12 February 2016

By email: energy.submissions@esc.vic.gov.au

Dear ESC,

RE: Inquiry into the true value of distributed generation – Proposed Approach paper

Thank you for the opportunity to make an initial submission to this inquiry. We consider it critical that the full range of benefits of distributed generation are taken into account when setting feed-in tariffs. At this stage on the inquiry, our focus is to draw to the ESC's attention known methods for quantifying the social benefits of avoided fossil fuel-based generation, and therefore the social benefit of distributed generation.

About Environment Victoria

Environment Victoria is one of Australia's leading independent environment groups. With over 40 member groups and tens of thousands of individual supporters, we've been representing Victorian communities on environmental matters for over 40 years.

Social costs of electricity generation

A large body of research exists around the social cost of carbon. The US EPA defines the social cost of carbon as "an estimate of the economic damages associated with a small increase in carbon dioxide emissions, conventionally one metric ton, in a given year." The social cost is equivalent to "the value of damages avoided for a small emission reduction (i.e. the benefit of a CO_2 reduction)."

This means that each tonne of abatement can be given a dollar value. By extension, a dollar value can be assigned to each MWh of reduced electricity generation. In the US, government agencies use a conservative estimate of $USD37/tonne, but recent research from Stanford University academics suggests that a more appropriate value of the social cost of carbon is $USD220.[1]

The air pollution created by fossil fuel-based electricity generation is known to be responsible for negative health impacts on communities near those generators.

Social benefit of distributed generation in Victoria

[1] http://news.stanford.edu/news/2015/january/emissions-social-costs-011215.html

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A reduction in demand from the grid's fossil fuel-based electricity generation is a reduction in the social costs of electricity. Whether this reduction in demand occurs through energy efficiency measures or through zero-emissions distributed generation is immaterial.

For this reason, the social cost of a kWh of electricity has the same value as the social benefits of a kWh of reduced grid demand. Using publicly available data (Clean Energy Regulator, AEMO) and modelling results produced by Ward and Power of the Harvard Kennedy School of Government,[2] it is possible to quantify the value of each avoided kWh of electricity in Victoria.

From 2008/09 to 2013/14, Victoria produced, on average, 54,444,000 MWh of electricity. 50,944,000 MWh were from sources that produce carbon and air pollution externalities.[3] Over the same period, carbon emissions from Victoria's electricity supply were on average 62,233,000 tonnes/year.

Modelling by Ward and Power (see Appendix; derived from US National Academy of Sciences modelling) shows that the social cost of the carbon pollution from Victorian electricity generation is approximately $2.86 billion, and the social cost of the air pollution is $830 million, coming to a total of $3.69 billion.[4] Dividing this annual cost by the annual electricity output of polluting generators yields a social cost of electricity in Victoria of 7.24 c/kWh. The corollary is that each kWh of reduced demand from the grid creates a social benefit of 7.24 c/kWh.

It should be noted that Ward and Power chose a relatively low value for their social cost of carbon - $AUD42 per tonne. A social cost of carbon of $100/tonne gives 12.2 c/kWh. Using the more recent and more comprehensive figure of $USD220 per tonne from the Stanford research cited above, this yields a Victorian social cost of electricity as high as 37.5 c/kWh.[5]

What these figures show is that there is a very significant public benefit in zero-emission distributed generation, and that this benefit can be readily quantified using reputable models. Based on the numbers presented here, there is a strong case for increasing Victorian feed-in tariffs to significantly higher rates than the current 5.0 c/kWh.

We look forward to engaging further in the next phase of the ESC's consultation in this Inquiry.

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[2] Jordan Ward and Mick Power, Harvard Kennedy School of Government, "Cleaning Up Victoria's Power Sector: The full social costs of Hazelwood Power Station" (2015). http://environmentvictoria.org.au/sites/default/files/Hazelwood%20Report_Social%20cost%20of%20carbon.pdf

[3] As noted by Ward and Power (cited above), other externalities of fossil fuel generation may exist, such as the impact of coal mining, but this has not been accounted for here.

[4] As above. See Table B7. Figures reported here are rounded off for simplicity.

[5] According to current exchange rates. Note that this does not include an air pollution component.

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Regards,

Dr Nicholas Aberle
Safe Climate Campaigner Manager
Environment Victoria

Cleaning up Victoria's Power Sector: the full social cost of Hazelwood power station

Jordan Ward and Mick Power

Harvard Kennedy School of Government

February 24th 2015

About this report

Jordan Ward is a Frank Knox Memorial Fellow and Mick Power is a Gleitsman Fellow and an American Australian Association Fellow at the Harvard Kennedy School of Government. They come from a background in energy and environment policy and business in Australia and New Zealand. The authors would like to acknowledge Assistant Professor Joe Aldy for his early comments and advice on the work.

Note:

1. All dollar values are 2014 Australian dollars unless otherwise specified
2. Electricity generation and intensity figures (e.g., cost per MWh) are on a sent-out basis unless otherwise specified

Contents

Executive Summary

The historical dominance of brown coal generators like Hazelwood in Victoria's energy market is based on their very low private costs, driven by cheap and plentiful fuel and low operating costs. However, this is only part of the picture, ignoring the significant external costs that these generators impose to human health, the environment, climate change and public infrastructure.

In this paper we estimate true cost of Hazelwood in both private and social terms. As expected, we find very low private short run marginal costs, in the order of $3/MWh. We also find very high external costs. Our central case estimates of the external costs of carbon emissions and air pollutants are $64/MWh and $8/MWh respectively. This gives a social marginal cost of $75/MWh, and social average unit cost of $87/MWh – well above the current Victorian wholesale electricity price of ~$30/MWh. This means Hazelwood imposes an external economic cost on Australians in the order of $900 million per year, and over $2.5 billion in our high case estimates.

We find the now-repealed carbon price regime went a long way to pricing these externalities, but still fell well short of the true social cost. Using the 2013-14 carbon price of $24.15/tonne-$CO_2$, we estimate Hazelwood's private marginal costs rose to $40/MWh. Our analysis suggests that during the two years the carbon price was in place, Hazelwood was likely operating close to its breakeven point from its core operations, and potentially kept in the black by the government's coal-fired generation industry assistance program.

We reconstruct the Victorian power stack based on social marginal costs and find Hazelwood to be the most expensive baseload generator, and forecast to get increasingly expensive as the social cost of carbon rises. We also find the long run marginal costs of new entrant generation options to be price competitive with Hazelwood’s social cost of production. This suggests continued operation of Hazelwood is economically inefficient, and likely to become more so as its carbon costs increase and new entrant costs decline. In the absence of putting a price on externalities to allow the market to resolve this inefficiency, there is a case for direct government intervention clean up or close Hazelwood, and potentially other brown coal generators.

1. Introduction

On the face of it, one might expect Australia to be leading the transition to clean energy, with vast renewable energy resources, strong research capacity, and a stable and developed economy. However, it continues to have one of the dirtiest electricity supplies in the world, with around 80% of electricity used by customers coming from coal.[1] In Victoria, the country's second most populous state, around 84% of electricity needs are met from four brown coal generators in the Latrobe Valley[2] - an area 150 km east of Melbourne characterized by agriculture and huge brown coal reserves.

Of those four major generators, Hazelwood has attracted particular attention. A 2005 study ranked the 50-year old 1,600 MW power station as the least carbon-efficient power station in the OECD, and it has been a lightning rod for national debate around climate and energy policy ever since.[3] In a state where 53% of total greenhouse gas emissions come from electricity generation (as do 37% of emissions nationally),[4] climate policy in Victoria is to no small degree about how to deal with this power station.

In the past five years, several policies have been introduced that bear directly on Hazelwood and the Latrobe Valley generators: a national carbon price (combined with multi-billion dollar assistance payments for large coal fired generators); a raft of renewable energy subsidies and standards; and two 'payment for closure' policies in which the state and then the federal

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[1] Energy Australia. http://www.energyaustralia.com.au/about-us/help-centre/faqs/carbon-price

[2] Department of Economic Development, Jobs, Transport and Resources, 'Victoria's Energy Statement' (December 2014) http://www.energyandresources.vic.gov.au/about-us/publications/victorias-energy-statement

[3] WWF. http://www.wwf.org.au/?2320/Hazelwood-tops-international-list-of-dirty-power-stations

[4] Department of Sustainability and Environment, 'Report on climate change and greenhouse gas emissions in Victoria' (March 2012) http://www.climatechange.vic.gov.au/__data/assets/pdf_file/0005/136490/DSE_Greenhouse-Report_online.pdf; Parliament of Australia, 'How much Australia emits' http://www.aph.gov.au/About_Parliament/Parliamentary_Departments/Parliamentary_Library/Browse_by_Topic/ClimateChange/whyClimate/human/howMuch

government proposed to contract with Hazelwood to close down. Yet for different reasons all of these policies have failed to close or even significantly reduce pollution from these generators. Current governments at both the federal and state level have shown little appetite for further action. The conservative federal government has declared its intention to rely on an Emissions Reduction Fund, though this scheme does not currently provide a methodology under which emissions from power stations might be reduced.[5] The previous state government deferred to the federal government for action, and the new state Labor government, elected in November last year, has yet to announce how they will achieve emissions reductions.

