STRANDED ASSETS
PROGRAMME

SMITH SCHOOL OF ENTERPRISE AND THE ENVIRONMENT

UNIVERSITY OF OXFORD

Subcritical Coal in Australia: Risks to Investors and Implications for Policymakers

Working Paper

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About the Stranded Assets Programme

The Stranded Assets Programme at the University of Oxford's Smith School of Enterprise and the Environment was established in 2012 to understand environment-related risks driving asset stranding in different sectors and systemically. We research the materiality of environment-related risks over time, how different risks might be interrelated, and the potential impacts of stranded assets on investors, businesses, regulators, and policymakers. We also work with partners to develop strategies to manage the consequences of environment-related risks and stranded assets.

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Executive Summary

Coal provides 40% of the world's electricity, with 1,617 GW of global capacity. Of this capacity, 75% is subcritical, 22% supercritical, and 3% ultra-supercritical. Subcritical is the least efficient and most polluting form of coal-fired generation - it requires more fuel and water to generate the same amount of power, and creates more pollution as a result. The average subcritical coal-fired power station (SCPS) emits 75% more carbon pollution than an average advanced ultra-supercritical - the most up-to-date form of coal-fired power station - and uses 67% more water.

To limit global emissions to a level consistent with a 2°C future, the IEA estimates that it will be necessary to close a quarter (290 GW) of subcritical generation worldwide by 2020. Subcritical coal accounted for 8.6 $GtCO_2$ of emissions globally in 2009. For context, in 2010 annual gross greenhouse gas emissions globally totalled ~50 $GtCO_2$-equivalent.

Since SCPSs are the least efficient and most greenhouse gas (GHG) intensive centralised generation technology, they are both vulnerable to regulation and a logical first step in any climate mitigation strategy. Moreover, due to their greater average fuel-burn, SCPSs are also more vulnerable to non-GHG policies, such as policies regulating the emission of PM, NO_x, SO_x, and mercury. SCPSs are also highly vulnerable to water policies. Given these potential drivers of asset stranding - carbon intensity, air pollution, and water stress - this working paper examines the exposure to these risks of Australia's 22 SCPSs and the 19 companies that own them. As part of this process we have ranked company exposure to SCPSs affected by these three different environment-related risk factors. The full rankings of company exposure can be found in Section 3. We also examine how risks facing subcritical coal assets might develop in the future.

Additionally, as policymakers may be interested in inducing early closure of SCPS assets due to concerns over climate change and localised environmental impacts, our research conservatively estimates the maximum cost required to compensate the owners of Australian subcritical assets for premature retirement. We examine why this could be desirable and also say something about how this could be done in the most cost-effective way possible.

This working paper is potentially useful for two groups. It could help investors to identify and screen specific companies with exposure to SCPS assets in Australia at particular risk from climate policy, air pollution, and water stress. It will also help Australian policymakers interested in understanding the costs, benefits, and mechanisms for prematurely closing SCPSs. The paper is an interim output from a global project on subcritical coal from investment risk and public policy perspectives. The first phase report on investment risk globally was published on the 13th March 2015 and can be downloaded here. The second phase report, on public policy implications will be published in Summer 2015. This paper brings together research from these two phases as they relate to Australia.

Determining carbon, air pollution, and water stress exposure

Following the IEA, this report defines SCPSs as power plants with carbon-intensity of ≥880kg CO_2/MWh, with cutoffs of 880-1,120kg CO_2/MWh defined for 'new subcritical', 1,120-1,340kg CO_2/MWh for 'old efficient subcritical', and >1,340kg CO_2/MWh for 'old inefficient subcritical'. To complete our analysis we have effectively defined the locations of all of Australia's SCPSs, the ownership of these plants, the annual megawatt hours of electricity produced at each plant, and the carbon intensity of each plant's electricity production.

To determine the potential vulnerability of SCPSs to air quality-related regulations, we took the 100km radius around each SCPS in the world and calculated the average satellite-based PM 2.5 observations within that area. Although we cannot directly attribute PM 2.5 levels measured to the corresponding SCPS, there is almost certainly a significant degree of causality, which may place plants in high PM 2.5 areas under greater risk from regulatory responses to air quality concerns.

Similarly, to determine the potential vulnerability of SCPSs to water-related regulations, we looked at the Baseline Water Stress (BWS) that SCPSs faced in their water catchment areas. SCPSs in extremely high water stress catchments, defined as watersheds with >80% withdrawal to available flow ratios, may be at more risk from water-related regulations or a shortage of water availability, than plants in areas with more water availability.

Subcritical coal in Australia

Coal is used to generate 56% of Australia's electricity and 89% of this comes from SCPSs. Power generation accounts for almost 30% of Australia's total CO_2 emissions, and 80% of this (24% of Australia's total CO_2 emissions) comes from SCPSs. In Australia there is a total of 29,467MW of subcritical and supercritical capacity, of which 26,088MW, is subcritical. Australia has no coal-fired power stations that use the most efficient ultra-supercritical technology.

Australia's Coal-fired Fleet

Total Coal-fired Capacity (MW)	Average Age of All Coal-fired Boilers	Subcritical Coal-fired Capacity (MW)	Average Age of Subcritical Capacity	Supercritical Coal-fired Capacity (MW)	Average Age of Supercritical Capacity
29,467	28	26,088	31	3,379	11

Average age is weighted by boiler capacity, and if a boiler has been refurbished then its age is reset to the date of the most recent refurbishment.

Of this 26,088MW of subcritical capacity, 24,608MW is currently operational and 1,480MW is currently mothballed and awaiting more favourable economic conditions. The 22 SCPSs in Australia are owned by 19 companies with three power stations owned jointly (see Section 3). Nine out of the top 10 highest carbon emitters in Australia are owners of subcritical assets. Four companies comprising 11 power stations (AGL Energy, Origin Energy, Stanwell Corporation, and Delta Electricity) are responsible for more than half of Australia's total SCPS capacity.

Operational and Mothballed Subcritical Capacity

Operational Subcritical Capacity (MW)	Average Age of Operational Subcritical Capacity	Mothballed Subcritical Capacity (MW)	Average Age of Mothballed Subcritical Capacity
24,608	30	1,480	34

Average age is weighted by boiler capacity, and if a boiler has been refurbished then its age is reset to the date of the most recent refurbishment.

Although Australia is only responsible for 2.2% of the world's SCPS generation, it has the highest average carbon intensity of any major SCPS emitting country. There is a significant portion of Australian SCPSs that are either past or approaching the end of their technical life (approximately 40 years). Given that 46% of Australian subcritical boilers 35 years and older are currently mothballed, the vulnerability of these assets is high. With the current situation of falling energy demand in Australia, any new regulation that would require capital expenditure for regulatory compliance could force the decommissioning and permanent closure of these assets.

National SCPS Fleet Generation and Carbon Intensity

	Number of SCPSs	Total SCPS TWh	Percentage of world SCPS TWh	Mean SCPS carbon intensity (kg CO_2/MWh)†
World	7,446	7,349	100.00%	1,042
China	930	2,718	36.98%	1,048
US	665	1,539	20.94%	1,040
EU	1,280‡	729	9.92%	1,051
India	608	783	10.65%	1,058
Australia	22	162	2.20%	1,132
South Africa	25	194	2.64%	1,034
Indonesia	337	87	1.18%	1,058

†SCPS mean carbon intensity is weighted by MWh of generation. The unweighted global SCPS mean carbon intensity is not materially different at 1,047 kg CO_2/MWh.
‡The EU has a particularly large number of micro power plants with poor carbon efficiency.

Although the carbon tax was repealed in 2014, many Australian subcritical generators are now mothballed due to lower-than-expected energy demand and competition from renewables. While these mothballed plants may represent option value to generating companies, they are particularly vulnerable to new non-GHG and water regulations that would require capital-intensive retrofits. Additionally, if policymakers wished to operate a voluntary compensation scheme, such as the operation of reverse auctions to permanently close subcritical boilers, it is likely that generating companies would be willing to accept lower than business-as-usual (BAU) compensation for mothballed plants. This would particularly be the case if the auctions were operated in tandem with the introduction of new emission regulations.

Costs of closure

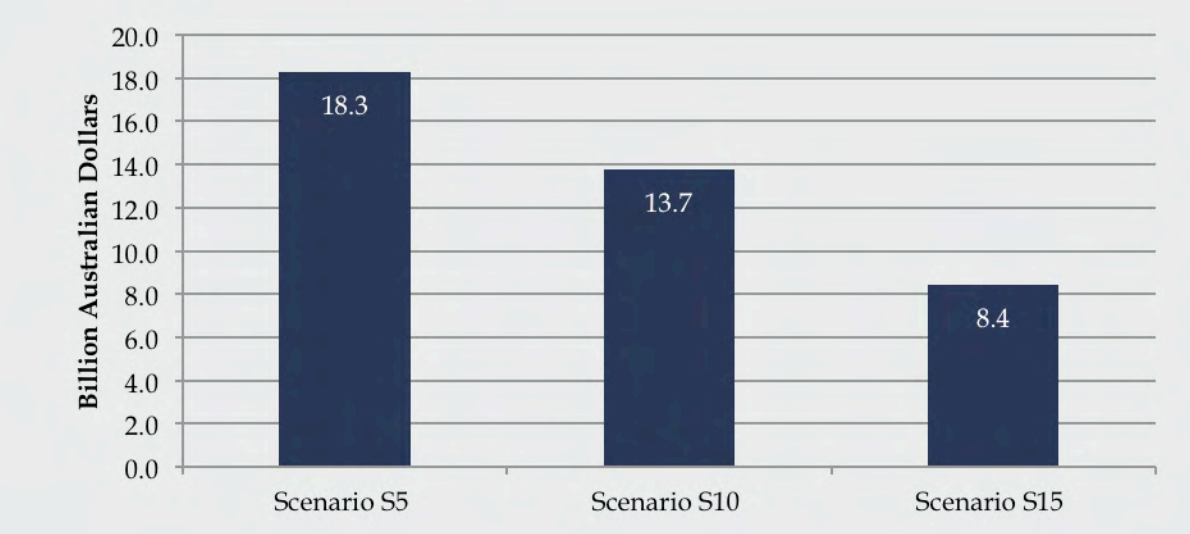
We have created illustrative scenarios in which all SCPSs in Australia are closed within 5, 10, or 15-year time horizons. As part of this, we calculated the maximum conceivable compensation that could be paid to owners of SCPSs to induce premature retirement of their assets over these time periods.

