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Environmental costs of electricity generation

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Te Kaunihera ā Rohe o Waikato

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Environmental Costs of Electricity Generation

Prepared for

Waikato Regional Council

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Executive Summary

This report examines the environmental costs of alternative technologies for electricity generation. It is an update to a previous report[1] that provided information on the market and environmental costs. It is intended to provide information to the Waikato Regional Council (WRC) that would inform decisions around policies relating to generation options.

The results are presented differently for existing and new plants.

- For existing plants, the costs of plant construction are already sunk and are unavoidable. The costs of interest to decision making are thus those that relate to continued use only. These are largely the variable costs of generation and they determine whether a plant will operate in the short run.

- For new plants, all costs are avoidable, including the capital costs of plant construction.

For existing plants, we examine the costs for:

- the Huntly stations — the 1,000 MW coal-fired plant, the E3P combined cycle gas turbine (CCGT) and the 40MW gas turbine (GT);

- geothermal, hydro and wind plants.

For new plants, we consider the costs of:

- an advanced CCGT;
- open-cycle gas turbine (OCGT);
- advanced super-critical coal (ASC); and
- geothermal, hydro and wind plants.

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.[2] The environmental effects considered are emissions of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), sulphur dioxide (SO_2), fine particulates (PM_{10}) and nitrogen oxides (NOx).

Total costs for the different pollutants and the other costs of generation, are shown in Figures ES1 and ES2 for existing (variable costs) and new plants (average costs) respectively. We use low cost and high cost assumptions for the different pollutants.

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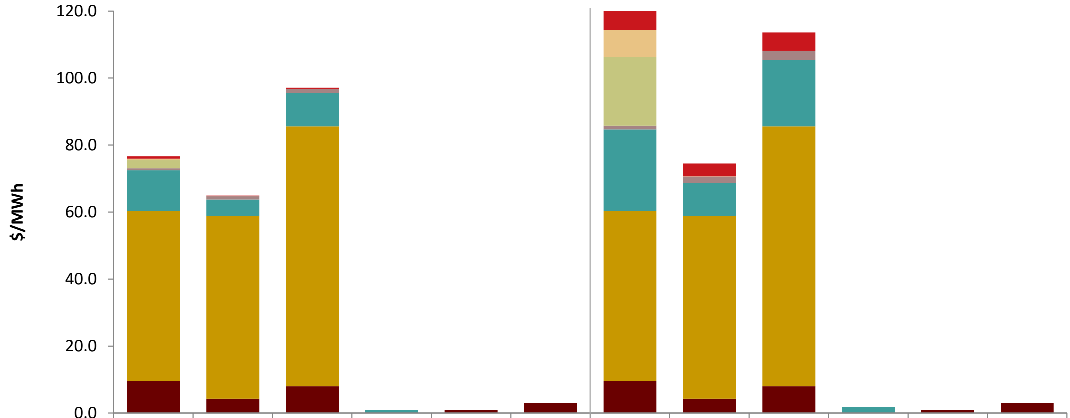
[1] Covec (2006) Environmental Costs of Electricity Generation. Report to Environment Waikato.

[2] We note particularly 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.

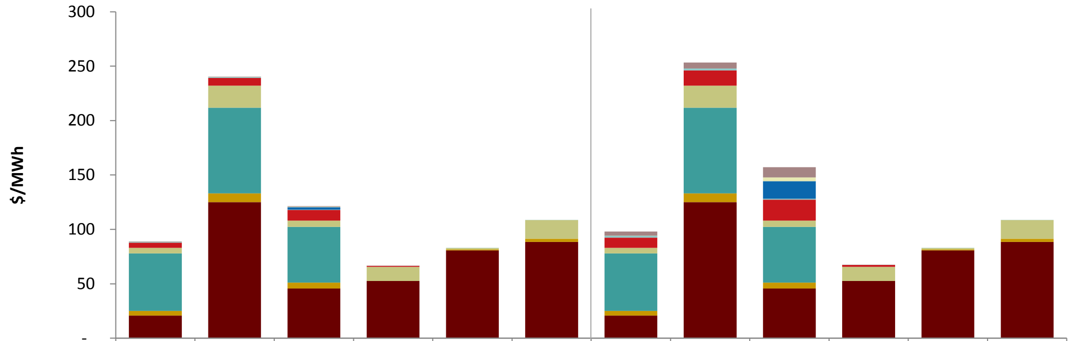
Figure ES1 Avoidable Costs of Existing Plants



	Huntly (Coal) (low)	Huntly (E3P) (low)	Huntly (GT) (low)	Geo-thermal (low)	Hydro (low)	Wind (low)	Huntly (Coal) (high)	Huntly (E3P) (high)	Huntly (GT) (high)	Geo-thermal (high)	Hydro (high)	Wind (high)
Total	76.6	64.9	97.1	0.9	0.9	3.0	126.4	74.5	113.6	1.8	0.9	3.0
NOx	0.7	0.2	0.3	0.0	0.0	0.0	12.0	3.8	5.5	0.0	0.0	0.0
PM10	0.5	0.0	0.0	0.0	0.0	0.0	8.1	0.1	0.1	0.0	0.0	0.0
SO2	2.4	0.0	0.0	0.0	0.0	0.0	20.5	0.0	0.0	0.0	0.0	0.0
CO2-other	0.6	1.0	1.4	0.0	0.0	0.0	1.2	1.9	2.7	0.0	0.0	0.0
CO2-comb	12.2	4.9	9.9	0.9	0.0	0.0	24.4	9.9	19.8	1.8	0.0	0.0
Fuel	50.7	54.5	77.6	0.0	0.0	0.0	50.7	54.5	77.6	0.0	0.0	0.0
VOM	9.6	4.3	8.0	0.0	0.9	3.0	9.6	4.3	8.0	0.0	0.9	3.0

Notes: CO2-comb = CO_2 from combustion; VOM = variable operating and maintenance costs

Figure ES2 Components of Average Costs for New Plants



	CCGT (low)	OCGT (low)	Coal (ASC) (low)	Geo-thermal (Med) (low)	Hydro (Med) (low)	Wind (low)	CCGT (high)	OCGT (high)	Coal (ASC) (high)	Geo-thermal (Med) (high)	Hydro (Med) (high)	Wind (high)
Total	89	240	121	67	83	109	98	253	157	68	83	109
NOx	0.2	0.3	1	-	-	-	4	5	9	-	-	-
PM10	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	3.4	0.0	0.0	0.0
SO2	-	-	2	-	-	-	-	-	16	-	-	-
CO2-other	1	1	0	0	0	0	2	2	1	0	0	0
CO2-Comb	5	7	10	1	-	-	9	14	19	2	-	-
FOM	5	20	6	13	1	17	5	20	6	13	1	17
Fuel	53	79	51	-	-	-	53	79	51	-	-	-
VOM	4	8	5	-	1	3	4	8	5	-	1	3
Capex	21	125	46	53	81	88	21	125	46	53	81	88

Notes: CO2-comb = CO_2 from combustion; VOM = variable operating and maintenance costs; FOM = Fixed operating and maintenance costs

1 Introduction

This report examines the environmental costs of alternative technologies for electricity generation. It is an update to a previous report[3] that provided information on the market and environmental costs. It is intended to provide information to the Waikato Regional Council (WRC) that would inform decisions around policies relating to generation options.

1.1 Scope

The report aims to provide technical information both to assist WRC 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.[4]

The previous (2006) study examined a limited number of costs. It included private costs of electricity generation based on recent studies undertaken for the Ministry of Economic Development (MED). The environmental effects were limited to emissions of CO_2, CH_4, N_2O, SO_2 and NOx. Since this publication there have been changes in the policy setting for greenhouse gas emissions that changes the nature of the costs of these emissions. In addition, there have been new studies that have examined the costs of individual pollutants, especially particulates. This report summarises this new information.

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.[5]

1.2 Rationale

WRC 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.[6] 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

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[3] Covec (2006) Environmental Costs of Electricity Generation. Report to Environment Waikato.
[4] Particularly in the context of the National Environmental Standards for Electricity Transmission – see: MfE (2007) Proposed National Environmental Standards for Electricity Generation.
[5] We note particularly 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.
[6] That is the impacts with respect to social, economic, environmental and cultural well-being.

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.

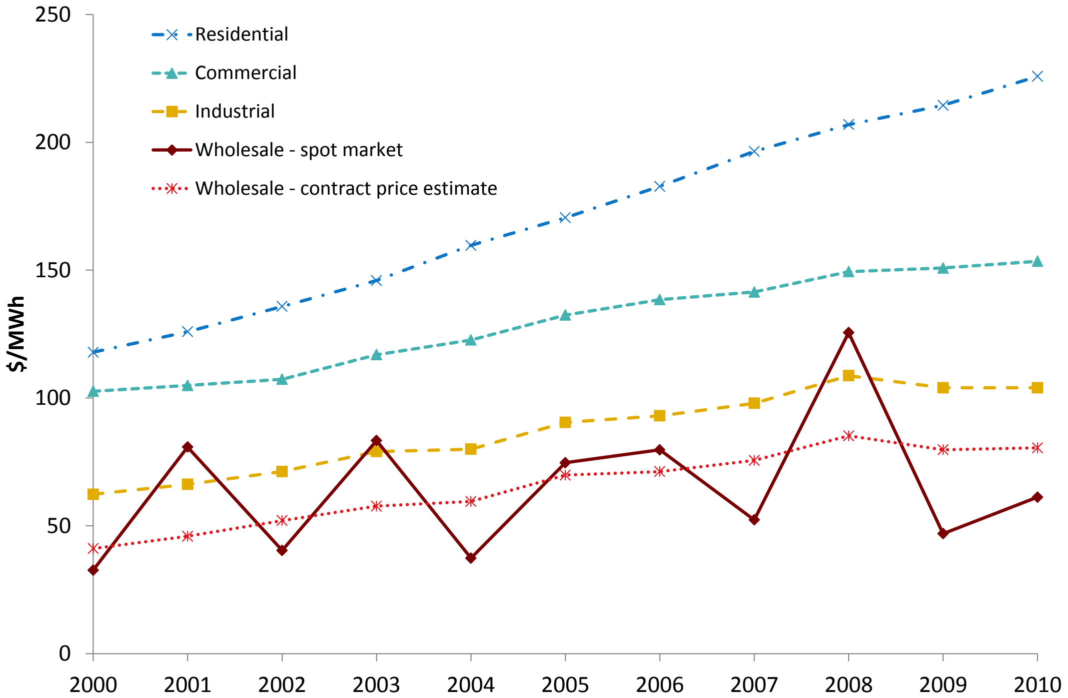
The report is divided into two main sections. The first (Section 2) compiles data on the costs to private developers of operating existing plants and of commissioning new plants. This will include some costs of environmental controls required by legislation. The next section (Section 3) reports on the 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

2.1 Structure of Electricity Costs

There are a number of components to consumer electricity prices. Figure 1 shows the annual average wholesale spot prices of electricity, estimated contract prices and average customer prices (excluding GST). The gap between the wholesale price and the customer (consumer) prices is the costs of transmission, distribution and retailing. Spot prices vary widely on an annual basis reflecting the availability of hydro water because of hydrological conditions. Most electricity is sold with associated hedge contracts (contracts for differences) which protect both buyers and sellers from this volatility. The spot price is taken from Electricity Authority (EA) data,[7] using annual average prices at the Haywards node; contract price estimates are taken from MED data – we have used the industrial price estimates less the quantity that MED estimates is attributable to lines charges (transmission and distribution).