Against that context, this report asks what the true cost of Hazelwood is, accounting for both private costs and externalities, and how this compares with alternatives sources of power for Victoria. We focus on quantifying two types of externalities, which have been shown to be the most significant source of externalities in several overseas studies: carbon emissions, and local air pollutants (specifically SO_2, NO_x, PM_{10} and $PM_{2.5}$). After developing an accounting methodology based largely on work by the US National Academy of Sciences, we compare the social cost of Hazelwood with other Victorian generators as well as new entrant technologies.

[5] Department of the Environment. http://www.environment.gov.au/climate-change/emissions-reduction-fund/methods

2. The true cost of Hazelwood

Markets achieve efficiency when the marginal social benefits to consumers are equal to the marginal social costs of production. When the cost of production is not fully captured by the producing firm, negative externalities arise and the firm is likely to over-produce relative to the efficient production level. Analysis of the thermal power sector has shown these externalities can be many times the costs internalized by the generator, but also idiosyncratic. A 2009 US study found that 10% of US coal plants accounted for 43% of all damages from coal fired generation.[6] In this section, we make a high level evaluation of both the internal (private) costs of Hazelwood, and its external costs. We then attempt to reconstruct the Victorian generation cost curve accounting for the external costs of generation. From this, we evaluate whether or not Hazelwood should be generating in an efficient market.

2.1 Private costs

Hazelwood's private costs are not a matter of public record. It was sold by the Victorian State Government in 1996 to International Power (now a subsidiary of GDF Suez), and its financial performance is consolidated into Asia-Pacific summary statistics in GDF Suez's public reports. We attempted an outside-in estimate of Hazelwood's costs based on publically available data from the Australian Energy Market Operator (AEMO). AEMO undertakes annual modeling of the electricity market as part of its mandate to forecast the adequacy of supply and future transmission requirements, and regularly publishes cost estimates of generators that participate in the National Electricity Market (NEM). Of particular relevance is a 2009 report (authored by ACIL Tasman) into generation costs of plants in the NEM, and the 2013 AEMO update on

[6] National Academy of Sciences, *Hidden Costs of Energy: Unpriced Consequences of Energy Production and Use* (October 2009) p.5

technical data of existing generators.[7] We segment Hazelwood's costs into three categories - variable operating costs, fixed operating costs, and sunk capital costs.

2.1.1 Short run marginal costs

ACIL Tasman divides short run marginal costs into fuel costs, and all other variable operating and maintenance costs (VOM). Fuel costs are estimated to be extremely low - approximately \$1.35/MWh (\$0.09/GJ), or \$4.80/tonne of mined coal.[8] This is partly due to the mine being owned and operated by Hazelwood, and the mine's fixed operating costs being included in Hazelwood's fixed operating costs. If Hazelwood was to buy coal from the third party coal miner, the price paid for a marginal tonne of coal would likely include the fixed costs of the miner. However, it also reflects very low mining costs and transport costs. Hazelwood's coal deposit has a thin overburden, and the power plant located at the mine mouth. VOM costs include coal-processing costs such as water, chemicals, auxiliary energy and ash handling, as well as plant maintenance that is a function of use. For Hazelwood, these are similarly low - \$1.31/MWh.[9] This brings Hazelwood's total short run marginal cost to \$2.66/MWh.

Under the Clean Energy Act (2011), Hazelwood was also faced with a carbon price. The repeal of the act in July 2014 ended the carbon price mechanism effective 1 July 2014. During its two years of operation, the carbon price was by far Hazelwood's largest short run variable cost. For FY 2013-14, the price was \$24.15/t-CO_2 translating into a cost for Hazelwood of \$36.87/MWh.[10] As part of the carbon price regime, generators were partially compensated for carbon costs but

[7] Acil Tasman, 'Fuel Resource, New Entry and Generation Costs in the NEM' (April 2009); AEMO, '2013 Planning Studies - Existing Generator Technical Data Summary' (June 2013)
[8] Electricity generation and intensity figures (e.g., cost per MWh) are on a sent-out basis unless otherwise specified
[9] AEMO, '2013 Planning Studies - Existing Generator Technical Data Summary' (June 2013)
[10] Based on emission intensity estimate of 1.53tonne CO_2/MWh sent out - see AEMO, '2013 Planning Studies - Existing Generator Technical Data Summary' (June 2013)

through a mechanism intended to preserve the incentives of the carbon price. Hazelwood received an annual allocation of approximately 11 million free carbon units, structured as a lump sum transfer.[11] Units not used to offset emissions could be sold back to the Clean Energy Regulator, albeit at a discount. In the *External costs* section below, we examine to what extent the former carbon price regime adequately accounted for carbon externalities.

2.1.2 Fixed costs

In the short run, a firm will produce provided the price exceeds its short run marginal costs. Over the longer run, though, a firm will choose to shut down if it cannot cover its total costs, both variable and fixed. Fixed operating and maintenance costs (FOM) are costs that do not vary by output. They include labor, major maintenance (pro-rated), insurance and other overheads for both the power plant and associated mine. They do not, however, include sunk capital costs. A firm's decision to produce should depend only on future revenues and costs related to the production decision. Sunk capital costs will be incurred regardless. (We do include capital costs for greenfield plants when considering new-build replacement options for Hazelwood, as these are not sunk costs.)

Hazelwood's FOM costs are estimated at \$148 million per year[12], which equates to \$11.73/MWh.[13] Adding in short run marginal costs of \$2.66/MWh, we estimate Hazelwood's average unit costs to be \$14.39/MWh. This is well below the average electricity price of

[11] Hazelwood was issued with 11,088,800 free units for 2013/14 through the Energy Security Fund. http://www.cleanenergyregulator.gov.au/Carbon-Pricing-Mechanism/Industry-Assistance/coal-fired-generators/issue-carbon-units/Pages/Issue-of-free-carbon-units.aspx
[12] Based on a reported FOM of \$92,482/MW-installed, multiplied by an installed capacity of 1,600MW. AEMO, '2013 Planning Studies - Existing Generator Technical Data Summary' (June 2013)
[13] Assuming 90% effective capacity factor for consistency with AEMO modelling. This equates to 12,600GWh/yr, which we note is ~10% higher than actual sent-out generation of Hazelwood in 2012/13 (11,400GWh)

approximately $30/MWh over the past five years, excluding the two years during which the carbon price was in effect (FY 2012-13 and 2013-14).[14]

Under the carbon price mechanism, Hazelwood's average unit costs rose dramatically to $51.27/MWh.[15] This was roughly equal to the average wholesale price of electricity in Victoria for 2013-14 ($52/MWh).[16] While Hazelwood appears to have been close to breakeven from its core operating activities, this analysis excludes the benefit of free carbon units that were worth nearly $270m in 2013-14.[17]

Table 1: Private costs of Hazelwood

	Status quo	With carbon price regime, 2013-14
Fuel costs $/MWh	1.35	1.35
Other VOM $/MWh	1.31	1.31
Carbon $/MWh	0	36.87
Total short run marginal cost $/MWh	2.66	39.53
FOM $/MWh	11.73	11.73
Total average unit cost $/MWh	14.39	51.27
Total cost[18] $ million	**182**	**647**

[14] AEMO average pricing data for Victoria, adjusted to 2014 AUD, as of 31 January 2015. http://www.aemo.com.au/Electricity/Data/Price-and-Demand/Average-Price-Tables/Average-Price-Tables-Annual
[15] Using 2013-14 carbon price of $24.15/t-$CO_2$
[16] AEMO average pricing data for Victoria for 2013/14. http://www.aemo.com.au/Electricity/Data/Price-and-Demand/Average-Price-Tables/Average-Price-Tables-Annual
[17] 11,088,800 free units priced at $24.15/unit
[18] Assuming 90% effective capacity factor. See footnote 13 for further detail

2.2 External costs

There are a number of studies that have estimated the external costs of coal-fired power stations at the plant level, most of them in the United States.[19] These studies typically take an 'Impact Pathway Approach', first estimating the impact that the marginal ton of pollution has on health, business, and the environment, and then monetizing those impacts. Most of them rely on integrated-assessment models that project the dispersion and effects of pollution (largely airborne) from the point source. In Australia, there has been much less analysis of this kind. The Australian Academy of Technological Sciences and Engineering (ATSE) published a report in 2009 on the externalities of power generation in Australia which noted the lack of any comparable research in this field, and adapted the work of a comprehensive European study from 2005 to estimate the external costs of electricity generation to be $19/MWh for gas, $42/MWh for black coal, $52/MWh for brown coal, $5/MWh for solar and $1.5/MWh for wind.[20] As valuable as that work was, it relies on work done in 2005 and much has changed in our understanding of climate change and pollution costs since then.

In the sub-sections that follow, we have adapted more recent work from the US to estimate the cost of two key externalities – climate change and air pollution – as well as considering possible mining externalities.

[19] See, for example, Muller Mendelsohn and Nordhaus 'Environmental Accounting in the US Economy' (August 2011) American Economic Review 1649-1675; Clean Air Task Force, 'The Toll from Coal: An Updated Assessment of Death and Disease from America's Dirtiest Energy Source' (September 2010); European Commission, 'ExternE: the external costs of energy' (2005).
[20] Externalities priced in 2009 AUD. ATSE *The Hidden Costs of Electricity: Externalities of Power Generation in Australia* (2009).