Subcritical Closure Scenarios

Scenario	Years of Plant Closures	% Generators Closed Annually	Order of Closure	Policy Assumptions
S5	2016-2020	20%	Oldest to Newest	Direct regulation used for closure, no new subcritical capacity added, mothballed generators receive compensation as if they were operational
S10	2016-2025	10%		
S15	2016-2030	6.7%		

Future profits are modelled using a revenues-minus-costs approach. Calculations are made individually for each generating unit until the end of their technical lives. We assume that mothballed units are operational from 2016 onwards. All calculations are made using highly conservative BAU assumptions (see the appendix for a list of all assumptions).

Maximum Conceivable Compensation (2015 AU$)



For Australian SCPSs, the maximum conceivable compensation in 2015 prices would be AU$18.3bn (or AU$3.66bn per year) in scenario S5, AU$13.7bn (or AU$1.37bn per year) in scenario S10, and AU$8.4bn (or AU$560 million per year) in scenario S15. Total compensation decreases with scenario length because more generators reach the end of their technical lifespan before they are eligible for compensation.

In the Australian case owners should only expect to receive partial compensation that is *significantly less than* the figures indicated above. This is due to the following reasons. First, Australia's takings jurisprudence gives no indication that government should compensate firms for impairment of profits. Second, we identify no implicit or explicit contractual bases for compensation of firms by government. This is particularly the case given that the competitive National Electricity Market has operated for over 15 years. Third, there is very little precedent supporting the compensated closure of assets in Australia. The CFC programme provides some precedent, though it did not close a single asset. Australia's carbon tax also provides precedent; however, we argue that this is more of a case of buyout of industry to allow policymaking than evidence of the necessity of compensation for the closure of assets. Fourth, as is recognized throughout this report, coal plays a significant factor in Australian politics. Because of this, we do not rule out investor compensation altogether. The evidence that this report cites for this conclusion is as follows. Australia's most carbon-intensive generators were compensated for the effects of the now-repealed carbon tax on their profits. However, the comparison of our valuation of Hazelwood Power Station and their 2011 plant self-valuation for the CFC programme suggests that the dirtiest power stations were not in danger of imminent collapse, as was claimed.

The compensation modelling has assumed that all subcritical power stations would be part of the closure programme. A potentially significant way to further reduce the total cost of compensation, as well as the costs of decommissioning and replacement capacity, is for the closure programme to target a subset of SCPSs.

Reverse auctions

Reverse auctions could be a policy mechanism for cost-effectively retiring SCPSs. Owners of SCPS assets would bid to receive a fixed price for each unit of generation capacity retired. The lowest bids would win the auction. While similar to the Contract for Closure and the Australian Emissions Reduction Fund, key design differences could lead to drastically different policy outcomes. For example:

- Reverse auctions should be operated in tandem with the introduction of new emission regulations.

- There should be a timeline for the retirement of subcritical generators, which could be based on the ratcheting up of an appropriately strict Emission Performance Standard (EPS).

- A Coal Closure Fund (CCF) could be established - this would be a ring-fenced fund used to pay for reverse auctions.

- Auctions could be operated annually or semi-annually until the year of mandatory closure or retrofit. The amount of compensation available could decrease with each auction in a "degression" model to further incentivise earlier retirement.

Reverse auctions eliminate the problem of information asymmetry between government and the owners of SCPS assets. As some owners will have sunk costs (i.e. maintenance and retrofits), this lets owners reach an equitable outcome amongst themselves.

This approach also establishes a robust framework for how owners can participate in negotiations. Political contestation around the closure of subcritical assets with reverse auctions is inevitable and should be expected; however, by creating a robust framework the potential for escalating compensation demands can be contained.

1. Introduction

The international community needs options for addressing the most significant contributors to anthropogenic climate change. One option, presented publicly by Christiana Figueres, executive secretary of the United Nations Framework Convention on Climate Change (UNFCCC), is the closure of subcritical coal-fired power stations (SCPSs).[1] To limit global emissions to a level consistent with a 2°C future, it is necessary to close a quarter, or 290 gigawatts (GW), of subcritical generation worldwide by 2020.[2]

Since SCPSs are the least efficient and most greenhouse gas (GHG) intensive centralised generation technology, they are both vulnerable to regulation and a logical first step in any climate mitigation strategy. In Australia, coal is used to generate 56% of total electricity demand and 89% of this comes from SCPSs[3]. Power generation accounts for almost 30% of Australia's total CO_2 emissions[4], and 80% of this (24% of Australia's total CO_2 emissions) comes from SCPSs.

Moreover, due to their greater average fuel-burn, SCPSs are also more vulnerable to non-GHG policies, such as policies regulating the emission of PM, NO_x, SO_x, and mercury. SCPSs are also highly vulnerable to water policies. Given these potential drivers of asset stranding - carbon intensity, air pollution, and water stress - this working paper examines the exposure to these risks of Australia's 22 SCPSs and the 19 companies that own them. We also examine how risks facing subcritical coal assets might develop in the future.

Additionally, as policymakers may be interested in inducing early closure of SCPS assets due to concerns over climate change and localised environmental impacts, our research conservatively estimates how much it would cost to compensate the owners of Australian subcritical assets to prematurely retire them. We examine why this could be desirable and also say something about how this could be done in the most cost-effective way possible.

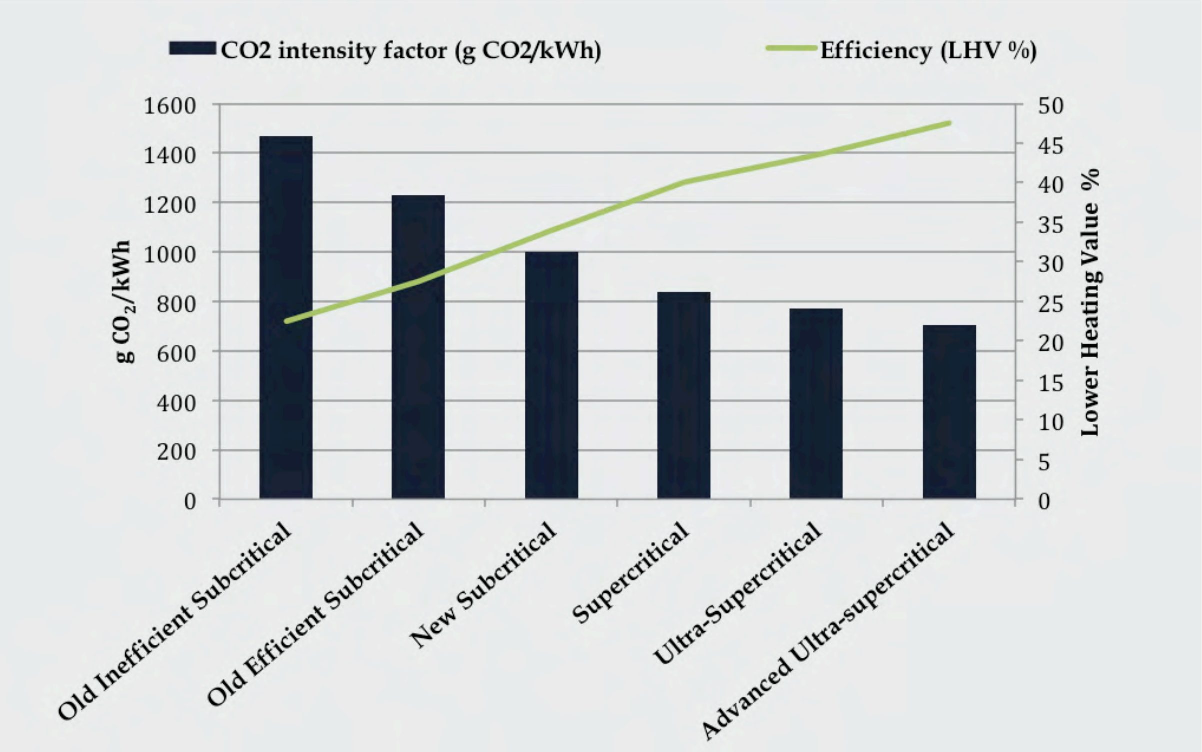
This working paper is therefore potentially useful for two groups. It could help investors to identify and screen specific companies with exposure to SCPS assets in Australia at particular risk from climate policy, air pollution, and water stress. It will also help Australian policymakers interested in understanding the costs, benefits, and mechanisms for prematurely closing SCPSs. The paper is an interim output from a global project on subcritical coal from investment risk and public policy perspectives. The first phase report on investment risk globally was published on the 13th March 2015 and can be downloaded here. The second phase report, on public policy implications will be published in Summer 2015. This paper brings together research from these two phases as they relate to Australia.