Figure 1 Wholesale prices compared to customer prices



Source: Wholesale spot prices from Electricity Authority Centralised Dataset; Customer prices and estimated contract prices from MED Energy Data File 2011 (adjusted for GST).

Our discussion in this report is focussed solely on the costs of electricity generation.

[7] It uses the EA's Centralised Dataset (see www.ea.govt.nz/industry/modelling/cds/centralised-dataset-web-interface/wholesale-prices-mean-price/)

2.2 Generation Costs and Wholesale 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:

- 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 achieve prices that reflect short run marginal costs of production (SRMC). Generators with more than 10MW of capacity, or that are grid connected, compete in the electricity spot market. Generators submit offers to generate a specified quantity of electricity in a future half-hour trading period in return for a nominated price.[8] The system operator (Transpower) ranks the offers in order of price and selects the lowest cost combination of resources to satisfy demand at every grid exit point. The highest-priced generator that has a bid accepted for a given half-hour usually determines the spot price for that trading period. Prices differ significantly over time with levels of demand, reflecting the generation mix that is required, including low cost hydro generation and high cost thermal plants. Spot prices can also vary significantly by location, reflecting electrical losses and constraints on the transmission system, with higher prices in locations further from generating stations.

Separate prices are set at each of approximately 248 nodes (grid injection points and grid exit points) every half-hour.[9] Final prices at each node, taking account of grid losses and constraints, are processed and confirmed on an interim basis the following day and confirmed as final prices the day after.

In a competitive market, SRMC is the price at which a generator is willing to produce another unit of electricity. It is equivalent to the variable costs of generation, which are largely fuel costs (for thermal plants) and some other operational and maintenance costs. Plants have additional costs that do not vary with the amount generated and these will need to be recovered through sales of electricity from a plant at a price above its SRMC. For existing plants, we report both SRMC and average costs, including these fixed annual costs.

For new plants, considering entering the market, they will only enter if they can obtain a return that is at least as high as their variable costs and full fixed costs, including a return on capital employed. This is the long run marginal cost, ie the cost of another unit of electricity in the long run when new capital is required in order to generate. These costs are discussed in Section 2.4 below.

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[8] This description is adapted from: Electricity Authority (2011) Electricity in New Zealand

[9] Generators make offers to supply electricity at 52 grid injection points (GIPs) at power stations, while retailers and major users make bids to buy electricity at 196 grid exit points (GXPs) on the national grid.

Table 1 describes the different elements of costs and their relevance to plant operation.

Table 1 Categories of Cost

Cost Type	Description	Requirement
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	Electricity price must be equal to or exceed these costs at all times (every half hour) that a plant generates
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	Electricity prices must be equal to or exceed these costs, on average, over a short period, eg one year
Capital costs	The costs of plant construction and grid connection	Electricity prices must be equal to or exceed these costs, and those above, on average over the life of the plant

2.3 Existing Plants

In this section we examine the costs of existing plant in the Waikato region. In the next Section we examine the costs of new plant. Waikato regional electricity plants include:[10]

- A complex of thermal plants at Huntly including a large coal-fired plant, a gas-fired peaker and a combined cycle gas turbine;
- Hydro plants on the Waikato and Tongariro rivers;
- Geothermal plants making up approximately 80% of New Zealand's total;
- Cogeneration plants; and
- Wind (Te Uku).

We examine the specific costs of the thermal plants, and the other plants using generic cost data.

2.3.1 Thermal Plants

The variable or short run marginal costs (SRMC) of a plant determine the way in which it is dispatched in a competitive market.[11]

Estimates of the variable costs of generation for different plant types are provided in Table 2 on the basis of published data. These are made up of some operating and maintenance costs, but are dominated by fuel costs. The cost estimates here do not include costs of emission units, despite the fact that these will be included in the costs of fossil fuels; we discuss these in a later section.

Within the Waikato region, there are currently three thermal plants at Huntly:

- a 1000MW pulverised coal plant;
- a 40MW open cycle gas turbine (OCGT) plant and
- a combined cycle gas turbine (CCGT) plant named E3P.

[10] Waikato Regional Energy Forum (undated) Waikato Regional Energy Strategy

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

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

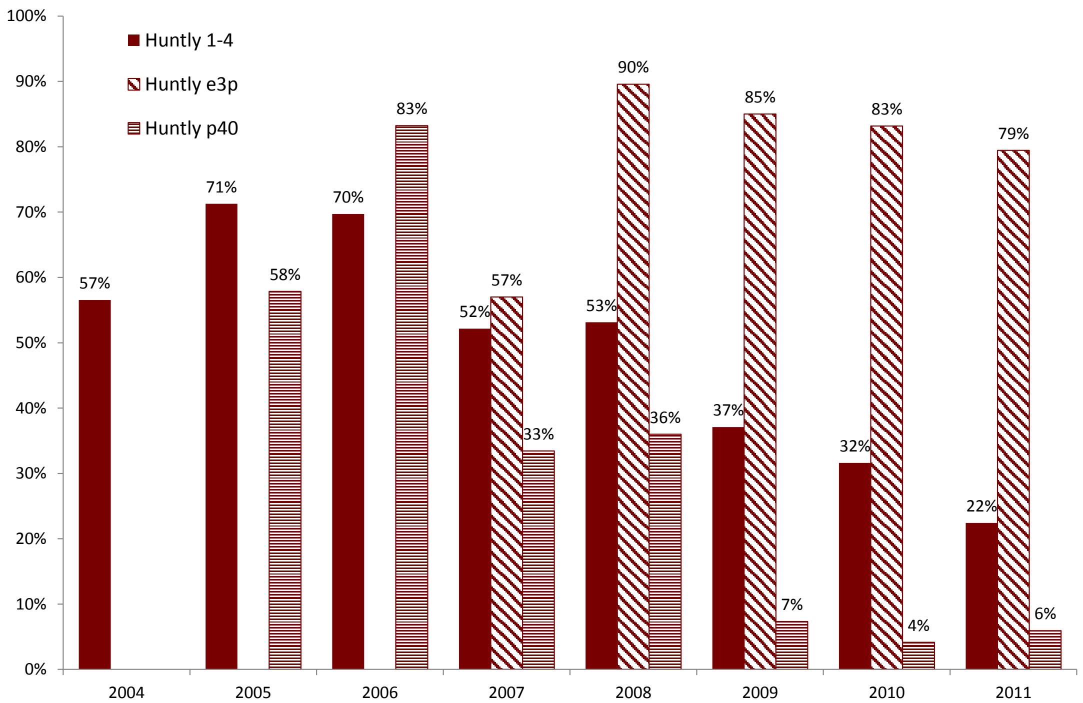
Plant	Fuel	Efficiency (GJ/MWh)	VOM[1] ($/MWh)	Fuel ($/GJ)	SRMC ($/MWh)
Huntly coal units 1-4	Coal	10.90	9.6	4.65	60
Huntly unit 5 (e3p)	Gas	7.40	4.3	7.37	59
Huntly unit 6 (P40)	Gas/diesel	10.53	8	7.37	86

[1] VOM = variable operating and maintenance costs

Source: PB (2012) 2011 NZ Generation Data Update. Report to the Ministry of Economic Development; coal costs from Denne T (2011) Coal Prices in New Zealand Markets: 2011 Update, Covec ; Gas prices from MED (2011) Energy Data File 2010 Calendar Year Edition

In addition to these variable costs that determine short run willingness to generate, there are fixed annual operating and maintenance costs that need to be recovered. These costs relate to the size of the plant rather than its level of activity and must be recovered from the amount generated and the market price at which they can sell. To estimate these we also make assumptions about the utilisation rates of the individual plants.

Figure 2 Utilisation rates of Waikato thermal plants



Source: generation data from Electricity Authority Centralised Dataset

We used the average utilisation over the last five years in Table 3 to estimate the fixed operating and maintenance (FOM) costs and we add these to the SRMC to estimate the average costs. Average costs are what the plant needs to recover to stay in business but they do not determine the offer price of the plant.

Table 3 Estimate of plant average costs of generation

Plant	Capacity (MW)	FOM[1] ($/KW/year)	Assumed utilisation (%)	FOM ($/MWh)	AC[2] ($/MWh)
Huntly coal units 1-4	1000	70	39%	20	81
Huntly unit 5 (e3p)	385	35	79%	5	64
Huntly unit 6 (P40)	44	16	17%	11	96

[1] FOM = fixed operating and maintenance costs; [2] AC = Average Costs

Source: PB (2012) 2011 NZ Generation Data Update.

2.3.2 Other Plants

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. Estimates of variable and fixed operating and maintenance costs are given in Table 4. Average costs for these plants, as calculated above for the existing thermal plants, are estimated in Section 2.4 below and included in Table 5.

Table 4 Short run costs for non-thermal plants

Plant type	VOM ($/MWh)	FOM ($/kW/year)
Hydro	0.86	6.38
Wind	3	10-50 MW = 70 51-150 MW = 60 >151 MW = 50
Geothermal	~0	105

Source: PB (2012) 2011 NZ Generation Data Update

2.4 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, also defined as the long run marginal cost (LRMC), it is the long run cost of generating another unit of electricity.

Cost estimates are given in Table 5. The plants considered include a number of technologies for gas and coal-fired thermal plants, plus different sizes of hydro, wind, geothermal and marine energy technologies. An 8% discount rate is used in analysis to convert capital costs to annualised costs, including the costs of grid connections. The original data include some capital costs in international currencies (US dollars, Euros and Japanese Yen); we have used the conversion rates included in the PB report.[12]

PB notes that no new large hydro schemes are considered viable in the Waikato because the Waikato River is already fully used for hydro and all other large rivers with suitable gradient have environmental and amenity issues associated with them. Nevertheless, we have included PB's estimates of generic costs for hydro plants.