2.2.1 Climate change

As Australia's most carbon-intensive power generator, Hazelwood's climate change externality is large. There is good publically available data on the plant's greenhouse gas emissions: facility-level emissions are reported to and published by the Clean Energy Regulator for 2012-13.[21] In previous years, emissions data were only reported at a corporate group level, but we can calculate facility emissions from historical generation reports and emissions intensity estimates published by the Australian Energy Market Operator.[22] These numbers include emissions from the Hazelwood's mining operation.

Calculating the marginal economic damages from greenhouse gas emissions is a far more complex exercise, which has drawn much attention and criticism since it was done in the 2006 Stern Review. For the purposes of this study, we use the Social Cost of Carbon (SCC) values adopted by the US Government for use across all of its agencies and departments, and updated in 2013.[23] This analysis draws on a number of sophisticated integrated-assessment models developed in the NAS which: (1) estimate the impact that marginal greenhouse gas emissions will have on global climate change; (2) predict the impact of that change on agriculture, health, property and other vulnerable assets and systems; and (3) estimate the economic cost of those damages. Because the value is highly sensitive to both the choice of discount rate and uncertainty in climate impacts, four SCC values are typically reported: one each for discount rates of 2.5%, 3% and 5% using a central estimate of impacts, and a fourth estimates which uses 95th percentile impacts from the three integrated assessment models, discounting at 3%,

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[21] Clean Energy Regulator, *Greenhouse and Energy Information 2012-13* (2013). http://www.cleanenergyregulator.gov.au/National-Greenhouse-and-Energy-Reporting/published-information/greenhouse-and-energy-information/Greenhouse-and-Energy-information-2012-2013/Pages/Default.aspx.

[22] AEMO, *NEM Historical Market Information Report* (2013); ACIL Tasman, *Fuel resource, new entry and generation costs in the NEM* (2009).

[23] Interagency Working Group on Social Cost of Carbon, *Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis* (November 2013).

to represent higher-than-expected impacts that might result from the ‘fat tails’ in climate impact probability distributions. These values range between \$11/t-CO_2 and \$90/t-CO_2 (USD 2007), which puts them considerably lower than those formerly used by the United Kingdom which range from \$41-124/t-CO_2 (USD 2009).[24] This estimate should be readily transferrable to an Australian context. As noted in the Garnaut Review on Climate Change, Australia is a country likely to be hit ‘first and worst’ by climate change due to its particularly hot and dry climate and likely damages to the agriculture and tourism industries.[25] If anything, we might expect Australia’s social cost of carbon to be higher.

Using the ‘central’ case of a 3% discount rate, we calculate the current cost of carbon pollution to be \$42/t-CO_2, much higher than the price of \$24.15/t-CO_2 used in the final year of Australia’s carbon pricing regime. Hazelwood’s emission intensity is estimated to be 1.53t-CO_2/MWh (including fugitive emissions from mining). This translates into a carbon cost of \$65/MWh, and a total annual cost of approximately \$800 million. Using the 2.5% discount rate (still higher than the 1.4% discount rate used in the Stern Review, and at the upper end of the discount rates of 1.35% and 2.65% used in the Garnaut Review)[26] brings that number to more than \$1 billion per year, and using the ‘tail’ scenario brings it to over \$2 billion per year.

There are two reasons to suggest our central estimate could be conservative. First, SCC models forecast the real cost of a marginal tonne of carbon to grow at an average compound annual growth rate of 2% between 2010 to 2050. We use values for 2014. By 2026 (the

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[24] Ruth Greenspan Bell, ‘The “Social Cost of Carbon” and Climate Change Policy’, *World Resources Institute Blog*, 13 July 2011: ‘http://www.wri.org/blog/%E2%80%9Csocial-cost-carbon%E2%80%9D-and-climate-change-policy.
[25] Ross Garnaut, *The Garnaut Climate Change Review* (2008) Chapter 6: http://www.garnautreview.org.au/pdf/Garnaut_Chapter6.pdf.
[26] Garnaut Review of Climate Change, p 18; Mark Harrison, ‘Addressing Wellbeing in the Long-Term: a Review of Intergenerational Equity and Discount Rates in Climate Change Analysis’: http://press.anu.edu.au/wp-content/uploads/2014/04/23.-Addressing-Wellbeing-in-the-Long-Term-a-Review-of-Intergenerational-Equity-and-Discount-Rates-in-Climate-Change-Analysis.pdf.

expiration date for Hazelwood's mining license), the central estimate for the cost of a marginal tonne of carbon is projected to be 32% higher in real terms. Second, these numbers exclude upstream 'embodied' carbon emissions in the construction of the plant and mine and the production of construction materials.

Table 2: Annual climate change impacts and costs for Hazelwood

	Low case 5%, Avg	**Central case** 3%, Avg	**High case I** 2.5%, Avg	**High case II** 3%, 95th	**2013-14 carbon price**
Cost of carbon $/t-$CO_2$	13	42	66	124	24
Unit cost of emissions $/MWh	20	64	101	189	37
Total cost of emissions[27] $ million	250	810	1,270	2,390	470

Note: See Appendix B, Table B1 for supporting calculations

2.2.2 Air pollution

In American studies of the costs of power generation, non-climate change air pollution costs are generally the largest externality, driven by the adverse health impacts and the increase in premature mortality. Like the climate change impacts discussed above, integrated-assessment models are used to arrive at an estimate. Specifically, these models:

1. Estimate point-source emissions;
2. Use air plume modeling to estimate the dispersion and transformation of those pollutants based on background concentrations, wind patterns and stack height;
3. Use dose-response functions to estimate the incremental impacts of higher pollutant concentrations on health, mortality, visibility, agriculture, and property damage; and

[27] Assuming 90% effective capacity factor. See footnote 13 for further detail

4. Use willingness-to-pay methodologies to calculate the monetary value of those impacts on health, business and the environment based on their shadow market value.

For the first step, we have access to reliable point-source pollution data for Hazelwood through the National Pollutant Inventory (NPI) which provides a solid basis for a first estimate.[28] As the National Academy of Sciences (NAS) notes, “Variation in damages per kWh is primarily due to variation in pollution intensity (emissions per kWh) across plants, rather than variation in damages per ton of pollutant, which varies with plant location.”[29] Interestingly, Hazelwood’s pollutant emission intensity (excluding CO_2) is, on a per kWh basis, relatively low compared with its US counterparts. For the four pollutants analyzed, SO_2 and $PM_{2.5}$ emission intensities were around the 20th percentile of US plants (see Appendix B, Table B2). The relatively low SO_2 content is especially important as this this accounts for a vast majority of air pollution costs in the US. PM_{10} was at the 40th percentile, and NO_x the 60th percentile.

The second and third steps are more challenging. Accurate modeling of local atmospheric responses, and constructing local dose-response functions are beyond the scope of this paper. We therefore took a similar approach to ATSE in their 2009 analysis of the externalities of power generation in Australia and adapted the results of existing models. Instead of using the ExternE model that ATSE adapted which is now ten years old, we used the more up-to-date APEEP model developed by Nicolas Muller and Robert Mendelsohn for the United States context, which was used in the National Academy of Science’s 2010 report on the Hidden Cost of Energy.[30]

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[28] National Pollutant Inventory: http://www.npi.gov.au/

[29] National Academy of Sciences, *Hidden Costs of Energy: Unpriced Consequences of Energy Production and Use* (October 2009) p.6

[30] Nicholas Muller and Robert Mendelsohn, ‘Measuring the damages of air pollution in the United States’ (2007) Journal of Environmental Economics and Management 1-14; Nicholas Muller, Robert Mendelsohn and William Nordhaus, ‘Environmental Accounting for Pollution in the United States Economy’ (2011) American Economic Review 1649.

The APEEP model applies to SO_2, NO_X, $PM_{2.5}$ and PM_{10} emissions from point sources around the United States. To calculate health impacts, it uses a set of dose-response functions from public health literature (summarized in Appendix B, Table B3). It then values these health responses according to the literature on revealed preference valuation of mortality and morbidity (summarized in Appendix B, Table B4). Since the bulk of these come from increased mortality, it is worth noting that the value of a statistical life used in this model is the same as that used by the US EPA, of US$6 million.[31] The APEEP model also calculates non-health economic damages to the agriculture and timber industries, property damage to buildings, and monetizes the damage to visibility and reduced recreational uses based on valuations used by the US EPA. Ultimately, health impacts make up the lion's share of these damages, accounting for over 90% of total damages.

We took a model run that was done for the NAS in 2010 and adapted it to an Australian context. The NAS ran the model for 406 coal-fired power plants in the US and came up with dollar-per-pollutant values for each power plant (see Appendix B, Table B5). These ranged widely from plant-to-plant due to local differences. To evaluate where Hazelwood might fit, we compared it to US coal plants along two major determinants of local impact - stack height and local population density.[32] At 137m, Hazelwood is equal to the median height of US plants, and is very close to the mean stack height of 144m (see Appendix C, Figure C2).[33] By contrast, local

[31] This value is broadly consistent with Australian studies of the VSL, which vary widely from a low of $2.9 million to $28.4 million with a mean of $11.2 million and a median of $6.8 million in occupational health and safety analyses: Safe Work Australia, *The Health of Nations* (2008) p 55, http://www.safeworkaustralia.gov.au/sites/SWA/about/Publications/Documents/330/TheHealthOfNations_Value_StatisticalLife_2008_PDF.pdf

[32] Absent the supporting data for the NAS study, we used the Energy Information Administration (EIA) 2012 database of individual electricity generators. We analyzed generators at the plant level, selecting for all operating plants that had a primary energy source coded as "Anthracite coal and bituminous coal", "Lignite coal", or "Subbituminous coal". 345 unique plants were identified. Stack heights were taken as average heights. Country population densities were taken from 2013 census bureau estimates.