[1] HSBC (17 January 2014). "Coal and carbon revisited."
[2] IEA (2013). Redrawing the Energy Climate Map. Paris, France, OECD/IEA.
[3] Simshauser, P. and T. Nelson (2012). "The second-round effects of carbon taxes on power project finance." Journal of Financial Economic Policy **4**(2): 104-127.
[4] Hannam, P. and L. Cox (18 March, 2015). AGL tops list of big carbon emitters after merger, ACF report finds. Sydney Morning Herald.

2. Subcritical Coal and Australia

Subcritical power stations use subcritical boilers. These boilers operate at relatively lower pressures and temperatures, which leads to an inefficient steam cycle in generation because water is present both as liquid and gas.[5] Because coal-fired power production is by far the most emissions-intensive form of power generation,[6] and subcritical the least efficient subset, subcritical coal-fired power stations are the most carbon-intensive technology used for centralised electricity generation. Although the efficiency of these power stations has improved over time, even the newest and most efficient subcritical generators are significantly more carbon-intensive than existing supercritical and ultra-supercritical technologies, as well as forthcoming advanced ultra-supercritical technology. Following the IEA, this report defines SCPSs as power stations with carbon-intensities of ≥880kg CO_2/MWh.

Figure 1: Average CO_2 Intensity and Efficiency by Coal-fired Generation Boiler Type



Source: IEA (2013). Redrawing the Energy Climate Map. Paris, France, OECD/IEA

In addition to efficiency, the age of generators also plays a role in their regulatory vulnerability. Because of the age of subcritical boiler technology, SCPSs generally represent the oldest part of national generation fleets. This is significant because it is financially (and potentially politically)

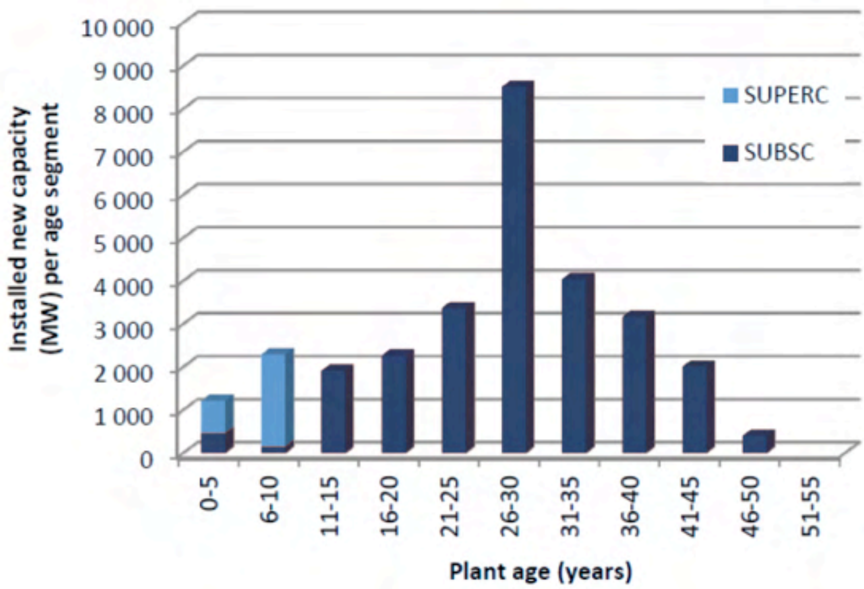
[5] Susta, M. and K. B. Seong (2004). Supercritical and Ultra-Supercritical Power Plants - SEA's Vision or Reality?, PowerGen Asia.

[6] Roughly a factor of two, Moomaw, W., G. Burgherr, M. Heath, M. Lenzen, J. Nyboer and A. Verbruggen (2011). 2011: Annex II: Methodology. In IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation. O. Edenhofer, R. Pichs-Madruga, Y. Sokona et al. Cambridge, United Kingdom and New York USA, Cambridge University Press.

simpler to regulate the closure of older power stations. This is due to the fact that capital costs have typically been recovered after 35 years of operation[7]; and when generators are near or past their technical lives, the financial need to compensate is greatly reduced or eliminated.[8]

This is particularly relevant in Australia. As seen in Figure 2, while SCPSs represent the bulk of Australian coal-fired capacity, a significant portion is either past or approaching the end of its technical life. Given that 46% of Australian subcritical boilers 35 years[9] and older are currently mothballed, the vulnerability of these assets is high. With the current situation of falling energy demand in Australia, any new regulation that would require capital expenditure for regulatory compliance could force the decommissioning and permanent closure of these assets.

Figure 2: Australia Coal-Fired Generation by Age and Boiler Technology



Source: IEA (2012)

Policy Vulnerability

The limited work on subcritical coal-fired power generation has thus far focused on the role of SCPS closures in climate change mitigation scenarios.[10] Because they are the most inefficient power stations, in these scenarios SCPS are closed quickly and at large scales. For instance, IEA modelling of a power sector transition compatible with 2°C global warming suggests that it would rely on the closure of a quarter of global SCPS capacity (290GW) by 2020.[11] Subcritical power stations are also highly vulnerable to non-GHG and water abstraction policies because of their emission-intensiveness and high water use.[12]

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[7] IEA (2014). Energy, Climate Change and Environment. Paris, France, OECD/IEA.
[8] This assertion is supported by the three case studies explored later in this report. In each, compensation amount was a function of expected future profits.
[9] Age is defined by the date of construction or most recent boiler replacement.
[10] IEA (2014). Energy, Climate Change and Environment. Paris, France, OECD/IEA.
[11] IEA (2013). Redrawing the Energy Climate Map. Paris, France, OECD/IEA.
[12] For full discussion of the vulnerability of subcritical power stations, see Caldecott, B. and J. Mitchell (Forthcoming 2015). "Generating Implications for Climate Policy: The Premature Retirement of Subcritical Coal-Fired Generation and the Potential Role of Compensation." Stranded Assets Programme, Smith School for Enterprise and Environment, University of Oxford.

Table 1: Coal-fired Environmental Effects by Generation Efficiency, Base-level = 100

Generation Efficiency	Carbon Intensity	Air Pollution	Water Stress
Old Inefficient Subcritical	100	100	100
Old Efficient Subcritical	84	84	85
New Subcritical	68	68	70
Supercritical	57	57	60
Ultra-Supercritical	52	52	55
Advanced Ultra-Supercritical	48	48	51

Note: Indicated levels of environmental effects based off of ceteris paribus generating conditions for a closed-cycle wet-cooled plant. Water stress levels based off of EPRI (2008).[13]

SCPSs in Australia

Australia's Contract for Closure (CFC) programme provides useful context for understanding the highly political role of SCPSs in Australia as well as potential future risks. The CFC programme was planned for implementation under Australia's 2011 Clean Energy Future package, which was meant to provide AU$5.5bn in transitional assistance to emissions-intensive generators and an undisclosed, capped amount via the CFC programme to "negotiate the closure of around 2,000 MW of highly emissions-intensive coal-fired electricity generation capacity by 2020."[14]

The programme was announced in June 2011. After the selection of five SCPSs for CFC in late 2011, negotiations for compensation payments began. However, no agreements were reached by June 2012 and negotiations were cancelled in September 2012.[15] Cancellation was due to fundamental disagreements and large disparities between government and firm valuation of assets.

This raises two important issues for any future closure of SCPSs in Australia. They are inherently intertwined but are presented separately for clarity. The first is the issue of compensation. The offer of compensation for the impairment of SCPSs' profits was extraordinary. Previous to the compensation paid to carbon-intensive generators for Australia's now-repealed carbon tax, there was no precedent to suggest "that owners of capital assets should be compensated for changes in government policy that reduce the expected flow of income from those assets."[16] Additionally, an analysis of explicit and implicit contracts, as well as Australian takings jurisprudence suggests that there were no legal or theoretical rationales for the offer of compensation through CFC.[17] This raises questions about the purpose of compensation. Menezes (2009) suggests that the purpose of compensation is actually to reduce the incentive to lobby against legislation that would reduce profits from capital assets.[18]

The second issue is the inevitable political role of coal in Australian politics, as suggested by Menezes (2009). Interviews with a government insider reveal another possible rationale for the CFC program.

[13] R. Goldstein, *Water Use for Electric Power Generation*, vol. 3 (Palo Alto, CA, 2008), EPRI.
[14] Department of Resources Energy and Tourism, Contract for Closure Programme Administrative Guidelines (Australia: 2011), 1-2.
[15] Tom Arup, "Latrobe Valley Generators Embrace ALP Carbon Plan," The Age, October 22, 2011.
[16] Flavio Menezes, John Quiggin, and Liam Wagner, "Grandfathering and Greenhouse: The Role of Compensation and Adjustment Assistance in the Introduction of a Carbon Emissions Trading Scheme for Australia," *Economic Papers: A journal of applied economics and policy* 28, no. 2 (June 2009): 86.
[17] Caldecott, B. and J. Mitchell (Forthcoming 2015). "Generating Implications for Climate Policy: The Premature Retirement of Subcritical Coal-Fired Generation and the Potential Role of Compensation." Stranded Assets Programme, Smith School for Enterprise and Environment, University of Oxford.
[18] Flavio Menezes, John Quiggin, and Liam Wagner, "Grandfathering and Greenhouse: The Role of Compensation and Adjustment Assistance in the Introduction of a Carbon Emissions Trading Scheme for Australia," *Economic Papers: A journal of applied economics and policy* 28, no. 2 (June 2009): 82–92.