[12] PB (2012) 2011 NZ Generation Data Update

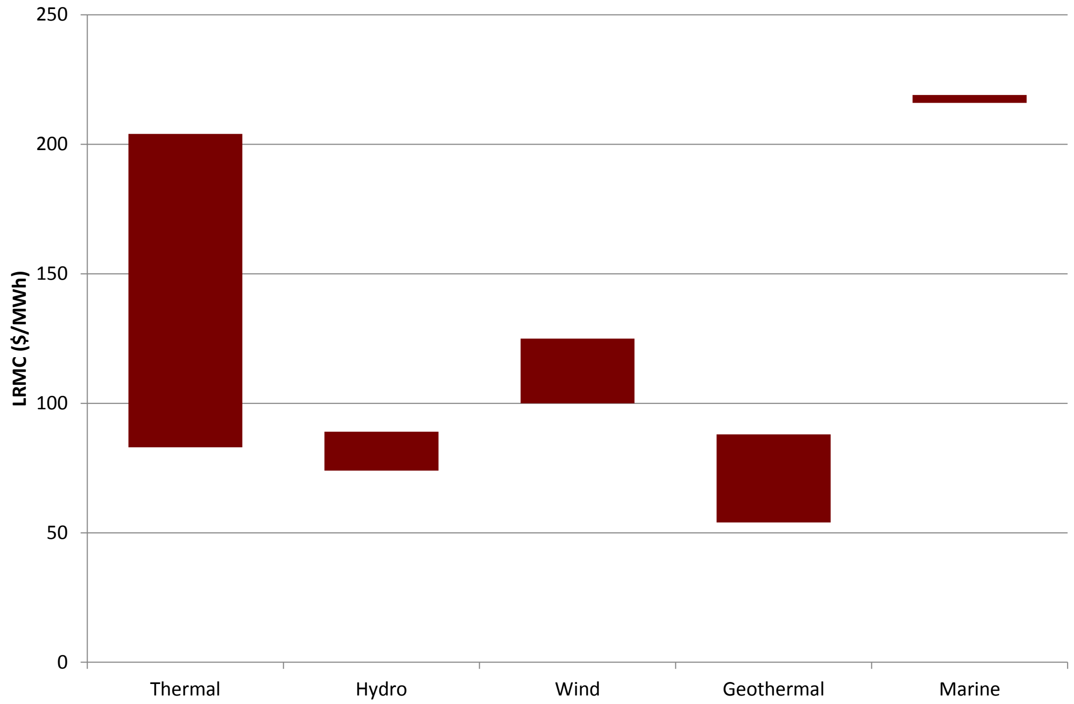
Table 5 Costs and other assumptions for generic new plant

Plant type	Fuel	Assumed capacity (MW)	Years	Heat rate (GJ/MWh)	Capex ($/kW)	VOM ($/MWh)	FOM ($/kW/yr)	Utilisation (%)	Lines connection ($M)	Fuel ($/GJ)	LRMC @ 8% ($/MWh)
Thermal											
CCGT	Gas	475	35	7.05	1,615	4.3	35	77	15	7.5	83
OCGT	Gas	200	30	10.5	1,100	8	16	9	10	7.5	232
ASC	Coal	560	45	8.56	3,712	5.4	38.9	77	15	6	108
ASC + CCS	Coal	440	40	11.83	6,269	18.5	65.1	76	15	6	178
IGCC	Coal	720	35	8.38	4,786	15.1	85.5	75	15	6	141
IGCC + CCS	Coal	570	30	11.56	6,753	23.5	122	74	15	6	204
Hydro											
Medium run of river		50	50		4,665	0.86	6.38	54	7.2		83
Medium dam and reservoir		150	80		5,102	0.86	6.38	54	14.1		89
Large dam and reservoir		450	80		4,187	0.86	6.38	54	21.5		74
Wind											
Small		10-100	25		3,825	3	70	40	8.75		125
Medium		101-300	25		3,291	3	60	40	18		109
Large		>301	25		3,068	3	50	40	25.2		100
Geothermal											
Small		<50	40		7,205	0	105	92	2.5		88
Medium		51-100	40		5,050	0	105	92	5		66
Large		>101	40		3,939	0	105	92	7.5		54
Marine											
Tidal/Wave small		10	20		5,717	0	100	29	9		269
Tidal/Wave medium		50	20		4,885	0	90	29	9		232
Tidal/Wave large		200	20		4,572	0	80	29	18		216

Notes: VOM = variable operating and maintenance costs ; FOM = fixed operating and maintenance costs ; LRMC = Long Run Marginal Costs; CCGT = Combined Cycle Gas Turbine; OCGT = Open Cycle Gas Turbine; ASC = Advanced Supercritical; CCS = Carbon Capture and Storage; IGCC = Integrated Gasification Combined Cycle
Assumptions: Cost of capital = 8%; exchange rates used: US$0.66:NZ$1, €0.47:NZ$1, ¥72:NZ$1 (based on PB assumptions – some capital costs are expressed in other currencies)
Source: Parsons Brinckerhoff (2012) 2011 NZ Generation Data Update; Covec fuel cost assumptions; Covec calculations of LRMC

The costs of the individual technologies vary with the assumed plant size. The entry costs (LRMC) estimates are presented in Figure 3 with costs grouped under broad categories of plants. Where suitable sites exist, geothermal and hydro plants can be very low cost. The costs of thermal plants vary widely with size and efficiency, with the highest costs associated with low capital cost, low efficiency peaking plants. Wind power costs are higher than hydro and geothermal, and costs vary with wind speeds. At this stage there are few estimates of the costs of marine technologies and they appear to be very expensive.

Figure 3 Cost Ranges for New Entrants



Source: Table 5

3 Costs of Emissions to Air

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 those from electricity generation via the inclusion of fossil fuels in the emissions trading scheme (ETS). From 1 July 2010 the energy sector is included in the ETS through the introduction of obligations to surrender emission units on those:

- coal and/or gas importers or miners; and
- users of geothermal fluid for generating electricity or industrial heat.

Electricity generators can 'opt-in' to hold the ETS obligations themselves if they purchase more than 250,000 tonnes of coal in a year or more than 2 PJ of natural gas.[13]

3.1.1 CO_2 Emission Rates from Generation

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 emissions factor for sub-bituminous coal combustion is 89.4kt CO_2/PJ (after oxidation).[14] 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 10.9GJ/MWh for Huntly coal based on PB's data (Table 2), equivalent to an efficiency of 33%. The resulting emissions factor for Huntly coal plant on an output basis is thus 0.974t CO_2/MWh. For new coal plant we use the efficiencies listed in Table 5.

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.

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[13] www.climatechange.govt.nz/emissions-trading-scheme/participating/energy/obligations/

[14] MED (2008) New Zealand Energy Greenhouse Gas Emissions 1990-2007; and calculated from MED Energy Greenhouse Emissions 2011 web tables at: www.med.govt.nz/sectors-industries/energy/energy-modelling/publications/energy-greenhouse-gas-emissions

[15] emissions per unit of fuel input

[16] emissions per unit of electrical output

The current weighted average estimated emissions factor for gas is 53.3kt CO_2/PJ.[17] This is combined with the conversion efficiencies (Table 2 and Table 5) to estimate emissions per MWh.

Wood Waste

The CO_2 emission factor for wood combustion is 104.2 kt CO_2/PJ.[18] 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.

Recently it has been agreed internationally to change the approach to measuring emissions associated with forestry and forest products to take account of the carbon stored in products; this would apply for the period after 2012, ie for any successor agreement to the Kyoto Protocol. [19] The default position is still that accounting is on the basis of instantaneous emissions, but a country can use harvested wood product (HWP) accounting where it has transparent and verifiable activity data for three product categories (paper, wood panels and sawn wood). For these three products emissions would be counted as occurring over time using a decay function.[20]

Wood used for energy purposes would still be assumed to result in instantaneous emissions as it is currently. Thus this change in approach, if adopted by New Zealand, does not change the measurement of emissions from bio-fuels. However, it is likely to change their relative costs. The value of wood in alternative uses, ie incorporation into products, would rise relative to the use of wood as a fuel because of the value of delaying emissions owing to the time value of money.

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

[17] See MED Energy Greenhouse Emissions 2011 web tables at: www.med.govt.nz/sectors-industries/energy/energy-modelling/publications/energy-greenhouse-gas-emissions

[18] MED (2008) New Zealand Energy Greenhouse Gas Emissions 1990-2007

[19] Decision CMP.7 Land use, land-use change and forestry. Annex I Definitions, modalities, rules and guidelines relating to land use, land-use change and forestry activities under the Kyoto Protocol. FCCC/KP/AWG/2011/L.3/Add.2 (http://unfccc.int/resource/docs/2011/awg16/eng/l03a02.pdf)

[20] The emissions are based on the following decay function: $Ct = Co * \exp(-(\ln(2)/H)*t)$
Where Co = initial carbon stock; Ct = carbon stock at time t (years); H = wood product half life in years; t = time (years). Half lives are assumed to be 35 years for sawn wood, 25 years for panel products and 2 years for pulp and paper

have used a weighted average emission factor of 73g CO_2/kWh (Table 6). This is equivalent to 3.04t CO_2/TJ at an assumed 15% efficiency.

Table 6 CO_2 Emission Rates from Geothermal Fields

Geothermal Field	GWh	CO2 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]

[1] Weighted average using GWh of generation for each station as reported by East Harbour
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 (2006) Environmental Costs of Electricity Generation. Report to Environment Waikato.

3.1.2 Life Cycle Emission Rates

In addition to generation, emissions are generated during other components of the life cycle of a plant. This includes generation during construction (eg associated with cement manufacture) and with the fuel cycle, including production, storage and processing. We present the results from recent US studies in Table 7.

Table 7 Contribution of Life Cycle Elements to Total Life-Time Emissions – US study results (%)

	Coal	Coal[1]	CCGT	CCGT[1]	Geo-thermal EGS[2]	Geo-thermal Flash[3]	Hydro	Wind	Biomass
Construction, Infrastructure	0.1	0.1	0.1	0.4	100.0	4.0	100	100	0.5
Fuel production & transport	4.1	1.8	13.8	17.9	-	-	-	-	64.2
Fuel use	95.9	98.1	86.1	81.7	-	96.0	-	-	35.3
Total	100	100	100	100	100	100	100	100	100

Source: Unless otherwise stated = Sullivan JL, Clark CE, Han J and Wang M (2010) Life-Cycle Analysis Results of Geothermal Systems in Comparison to Other Power Systems. Energy Systems Division, Argonne National Laboratory. ANL/ESD/10-5; [1] Meier P (2002) Life-Cycle Assessment of Electricity Generation Systems and Applications for Climate Change Policy Analysis. Fusion Technology Institute, University of Wisconsin, Madison. UWFDM-1181
[2] Enhanced Geothermal System - uses low temperature geothermal fluids and requires pumping during production; [3] high temperature geothermal fluids produced at natural pressure.

Coal

Coal plants are dominated by fuel use but there are emissions from fuel production and transport also. This includes methane released during coal mining and transport emissions. The coal mining emissions (as methane) are estimated in Section 3.2 below. Transport is the other element included in these studies. For example, Spath et al,[21] one of the studies used as an input to the meta-analyses reported in Table 7, estimates that 65% of the fuel production and transport emissions are from the transportation element.