[33] GDF Suez Australia, *Hazelwood Media Factsheet*: [33]http://www.gdfsuezau.com/media/factsheets/2/GDF%20SUEZ%20Australian%20Energy%20Hazelwood.pdf

population density is significantly less than the average US plant. The population density of the Gippsland region, where Hazelwood is located, is 6.2 people/km^2.[34] This puts it in the 14th percentile when ranked against county population densities of US plants (see Appendix C, Figure C3), well below the median density of 31 people/km^2 and mean density of 127 people/km^2.[35] Considering Hazelwood's average stack height, and low population density, we used the 25th percentile of US plants as a central estimate, with the 5th percentile and 75th percentiles as low and high cases.

Finally, we assumed the dose-response and valuation aspects of the NAS model to be applicable to Australia. There is unlikely to be any significant differences in health impacts between the US and Australia. Valuation of impacts is also likely to be similar. Health effects are likely to have similar valuations, with Australia having a similar per capita income to the US and the two countries having a strong overlap in consumer behavior and cultural values. Non-health effects will be different in Australia, with differences in local economic activity. However, the impact of these differences on valuation is likely to be negligible, as non-health effects across a wide range of industries were shown to be much smaller than health effects in the US study.

Table 2 below shows the resulting estimates (see Appendix B, Table B6 for supporting calculations). The central estimate of $7.94/MWh is relatively low. It compares with a median value for US plants of $34.16/MWh, and sits between the 5th and 25th percentile. This low value is being driven primarily by low emission intensities, especially for sulfur. In the US, sulfur accounts for over 80% of damages, and is responsible for a majority of air pollution costs at Hazelwood. However, sulfur emission intensities for Hazelwood are in the 20th percentile of US

[34] Australian Bureau of Statistics, *National Regional Profile - Latrobe-Gippsland*, http://www.abs.gov.au/AUSSTATS/abs@nrp.nsf/Latestproducts/205Population/People12007-2011?opendocument&tabname=Summary&prodno=205&issue=2007-2011

[35] A small number of coal plants near major urban centers skew the data.

plants. Local differences are less important, albeit more uncertain. Even in the high case, allowing for dollar-per-pollutant values to be at the 75th percentile of US plants, costs only rise to $14.83/MWh, still less than half the US median.

Table 3: Annual air pollutant emissions and damages from Hazelwood

	Low case Local impacts at 5th percentile of US plants	**Central case** Local impacts at 25th percentile of US plants	**High case** Local impacts at 75th percentile of US plants
SO_2 unit cost $/MWh	2.34	4.81	8.97
NO_x unit cost $/MWh	1.88	2.71	4.98
PM_{10} unit cost $/MWh	0.05	0.08	0.17
$PM_{2.5}$ unit cost $/MWh	0.18	0.33	0.71
Total unit cost $/MWh	4.45	7.94	14.83
Total cost[36] $ million	**56**	**100**	**187**

Note: See Appendix B, Table B3 for supporting calculations

To sense-check this estimate, we compare the implied impact on mortality rates. Based on previous model runs in which premature mortality has accounted for 70% of the total cost, this implies that air pollution from Hazelwood causes approximately 18 deaths per year in Gippsland — around 1% of total annual mortalities in that region based on census data.[37] Since Hazelwood is but one of four big coal-fired power stations in Gippsland, this suggests that potentially a small but significant proportion of deaths in the region are attributable to these power stations.

[36] Assuming 90% effective capacity factor. See footnote 13 for further detail
[37] ABS, *Deaths, Summary, Statistical Area Level 4*: http://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/3302.02012?OpenDocument

Our air pollution cost estimates are rough. Without the capacity to do a full model run using software like APEEP, or complete data on background air pollutant concentration rates or health complications in Gippsland, we cannot be certain that these cost or health impact estimates are accurate. Further, this estimate only partially captures the full suite of air pollutants emitted from Hazelwood. The model run used by NAS only looks at four pollutants - $PM_{2.5}$, PM_{10}, SO_2 and NO_x. Hazelwood emits significant quantities mercury, lead, arsenic and other heavy metals which are significant public health hazards, especially to children. Epstein's best estimate of the cost of mercury from US coal (both combustion and mining) is equal to $3.80/MWh.[38] Indeed much of regulation both in Australia and the US concerns emissions of hazardous heavy metals. Also not included in the analysis are ammonia, volatile organic compounds, and coal combustion by-products like fly ash or flue gas desulfurization materials, some of which are emitted from Hazelwood in quite large quantities.[39] In that sense, we are likely to have underestimated the true cost of air pollution, if anything.

2.2.3 Mining

A third major externality involves the mining of coal for use at the Hazelwood plant. Hazelwood sources its coal from an open-cut mine located directly adjacent to the plant. The mine involves a number of externality costs which we have not quantified, but which we briefly describe here and highlight as an area for further analysis. Specifically, public impacts, environmental impacts, disaster costs, and potential remediation costs.

[38] Epstein et al. "Full cost accounting for the life cycle of coal" *Ann. NY Acad. Sci* 1219 (2011) pp73-98
[39] National Academy of Sciences, *Hidden Costs of Energy: Unpriced Consequences of Energy Production and Use* (October 2009), pp 71-108.

The mining and transport of coal carries a substantial risk of injury and death, due to both accidents and long-term exposure to pollutants. Coal transport accidents impose a significant cost in the US but are likely to be relatively minor for Hazelwood as the power station is located at the mouth of a dedicated coal mine. We should also be careful about counting occupational injuries and fatalities as externalities, as the occupational risks of workers are likely being at least partially compensated for by increased wages and workers compensation schemes. What *is* included as an externality, though, are the injuries or deaths in the community caused by mining. Open-cut mines such as Hazelwood can cause serious health impacts in the event of a mine fire which occurred at the Hazelwood mine from February 9th to March 25th earlier this year.[40] That fire led to dramatic increases in air pollution, especially $PM_{2.5}$, and the partial evacuation of the town of Morwell (which lies adjacent to the Hazelwood power station).

The open-cut mining process also generates slurry, the disposal of which can harm public health due to possible contamination of the Morwell River or the Hazelwood cooling ponds which are used by the public for swimming and watersports year-round.[41] (Note, recreational use of the cooling ponds is also likely to generate positive externalities.) To properly quantify the value of these health externalities, we would have to estimate the point-source pollution, its impact on background air and water pollutant levels, the dose-response impact on health in the area, and the value of those impacts.

Environmental impacts of mining can also be significant. The level of stormwater discharge into the Morwell River and nearby wetlands is likely to increase concentrations of zinc, sodium, selenium, sulfates, and other minerals, which could in turn have a negative impact on local aquatic wildlife and waterfowl. The construction and expansion of the Hazelwood mine has also

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[40] Hazelwood Mine Fire Inquiry. http://hazelwoodinquiry.vic.gov.au/
[41] http://www.visitlatrobevalley.com/pages/hazelwood-pondage/

involved the moving of the Morwell River, causing unknown impacts on local hydrology and wildlife.[42] The mining of coal at the Hazelwood mine also leads to subsidence - movement in the ground surface caused by the mining process - which may in turn lead to the depressurization of the two aquifer systems (the Morwell Formation and the Traralgon Formation) which lie underneath the Hazelwood Mine.[43] Further, there is an opportunity cost to the water used by Hazelwood (1,300 L/MWh). Possible approaches to quantifying these environmental externalities would include contingent valuation surveys, looking at Victorian's willingness or pay or accept the degradation, or revealed preference analysis.

The third set of costs relate to damage to, and use of, public infrastructure and services as a result of disasters and unanticipated events. We highlight two examples as illustrations. In the recent fire at the Hazelwood mine, the Country Fire Authority reported using between 300 and 500 workers per day across the 35 day firefighting effort.[44] Since the Country Fire Authority is a mix of paid and volunteer staff, there are external costs to both to the state and to individual volunteers. Both the opportunity cost to the state of these resources, and the opportunity cost of the value of volunteer labor would depend on different alternative uses of each firefighter's time and would be harder to quantify. The Hazelwood Mine Fire Inquiry estimated the total cost of the fire to be in excess of $100m, including $32.5m for state government fire suppression activities alone.[45] Another second example is the closure of the Princes Freeway in 2011 due to cracks in the freeway caused by subsidence at the Hazelwood mine.[46] This incurred costs both to the state (in closing, investigating and repairing the freeway) and to the regional economy

[42] Latrobe City Neighbourhood Environment Improvement Plan
[43] International Power (Hazelwood), *Annual Report 2002*.
[44] Country Fire Authority, 'Hazelwood mine fire - update from the Incident Controller' March 16th 2014: http://news.cfa.vic.gov.au/blog-mainmenu-8/blog-mainmenu-8/Hazelwood-mine-fire-a-update-from-the-Incident-Controller.html.
[45] Hazelwood Mine Fire Inquiry report, p222. http://report.hazelwoodinquiry.vic.gov.au/
[46] Thomas Hunter, 'Fears of collapse to shut Princes Highway for 3 months' *The Age* February 11 2011, http://www.theage.com.au/environment/weather/fears-of-collapse-to-shut-princes-highway-for-three-months-20110211-1ap1r.html.

