following question "*The chance for a man/woman of your age to become at least 75 years old is x percent. On average, a 75-year old lives for another 10 years. Assume that if you survive to the age of 75 years you are given the possibility to undergo a medical treatment. The treatment is expected to increase your expected remaining length of life to 11 years. Would you choose to buy this treatment if it costs y and has to be paid for this year?*"[69] The resulting VOLY values are very low, in the range of NZ$1,000 to $2,000.

Values for Analysis

In the analysis of the value of reduction in emissions in the Waikato region a number of issues need to be considered based on the analysis above.

For analysis of the costs of emissions we take a marginal approach, ie we measure the impacts of one more tonne of pollution. The research on causes of death show that there are some acute (sudden) impacts of pollution, but the greatest effects are chronic as a result of increased frailty. So when one more tonne is emitted, the main effect is

[67] Desaigues B, Rabl A, Ami D, Boun My K, Masson S, Salomon M-A and Santoni L (2004) Monetary Valuation of Air Pollution Mortality: Current Practice, Research Needs and Lessons from a Contingent Valuation (www.arirabl.com/papers/MortalVal-Desaigues%20et%20al04.pdf)

[68] Ministry for the Environment (2004) Proposed National Environmental Standards for Air Quality. Resource Management Act Section 32 Analysis of the costs and benefits.

[69] Johannesson M & P-O Johansson 1997. "Quality of life and the WTP for an increased life expectancy at an advanced age". *J Public Economics*, 65, 219-228 in: Desaigues B, Rabl A, Ami D, Boun My K, Masson S, Salomon M-A and Santoni L (2004) Monetary Valuation of Air Pollution Mortality: Current Practice, Research Needs and Lessons from a Contingent Valuation (www.arirabl.com/papers/MortalVal-Desaigues%20et%20al04.pdf)

that people are less frail and will live longer. The effect of small changes in pollution levels is some more life, many years in the future for most of us.

In this context, the approaches used to derive VSLs, such as in the cost benefit analysis of the air quality standard, are an inappropriate basis for valuing this effect. Even if a VSL was available specifically for air pollution, it would be appropriate only for acute mortality, which is a small component of the total impact.[70]

The VOLY approaches come closer to an estimate of the actual effect but even these do not take proper account of the nature of delay and are typically based on VSLs derived from other studies, eg accident costs, which are inappropriate. The Johannesson & Johansson study above is one of the only studies that has directly asked willingness to pay questions that approximate the real impact, and it resulted in a very low estimate.

For analysis here we employ a range of estimates, from the AEAT VOLY estimates at the high end and the Johannesson & Johansson values as an alternative estimate. However, we note that even these may be over-estimates for marginal effects that result in small changes in life expectancy rather than whole years of life saved.

We start with the estimates of damage published by AEAT.[71] Its work on damage costs provides costs on a per tonne basis for a range of pollutants, using the VSL and VOLY data listed in Table 15.

AEAT provides results for each EU member state. The same VOLY value is used for each country but damage cost estimates differ per tonne of pollutant reflecting population density and the geographical spread of the pollutants.

For comparison Figure 7 shows population density of New Zealand and EU Member States. New Zealand has a lower density than all member states. In addition, it is more remote than these countries from surrounding countries. For comparative purposes we use the Finland data as the basis for New Zealand estimates; this is confirmed as appropriate by the EU researchers.[72]

70 Desaigues B, Rabl A, Ami D, Boun My K, Masson S, Salomon M-A and Santoni L (2004) Monetary Valuation of Air Pollution Mortality: Current Practice, Research Needs and Lessons from a Contingent Valuation (www.arirabl.com/papers/MortalVal-Desaigues%20et%20al04.pdf)

71 AEA Technology Environment (2005) Damages per tonne emission of $PM_{2.5}$, NH_3, SO_2, NOx and VOCs from each EU25 Member State (excluding Cyprus) and surrounding seas. Service Contract for Carrying out Cost-Benefit Analysis of Air Quality Related Issues, in particular in the Clean Air for Europe (CAFE) Programme.