On average, US coal plants are using coal that is shipped for much larger distances that is undertaken in the Waikato where the Huntly plant is very close to the coal fields providing the fuel; the coal is transported by overland conveyor approximately 10km

[21] Spath PL, Mann MK and Kerr DR (1999) Life Cycle Assessment of Coal-fired Power Production. National Renewable Energy Laboratory. NREL/TP-570-25119

from Rotowaro. Some coal is imported to supply the Huntly plant and there will be larger emissions associated with that transport. The amount imported differs by year; for example, approximately 51% of its consumption was imported in 2009 but only 26% in 2008 and 32% in 2010.[22] Thus the transport emissions component will vary by year.

To estimate the impacts for Huntly, we provide data in Table 8.

Table 8 Impact of CO_2 Cost of Domestic Transport on Costs of Coal

Component	Value
A Coal price ($/GJ)	5.92[1]
B Transport costs as % of coal price	18%[1]
C Fuel costs as % of transport costs	15%[2]
D Fuel costs ($/GJ) (A × B × C)	0.16
E Fuel price ($/litre)	1.5[3]
F Fuel (litre/GJ) (D ÷ E)	0.11
G Emission factor (kg CO_2/litre)	2.68[4]
H Imported coal (% of total)	40%[5]
I Transport emissions – average emission factor (kg CO_2/GJ) (F × G × H)	0.12
J % of combustion emissions	0.13%[6]

Source: [1] Table 4 in Denne T (2011) Coal Prices in New Zealand Markets: 2011 Update, Covec ; [2] Rural North estimates in Table 2 of Ministry of Transport (2010) Understanding Transport Costs and Charges. Phase two – Transport costs in freight logistics; [3] MED Oil Prices Monitoring Report; [4] Assumes 38.45MJ/litre (MED Energy Data File 2011) and 69.6kg CO_2/GJ (MED 2011 New Zealand Energy Greenhouse Gas Emissions Table 6.1); [5] Assumption based on history; [6] % of 89.4 (Table 12)

The emission rates relating to domestic transport are very low. In contrast, Table 9 estimates the CO_2 emissions relating to the international freight component. It is a much more significant component, with transport emissions for the coal imported being approximately 12% of combustion emissions, or averaging 4.7%, taking account of the estimate that 40% of coal is imported. This is slightly above the higher of the two estimates for the US (4.3%).[23]

Table 9 Estimated CO_2 Contribution of International Freight

Component	Value
A Ship Tonnage	35,000[1]
B Energy value of coal (GJ/t)	22[2]
C GJ imported (A ×B)	770,000
D Fuel consumption (tonnes/day)	200[3]
E Days from Indonesia	12.7[4]
F Energy content (light fuel oil MJ/kg)	43.7[5]
G Fuel consumption (GJ) (D × E × F)	110,998
H Emission factor (kg/GJ)	72.13[6]
I Emissions (tonnes) (G × H)	8,006
J Transport CO_2 (kg CO_2/GJ of coal imported)	10.40
K Imported coal (% of total)	40%[7]
L % of combustion emissions ((J × K)) ÷ 89.4)[8]	4.7%

Source: [1] Port of Tauranga (2012) Port Operational Information; [2] Table 4 in Denne T (2011) Coal Prices in New Zealand Markets: 2011 Update, Covec; [3] Ports of Auckland Ltd (personal communication); [4] Estimated from: http://sea-distances.com/; [5] MED Energy Data File 2011; [6] MED (2008) New Zealand Greenhouse Gas Emissions 1990-2007; [7] Assumption based on historical data; [8] Table 12

[22] Denne T (2011) Coal Prices in New Zealand Markets: 2011 Update, Covec

[23] As a percentage of combustion emissions, ie 4.1%/95.9%

We do not have information on the electricity requirements for the conveyor, but it is likely to be very small compared with these other contributions. In total, emissions relating to transport add to approximately 4.8% of combustion emissions, with those associated with construction adding a further 0.1% (Table 7). The transport emissions would apply to the existing plant (Huntly coal) and transport plus construction emissions to new coal plants.

This suggests that the transport CO_2 costs would be equivalent to an approximate 0.05% increase in the average costs of coal at Huntly.

Gas

The Gas leakage rates during transmission are estimated in Section 3.2. Additional emissions attributable to the fuel cycle in the US studies (Table 7) include those associated with original exploration, production, storage, processing and transmission.[24] This includes CO_2 released in the manufacture of steel pipes and the electricity consumption of compression stations. The complexities of this analysis are beyond the scope of this review. We use the average of the US results as the basis of our estimates here but note that these are highly uncertain for application in New Zealand.

However, the gas transport emissions in Table 7 are largely those of pipe construction and given that the duration of a pipe is likely to be similar to that of a generation plant, we do not include these additional costs of CO_2 for existing plants.

Other Technologies

As for gas, for the other technologies, we use the US results. This includes geothermal analysis based on Flash technology (Table 7). As for gas, the emissions apply to new plants only.

Summary

We summarise the assumptions for all technologies in Table 10. The output emission estimates for the fossil fuel plants are based on the efficiencies (heat rates) in Tables 2 and 5.

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[24] Meier P (2002) Life-Cycle Assessment of Electricity Generation Systems and Applications for Climate Change Policy Analysis. Fusion Technology Institute, University of Wisconsin, Madison. UWFDM-1181

Table 10 Estimated Life Cycle Emissions of CO_2 for Different Generation Fuels and Technologies

	Combustion emissions[1]	Construction, Infrastructure	Fuel production and transport	Total
Inputs (kg/GJ)				
Coal	89.4	0.05	4.3	93.7
Gas	53.3	0.1	10.0	63.5
Outputs (kg/MWh)				
Coal - Huntly	974	1	47	1,022
Coal - new (ASC)	765	0.5	37	802
Gas - E3P	394	1	74	470
Gas - Huntly GT	561	2	106	668
Gas - new CCGT	376	1	71	448
Gas - new OCGT	560	2	106	667
Geothermal[2]	73[3]	3	-	76
Hydro[2]	-	5	-	5
Wind[2]	-	8	-	8

Source: [1] MED (2008) New Zealand Energy Greenhouse Gas Emissions 1990-2007; and calculated from MED Energy Greenhouse Emissions 2011; [2] Meier P (2002) Life-Cycle Assessment of Electricity Generation Systems and Applications for Climate Change Policy Analysis. Fusion Technology Institute, University of Wisconsin, Madison. UWFDM-1181; [3] Table 6

3.1.3 CO_2 Costs

Estimates have been made of the damage costs of greenhouse gases—the social costs of carbon.[25] However, these do not represent the costs to New Zealand or the Waikato. CO_2 has no local effects at the concentrations emitted; rather it is a global pollutant, and the impacts of emissions from the Waikato, on communities in the Waikato region or on New Zealand, will be very small. CO_2, and other greenhouse gases, have global effects because it 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.

The costs to New Zealand of emissions of CO_2 and other greenhouse gases are the costs of compliance with international agreements to which New Zealand has agreed to be bound. Currently these costs are relatively low because the limited number of countries involved has limited demand for emission units, plus the relatively low barriers to producing some emission units, particularly certified emission units (CERs) under the Clean Development Mechanism (CDM). Covec estimated future international carbon prices using a variety of methodologies; this resulted in a range of estimates that varied with the level of global ambition in greenhouse gas emission reduction. The "best guess" cost for 2020 under medium levels of ambition was $50/tonne (Table 11). In the short run the costs will be less than this; we assume a cost of $25/tonne consistent with the assumptions used by MED in its Energy Outlook Reference Scenario.[26]

[25] See discussion of these in Covec (2010) Carbon Price Forecasts. Report to Parliamentary Commissioner for the Environment

[26] MED (2011) New Zealand's Energy Outlook 2011 Reference Scenario and Sensitivity Analysis

Table 11 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

Source: Covec (2010) Carbon Price Forecasts. Report to Parliamentary Commissioner for the Environment

The resulting impacts on SRMC of combustion emissions for existing plants are shown in Table 12 and the effects on a number of new plant types are shown in Table 13; those with no carbon emissions (hydro, wind, marine) are not included. The emissions associated with the fuel cycle are included in the summary in Section 4.

Table 12 Impact of Carbon Price on SRMC

Plant	SRMC ($/MWh)	Heat rate (GJ/MWh)	kg CO_2/GJ	tCO_2/MWh	CO_2 cost ($/MWh)	SRMC incl CO_2 ($/MWh)
Huntly coal units 1-4	60	10.9	89.4	0.974	24	84
Huntly unit 5 (e3p)	59	7.4	53.3	0.394	10	69
Huntly unit 6 (P40)	86	10.53	53.3	0.561	14	100

Table 13 New plant LRMC including carbon cost

Plant type	Fuel	LRMC ($/MWh)	Heat rate (GJ/MWh)	CO_2 (kg/GJ)	tCO_2/ MWh	CO_2 cost ($/MWh)	LRMC incl CO_2 ($/MWh)	% increase
CCGT	Gas	83	7.05	53.3	0.376	9	92	11%
OCGT	Gas	232	10.5	53.3	0.560	14	246	6%
ASC	Coal	108	8.56	89.4	0.765	19	127	18%
Medium Geothermal		66			0.073	2	68	3%

The most significant impact is on coal plants as coal has a high carbon content—considerably higher than for gas. Geothermal plants have CO_2 mixed with the steam.

3.2 Methane (CH_4) and Nitrous Oxide (N_2O)

3.2.1 Emission Rates

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.

CH_4 is emitted as a fugitive emission during coal mining (Table 14) and this adds to the quantity emitted in combustion. Fugitive emissions of gas 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. There are additional methane and nitrous oxide emissions from fuel combustion. These are shown in Table 15.

Table 14 Fugitive emissions from coal mining

	kg/t	MJ/kg	kg/GJ	Kg CO_2-e/GJ
Mining	0.77	22	0.035	0.735
Post-mining	0.07	22	0.003	0.067

Source: MfE (2011) New Zealand's Greenhouse Gas Inventory 1990–2009

Table 15 CH_4 and N_2O Emission Factors - Combustion

	t/PJ	kg/GJ	Kg CO_2-e/GJ
Natural gas - methane	0.09	0.00009	0.00189
Natural gas – N_2O	0.09	0.00009	0.0279
Coal – methane	0.67	0.00067	0.01407
Coal - N_2O	1.5	0.0015	0.465

Source: MED (2008) New Zealand Energy Greenhouse Gas Emissions 1990-2007

In total these emissions are very low on a per GJ basis and, at $25/tonne of CO_2, the highest cost element is the methane emissions from mining, totalling approximately $0.01/GJ. We ignore these effects in analysis.

Methane is released from the decay of vegetation when a hydro lake is initially formed. However, in this report we have restricted our analysis to run of river hydro as the most likely design of new plants in the Waikato region.