(due to the working hours lost in the closure of a major regional transport route). The first of these costs should be readily measurable but has not been made public, while the second of these costs is likely to be more difficult in the absence of detailed traffic data.

A final source of potential externalities is those associated with remediation. As a condition of its mining license, GDF Suez Hazelwood is required to rehabilitate the mine site in accordance with a state government approved rehabilitation plan. Should the company adequately rehabilitate the site, the cost has been internalized. However, mining operations have a track record of incomplete rehabilitation. Of particular concern with Hazelwood is that the owners have paid only \$15 million as a 'rehabilitation bond' while full rehabilitation costs have been estimated to be as high as \$200-500 million.[47] Should GDF Suez walk away from Hazelwood on closure (which they have a strong incentive to do), the taxpayer would likely bear these rehabilitation costs.[48]

2.3 Comparative costs of Hazelwood

Factoring in only the externalities of carbon emissions and four key air pollutants, the cost of Hazelwood rises significantly above its private costs. The SRMC rises from \$3/MWh with no externality pricing, \$40/MWh under the 2013-14 carbon price, and \$75/MWh under our central estimates for carbon and air pollution externalities. The average unit cost of production rises from \$14/MWh to \$51/MWh to \$87/MWh respectively.

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[47] Martin McKenzie-Murray, 'Why Morwell is Burning' *The Saturday Paper* Mar 8 2014: http://www.thesaturdaypaper.com.au/2014/03/08/why-morwell-burning/1394197200#.VQegD-GGOzd; Environment Victoria, 'Preventing the preventable: Policy options for accelerating coal mine rehabilitation and creating jobs in the Latrobe Valley' (November 2014).

[48] Samantha Hepburn, 'Stronger laws needed to prevent another Hazelwood coal mine fire' March 12th 2014: http://theconversation.com/stronger-laws-needed-to-prevent-another-hazelwood-coal-mine-fire-24215.

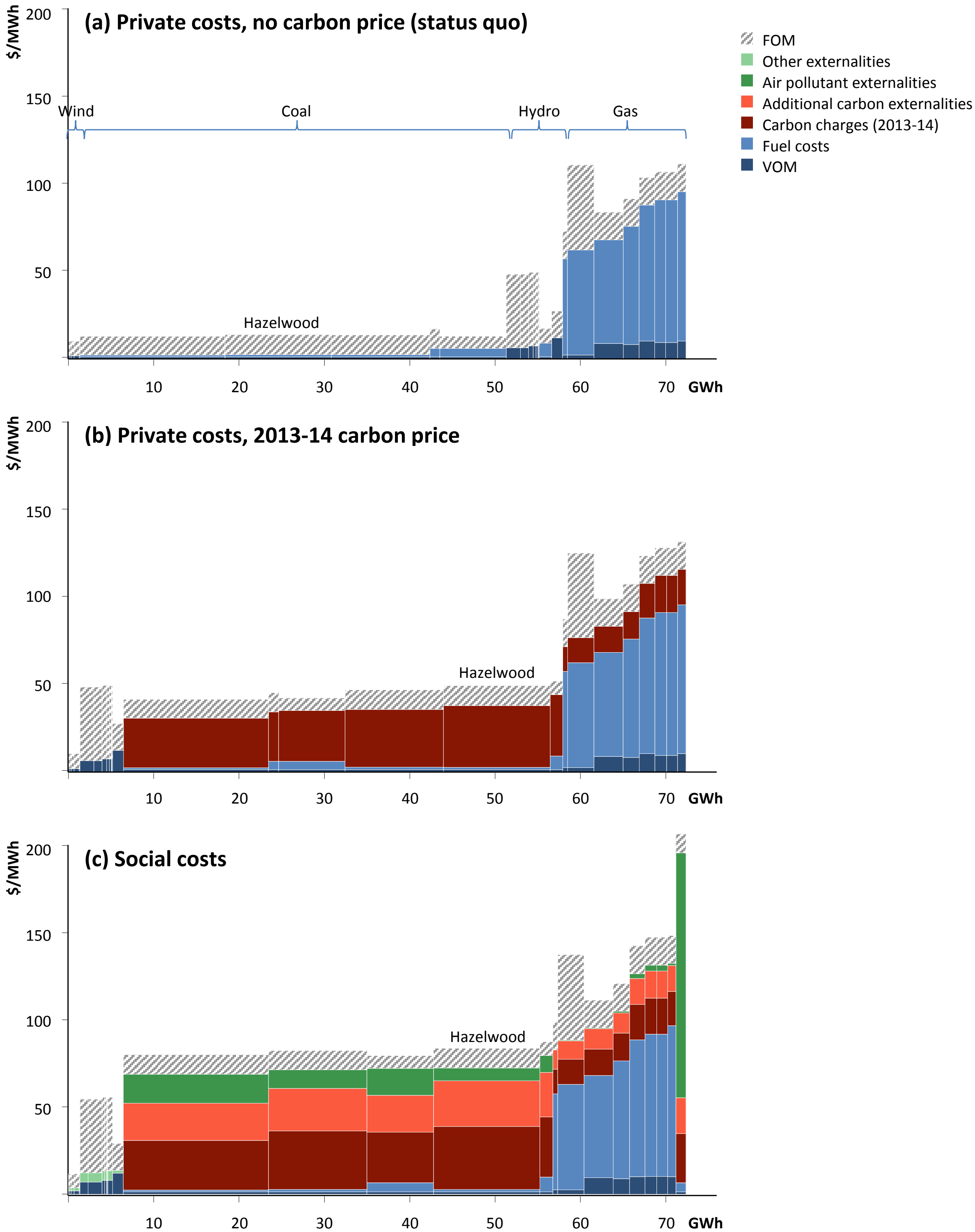
The average wholesale price of electricity in Victoria over the past five years was approximately $30/MWh for the period without a carbon tax and $55/MWh for the two-year period with the carbon tax. This means that even when the carbon tax was in place, consumers were still paying a price well below the social cost of production from Hazelwood – a cost that is continuing to rise with the growing cost of carbon. The key question, though, is if we were to price externalities for power production, should Hazelwood continue to produce?

We first look at how externalities shift Hazelwood's location in the Victorian cost curve. We used the same methodology described above to calculate carbon and air pollution externalities for all existing Victorian plants.[49] Figure 1 below shows the Victorian power stack before and after pricing externalities (central cases), using short run marginal costs. See Appendix B, Table B7 for supporting data.

Figure 1(a) shows private costs with no price on carbon status quo with no price on carbon. In Figure 1(b), we show the situation prior to the abolishment of the carbon tax. Figure 1(c) shows social costs, accounting for climate change and air pollutant externalities. We also show non-sunk fixed costs (FOM) to indicate the price that a plant requires to stay operational over the longer term.

[49] We use the same value for air pollutant impacts ($/tonne-pollutant) as used for Hazelwood. Note that all other major coal fired power plants and some gas peaking plants are located very close to Hazelwood in the Latrobe Valley. Other peaking plants, though, are spread across the state and may have significantly different local impacts.