According to this source, the full purpose of the program was not to just close generators. Rather, it also had the goal of forcing generating companies to publicly value themselves, and thereby reveal whether they had in fact been bluffing when they had initially stated that Australia's Carbon Tax would cause the unanticipated closure of power plants.[19] Although this assertion could not be corroborated, in retrospect, claims of sudden closure forced by the carbon tax seem unfounded. This is supported by the similarities between our valuation and firm valuations of Hazelwood SCPS: previously regarded as the most carbon intensive power station in the OECD.[20] The firm's self-valuation of the plant was purportedly AU$3bn.[21] Our conservative BAU valuation produced very similar results[22]. This suggests that Australia's carbon tax was not impacting the profits of generators so heavily that they would have been on the brink of closure.

There are lessons here for investors and policymakers. As a recent analysis of the impacts of the European Emissions Trading Scheme (EU ETS) showed, it is incredibly difficult to close aging generators with carbon taxation or emission trading systems alone. For example, in Germany, an EU ETS carbon price of US$110 would be necessary to dispatch a new gas plant ahead of an older coal-fired plant.[23] This is the case for two reasons. First, incredibly high carbon prices are necessary to shut down coal-fired generators that have recovered most or all of their capital costs.[24] Second, compensation in the form of free emission credits (as in the EU) or cash handouts (as in Australia) exacerbates this problem by artificially increasing the profitability of operation.

In 2015 the Australian context has changed. Although the carbon tax was repealed in 2014, many Australian subcritical generators are now mothballed due to lower-than-expected energy demand and competition from renewables.[25] While these mothballed plants may represent option value to generating companies, they are particularly vulnerable to new non-GHG and water regulations that would require capital-intensive retrofits. Additionally, if policymakers wished to operate a voluntary compensation scheme, such as the operation of reverse auctions to permanently close subcritical boilers,[26] it is likely that generating companies would be willing to accept lower than BAU compensation for mothballed plants. This would particularly be the case if the auctions were operated in tandem with the introduction of new emission regulations.

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[19] Weller, S. (2015). Direct Action is No Action? Australia's 'Contract for Closure' of Coal-Fired Power Stations. Fouth Annual Conference on Economic Geography. University of Oxford.
[20] WWF (12 July, 2005). "Hazelwood tops international list of dirty power stations."
[21] Tom Arup, "Latrobe Valley Generators Embrace ALP Carbon Plan," The Age, October 22, 2011.
[22] We estimated required compensation of AU$2.6bn, 2.3bn, and 1.9bn to close Hazelwood power station in 5, 10, and 15 years, respectively. Note that, by contrast, the AU$3bn figure implies immediate closure. Weller (2015) shows that it is likely that this figure also incorporates the costs of closure and decommissioning, which was not included in our analyses.
[23] IEA (2014). Energy, Climate Change and Environment. Paris, France, OECD/IEA. Paris, France, OECD/IEA.
[24] Ibid.
[25] Nelson, Reid, and McNeil (2014), "Energy-only markets and renewable energy targets: complementary policy or policy collision?" AGL Applied Economic and Policy Research Working Paper No.43
[26] Caldecott and Mitchell (Forthcoming 2015). "Premature Retirement of Sub-critical Coal Assets: The Potential Role of Compensation and the Implications for International Climate Policy," *Seton Hall Journal of Diplomacy and International relations* Spring/Summer 2015.

3. Australian SCPS Portfolios

Analysing Australia's coal-fired generation, we find that there is a total of 29,467MW of subcritical and supercritical capacity, of which 26,088MW, or 89%, is subcritical. Australia has no coal-fired power stations that use the most efficient ultra-supercritical technology.

Table 2: Australia's Coal-fired Fleet

Total Coal-fired Capacity (MW)	Average Age of All Coal-fired Boilers	Subcritical Coal-fired Capacity (MW)	Average Age of Subcritical Capacity	Supercritical Coal-fired Capacity (MW)	Average Age of Supercritical Capacity
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Average age is weighted by boiler capacity, and if a boiler has been refurbished then its age is reset to the date of the most recent refurbishment.

Of this 26,088MW of subcritical capacity, 24,608MW is currently operational and 1,480MW is currently mothballed and awaiting more favourable economic conditions.

Table 3: Operational and Mothballed Subcritical Capacity

Operational Subcritical Capacity (MW)	Average Age of Operational Subcritical Capacity	Mothballed Subcritical Capacity (MW)	Average Age of Mothballed Subcritical Capacity
24,608	30	1,480	34

Average age is weighted by boiler capacity, and if a boiler has been refurbished then its age is reset to the date of the most recent refurbishment.

Although Australia is only responsible for 2.2% of the world's SCPS generation, it has the highest average carbon intensity of any major SCPS emitting country.

Table 4: National SCPS Fleet Generation and Carbon Intensity

	Number of SCPSs	Total SCPS TWh	Percentage of world SCPS TWh	Mean SCPS carbon intensity (kg CO_2/MWh)†
World	7,446	7,349	100.00%	1,042
China	930	2,718	36.98%	1,048
US	665	1,539	20.94%	1,040
EU	1,280‡	729	9.92%	1,051
India	608	783	10.65%	1,058
Australia	22	162	2.20%	1,132
South Africa	25	194	2.64%	1,034
Indonesia	337	87	1.18%	1,058

†SCPS mean carbon intensity is weighted by MWh of generation. The unweighted global SCPS mean carbon intensity is not materially different at 1,047 kg CO_2/MWh.
‡The EU has a particularly large number of micro power plants with poor carbon efficiency.

The following table discloses relevant characteristics of each of the 22 operational and mothballed subcritical generators in Australia by order of generating capacity. This information was derived from the most recent version (v3) of Carbon Monitoring for Action (CARMA) and Enipedia, and verified with internet research[27].

[27] See the Appendix for greater detail on the data methodology.

Table 5: All Australian SCPSs by Capacity

Name	State	Owner(s)	Boiler(s) (MW)	Total Capacity (MW)	Fuel	Boiler(s) Opened	Refurbished	Boiler Age(s)	Status
Eraring Power Station	New South Wales	Origin Energy	4x720	2,880	Bituminous Coal	1982-1984		31-33	Operational
Bayswater Power Station	New South Wales	AGL Energy	4x660	2,640	Coal	1985-1986		29-30	Operational
Loy Yang A Power Station	Victoria	AGL Energy	4x525	2,200	Brown Coal	1985		30	Operational
Liddell Power Station	New South Wales	AGL Energy	4x500	2,000	Coal	1971		44	Operational
Gladstone Power Station	Queensland	Rio Tinto (42.125%) NRG Energy (37.5%) SLMA GPS (8.5%) Ryowa II GPS (7.125%) YKK GPS (4.75%)	6x280	1,680	Bituminous Coal	1976		39	Operational
Hazelwood Power Station	Victoria	GDF Suez Australian Energy (72%) Mitsui & Co (28%)	8x200	1,600	Brown Coal	1971	1996	19	Operational
Yallourn W Power Station	Victoria	CLP	2x350, 2x375	1,450	Coal	1982		33	Operational
Mount Piper Power Station	New South Wales	EnergyAustralia	2x700	1,400	Coal	1992-1993		22-23	Operational
Stanwell Power Station	Queensland	Stanwell Corporation	4x350	1,400	Coal	1996		19	Operational
Tarong Power Station	Queensland	Stanwell Corporation	4x350	1,400	Bituminous Coal	1984-1986		29-31	Operational
Vales Point Power Station	New South Wales	Delta Electricity	2x660	1,320	Coal	1978		37	Operational
Loy Yang B Power Station	Victoria	GDF Suez Australian Energy (70%) Mitsui & Co (30%)	2x525	1,050	Brown Coal	1985		30	Operational
Wallerawang Power Station	New South Wales	Delta Electricity	2x500	1,000	Bituminous	1976-1980		35-39	Mothballed

Muja Power Station‡	Western Australia	Synergy	2x200, 2x227	854	Coal	1980-1985		30-35	Operational
Callide Power Station	Queensland	CS Energy	2x350, 4x30	820	Coal	1965-1988	partly 1998	17-27	Operational
Kwinana Power Station	Western Australia	Synergy	2x120, 2x200	640	Coal†	1976-1978		37-39	Operational
Northern Power Station	South Australia	Alinta Energy	2x260	520	Subbituminous Coal	1985		30	Operational
Collie Power Station	Western Australia	Synergy	1x300	300	Coal	1999		16	Operational
Muja Power Station‡	Western Australia	Synergy	4x60	240	Coal	1965-1969		46-50	Mothballed
Playford B Power Station	South Australia	Alinta Energy	4x60	240	Subbituminous Coal	1963	2005	10	Mothballed
Collinsville Power Station	Queensland	Ratch Corporation	4x31, 1x66	190	Coal	1968-1976	1999	16	Operational
Anglesea Power Station	Victoria	Alcoa	1x150	150	Coal	1969		46	Operational
Worsley Alumina	Western Australia	GE	2x57	114	Bituminous	2012		3	Operational

†Kwinana Power Station has the ability to burn coal, gas, and oil fuels. This power station is scheduled to close in 2015.
‡Muja power station is listed twice to account separately for the 4 boilers that are operational and the 4 that are mothballed.