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.[27] That for wood waste and for sub-bituminous coal is taken from the national greenhouse gas inventory; we use the same values as in our previous report (Table 16).

Table 16 SO_2 Emission Factors

	t SO_2/PJ	Kg SO_2/GJ
Coal - sub-bituminous	387.2	0.387
Wood	331.1	0.331

Source: MfE www.mfe.govt.nz/publications/climate/nir-apr05/a81-worksheets-energy-sector.pdf

[27] Approximately 0.00025kg/GJ using US data in Table 1.4-2 in US EPA (1998) Emissions Factors & AP 42, Compilation of Air Pollutant Emission Factors (www.epa.gov/ttnchie1/ap42/ch01/final/c01s04.pdf).

3.3.2 Emission Impacts

SO_2 can have direct health effects. Previously we had noted that it is not clear that this effect is measurable, but recent analysis by the US EPA has concluded that "following an extensive analysis of health evidence from epidemiologic and laboratory studies, the US EPA has concluded that there is a causal relationship between respiratory health effects and short term exposure to SO_2."[28] However, the direct effects are regarded as minor in New Zealand compared to the indirect effects.[29] More importantly, SO_2 has secondary effects as it combines with other molecules to form sulphate aerosols (a small particulate); in other countries SO_2 also produces sulphuric acid in the atmosphere (acid rain), but there is no evidence of acidification effects in New Zealand and we ignore these effects.

The European work under ExternE and the more recent work for CAFE quantifies the sulphate aerosol effects; questions have been asked about the extent of the sulphate impact. As AEA Technology notes[30]:

> *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.

In this report we limit our analysis to 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[31] notes the presence of sulphates; citing this work, Fisher and King[32] suggest that the fraction of

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[28] US EPA (2010) Final Regulatory Impact Analysis (RIA) for the SO_2 National Ambient Air Quality Standards (NAAQS).

[29] Fisher G, Kjellstrom T, Kingham S, Hales S, Shrestha R (2007). Health and Air Pollution in New Zealand Executive Summary. A Research Project Funded by: Health Research Council of New Zealand, Ministry for the Environment and Ministry of Transport

[30] 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

[31] 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)

[32] 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.

particulates due to sulphates might be 10-30% of the total, depending on the atmospheric conditions.

3.3.3 Impacts of Sulphur as a Particulate[33]

Small particulates are responsible for a number of respiratory health problems. When inhaled they can be absorbed into the lungs and, as a result, can cause significant health effects, particularly for the elderly and infants, people with asthma and other respiratory diseases, and sufferers of other chronic diseases, such as heart disease.

As an input to the 2009 Ministerial review of the PM_{10} regulations in the Air Quality Standards, NZIER undertook a cost benefit analysis for MfE that provided estimates of the costs of PM_{10} concentrations and exposure.[34] As with a number of international studies, the cost estimates are dominated by the impacts on "premature deaths" – approximately 90% of the total benefit. However, there are large uncertainties involved and they use a relatively simple method as was employed in a 2004 NZ cost benefit analysis.[35] In contrast, international analyses have used more complex approaches to take account of some key characteristics of the health effects and present the results in a more usable format for this study ($/tonne). We provide a brief discussion of the issues and estimates below, while noting that this is not the place to canvass all the issues.

The approach NZIER takes is to estimate the increase in death rates using international dose response functions; they assume a 4.3% increase in the annual death rate per 10μg increase in PM_{10} concentrations (and emissions) and multiply this change in death rates by an estimate of the value of statistical life (VOSL); NZIER uses a value of life based on the estimated costs of death from road accidents ($3.35 million per life lost). In response to anticipated arguments over the value of death at different ages, and recognising that deaths from respiratory problems can bring forward the time of death amongst the elderly, they argue that there may be prolonged periods of illness prior to death, and that the impacts also affect infants. On this basis they suggest that the approach is an underestimate of the benefits.

Covec[36] argues that this simple approach over-estimates the benefits, particularly in the context of policy decisions over marginal changes in levels of emissions and concentrations. The major impacts on premature deaths are chronic and cumulative and the impacts on death rates have been estimated from studies comparing locations that have had different levels of concentration over the long term. Thus the full benefits of reduced concentrations, derived from these dose-response factors, will not occur until people have lived their whole lives in reduced concentrations, rather than immediately subsequent to emission reductions. Changes in emission levels may change the number of deaths that are immediately related to air pollution (acute impacts), but the average levels of long term frailty in the population will change only slowly over time, and

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[33] Particulate

[34] NZIER (2009) The value of air quality standards. Review and update of cost benefit analysis of National Environmental Standards on air quality. Report to Ministry for the Environment.

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

[36] Denne T (2009) Benefits of Reductions in PM_{10} Emissions. Note to Ministerial Review of PM_{10} Regulations in the Air Quality Standards. Covec

people who are already frail as a result of air pollution will die prematurely, even if air pollution is reduced or increased. Our argument was that the increased mortality rate estimates being used are not appropriate for measuring response to changes in concentrations, ie to marginal effects. We noted developments internationally using delayed or lagged impacts, particularly those of the US EPA.[37]

In addition, building on European analyses, Covec made comments on the inappropriateness of using a VOSL based approach when the impact is better typified as a shortening of lifespan rather than premature death; NZIER makes the comment that VOSL is being applied to a "statistical life" not an actual life, ie it is representative of a change in the mortality rate and is not representing a discreet number of deaths and thus this approach is valid.

We explore these issues below, noting more recent international developments.

Impact Delay

The lagged benefits approach has continued to be used and explored in the US. In its recent analysis of the costs and benefits of the Clean Air Act, the EPA stated that its *"primary estimate reflects a 20-year distributed lag structure … Under this scenario, 30 percent of the mortality reductions occur in the first year, 50 percent occur equally in years two through five, and the remaining 20 percent occur equally in years six through 20. Our valuation of avoided premature mortality applies a five percent discount rate to the lagged estimates …"* [38] This reflects advice given by the Advisory Council on Clean Air Compliance Analysis. [39] Analyses for the EPA have explored a number of different lag structures.[40]

In addition, a growing number of reports have addressed the issue of marginal impacts of changes in emission rates.[41] They refer, particularly, to a study by Laden et al[42] that has reanalysed the mortality rates in a number of cities included in previous epidemiological studies and in which particle concentrations have changed over time. Laden et al looked at how changes in concentrations over time affected changes in mortality rates. Their analysis was highly influential on the opinions given in a

[37] 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.
[38] US EPA (2010) The Benefits and Costs of the Clean Air Act: 1990 to 2020. Revised Draft Report Prepared by the USEPA Office of Air and Radiation. Second Section 812 Prospective Analysis. Revised SAB Council Review Draft – August 2010
[39] US EPA (2004) Advisory Council on Clean Air Compliance Analysis Response to Agency Request on Cessation Lag. EPA-COUNCIL-LTR-05-001
[40] Industrial Economics (2010) Uncertainty Analyses to Support the Second Section 812 Benefit-Cost Analysis of the Clean Air Act. Prepared for US EPA
[41] US EPA (2006) National Ambient Air Quality Standards for Particle Pollution; US EPA (2011) Regulatory Impact Analysis: Standards of Performance for New Stationary Sources and Emission Guidelines for Existing Sources: Commercial and Industrial Solid Waste Incineration Units.
[42] Laden F, Schwartz J, Speizer FE, and Dockery DW (2006) Reduction in Fine Particulate Air Pollution and Mortality Extended Follow-up of the Harvard Six Cities Study. American Journal of Respiratory and Critical Care Medicine, 173: 667-672.

subsequent study that asked a number of experts their views on the appropriate health benefit values.[43]

These appear to be different approaches: (1) using lagged benefits as a proxy for distributing long run benefits over time and (2) the marginal analysis that actually measures changes in benefits over time in response to marginal changes in emissions and concentrations. A recent US EPA analysis[44] notes that the Laden et al study results have been used as an alternative estimate alongside those of the expert elicitation (that was influenced by Laden et al) and a 2002 study by Pope et al,[45] and that the lagged approach has been used throughout.

The lagged impact approaches have been adopted in the UK also. The Committee on Medical Effects of Air Pollutants (COMEAP) notes that "while in principle it might take 40 years for all benefits to be achieved, in practice benefits were likely to occur significantly earlier, with a noteworthy proportion in the first five years."[46] Building on this, COMEAP decided to use the approach recommended by the US EPA, as noted above.[47] COMEAP also considered a range of lag approaches building off a separate paper on alternative lag structures (Figure 4); the EPA approach was within this range and is shown as the dotted line in the figure. COMEAP uses 5, 10, 20 and 30 year phased in lags as sensitivity analysis.

When the impacts are discounted, all of these approaches result in lower estimates of the impacts than those used to date in New Zealand.

Valuing the Impacts

Some of the health impacts are relatively straightforward to value, eg hospitalisations. However, the value of premature deaths has been controversial. As noted above, NZIER and MfE previously used an estimate of the number of deaths avoided, multiplied by a value of a statistical life based on traffic accident studies. This simple approach is described by the AEA Technology team advising the European Commission as easy to do and to communicate but wrong.[48] Noting that reporting the effect as a number of premature deaths may not be an appropriate metric for total mortality[49] it is suggested

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[43] Industrial Economics (2006) Expanded Expert Judgment Assessment of the Concentration-Response Relationship Between $PM_{2.5}$ Exposure and Mortality. Final Report to US EPA.

[44] US EPA (2011) Regulatory Impact Analysis: Standards of Performance for New Stationary Sources and Emission Guidelines for Existing Sources: Commercial and Industrial Solid Waste Incineration Units.