Figure 1: SRMC curves of Victorian generators



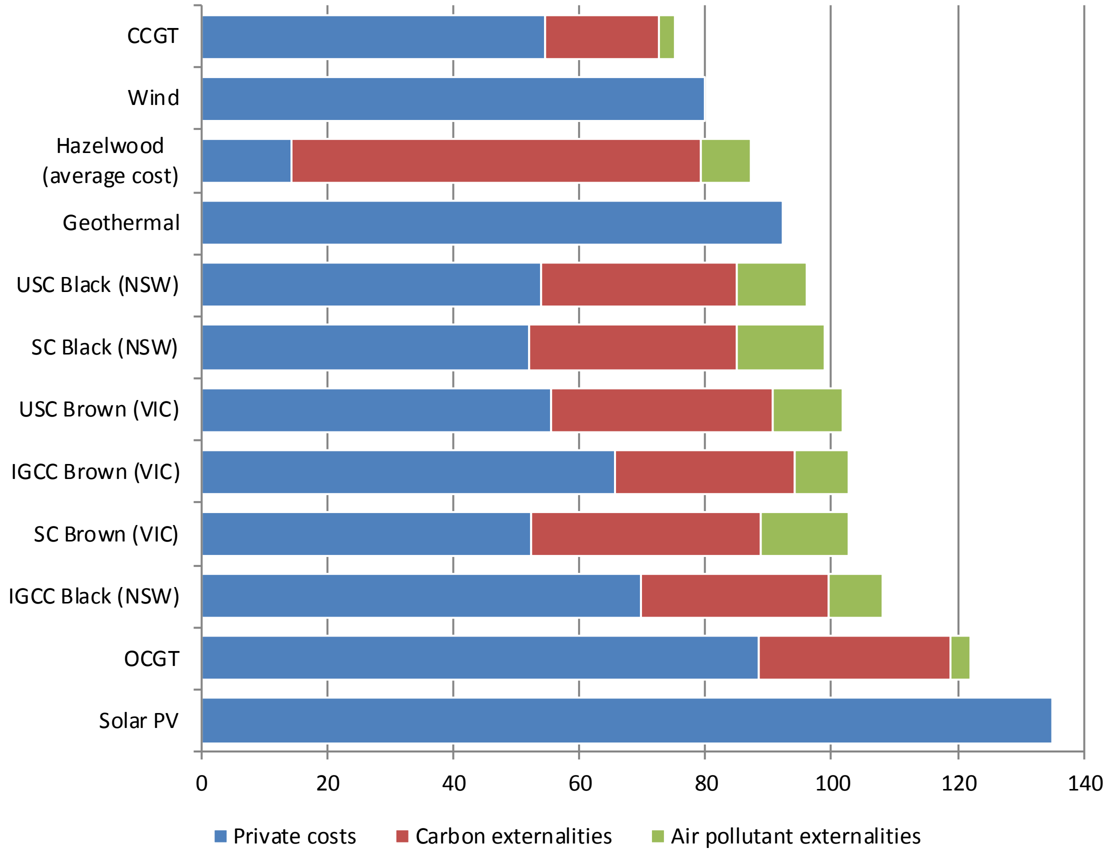
Note: GWh values (x-axis) represent estimation of maximum annual generation and assume capacity factors of 90% for coal, 70% for gas, 35% for wind and 20% for hydro. See Appendix B, Table B7 for supporting calculations. Central case estimates used for pricing externalities.

We observe no major changes in the stack order as a result of including externalities. The stack continues to have a small amount of low cost renewables on the left (wind and hydro), the four large baseload coal generators in the middle, and higher cost peaking gas plants on the right. The four baseload generators all have roughly similar total costs. However, their mix of externalities is different with Hazelwood having the highest carbon costs, but lowest air pollutant costs.[50] Given the forecast escalation in the cost of carbon, we expect Hazelwood should become comparatively more expensive over time.

At $87/MWh, Hazelwood is also likely to be more expensive than the long run marginal (LRMC) cost of alternative generation. We reviewed the LRMCs of 12 different generation technologies for Victoria and New South Wales (NSW), factoring in carbon and air pollutant externalities - see Figure 2 below. (Victoria currently exports electricity to NSW, suggesting that new generation in NSW could offset reduced generation in Victoria without major investment in new transmission.) The LRMC for new entrant generators includes construction capital costs, as well as carbon and air pollutant externalities. CCGT and high quality wind both have LRMCs around $80/MWh. Geothermal, supercritical and ultra-supercritical black coal generation are in the $90 - $100/MWh range. These figures should be treated as indicative only. Gas, coal and geothermal estimates are from 2009 bottom-up costings, and increases in especially gas prices may have pushed up CCGT costs. Wind and solar costs are based on media reports of project costs. However, the key point is that there are a range of generation technologies that are roughly cost competitive with Hazelwood when factoring in externalities.

[50] Hazelwood's carbon costs are 25% higher than Loy Yang A, but its air pollutant externalities are less than half.

Figure 2: LRMC of new entrant generation



Note: ACIL Tasman (2009) estimates for construction, fuel and operating costs, as well as the cost of capital for all technologies except wind and solar which are not included in the ACIL Tasman dataset. Carbon priced using central case estimate of $42/tCO$_2$. Assumed price of air pollutant externalities are: $3/MWh for OCGT (average for Victoria plants); $2.40/MWh for CCGT (20% less than OCGT); $14/MWh for supercritical coal (SC) based on pollution data from the Kogan Creek SC plant in Queensland; $11.20/MWh for ultra supercritical coal (20% less than SC); and $8.40/MWh for integrated gasification combined cycle (40% less than SC). We use the same value for air pollutant impacts ($/kg-pollutant) as used for Hazelwood. Wind and solar costs based on project disclosures and bank estimates (see http://reneweconomy.com.au/2013/renewables-now-cheaper-than-coal-and-gas-in-australia-62268).

On the demand side, we note little forecast growth. Contrary to historic expectations, electricity demand has fallen in recent years.[51] Combined with the additional supply from new generation, there is now significant surplus capacity across the NEM. The most recent assessment by AEMO is that Victoria currently has 1,950 – 2,200MW of surplus generation capacity.[52] This

[51] This decline has been driven by high take-up of rooftop photovoltaic (PV) cells (one in seven Australian households now have PV), increased energy efficiency in the residential and consumer sectors in response to higher prices (energy consumption per capita has fallen by 10%), and reduced demand by major industrials, in part due to plant closures. See AEMO, *National Electricity Forecasting Report* (2013).
[52] AEMO, Electricity Statement of Opportunities (2014).

means Hazelwood's 1,600MW could be switched off without breaching AEMO's reliability standard for security of supply. Forecast surplus capacity for 2023-24 is 1,450 – 3,100MW, meaning the loss of Hazelwood's capacity is also highly unlikely to present security of supply problems in the medium term future.

In summary, we find that there are a range of new build generation technologies that have LRMCs similar to the average social cost of electricity generated from Hazelwood. This suggests that if externalities were properly priced, cleaner generation could be financially viable and replace Hazelwood as well as other Victorian coal generators. With significant surplus generation capacity, there is also the opportunity to switch off a high-social-cost base load generator like Hazelwood without even requiring replacement generation.

3. Conclusion

Hazelwood faces a private SRMC of approximately $3/MWh. We estimate its true social SRMC to be $75/MWh – more than 20 times larger. In total dollar terms, the difference adds up to annual external cost of $910 million. This massive difference speaks to the need to regulate externalities to ensure an outcome that is optimal for society rather than the firm.

The largest unpriced externality is carbon emissions. Efforts to price carbon under the previous Federal government dramatically changed Hazelwood's private costs, increasing its SRMC more than ten-fold when the carbon price reached $24.15/tonne-$CO_2$ in 2013-14. It also pushed up Hazelwood's average unit cost of production to a point where we find it was operating close to its breakeven point. Industry support in the form of $270 million of free carbon permits may have been critical for keeping the plant profitable. However, even under a carbon price of $24.15, we find its private SRMC to have been only around half of its social marginal cost.

New entrant competition appears to be cost competitive with Hazelwood's social cost of production. We find a range of new entrant generation options with long run marginal costs that are in the range of Hazelwood's average social cost of production (~$80/MWh). Given we expect Hazelwood's social costs to increase over time, and technological progress to decrease new entrant costs, continuing to operate Hazelwood is likely to become increasingly economically inefficient.

If externalities were properly priced, and in the absence of other market failures, the market should resolve this allocative inefficiency. In the absence of pricing externalities, there is a case for direct government intervention to force closure or clean up, especially given the large surplus of generation capacity in the Victorian market.

Our externality analysis has been limited. We have focused on what US experience suggests are the largest externalities – air pollutants and carbon emissions. Hazelwood (and Victorian plants more generally) proved to have a significantly different pattern of externalities than the typical US generator. Air pollutant costs were much lower, and carbon costs much higher. Given this dissimilarity, other types of externalities should be considered, and further analysis should be carried out to more accurately estimate especially air pollutant costs.

Nonetheless, even with our limited scope, Hazelwood's externalities are large and growing. Failure to properly price them is not an academic point. We find that it is distorting the market and preventing a shift to cleaner generation.

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Appendix A: Overview of Australian electricity market

Victoria is part of the Australian National Electricity Market (NEM) - a wholesale electricity market covering Queensland, New South Wales, Victoria, Australian Capital Territory, South Australia and Tasmania.[53] Generators sell through a centralized dispatch process managed by the Australian Energy Market Operator (AEMO), ranking bids on a 5-minute bid schedule.

The market is structurally separated into generation, transmission, distribution and retail segments, with significant and growing concentration of market power in both generation and retail. In Victoria, the electricity sector is fully privatized, and the four largest generators control 90% of the market.[54] Pricing of monopoly assets (transmission and distribution) are regulated by the Australian Energy Regulator. Generation is relatively unconstrained - there is a wholesale price ceiling at A$12,500/MWh, and a price floor at -A$1,000/MWh.

While the entire NEM is interconnected (spanning nearly 5,000km), it operates with five distinct electrical regions which are approximately aligned with state boundaries. Transmission between regions occurs via regulated interconnectors which have limited capacity and can be binding constraints on the system.[55] As a result, regions tend to be largely self-sufficient.