The primary environmental and policy risks that SCPSs face are related to carbon intensity, air quality, and water stress. The following section delineates these risks with respect to each of Australia's existing SCPSs.

The carbon intensity data by power plant again comes from CARMA v3 estimates. According to this source, some power plants that are typically classified as 'subcritical', such as Western Australia's Bluewaters power plant at 825kg CO_2/MWh, fall into the supercritical category and are therefore not examined here.

To determine the potential vulnerability of SCPSs to air quality-related regulations, we took the 100km radius around each SCPS in the world and calculated the average of the PM 2.5 observations from Boys, Martin et al. (2014) measured within that radius[28]. Although we cannot directly attribute PM 2.5 levels measured within each 100km radius to emissions from the corresponding SCPS, there would almost certainly be a significant degree of causality relevant for policy. Australia's national PM 2.5 limit is among the world's strictest at only 8 $\mu g/m^3$. The World Health Organisation's maximum limit is 20 $\mu g/m^3$.

The measure for water stress used in this report is Baseline Water Stress (BWS) from Aqueduct created by the World Resources Institute (WRI). BWS is defined as total annual water withdrawals (municipal, industrial, and agricultural) expressed as a percent of the total annual available flow within the given catchment area. Higher values indicate greater competition for water among users. Extremely high water stress areas are defined by WRI as watersheds with >80% withdrawal to available flow ratios, 80-40% as high water stress, 40-20% as high to medium, 20-10% as medium to low, and <10% as low. The water stress level for a given SCPS is the level corresponding to that of the catchment where the station is located.

Table 6: Australian SCPS Carbon Intensity, 100km Radius PM 2.5 Air Quality, and Baseline Water Stress by Generation Capacity

Name	Capacity (MW)	Carbon Intensity kg CO2/MWh	100km Radius Average PM 2.5 $\mu g/m^3$	Baseline Water Stress
Eraring Power Station	2,880	1,130	2	100.00%
Bayswater Power Station	2,640	1,130	2	53.77%
Loy Yang A Power Station	2,200	1,150	3	57.59%
Liddell Power Station	2,000	1,090	2	53.77%
Gladstone Power Station	1,680	1,100	2	100.00%
Hazelwood Power Station	1,600	1,550	3	57.59%
Yallourn W Power Station	1,450	1,190	3	57.59%
Mount Piper Power Station	1,400	978	2	30.97%
Stanwell Power Station	1,400	1,070	2	1.40%
Tarong Power Station	1,400	1,100	2	75.03%
Vales Point Power Station	1,320	1,030	2	100.00%
Loy Yang B Power Station	1,050	1,110	3	57.59%
Wallerawang Power Station	1,000	1,020	2	30.97%
Muja Power Station	854	1,140	2	2.73%
Callide Power Station	820	1,000	2	23.26%
Kwinana Power Station	640	1,060	2	0.00%

[28]On average there were 270 PM 2.5 observations within each 100km radius. See appendix for PM 2.5 air pollution data sources and methods.

Northern Power Station	520	1,110	2	21.97%
Collie Power Station	300	1,130	2	2.73%
Muja Power Station	240	1,140	2	2.73%
Playford B Power Station	240	1,100	2	21.97%
Collinsville Power Station	190	1,310	2	4.37%
Anglesea Power Station	150	1,450	3	18.73%
Worsley Alumina	114	1,310	2	23.06%

Portfolio Risk

The 22 SCPSs in Australia are owned by a total of 19 companies, with three power stations owned jointly. Nine out of the top 10 highest carbon emitters in Australia are owners of subcritical assets[29]. In order to assess the risks borne by the owners of these assets, we also calculate the total subcritical capacity owned by each corporation, the capacity weighted average, plant age, carbon intensity, PM 2.5 air pollution, and baseline water stress. We see from Table 7 below that just four companies comprising 11 power stations (AGL Energy, Origin Energy, Stanwell Corporation, and Delta Electricity) are responsible for more than half of Australia's total SCPS capacity.

In term of age, 64% of Australia's SCPS capacity is 30 years old or greater. And only GE and Ratch Corporation have average boiler ages under 20 years, with the oldest average ages held by Alcoa (46 years) and Rio Tinto/NRG Energy/SLMA GPS/Ryowa II GPS/YKK GPS (39 years).

[29] The top 10 list comes from Australian Conservation Foundation (2015). "Australia's top 10 climate polluters." Macquarie Generation is now a subsidiary of AGL Energy, and the missing 10th largest polluter is Woodside Petroleum.

Table 7: Australian Portfolios by Total Generation Capacity

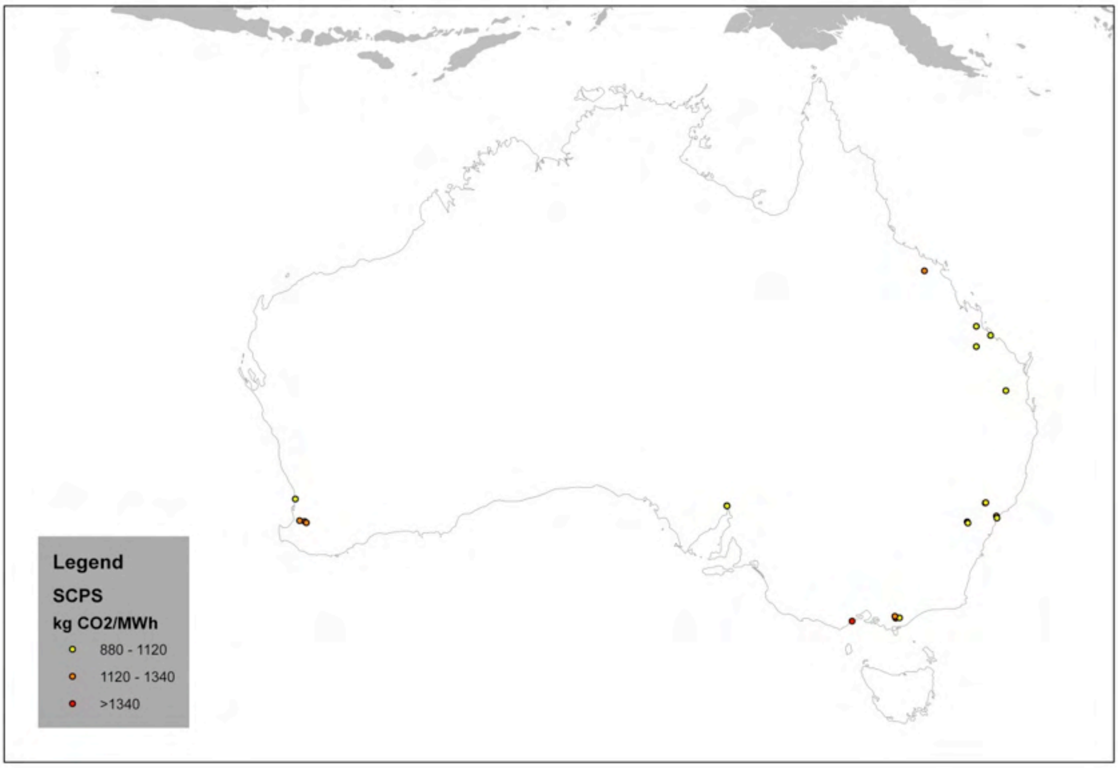
Owner	Total Capacity (MW)	Number of SCPSs	Number of Boilers	Average Boiler Age	Carbon Intensity kg CO2/MWh	Average PM 2.5 µg/m³	Average Baseline Water Stress
AGL Energy	6,840	3	12	34	1,125	2	55.00%
Origin Energy	2,880	1	4	32	1,130	2	100.00%
Stanwell Corporation	2,800	2	8	25	1,085	2	38.22%
Delta Electricity	2,320	2	4	37	1,026	2	70.25%
Synergy	2,034	3	13	34	1,113	2	1.87%
GDF Suez Australian Energy*	1,855	2	10	38	1,376	3	57.59%
CLP	1,450	1	4	33	1,190	3	57.59%
EnergyAustralia	1,400	1	2	23	978	2	30.97%
CS Energy	820	1	6	22	1,000	2	23.26%
Mitsui & Co*	795	2	10	38	1,376	3	57.59%
Alinta Energy	760	2	6	24	1,107	2	21.97%
Rio Tinto **	708	1	6	39	1,100	2	100.00%
NRG Energy**	630	1	6	39	1,100	2	100.00%
Ratch Corporation	190	1	5	19	1,310	2	4.37%
Alcoa	150	1	1	46	1,450	3	18.73%
SLMA GPS**	143	1	6	39	1,100	2	100.00%
Ryowa II GPS**	120	1	6	39	1,100	2	100.00%
GE	114	1	2	3	1,310	2	23.06%
YKK GPS**	80	1	6	39	1,100	2	100.00%

All averages are weighted by the capacities of each SCPSs in the portfolio.
*Jointly own Hazelwood and Loy Yang B Power Stations. Individual corporate MW capacity is listed as the fraction of the plant owned multiplied by the SCPS's total MW capacity.
**Jointly own Gladstone Power Station. Individual corporate MW capacity is listed as the fraction of the plant owned multiplied by the SCPS's total MW capacity.