[45] Pope CA., Burnett RT III, Thun MJ, Calle EE, Krewski D, Ito K and 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

[46] Committee on the Medical Effects of Air Pollutants (2010) The Mortality Effects of Long-Term Exposure to Particulate Air Pollution in the United Kingdom. A report by the Committee on the Medical Effects of Air Pollutants., p32

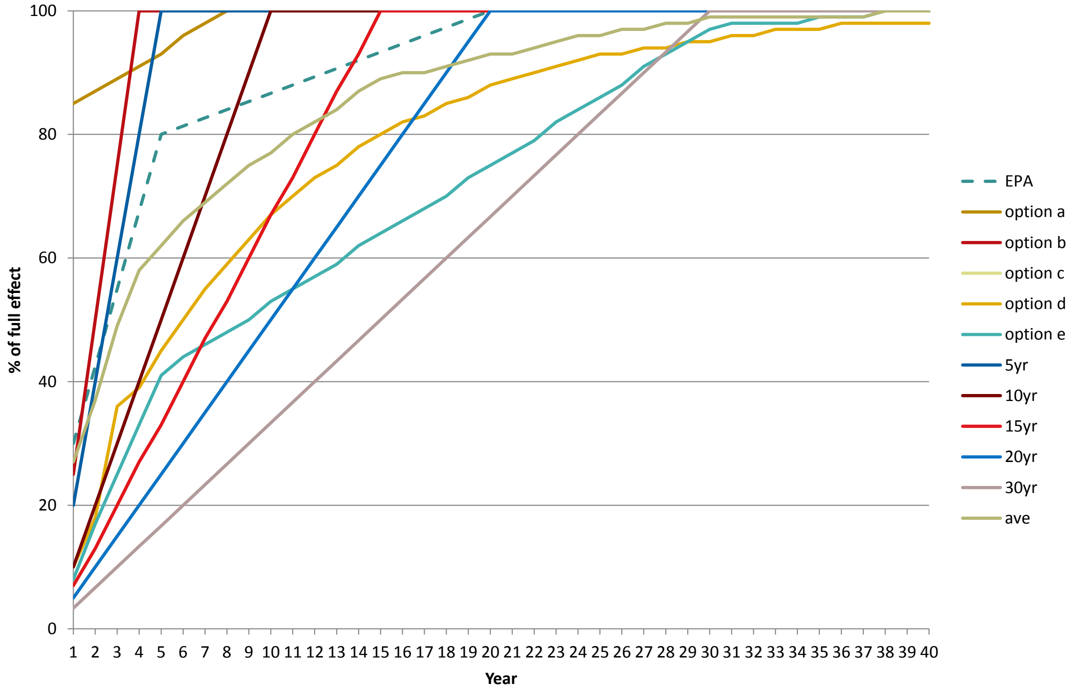
[47] 30% of the risk reduction occurs in the first year after pollution reduction, 50% across years 2–5 (ie 12.5% per year) and the remaining 20% of the risk reduction distributed across years 6–20.

[48] 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.

[49] See eg: 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

that a more useful metric is the loss of life expectancy (LE).[50] This is a view also expressed by Hoare writing in the New Zealand Medical Journal.[51]

Figure 4 Various lag structures over which full health impacts of particulates are observed



Source: Walton H (2010). Development of Proposals for Cessation Lag(s) for Use in Total Impact calculations. Supporting paper for the 2010 COMEAP Report.

AEA Technology suggests 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.[52]

More recently, COMEAP in the UK notes that there are immediate benefits of reducing particulate pollution in terms of fewer deaths in the first year (and different numbers in subsequent years), but this is accompanied by a longer-term benefit of prolonging life or increasing life expectancy by delaying death; the result is a larger and older population.[53] Noting in support the report by the Interdepartmental Group on Costs and

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Contingent Valuation; and 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).

50 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.

51 Hoare JL (2011) Limitations of the scientific basis for the management of air quality in urban New Zealand. New Zealand Medical Journal, Vol 124 No 1330: 66-73

52 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.

53 Committee on the Medical Effects of Air Pollutants (2010) The Mortality Effects of Long-Term Exposure to Particulate Air Pollution in the United Kingdom. A report by the Committee on the Medical Effects of Air Pollutants.

Benefits,[54]COMEAP concludes that population total survival time (life years) better reflects the benefits than reductions in premature deaths. One of COMEAP's criticisms of the savings in the number of deaths approach is that these are not sustained; the results only occur until the age distribution of the population adjusts as a result of people living longer. Reductions in pollution levels will still have premature deaths, and possibly just as many as before, they will simply be less premature. In fact COMEAP suggests that "more deaths will occur annually under lower pollution levels"[55] because of the changes to population structure.

Building on this, the UK policy approach has tended to use a value of life years (VOLY) approach, and this approach has also been adopted in European studies. The UK has used a value of £29,000 (approx. NZ$58,000) per life year lost in 'good' health and £15,000 (c.NZ$30,000) per life year lost in 'poor' health, in 2005 prices.[56]

In contrast, the US EPA notes that it uses "*functions for mortality that express the increase in mortality risk as cases of "excess premature mortality" per year. The benefit provided by air pollution reductions, however, is the avoidance of small increases in the risk of mortality. By summing individuals [willingness to pay] to avoid small increases in risk over enough individuals, we can infer the value of a statistical premature death avoided. For expository purposes, we express this valuation as "dollars per mortality avoided," or "value of a statistical life" (VSL), even though the actual valuation is of small changes in mortality risk experienced by a large number of people.*[57] This is the same point made by NZIER, ie that the VSL or VOSL is being used as a proxy for life years lost and is not assuming that a small and discreet number of lives can be directly attributed to air pollution. This point is often lost by those using these studies.

The international policy approaches appear to be converging on the use of marginal analysis, or lagged formulae as a proxy, but diverging somewhat over the use of values based on life years versus statistical lives.

3.3.4 Expressing the Effect per Tonne

Both in the US, the EU and the UK, studies on impacts have taken the additional step of turning the impacts of changes in concentrations into impacts per tonne (or ton) of emissions.

The US EPA has developed a benefits mapping model (BenMAP)[58] that uses detailed geographical data to estimate $/ton damage costs in different locations for different

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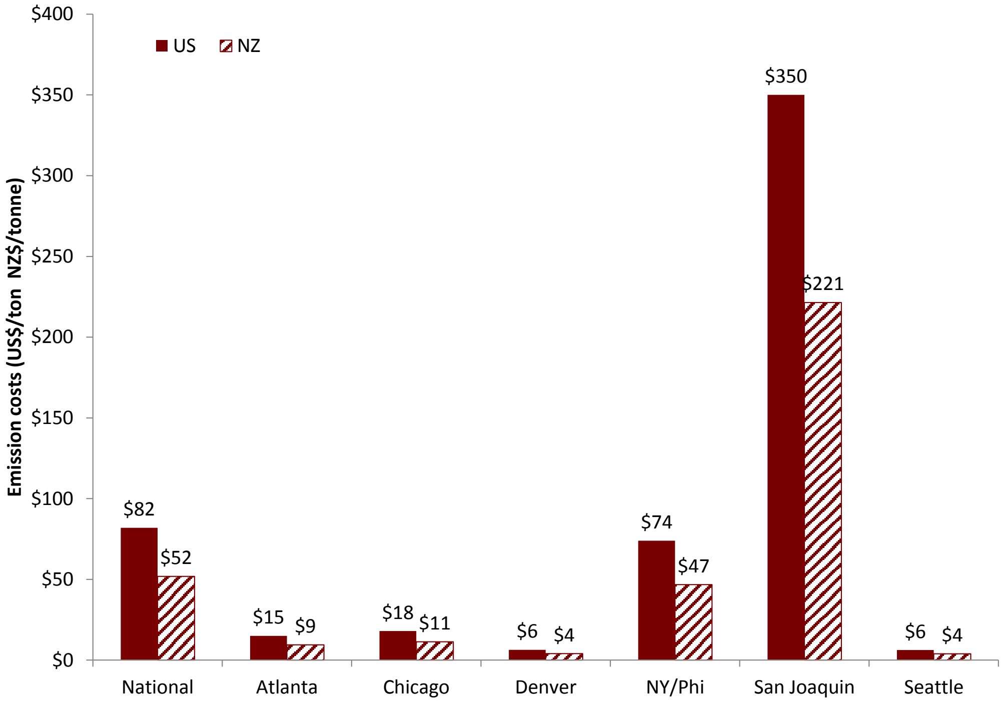
[54] Interdepartmental Group on Costs and Benefits (2007) Economic analysis to inform the air quality strategy
[55] COMEAP (op cit) p17
[56] Interdepartmental Group on Costs and Benefits (2007) An Economic Analysis of the Air Quality Strategy. Updated Third Report of the Interdepartmental Group on Costs and Benefits. Defra.
[57] US EPA (2010) The Benefits and Costs of the Clean Air Act: 1990 to 2020. Revised Draft Report Prepared by the USEPA Office of Air and Radiation. Second Section 812 Prospective Analysis. Revised SAB Council Review Draft – August 2010
[58] www.epa.gov/air/benmap/index.html

precursors of particulates (as $PM_{2.5}$), including SO_2 and NO_x.[59] BenMap does not have the capability to apply a cessation lag[60] but uses a simple mortality change x value of statistical life approach;[61] it bases the mortality change impacts on the marginal assessment approach.[62] The results are presented initially using a VOSL of US$6.2 million.

This appears to be a useful approach and would be readily translated into values that can be used in this study. To adjust to New Zealand dollars we translate these values using the latest estimate of the VOSL for New Zealand: $3.6 million.[63] In addition, we translate the impacts from $/ton to $/tonne. The results from different areas of the US are shown in Figure 5; many of these values are taken from areas with very large populations and population densities. Using the values for Denver (pop 600,000) and Seattle (609,000), the estimated cost of SOx emissions is approximately $4,000/tonne.

Figure 5 Costs of SOx Emissions



Source: US ($/ton) data from Fann N, Fulcher CM and Hubbell BJ (2009). The influence of location, source, and emission type in estimates of the human health benefits of reducing a ton of air pollution. Air Qual Atmos Health 2:169–176. Converted to NZ$ using ratio of 6.2:3.5994 and converted to $/tonne

[59] Fann N, Fulcher CM and Hubbell BJ (2009). The influence of location, source, and emission type in estimates of the human health benefits of reducing a ton of air pollution. *Air Qual Atmos Health* 2:169–176. See updated values also at: www.epa.gov/oaqps001/benmap/bpt.html

[60] Industrial Economics (2010) Uncertainty Analyses to Support the Second Section 812 Benefit-Cost Analysis of the Clean Air Act. Prepared for US EPA

[61] Fann et al (op cit)

[62] Laden et al (op cit)

[63] $3.5594 million; taken from Ministry of Transport (2010) The Social Cost of Road Crashes and Injuries. June 2010 Update.

In the UK, an economic analysis to inform the air quality strategy[64] has examined the impacts per tonne for PM_{10}, NO_x and SO_2 based on a 1-year reduction in the pollution level. This is appropriate as a measure of the marginal damage costs of an additional tonne. These have been undertaken using different lag times (from zero to 40 years). The value of a life year was valued at £29,000 as discussed above. To convert to current NZ dollars we use current exchange rate (assume £1:NZ$2) multiplied by a ratio reflecting gross national income per capita (in purchasing power parity terms = 0.77),[65] ie the UK values are multiplied by 1.54. The range of values ($567-$4,863/t) is given in Table 17; the US-derived value ($4,000/t) is within this range.

Table 17 Impact per tonne of SO_2

	Low[1] (£/t)	High[2] (£/t)	Low (NZ$/t)	High (NZ$/t)
1% PM concentration response function	368	476	567	733
6% PM concentration response function	1,208	1,695	1,860	2,610
12% PM concentration response function	2,217	3,158	3,414	4,863

[1] Low = 1% per 10µg.m^3, 40 year lag, low central valuation for chronic PM effects and low central valuation for other health effects; [2] High = 12% per 10µg.m^3, no lag, high central valuation for chronic PM effects and high central valuation for other health effects
Source: Annex 3 – Damage Costs in: Interdepartmental Group on Costs and Benefits (2007) An Economic Analysis of the Air Quality Strategy. Updated Third Report of the Interdepartmental Group on Costs and Benefits. Defra.