[53] In other words, everywhere except Western Austalia and the Northern Territory: https://www.aer.gov.au/sites/default/files/Chapter%201%20National%20electricity%20market.pdf
[54] http://www.aer.gov.au/sites/default/files/Chapter%201%20-%20National%20electricity%20markets%20A4.pdf
[55] http://www.abc.net.au/mediawatch/transcripts/1234_aemo2.pdf

Appendix B: Tables

Table B1: Calculation of Hazelwood's carbon costs

	Units	Source	All cases	Low case	Central case	High case I	High case II	AU carbon price
Case definition								
Damage point estimate				Average	Average	Average	%	n/a
Discount rate				5.0%	3.0%	2.5%	3.0%	n/a
Calculation of carbon intensity								
Reported emissions 2012/13	tCO2e-	NGER	17,446,858					
Reported generation 2012/13	MWh	AEMO	11,440,000					
Calculated carbon intensity	tCO2e-/MWh		1.53					
Reported carbon intensity	tCO2e-/MWh	Acil Tasman	1.53					
Conversion assumptions								
Inflation discount factor, USD, 2007-2014			1.101					
AUD/USD exchange rate (April 2014)			1.070					
Carbon price								
US2007$/tCO2e0	US07$/tCO2e-	Whitehouse 2013		11.00	36.00	56.00	105.00	
US2014$/tCO2e0	US14$/tCO2e-			12.11	39.64	61.66	115.61	
AU2014$/tCO2e0	AU14$/tCO2e-			12.96	42.41	65.97	123.70	24.15
Cost of carbon for Hazelwood								
Unit cost	AU14$/MWh			19.83	64.89	100.94	189.26	36.95
Annual cost, 90% effective capacity	AU14$			250,143,552	818,548,416	1,273,297,536	2,387,401,344	466,102,080

Table B2: Comparison of emission intensity of air pollutants from Hazelwood with US plants

	Units	Source	All cases	SO2	NOx	PM10	PM2.5
Emission intensity - Hazelwood							
Emissions 2010/11	kg	NPI		12,000,000	26,000,000	3,300,000	690,000
Emissions 2011/12	kg	NPI		12,000,000	25,000,000	3,100,000	610,000
Average emissions, 2010 - 12	kg			12,000,000	25,500,000	3,200,000	650,000
Generation 2010/11	MWh	AEMO	11,328,000				
Generation 2011/12	MWh	AEMO	12,726,000				
Average generation, 2010-12	MWh		12,027,000				
Average emission intensity	kg/MWh			1.00	2.13	0.27	0.05
Emission intensity - US plants							
Mean	lb/MWh	NAS		12.00	4.10	0.72	0.59
Std dev	lb/MWh	NAS		11.00	2.30	0.67	0.58
5th %	lb/MWh	NAS		1.50	1.30	0.12	0.09
25th %	lb/MWh	NAS		5.40	2.60	0.28	0.20
50th %	lb/MWh	NAS		8.90	3.70	0.48	0.35
75th %	lb/MWh	NAS		16.00	4.90	0.94	0.81
95th %	lb/MWh	NAS		33.00	9.00	2.10	1.80
Mean	kg/MWh			5.44	1.86	0.33	0.27
Std dev	kg/MWh			4.99	1.04	0.30	0.26
5th %	kg/MWh			0.68	0.59	0.05	0.04
25th %	kg/MWh			2.45	1.18	0.13	0.09
50th %	kg/MWh			4.04	1.68	0.22	0.16
75th %	kg/MWh			7.26	2.22	0.43	0.37
95th %	kg/MWh			14.97	4.08	0.95	0.82
Percentile ranking of Hazelwood	Percentile			19%	60%	42%	21%

Table B3: Epidemiology Studies Used in APEEP

Health Event	Pollutant	Study
All-cause adult chronic-exposure mortality[a]	$PM_{2.5}$	Pope et al. 2002
Infant chronic-exposure mortality	$PM_{2.5}$	Woodruff et al. 2006
Chronic bronchitis	PM_{10}	Abbey et al. 1993
Chronic asthma	O_3	McDonnell et al. 1999
Acute-exposure mortality	O_3	Bell et al. 2004
Respiratory admissions	O_3	Schwartz 1995
ER visits for asthma	O_3	Steib et al. 1996
COPD admissions	NO_2	Moolgavkar 2000
IHD admissions	NO_2	Burnett et al. 1999
Asthma admissions	SO_2	Sheppard et al. 1999
Cardiac admissions	SO_2	Burnett et al. 1999

[a]Acute exposure mortality for $PM_{2.5}$ was not included in this analysis as a separate effect. See Muller and Mendelsohn (2007) for further discussion.

SOURCE: Muller and Mendelsohn 2006. Reprinted with permission; copyright 2007, *Journal of Environmental Economics and Management*.

Table B4: Value of Human Health Effects in APEEP

Health Event	Unit	U.S. Dollars
Chronic Exposure Mortality	Case	5,910,000
Chronic Bronchitis	Case	320,000
Chronic Asthma	Case	30,800
General Respiratory	Hospital Admission	8,300
General Cardiac	Hospital Admission	17,526
Asthma	Hospital Admission	6,700
COPD	Hospital Admission	11,276
Ischemic Heart Disease	Hospital Admission	18,210
Asthma	ER Visit	240

[a]Values are in 2000 U.S. dollars; see Muller and Mendelsohn 2007.

SOURCE: Modified from Muller and Mendelsohn 2006.

Table B5: Distribution of Criteria-Air-Pollutant Damages per Ton of Emissions from Coal-Fired Power Plants (2007 US Dollars)

	Mean	Standard Deviation	5th Percentile	25th Percentile	50th Percentile	75th Percentile	95th Percentile
SO_2	5,800	2,600	1,800	3,700	5,800	6,900	11,000
NO_x	1,600	780	680	980	1,300	1,800	2,800
$PM_{2.5}$	9,500	8,300	2,600	4,700	7,100	10,000	26,000
PM_{10}	460	380	140	240	340	490	1,300

NOTE: All plants are weighted equally, rather than by the fraction of electricity they produce.

ABBREVIATIONS: SO_2 = sulfur dioxide; NO_x = oxides of nitrogen; PM = particulate matter.

Table B6: Calculation of Hazelwood's air pollution costs

	Units	Source	All cases	Low case	Central case	High case
Case definition						
Damage point estimate				5th %	25th %	75th %
Average emission intensity						
SO2	kg/MWh	Table B2	1.00			
NOx	kg/MWh	Table B2	2.13			
PM10	kg/MWh	Table B2	0.27			
PM2.5	kg/MWh	Table B2	0.05			
Damage function (US$2007/ton)						
SO2	US$07/ton	NAS/APEEP		1,800	3,700	6,900
NOx	US$07/ton	NAS/APEEP		680	980	1800
PM10	US$07/ton	NAS/APEEP		140	240	490
PM2.5	US$07/ton	NAS/APEEP		2,600	4,700	10,000
Conversion assumptions						
Inflation discount factor, USD, 2007-2014			1.10	2,600	4,700	10,000
AUD/USD exchange rate (April 2014)			1.07			
Tons to kg			907			
Damage function (AU$2014/kg)						
SO2	AU$14/kg			2.34	4.80	8.96
NOx	AU$14/kg			0.88	1.27	2.34
PM10	AU$14/kg			0.18	0.31	0.64
PM2.5	AU$14/kg			3.38	6.10	12.99
Unit cost estimate						
SO2	AU$14/MWh			2.34	4.81	8.97
NOx	AU$14/MWh			1.88	2.71	4.98
PM10	AU$14/MWh			0.05	0.08	0.17
PM2.5	AU$14/MWh			0.18	0.33	0.71
All	**AU$14/MWh**			4.45	7.94	14.83
Annual cost estimate						
Generation, 90% eff. cap.	MWh		12,614,400			
SO2	AU$14			29,519,414	60,678,796	113,157,755
NOx	AU$14			23,724,535	34,191,242	62,800,241
PM10	AU$14			613,366	1,051,485	2,146,782
PM2.5	AU$14			2,317,882	4,190,016	8,914,928
All	**AU$14**			56,175,198	100,111,540	187,019,707
Unit cost comparison with US plants						
US 5th percentile	AU$14/MWh	NAS/APEEP	6.24			
US 25th percentile	AU$14/MWh	NAS/APEEP	16.49			
US median	AU$14/MWh	NAS/APEEP	34.16			