72 Paul Watkiss, AEA Technology, personal communication

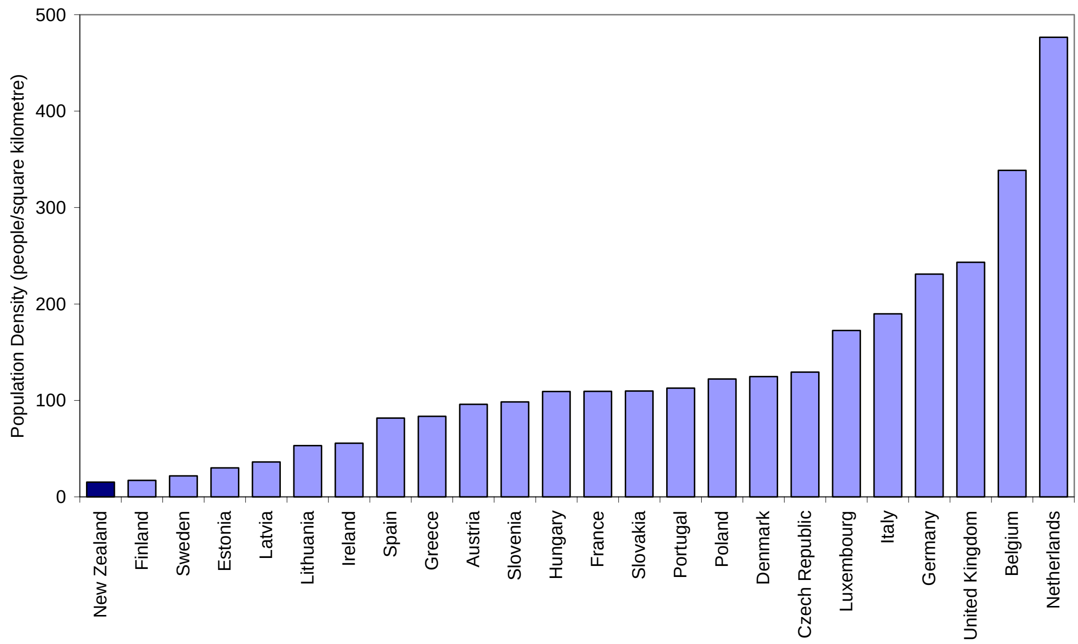

Figure 7 Population Density - NZ and EU Member States

Values of damages for Finland are shown in Table 16.

Table 16 Marginal Damage Costs per Tonne of Emission based on VOLY Estimates (NZ$/t)

	VOLY median	VOLY median Health sensitivity
PM	9818	20000
SO_2	3273	6545
NOx	1364	2727

AEA Technology Environment (2005) Damages per tonne emission of $PM_{2.5}$, NH_3, SO_2, NOx and VOCs from each EU25 Member State (excluding Cyprus) and surrounding seas. Service Contract for Carrying out Cost-Benefit Analysis of Air Quality Related Issues, in particular in the Clean Air for Europe (CAFE) Programme

These numbers are based on assumptions that do not seem credible based on the discussion above. We use two approaches to alter them.

- We assume that the acute effect is 10% of the total effect in the baseline EU analysis. This acute impact is kept constant;[73]
- We spread the effect over a number of years reflecting the delay in impact. For analysis we use the US EPA assumptions.
- We use a value of a life year based on the Johannesson & Johansson work in Sweden, ie a value of $2,000 as opposed to $90,909 (median value).

The modifications apply to the chronic mortality costs of air pollution. The morbidity costs would not change to the same degree. We use AEAT's baseline analysis to estimate the percentage of total costs attributed to mortality versus morbidity; mortality is estimated at 68% of total costs with 28% being morbidity, the remainder includes effects related to ozone and are ignored in our analysis.

Starting with the lower (VOLY median) values above, and taking 28% of these values plus the revised analysis for the mortality effect produces the low estimates shown in Table 17. Alongside this, our high estimate is based on the higher VOLY median with additional health sensitivity from Table 16 above, but with the costs spread over twenty years using the EPA methodology. This gives a very wide spread of possible costs of the different pollutants from $1,012-5,113/t for SO_2 and from $422-2,130/t for NOx. Our

[73] It is based on a 0.75% increase in mortality per 10µg/m^3 increase in PM_{10} concentrations

estimate is that costs are likely to be closer to the low value used here and might be less than this, given the uncertainty in the approach used to delay the benefits.

Table 17 Impacts of Pollutants (NZ$/tonne)

	Low			High		
	Mortality	Morbidity	Total	Mortality	Morbidity	Total
PM	800	2236	3036	11066	4556	15622
SO_2	267	745	1012	3622	1491	5113
NOx	111	311	422	1509	621	2130

Glossary of Terms

Decimal Prefixes

Prefix	Multiplier
Kilo (k)	10^{3}
Mega (M)	10^{6}
Giga (G)	10^{9}
Tera (T)	10^{12}
Peta (P)	10^{15}

Combined Cycle Gas Turbine (CCGT): Turbines, typically fuelled by natural gas, are used to drive generators to produce electricity. The exhaust gases are then passed through a boiler to produce steam that in turn drives an additional turbine coupled to a generator.

Gigajoule (GJ): a unit of energy, equal to one billion (10^{9}) joules.

Kilowatthour (kWh): A unit of electrical energy which equals one kilowatt of power used for one hour.

Megawatthour (MWh): A unit of electrical energy which equals one megawatt of power used for one hour.

Open Cycle Gas Turbine (OCGT): Turbines, typically fuelled by gas or diesel oil, are used to drive the generators to produce electricity

Short Run Marginal Costs (SRMC): Marginal costs are the costs of one extra unit of something, in this case electricity. Short run marginal costs are the costs of generating one more unit (MWh or kWh). They consist of the fuel costs and some other small variable costs.

Long Run Marginal Costs (LRMC): Marginal costs are the costs of one extra unit of something, in this case electricity. Long run marginal costs are the costs of the next plant to come on line. LRMC is equal to the average costs of generation for an expected level of output and will include variable costs (as included in SRMC) plus annual fixed costs (eg labour costs) and the costs of capital.

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