We use the range from the UK study to examine the impacts on fuel costs.

Table 18 Costs of SO_2 Emissions

Fuel	kg SO_2/GJ	$/GJ (low)	$/GJ (high)
Coal - sub-bituminous	0.387	0.22	1.88
Wood	0.331	0.24	2.08

Source: emission factor from Table 16; $/GJ estimates from low and high range of per tonne costs in Table 17

3.4 Small Particulates

There are small particulates in addition to SO_2 that result from combustion. In general the emission rates are much smaller than they are for sulphur but the unit costs are higher. Uncontrolled emission factors are shown in Table 19 and the resulting costs using the $ values derived from the report of the UK Interdepartmental Group on Costs and Benefits, as we did for SO_2 in Table 17 above. The costs are highly significant for wood waste combustion and for coal, especially if using the high cost estimates; given the discussion on estimates of particulates in Section 3.3.3 above, these cost estimates are highly uncertain.

[64] Interdepartmental Group on Costs and Benefits (2007) An Economic Analysis of the Air Quality Strategy. Updated Third Report of the Interdepartmental Group on Costs and Benefits. Defra.
[65] World Bank (2011) World Development Indicators database, World Bank 1 July 2011

Table 19 PM_{10} Emission Factors and costs (uncontrolled)

Fuel	kg/GJ[1]	$/GJ[2]
Coal - sub-bituminous	0.052	0.50 – 8.06
Natural gas	0.00005	0.004 – 0.06
Wood (bark and wet wood)	0.215	2.06 – 33.15

Source: [1] Table 1.1-4 and Table 1.6-1 in US EPA (1998) Emissions Factors & AP 42, Compilation of Air Pollutant Emission Factors ; England GC (2004) Development of Fine Particulate Emission Factors and Speciation Profiles for Oil- and Gas-Fired Combustion. Systems Final Report. Prepared for US Department of Energy; [2] using $ values in Table 17

Table 20 Impact per tonne of PM_{10}

	Low[1] (£/t)	High[2] (£/t)	Low (NZ$/t)	High (NZ$/t)
1% PM concentration response function	6,221	9,034	9,580	13,912
6% PM concentration response function	34,573	50,439	53,242	77,676
12% PM concentration response function	68,911	100,126	106,123	154,194

[1] Low = 1% per 10µg.m^3, 40 year lag, low central valuation for chronic PM effects and low central valuation for other health effects; [2] High = 12% per 10µg.m^3, no lag, high central valuation for chronic PM effects and high central valuation for other health effects
Source: Annex 3 – Damage Costs in: Interdepartmental Group on Costs and Benefits (2007) An Economic Analysis of the Air Quality Strategy. Updated Third Report of the Interdepartmental Group on Costs and Benefits. Defra.

3.5 Nitrogen Oxides (NOx)

3.5.1 Emission Rates

Nitrogen oxide 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 21.

Table 21 NOx Emission Factors

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

Source: Ministry of Economic Development (2006) New Zealand Energy Greenhouse Gas Emissions 1990-2005

3.5.2 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 the recent UK cost estimates based on analysis by the Interdepartmental Group on Costs and Benefits. The results are shown in Table 22.

Table 22 Impact per tonne of NO_x

	Low[1] (£/t)	High[1] (£/t)	Low (NZ$/t)	High (NZ$/t)
1% PM concentration response function	113	165	174	254
6% PM concentration response function	680	987	1,047	1,520
12% PM concentration response function	1,360	1,974	2,094	3,040

[1] Low and High definitions as for SO_2 (see Table 17)
Source: Annex 3 – Damage Costs in: Interdepartmental Group on Costs and Benefits (2007) An Economic Analysis of the Air Quality Strategy. Updated Third Report of the Interdepartmental Group on Costs and Benefits. Defra.

The range is $174-3,040/t and the effect on fuel costs is shown in Table 23.

Table 23 Costs of NOx Emissions

	t NOx/PJ	kg NOx/GJ	$/GJ (low)	$/GJ (high)
Coal	361	0.361	0.06	1.10
Natural gas	171	0.171	0.03	0.52
Wood	62	0.062	0.01	0.19

3.6 Summary of Impacts

The emission factors derived for the different technologies are summarised in Table 24 in kg/MWh of output.

The resulting additional costs per MWh are shown in Table 25. For SO_2, PM_{10} and NOx we use an average cost per tonne based on the average of the highest and the lowest estimates from Table 17, Table 20 and Table 22.

Table 24 Emission factors for generation technologies (kg/MWh)

	CO_2 combustion	CO_2 other	CO_2 total	SO_2	PM_{10}	NOx
Existing Plants						
Huntly (Coal)	974.5	46.8	1,021.2	4.2	0.052	3.9
Huntly (E3P)	394.4	0.0	394.4	0	0.0004	1.3
Huntly (GT)	561.2	0.0	561.2	0	0.0005	1.8
Geothermal	73.0	0.0	73.0	0	0	0
Hydro	0.0	0.0	-	0	0	0
Wind	0.0	0.0	-	0	0	0
New Plants						
CCGT	375.8	71.9	447.7	0	0.0004	1.2
OCGT	559.7	71.9	631.6	0	0.0005	1.8
Coal (ASC)	765.3	37.2	802.4	3.3	0.041	3.1
Geothermal (Medium)	73.0	3.0	76.0	0	0	0
Hydro (Medium)	0.0	5.4	5.4	0	0	0
Wind	0.0	8.0	8.0	0	0	0

Note: For efficiency (heat rate) assumptions, see Table 2and Table 5

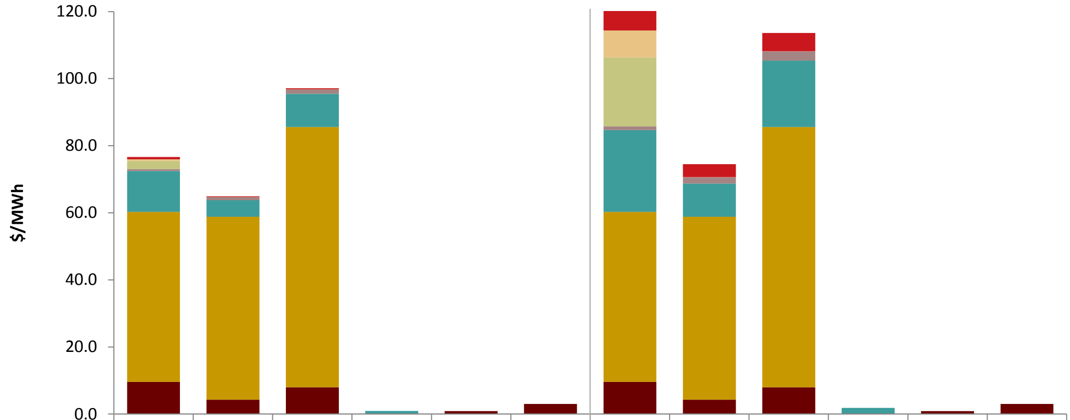
Table 25 Emission factors for generation technologies (kg/MWh)

	CO_2 combustion	CO_2 other	CO_2 total	SO_2	PM_{10}	NOx	Total
Emission cost ($/tonne)	25	25	25	2,715	81,887	1,607	
Existing Plants							
Huntly (Coal)	24.4	1.2	25.5	11.5	4.28	6.3	47.6
Huntly (E3P)	9.9	0.0	9.9	0.0	0.03	2.0	11.9
Huntly (GT)	14.0	0.0	14.0	0.0	0.04	2.9	17.0
Geothermal	1.8	0.0	1.8	0.0	0.00	0.0	1.8
Hydro	0.0	0.0	0.0	0.0	0.00	0.0	0.0
Wind	0.0	0.0	0.0	0.0	0.00	0.0	0.0
New Plants							
CCGT	9.4	1.8	11.2	0.0	0.03	1.9	13.2
OCGT	14.0	1.8	15.8	0.0	0.04	2.9	18.7
Coal (ASC)	19.1	0.9	20.1	9.0	3.36	5.0	37.4
Geothermal (Medium)	1.8	0.1	1.9	0.0	0.00	0.0	1.9
Hydro (Medium)	0.0	0.1	0.1	0.0	0.00	0.0	0.1
Wind	0.0	0.2	0.2	0.0	0.00	0.0	0.2

4 Total Costs

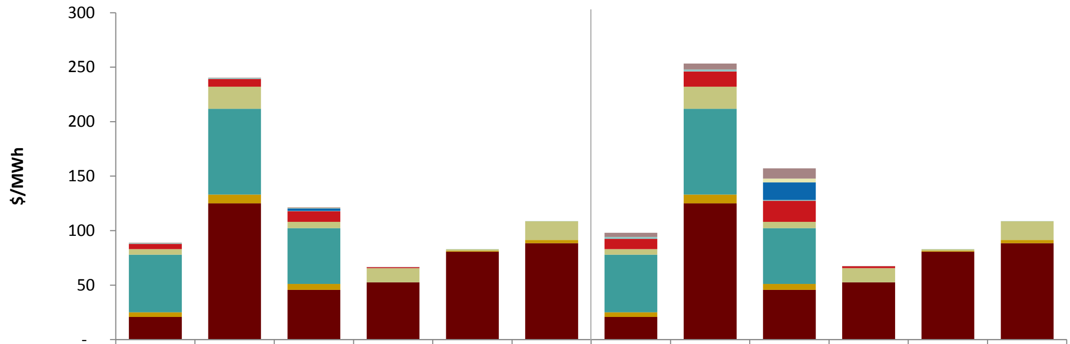
Total costs for the different pollutants, in comparison with the other costs of generation, are shown in Figure 6 below and Figure 7 for existing plants (variable only) and new entrants (LRMC) respectively, and using low cost and high cost assumptions for the different pollutants.