Table B7: Costs of existing Victorian electricity generators

Station	Power source	VOM	FOM				Fuel		CO2			Air pollutants****					Full unit cost: status quo		Full unit cost: inc. externalities	
			Plant cost	Installed capacity	Capacity factor	Av. Unit cost			Intensity	Cost – Current price*	Cost - central case**	SO2	NOx	PM10	PM2.5	Cost - central case***	SMRC	AC	SMRC	AC
Unit		$/MWh	$mn	MW		$/MWh	$/GJ	$/MWh	t/MWh	$/MWh	$/MWh	kg/MWh	kg/MWh	kg/MWh	kg/MWh	$/MWh	$/MWh	$/MWh	$/MWh	$/MWh
Source		[1]	[1]	[1]			[1] [2]		[1]	[3]		[4] [5]	[4] [5]	[4] [5]	[4] [5]					
Anglesea	Brown coal	1.31	13.37	150	0.90	11.31	0.43	5.11	1.21	29.18	51.25	29.44	2.23	0.10	0.02	144.39	35.61	46.91	202.06	213.37
Energy Brix	Brown coal	1.31	12.48	189	0.90	8.38	0.65	8.34	1.49	35.97	63.17	1.27	2.41	0.08	0.05	9.48	45.62	54.00	82.30	90.68
Hazelwood	Brown coal	1.31	147.97	1600	0.90	11.73	0.09	1.35	1.53	36.87	64.75	1.00	2.13	0.27	0.05	7.94	39.53	51.27	75.35	87.08
Loy Yang A	Brown coal	1.31	189.54	2180	0.90	11.03	0.09	1.11	1.22	29.34	51.53	3.17	1.32	0.23	0.12	17.73	31.76	42.79	71.67	82.70
Loy Yang B	Brown coal	1.31	56.35	1000	0.90	7.15	0.41	5.12	1.24	30.00	52.69	2.72	1.66	0.18	0.10	15.86	36.43	43.58	74.98	82.12
Yallourn	Brown coal	1.31	134.22	1480	0.90	11.50	0.10	1.43	1.42	34.33	60.29	1.69	1.52	0.27	0.17	11.21	37.07	48.57	74.24	85.74
Bairnsdale	Gas (OCGT)	2.49	1.34	94	0.10	16.33	5.54	56.90	0.60	14.60	25.64	0.00	0.50	0.03	0.03	0.86	73.98	90.32	85.88	102.21
Jeeralang A	Gas (OCGT)	9.96	3.03	212	0.10	16.33	5.54	84.47	0.90	21.68	38.07	0.03	2.14	0.06	0.06	3.24	116.11	132.44	135.75	152.08
Jeeralang B	Gas (OCGT)	9.96	3.26	228	0.10	16.33	5.54	84.47	0.90	21.68	38.07	0.03	2.14	0.06	0.06	3.24	116.11	132.44	135.75	152.08
Laverton Nth	Gas (OCGT)	8.73	4.46	312	0.10	16.33	6.06	69.96	0.68	16.33	28.68	0.00	0.54	0.04	0.03	0.92	95.02	111.35	108.29	124.62
Mortlake	Gas (OCGT)	9.35	8.10	566	0.10	16.33	5.60	61.13	0.64	15.51	27.24	0.00	0.29	0.02	0.02	0.50	86.00	102.34	98.23	114.56
Newport	Gas (OCGT)	2.48	22.45	510	0.10	50.25	6.06	62.23	0.62	14.91	26.18	0.00	0.21	0.03	0.03	0.50	79.61	129.87	91.38	141.64
Somerton	Gas (OCGT)	10.58	2.29	160	0.10	16.33	6.06	88.62	0.86	20.68	36.32	0.00	0.77	0.04	0.04	1.24	119.88	136.21	136.75	153.09
Valley Power	Gas (OCGT)	10.58	4.29	300	0.10	16.33	5.54	80.60	0.86	20.68	36.32	0.00	2.24	0.11	0.10	3.54	111.86	128.20	131.04	147.37
Dartmouth	Hydro	7.87	10.59	185	0.15	43.55	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.87	51.42	7.87	51.42
Eildon	Hydro	7.87	7.73	135	0.15	43.55	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.87	51.42	7.87	51.42
Hume (VIC)	Hydro	7.87	1.66	29	0.15	43.55	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.87	51.42	7.87	51.42
Macarthur	Hydro	12.50	17.49	420	0.15	15.85	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	12.50	28.35	12.50	28.35
McKay Creek	Hydro	7.87	17.74	310	0.15	43.55	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.87	51.42	7.87	51.42
Murray 1	Hydro	6.77	54.37	950	0.15	43.55	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.77	50.32	6.77	50.32
Murray 2	Hydro	6.77	31.59	552	0.15	43.55	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.77	50.32	6.77	50.32
West Kiewa	Hydro	7.87	3.43	60	0.15	43.55	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.87	51.42	7.87	51.42
Challicum Hills	Wind	1.93	1.18	53	0.30	8.59	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.93	10.51	1.93	10.51
Oaklands Hill	Wind	1.93	1.52	67	0.30	8.59	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.93	10.51	1.93	10.51
Portland	Wind	1.93	2.30	102	0.30	8.59	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.93	10.51	1.93	10.51
Waubra	Wind	1.93	4.33	192	0.30	8.59	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.93	10.51	1.93	10.51
Yambuk	Wind	1.93	0.68	30	0.30	8.59	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.93	10.51	1.93	10.51

* 2013-14 carbon price of $24.15/tonne-CO2

** Using central case cost estimates of $40.42/t-$CO_2$

*** Using central case cost estimates of $4.80/kg-$SO_2$, $1.27/kg-NOx, $0.31/kg-PM10, $6.10/kg-PM2.5. We use the same value for air pollutant impacts ($/kg-pollutant) as used for Hazelwood. Note that all other major coal fired power plants and some gas peaking plants are located very close to Hazelwood in the Latrobe Valley. Other peaking plants, though, are spread across the state and may have significantly different local impacts.

**** Emission intensity is average for 2010/11 and 2011/12

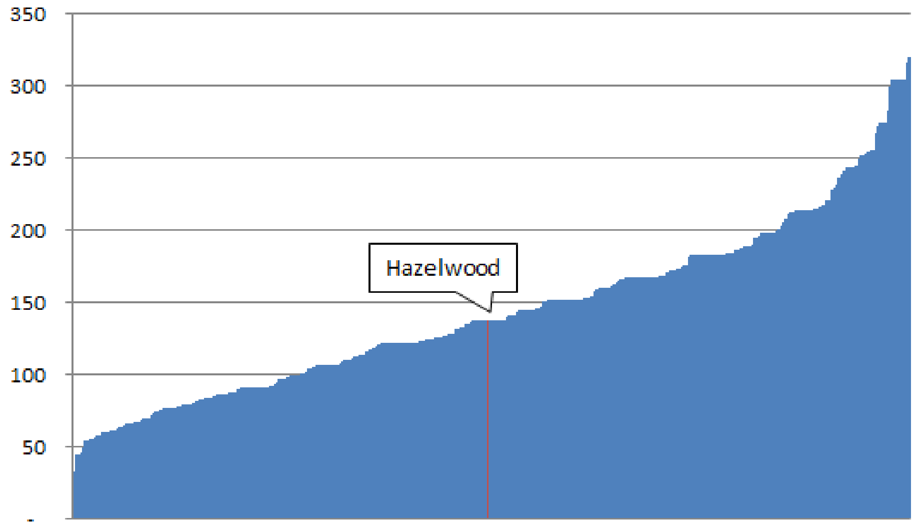
Sources: [1] AEMO, '2013 Planning Studies - Existing Generator Technical Data Summary' (Jan 2013); [2] AEMO, '2013 Planning Studies - New Generation Technical Data and Assumptions Summary' (Jan 2013); [3] Clean Air Energy Regulator; [4] National Pollutant Inventory online database: http://www.npi.gov.au/npi-data; [5] AEMO, *NEM Historical Market Information Report* (2013)

Appendix C: Figures

Figure C1: Map of the Hazelwood power station and coal mine (Google Earth)

Figure C2: Comparison of stack heights of Hazelwood with US coal plants

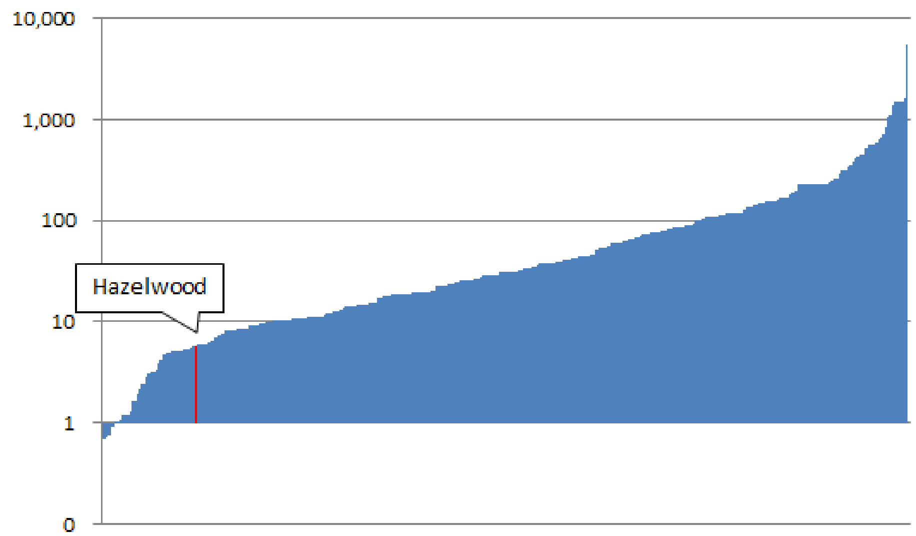
Meters (average of plant)



Note: Energy Information Administration (EIA) 2012 database of individual electricity generators. We analyzed generators at the plant level, selecting for all operating plants that had a primary energy source coded as "Anthracite coal and bituminous coal", "Lignite coal", or "Subbituminous coal". 345 unique plants were identified. Stack heights are average for plant.

Figure C3: Comparison of local population density of Hazelwood with US coal plants

People per km2 (logarithmic scale)



Note: Energy Information Administration (EIA) 2012 database of individual electricity generators. We analyzed generators at the plant level, selecting for all operating plants that had a primary energy source coded as "Anthracite coal and bituminous coal", "Lignite coal", or "Subbituminous coal". 345 unique plants were identified. Country population densities were taken from 2013 census bureau estimates.

Figure C4: Fire at the Hazelwood coal mine (Mike Keating, Herald Sun, February 25th 2014)