Carbon Intensity

Following the IEA, the figures below define cutoffs of 880-1,120kg CO_2/MWh for relatively efficient 'new subcritical' (coloured in yellow), 1,120-1,340kg CO_2/MWh for 'old efficient subcritical' (orange), and >1,340kg CO_2/MWh (red) for 'old inefficient subcritical'.[30] As was noted in Table 4, among the other major SCPS generating countries, Australia has the worst average SCPS CO2 intensity by a considerable margin. The locations and carbon intensity of these power stations are depicted below. We invite firms who believe the data contained in this paper to be inaccurate to disclose this information publicly so we can revise the data accordingly.

Figure 3: Australian SCPS Carbon Intensity by Total Generation Capacity



With the exception of GDF Suez and Mitsui's combined stake in the Hazelwood and Loy Yang B power stations, which both burn highly polluting brown coal; the top five companies with the most carbon intensive SCPS generation own relatively small and inefficient plants.

[30] IEA (2012). Technology Roadmap: High Efficiency, Low-Emissions Coal-Fired Power Generation. Paris, France, OECD/IEA.

Table 8: Australian Portfolios by Carbon Intensity

Owner	Total Capacity (MW)	Number of plants	Number of Boilers	Average Boiler Age	Carbon Intensity kg CO2/MWh
Alcoa	150	1	1	46	1,450
GDF Suez Australian Energy*	1,855	2	10	38	1,376
Mitsui & Co*	795	2	10	38	1,376
Ratch Corporation	190	1	5	19	1,310
GE	114	1	2	3	1,310
CLP	1,450	1	4	33	1,190
Origin Energy	2,880	1	4	32	1,130
AGL Energy	6,840	3	12	34	1,125
Synergy	2,034	3	13	34	1,113
Alinta Energy	760	2	6	24	1,107
Rio Tinto**	708	1	6	39	1,100
NRG Energy**	630	1	6	39	1,100
SLMA GPS**	143	1	6	39	1,100
Ryowa II GPS**	120	1	6	39	1,100
YKK GPS**	80	1	6	39	1,100
Stanwell Corporation	2,800	2	8	25	1,085
Delta Electricity	2,320	2	4	37	1,026
CS Energy	820	1	6	22	1,000
EnergyAustralia	1,400	1	2	23	978

All averages are weighted by the capacities of each SCPSs in the portfolio.
*Jointly own Hazelwood and Loy Yang B Power Stations. Individual corporate MW capacity is listed as the fraction of the plant owned multiplied by the SCPS's total MW capacity.
**Jointly own Gladstone Power Station. Individual corporate MW capacity is listed as the fraction of the plant owned multiplied by the SCPS's total MW capacity.

Air Pollution

Of the pollutants associated with coal combustion, particulate matter (PM) is considered to be the most hazardous to human health. PM consists of the fly ash and dust particles generated during coal combustion,[31] and is commonly classified into groups, either below 10 (PM 10) or below 2.5 (PM 2.5) microns in diameter,[32] with PM 2.5 considered to be the more dangerous of the two. These fine particles consist of a mixture of all the air pollutants associated with coal combustion, and due to their small size can penetrate deep into the lungs and enter the bloodstream directly.

[31] These particles can contain noxious compounds such as: acid droplets, arsenic, beryllium, cadmium, chromium, lead, manganese, nickel, radium, selenium, and other metals.
[32] Micron = One millionth of a meter: about 1/20th the width of a human hair.

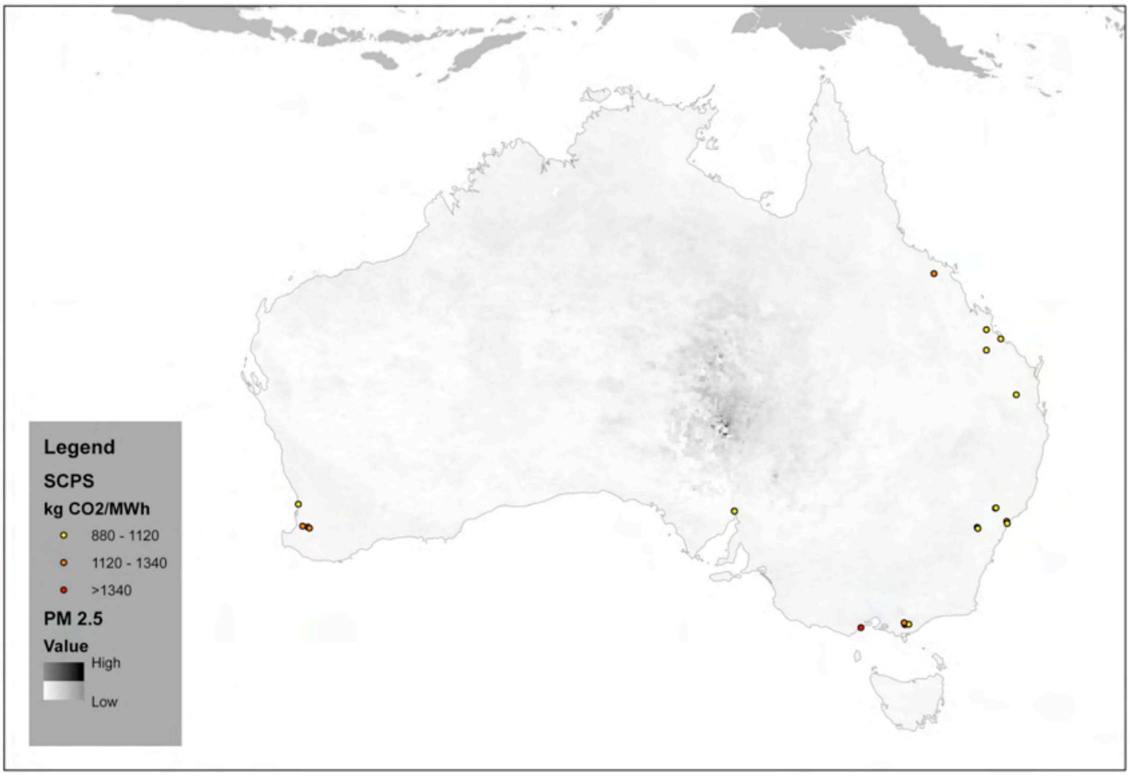
Table 9: National SCPS Fleet Ambient Air Pollution

	SCPS mean 100km Radius PM 2.5 Levels (μg/m³)	Number of SCPSs located in areas with air pollution exceeding the WHO PM 2.5 limit	Percentage of SCPSs located in areas with air pollution exceeding the WHO PM 2.5 limit	National PM 2.5 Limit (μg/m³)	Number of SCPSs located in areas with air pollution exceeding their national PM 2.5 limits	Percentage of SCPSs located in areas with air pollution exceeding their national PM 2.5 limits
World	15	2,092	28.10%	20	n/a	n/a
China	50	825	88.71%	35	618	66.45%
US	7	0	0.00%	12	0	0.00%
EU	12	38	2.97%	25	0	0.00%
India	32	539	88.65	40	115	18.91%
Australia	2	0	0.00%	8	0	0.00%
South Africa	8	0	0.00%	25	0	0.00%
Indonesia	8	0	0.00%	none	n/a	n/a

Note: The WHO Annual Average PM 2.5 limit is 20 μg/m³. Indonesia lacks a PM 2.5 limit. The South African PM 2.5 limit is scheduled to be tightened from 25 to 20 μg/m³ beginning January 2016. 'SCPSs located in areas with air pollution exceeding [specified] PM 2.5 limits' consist of SCPSs which have average observed PM 2.5 levels within 100km which exceed the specified limits.

Although PM 2.5 pollution surrounding SCPSs is a major issue for China and India, in Australia PM 2.5 levels nearby SCPSs appear not be a major concern. Despite Australia possessing the tightest national PM 2.5 limit among all major SCPS generating nations, no SCPS is located in an area that has average PM 2.5 levels exceeding the national 8 μg/m³ limit.

Figure 4: Australian SCPS by 100 km radius PM 2.5 Pollution



Note: Desert conditions produce natural PM 2.5 that is also recorded by satellites as pollution. This effect is responsible for the higher levels of PM 2.5 measured across central Australia.