Figure 6 Components of Avoidable Costs of Existing Plants



	Huntly (Coal) (low)	Huntly (E3P) (low)	Huntly (GT) (low)	Geo-thermal (low)	Hydro (low)	Wind (low)	Huntly (Coal) (high)	Huntly (E3P) (high)	Huntly (GT) (high)	Geo-thermal (high)	Hydro (high)	Wind (high)
Total	76.6	64.9	97.1	0.9	0.9	3.0	126.4	74.5	113.6	1.8	0.9	3.0
NOx	0.7	0.2	0.3	0.0	0.0	0.0	12.0	3.8	5.5	0.0	0.0	0.0
PM10	0.5	0.0	0.0	0.0	0.0	0.0	8.1	0.1	0.1	0.0	0.0	0.0
SO2	2.4	0.0	0.0	0.0	0.0	0.0	20.5	0.0	0.0	0.0	0.0	0.0
CO2-other	0.6	1.0	1.4	0.0	0.0	0.0	1.2	1.9	2.7	0.0	0.0	0.0
CO2-comb	12.2	4.9	9.9	0.9	0.0	0.0	24.4	9.9	19.8	1.8	0.0	0.0
Fuel	50.7	54.5	77.6	0.0	0.0	0.0	50.7	54.5	77.6	0.0	0.0	0.0
VOM	9.6	4.3	8.0	0.0	0.9	3.0	9.6	4.3	8.0	0.0	0.9	3.0

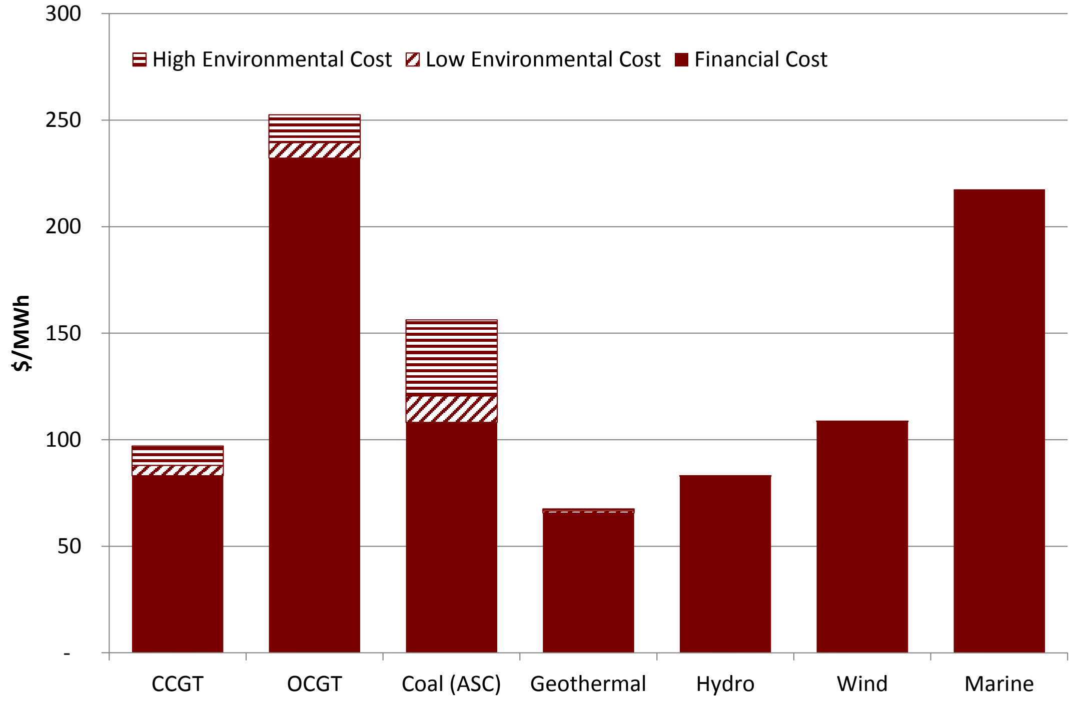
Figure 7 Components of Average Costs for New Plants



	CCGT (low)	OCGT (low)	Coal (ASC) (low)	Geo-thermal (Med) (low)	Hydro (Med) (low)	Wind (low)	CCGT (high)	OCGT (high)	Coal (ASC) (high)	Geo-thermal (Med) (high)	Hydro (Med) (high)	Wind (high)
Total	89	240	121	67	83	109	98	253	157	68	83	109
NOx	0.2	0.3	1	-	-	-	4	5	9	-	-	-
PM10	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	3.4	0.0	0.0	0.0
SO2	-	-	2	-	-	-	-	-	16	-	-	-
CO2-other	1	1	0	0	0	0	2	2	1	0	0	0
CO2-Comb	5	7	10	1	-	-	9	14	19	2	-	-
FOM	5	20	6	13	1	17	5	20	6	13	1	17
Fuel	53	79	51	-	-	-	53	79	51	-	-	-
VOM	4	8	5	-	1	3	4	8	5	-	1	3
Capex	21	125	46	53	81	88	21	125	46	53	81	88

Figure 8 shows the impacts of the environmental costs on the costs for new entrants. The costs for thermal plants are considerably increased over the initial financial costs (CO_2 is treated as a non-financial cost). It means that renewable plants are lower cost options over a wider range of input assumptions. In particular, hydro plants are now more competitive relative to CCGT plants and wind relative to coal. Marine generation, which has not been examined in detail in this report because of an absence of data, is still more expensive than other potential base-load generation.

Figure 8 Impacts of Environmental Costs on Generation Costs for New Entrants



5 References

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.

Committee on the Medical Effects of Air Pollutants (2010) The Mortality Effects of Long-Term Exposure to Particulate Air Pollution in the United Kingdom. A report by the Committee on the Medical Effects of Air Pollutants.

Covec (2006) Environmental Costs of Electricity Generation. Report to Environment Waikato.

Covec (2010) Carbon Price Forecasts. Report to Parliamentary Commissioner for the Environment

Denne T (2009) Benefits of Reductions in PM_{10} Emissions. Note to Ministerial Review of PM_{10} Regulations in the Air Quality Standards. Covec

Denne T (2011) Coal Prices in New Zealand Markets: 2011 Update, Covec

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

Electricity Authority Centralised Dataset (see www.ea.govt.nz/industry/modelling/cds/centralised-dataset-web-interface/wholesale-prices-mean-price/)

Electricity Authority (2011) Electricity in New Zealand

England GC (2004) Development of Fine Particulate Emission Factors and Speciation Profiles for Oil- and Gas-Fired Combustion. Systems Final Report. Prepared for US Department of Energy

European Commission ExternE study (www.externe.info/).

Fann N, Fulcher CM and Hubbell BJ (2009). The influence of location, source, and emission type in estimates of the human health benefits of reducing a ton of air pollution. *Air Qual Atmos Health* 2:169–176.

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.

Fisher G, Kjellstrom T, Kingham S, Hales S, Shrestha R (2007). Health and Air Pollution in New Zealand Executive Summary. A Research Project Funded by: Health Research Council of New Zealand, Ministry for the Environment and Ministry of Transport

Fisher GW, Thompson A and Kuschel GI (1998) An Overview of the Elemental Analysis of Ambient Particulates in New Zealand. NIWA Report AK98029

Hoare JL (2011) Limitations of the scientific basis for the management of air quality in urban New Zealand. New Zealand Medical Journal, Vol 124 No 1330: 66-73

Industrial Economics (2006) Expanded Expert Judgment Assessment of the Concentration-Response Relationship Between $PM_{2.5}$ Exposure and Mortality. Final Report to US EPA.

Industrial Economics (2010) Uncertainty Analyses to Support the Second Section 812 Benefit-Cost Analysis of the Clean Air Act. Prepared for US EPA

Interdepartmental Group on Costs and Benefits (2007) An Economic Analysis of the Air Quality Strategy. Updated Third Report of the Interdepartmental Group on Costs and Benefits. Defra.

Laden F, Schwartz J, Speizer FE, and Dockery DW (2006) Reduction in Fine Particulate Air Pollution and Mortality Extended Follow-up of the Harvard Six Cities Study. American Journal of Respiratory and Critical Care Medicine, 173: 667-672.

Meier P (2002) Life-Cycle Assessment of Electricity Generation Systems and Applications for Climate Change Policy Analysis. Fusion Technology Institute, University of Wisconsin, Madison. UWFDM-1181

Ministry of Economic Development (2008) New Zealand Energy Greenhouse Gas Emissions 1990-2007

Ministry of Economic Development (2011) Energy Data File 2010 Caledar Year Edition

Ministry of Economic Development (2011) Energy Greenhouse Emissions 2011

Ministry of Economic Development (2011) New Zealand's Energy Outlook 2011 Reference Scenario and Sensitivity Analysis

Ministry of Economic Development (2012) Oil Prices Monitoring Report

Ministry for the Environment (2007) Proposed National Environmental Standards for Electricity Generation.

Ministry for the Environment (2011) New Zealand's Greenhouse Gas Inventory 1990-2009.

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

Ministry of Transport (2010) The Social Cost of Road Crashes and Injuries. June 2010 Update.

Ministry of Transport (2010) Understanding Transport Costs and Charges. Phase two – Transport costs in freight logistics

NZIER (2009) The value of air quality standards. Review and update of cost benefit analysis of National Environmental Standards on air quality. Report to Ministry for the Environment.

Parsons Brinckerhoff (2012) 2011 NZ Generation Data Update

Pope CA., Burnett RT III, Thun MJ, Calle EE, Krewski D, Ito K and 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

Port of Tauranga (2012) Port Operational Information

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).

Spath PL, Mann MK and Kerr DR (1999) Life Cycle Assessment of Coal-fired Power Production. National Renewable Energy Laboratory. NREL/TP-570-25119

Sullivan JL, Clark CE, Han J and Wang M (2010) Life-Cycle Analysis Results of Geothermal Systems in Comparison to Other Power Systems. Energy Systems Division, Argonne National Laboratory. ANL/ESD/10-5

UNFCCC (2011) Decision CMP.7 Land use, land-use change and forestry. Annex I Definitions, modalities, rules and guidelines relating to land use, land-use change and forestry activities under the Kyoto Protocol. FCCC/KP/AWG/2011/L.3/Add.2

US EPA (1998) Emissions Factors & AP 42, Compilation of Air Pollutant Emission Factors.

US EPA (2004) Advisory Council on Clean Air Compliance Analysis Response to Agency Request on Cessation Lag. EPA-COUNCIL-LTR-05-001

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.

US EPA (2006) National Ambient Air Quality Standards for Particle Pollution; US EPA (2011) Regulatory Impact Analysis: Standards of Performance for New Stationary Sources and Emission Guidelines for Existing Sources: Commercial and Industrial Solid Waste Incineration Units.

US EPA (2010) Final Regulatory Impact Analysis (RIA) for the SO_2 National Ambient Air Quality Standards (NAAQS).

US EPA (2010) The Benefits and Costs of the Clean Air Act: 1990 to 2020. Revised Draft Report Prepared by the USEPA Office of Air and Radiation. Second Section 812 Prospective Analysis. Revised SAB Council Review Draft – August 2010

US EPA (2011) Regulatory Impact Analysis: Standards of Performance for New Stationary Sources and Emission Guidelines for Existing Sources: Commercial and Industrial Solid Waste Incineration Units.

Waikato Regional Energy Forum (undated) Waikato Regional Energy Strategy

Walton H (2010). Development of Proposals for Cessation Lag(s) for Use in Total Impact calculations. Supporting paper for the 2010 COMEAP Report.

World Bank (2011) World Development Indicators database, World Bank 1 July 2011