Table 10: Australian Portfolios by 100km Radius PM 2.5

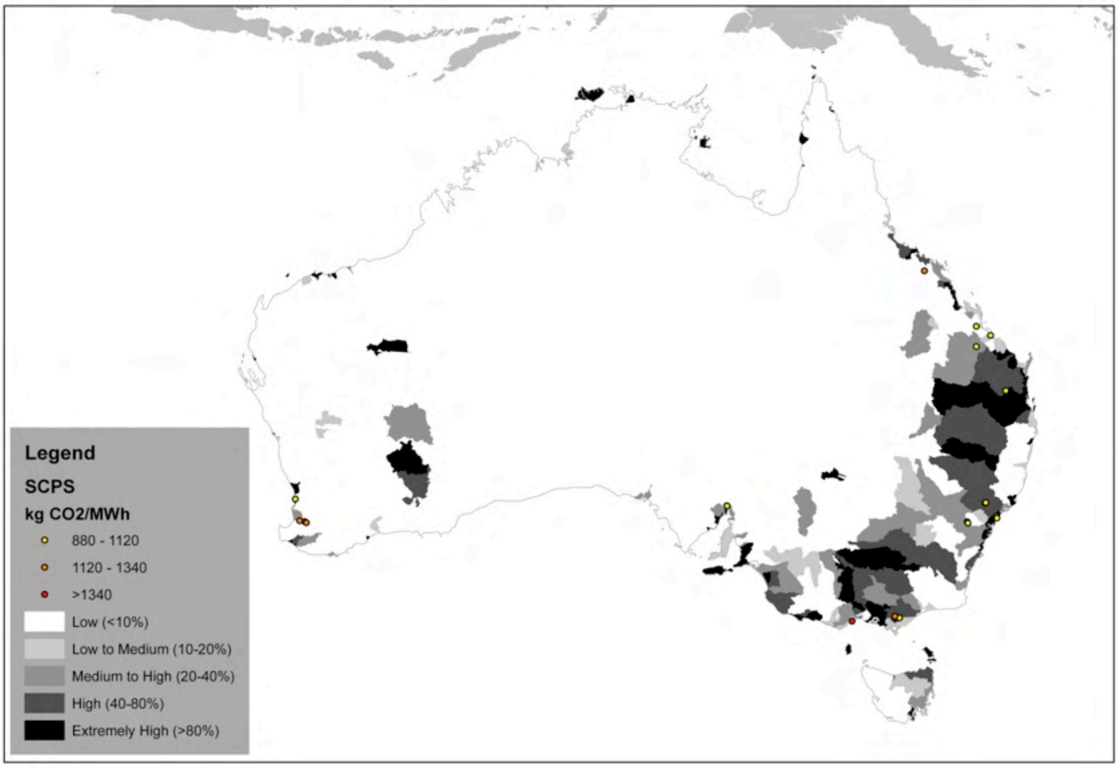
Owner	Total Capacity (MW)	Number of plants	Number of Boilers	Average Boiler Age	Average PM 2.5 μg/m³
Alcoa	150	1	1	46	3
GDF Suez Australian Energy*	1,855	2	10	38	3
Mitsui & Co*	795	2	10	38	3
CLP	1,450	1	4	33	3
AGL Energy	6,840	3	12	34	2
Synergy	2,034	3	13	34	2
GE	114	1	2	3	2
Delta Electricity	2,320	2	4	37	2
EnergyAustralia	1,400	1	2	23	2
Origin Energy	2,880	1	4	32	2
Rio Tinto**	708	1	6	39	2
NRG Energy**	630	1	6	39	2
SLMA GPS**	143	1	6	39	2
Ryowa II GPS**	120	1	6	39	2
YKK GPS**	80	1	6	39	2
Ratch Corporation	190	1	5	19	2
Stanwell Corporation	2,800	2	8	25	2
Alinta Energy	760	2	6	24	2
CS Energy	820	1	6	22	2

All averages are weighted by the capacities of each SCPSs in the portfolio.
*Jointly own Hazelwood and Loy Yang B Power Stations. Individual corporate MW capacity is listed as the fraction of the plant owned multiplied by the SCPS's total MW capacity.
**Jointly own Gladstone Power Station. Individual corporate MW capacity is listed as the fraction of the plant owned multiplied by the SCPS's total MW capacity.

Water Stress

Because SCPSs require greater water inputs for a given amount of generation, local water stress is also a factor that may affect the vulnerability of SCPSs to regulation.

Figure 5: Australia SCPS by Water Stress



Although Australia's interior is the driest part of the country, the most water stressed that contain SCPSs are located around centres of population in the East. There are three power plants located in catchments with 100% baseline water stress, these are Eraring, Vales, and Gladstone power stations owned by, respectively, Origin Energy, Delta Electricity, and Rio Tinto/NRG Energy/SLMA GPS/Ryowa II GPS/YKK GPS.

Table 11: Australian Portfolio Water Stress

Owner	Total Capacity (MW)	Number of plants	Number of Boilers	Average Boiler Age	Average Baseline Water Stress
Origin Energy	2,880	1	4	32	100.00%
Rio Tinto**	708	1	6	39	100.00%
NRG Energy**	630	1	6	39	100.00%
SLMA GPS**	143	1	6	39	100.00%
Ryowa II GPS**	120	1	6	39	100.00%
YKK GPS**	80	1	6	39	100.00%
Delta Electricity	2,320	2	4	37	70.25%
GDF Suez Australian Energy*	1,855	2	10	38	57.59%
CLP	1,450	1	4	33	57.59%
Mitsui & Co*	795	2	10	38	57.59%
AGL Energy	6,840	3	12	34	55.00%
Stanwell Corporation	2,800	2	8	25	38.22%
EnergyAustralia	1,400	1	2	23	30.97%
CS Energy	820	1	6	22	23.26%
GE	114	1	2	3	23.06%
Alinta Energy	760	2	6	24	21.97%
Alcoa	150	1	1	46	18.73%
Ratch Corporation	190	1	5	19	4.37%
Synergy	2,034	3	13	34	1.87%

All averages are weighted by the capacities of each SCPSs in the portfolio.
*Jointly own Hazelwood and Loy Yang B Power Stations. Individual corporate MW capacity is listed as the fraction of the plant owned multiplied by the SCPS's total MW capacity.
**Jointly own Gladstone Power Station. Individual corporate MW capacity is listed as the fraction of the plant owned multiplied by the SCPS's total MW capacity.

4. Costs of Closure

As policymakers may be interested in inducing early closure of SCPS assets due to concerns over climate change and localised environmental impacts, our research conservatively models the maximum cost required to compensate the owners of Australian subcritical assets for premature retirement. This gives an indication of the maximum compensation cost for the phased closure of Australia's SCPS fleet.

These estimates do not include decommissioning costs or the costs of replacing closed capacity with new generation capacity or energy efficiency measures. However, our estimates of compensation are very conservative, and so are likely to significantly overestimate the total compensation required to induce permanent closure of Australian SCPSs, especially in the context of lower than anticipated power demand and the prospect of new emission regulations.

We have created illustrative scenarios in which all SCPSs in Australia are closed within 5, 10, or 15-year time horizons. As part of this, we calculated the maximum conceivable compensation that could be paid to owners of SCPSs to induce premature retirement of their assets over these time periods. These estimates were made by calculating the Net Present Value (NPV) of profits foregone from the date of an asset being closed (e.g. 2020) and the end of the asset's technical lifespan (e.g. 2030, assuming the asset had 10 more years of technical life at 2020) - we did this for all of the SCPS assets in Australia.

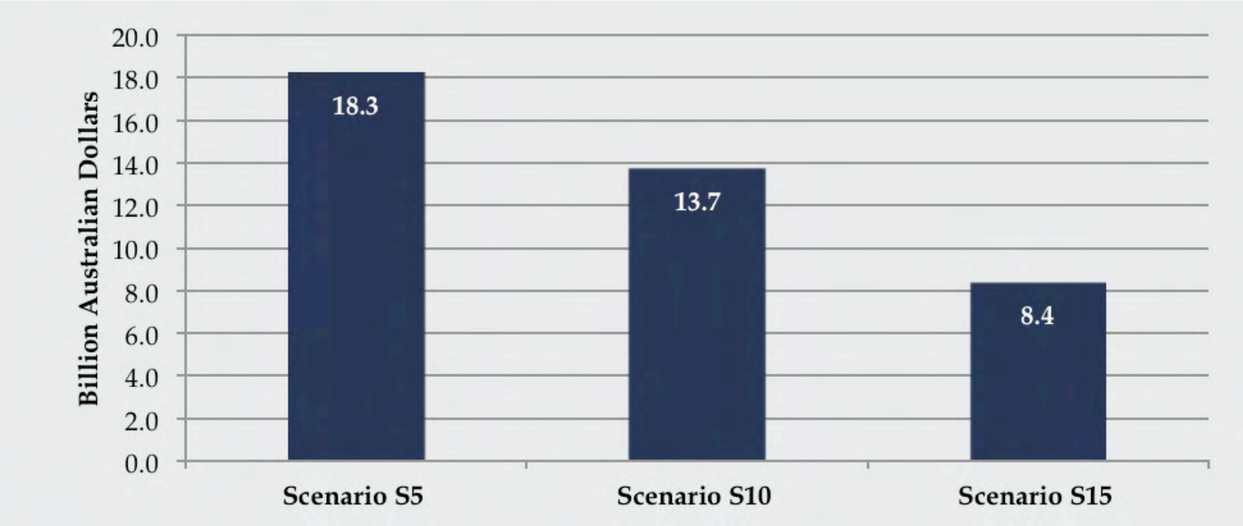
Future profits are modelled using a revenues-minus-costs approach. Calculations are made individually for each generating unit until the end of their technical lives. Required compensation for mothballed plants is treated equivalently[33] to operational plants because the deliberate closure of currently operational plants could cause an increase in energy prices and incentivise mothballed plants to reopen. All calculations are made using highly conservative BAU assumptions.[34]

Table 12: Subcritical Closure Scenarios

Scenario	Years of Plant Closures	% Generators Closed Annually	Order of Closure	Policy Assumptions
S5	2016-2020	20%	Oldest to Newest	Direct regulation used for closure, no new subcritical capacity added, mothballed generators receive compensation as if they were operational
S10	2016-2025	10%		
S15	2016-2030	6.7%		

[33] With the exception that mothballed units are assumed to become operational from 2016 onwards.
[34] See the appendix for a list of all assumptions.

Figure 6: Maximum Conceivable Compensation (2015 AU$)



For Australian SCPSs, the maximum conceivable compensation in 2015 prices would be AU$18.3bn (or AU$3.66bn per year) in scenario S5, AU$13.7bn (or AU$1.37bn per year) in scenario S10, and AU$8.4bn (or AU$560 million per year) in scenario S15. As is expected, total compensation decreases with scenario length because more generators reach their technical lifespan before they are eligible for compensation.

Actual Compensation Necessary

To estimate the compensation that would likely be necessary, a compensation estimation framework is applied to Australia. This framework is developed from three highly relevant case studies of compensation: the deregulation of US electricity generation, Australia's own Contract for Closure programme, and the Montreal Protocol.[35]

In the Australian case owners should only expect to receive partial compensation that is *significantly less than* the AU$18.3bn indicated in scenario S5, AU$13.7bn in scenario S10, and AU$8.4bn in scenario S15. This is due to the following reasons. First, Australia's takings jurisprudence gives no indication that government should compensate firms for impairment of profits. Second, we identify no implicit or explicit contractual bases for compensation of firms by government. This is particularly the case given that the competitive National Electricity Market has operated for over 15 years. Third, there is very little precedent supporting the compensated closure of assets in Australia. The CFC programme provides some precedent, though it did not close a single asset. Australia's carbon tax also provides precedent; however, we argue that this is more of a case of buyout of industry to allow policymaking than evidence of the necessity of compensation for the closure of assets. Fourth, as is recognized throughout this report, coal plays a significant factor in Australian politics. Because of this, we do not rule out investor compensation altogether. The evidence that this report cites for this conclusion is as follows. Australia's most carbon-intensive generators were compensated for the effects of the now-repealed carbon tax on their profits. However, the comparison of our valuation of Hazelwood Power Station and their 2011 plant self-valuation for the CFC programme suggests that the dirtiest power stations were not in danger of imminent collapse, as was claimed.

[35] Caldecott, B. and J. Mitchell (Forthcoming 2015). "Generating Implications for Climate Policy: The Premature Retirement of Subcritical Coal-Fired Generation and the Potential Role of Compensation." Stranded Assets Programme, Smith School for Enterprise and Environment, University of Oxford.

The compensation modelling has assumed that all subcritical power stations would be part of the closure programme. A potentially significant way to further reduce the total cost of compensation, as well as the costs of decommissioning and replacement capacity, is for the closure programme to target a subset of SCPSs.

Reverse Auctions

Reverse auctions could be a policy mechanism for cost-effectively retiring SCPSs. Owners of SCPS assets would bid to receive a fixed price for each unit of generation capacity retired. The lowest bids would win the auction. While similar to the Contract for Closure and the Australian Emissions Reduction Fund, key design differences could lead to drastically different policy outcomes. For example:

- Policies should combine both "carrots" and "sticks" to ensure that generators are retired as quickly and efficiently as possible, and that this process is politically viable.
- Reverse auctions should be operated in tandem with the introduction of new emission regulations.
- There should be a timeline for the retirement of subcritical generators, which could be based on the ratcheting up of an appropriately strict Emission Performance Standard (EPS).
- A Coal Closure Fund (CCF) could be established - this would be a ring-fenced fund used to pay for reverse auctions.
- Auctions could be operated annually or semi-annually until the year of mandatory closure or retrofit. The amount of compensation available could decrease with each auction in a "degression" model to further incentivise earlier retirement.

Reverse auctions eliminate the problem of information asymmetry between government and the owners of SCPS assets. As some owners will have sunk costs (i.e. maintenance and retrofits), this lets owners reach an equitable outcome amongst themselves.

This approach also establishes a robust framework for how owners can participate in negotiations. Political contestation around the closure of subcritical assets with reverse auctions is inevitable and should be expected; however, by creating a robust framework the potential for escalating compensation demands can be contained.

5. Conclusion

In this working paper we analyse the environmental and regulatory risk exposure of all of Australia's 22 SCPSs comprising 26,088MW in total and the 19 companies that hold stakes in them. In addition, we provide conservative estimates for the compensation that would be required to voluntarily close these power stations within 5, 10, and 15-year time horizons.

We find that Australia's SCPS fleet is vulnerable to asset stranding caused by concerns over climate change and water stress and this is exacerbated due to advanced age and inefficiency. An average coal-fired power plant's operating life should be expected to be 40 years - currently the average age of Australia's subcritical capacity is 31 years, and 64% of SCPSs are 30 years old or greater. In addition, Australia's SCPS fleet has the highest carbon intensity of any other major SCPS generating nation at 1,132 kg CO_2/MWh. This leaves its SCPSs vulnerable to climate change legislation.

Ambient PM 2.5 air pollution is not a pressing concern for SCPSs when compared with pollution problems in India and China, for example. However, an upcoming 2016 revision of the National Environmental Protection Measure for Ambient Air Quality (Air NEPM) could create a large-scale closure scenario similar to the US and EU.[36] Aging SCPSs could be required to decide between permanent closure and large capital investment.

Using standard assumptions we estimate that the compensation required to reimburse companies for the foregone revenues associated with closing all Australian SCPSs within 5, 10, and 15 years in 2015 prices would be AU$18.3bn. 13.7bn, and 8.4bn, respectively.

[36] See Caldecott, Dericks, and Mitchell (March 2015). "Stranded Assets and Subcritical Coal, The Risk to Companies and Investors." Stranded Assets Programme, Smith School for Enterprise and Environment, University of Oxford.

Appendix

Power Plant Data Notes

Individual power plant information is taken from the most recent version (v3) of the Carbon Monitoring for Action (CARMA) database. This data is merged with plant-level data from Enipedia and new plant data from CoalSwarm. For CoalSwarm data only plants classified as currently operational are considered. Although CARMA was last systematically updated in 2009, Enipedia is continuously updated on an individual power plant basis. The merger between these datasets produced a dataset which effectively defined the locations of all of Australia's power plants, the ownership of these plants, the annual megawatt hours of electricity produced at each plant, and the carbon intensity of each plant's electricity production. Because subcritical coal power plants are the most carbon intensive form of energy production, we can infer which power plants are SCPSs based solely on their carbon intensity. Following the IEA, this report defines SCPSs are defined as power stations with ≥880 kg CO_2/MWh.

The CARMA data has a number of caveats which are thoroughly enumerated on its website (carma.org), but there are two points which are particularly relevant to this paper. The first is that, when actual measurements are unavailable, CARMA estimates CO_2 emissions using statistical models. CARMA reports that the fitted CO_2 emissions values are within 20% of the true value 60% of the time. Second, CARMA geographical location data varies in its degree of precision. For almost all power plants the state/province location is known, for 80% of power plants at least the city location is known, for 40% county/district data is known, and for 16% of power stations a unique postal code is assigned. Comparisons of approximate and precise coordinates suggest that the average spatial error is about 7 km.

Particulate Matter (PM) 2.5 Data Notes

For analysis of air quality risks associated with SCPSs, a measure of PM 2.5 is used. This data is taken from the analysis of Boys, Martin et al. (2014), and consists of annual ground-level PM 2.5 averages between 2010-12 derived from satellite observation. Particulate matter levels are naturally high above deserts due to windborne dust, and both this natural and anthropogenic sources of PM 2.5 show up in the Boys, Martin et al. (2014) data. This phenomenon appears to account for the high levels of PM 2.5 visible across the Sahara Desert and the Arabian Peninsula in spite of the low-levels of industrial activity in these locations. However, both of these regions are outside the study areas of this report.

Water Stress Data Notes

The measure for water stress used in this report is Baseline Water Stress (BWS) from Aqueduct created by the World Resources Institute (WRI). BWS is defined as total annual water withdrawals (municipal, industrial, and agricultural) expressed as a percent of the total annual available flow within a given watershed. Higher values indicate greater competition for water among users. Extremely high water stress areas are defined by WRI as watersheds with >80% withdrawal to available flow ratios, 80-40% as high water stress, 40-20% as high to medium, 20-10% as medium to low, and <10% as low. Mean water stress is calculated by taking the unweighted average of the water stress levels in each of the catchments where the applicable SCPSs are located.

Modelling Assumptions

Modelling Assumptions are based on Australian industry literature, International Energy Agency publications, and industry research[37]. Its intent is to provide a conservative business-as-usual case to estimate future profits, not to delve into the complexities of the Australian energy market. This method is in line with the approaches taken in two highly relevant cases of compensation: US Generation Deregulation and the closure of CFC-producing facilities by the Montreal Protocol.

[37] Simshauser, P. (2014). The cost of capital for power generation in atypical capital market conditions. AGL Applied Economic and Policy Research.

	2016 Baseline Assumption	Projections
Effective Tax Rate	21%	Stable
Brown Coal Cost (AU$/MWh)	$8	Tracking Inflation
Black Coal Cost (AU$/MWh)	$13.00	Tracking Inflation
Total O&M (AU$/MWh)	1.28	Tracking Inflation
Inflation rate (%/Year)	2.5%	Stable
AU$/US$	1.3	Stable
Wholesale Electricity Price (AU$/MWh)	$41.015	Increases Approximately AU$.79/Year[i]
Auxiliary Consumption %	6%	Stable
Discount Rate	9%	Stable
Plant Life (Years)	40	N/A
Payback Period (Years)	35	N/A
Finance Interest Rate	10%	Stable

[i] Average wholesale prices for NEM territories with SCPSs were analysed from 1998-2015 using linear regression. We then averaged the annual increases in territorial wholesale prices. We assume that increases will continue to occur at this rate.

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