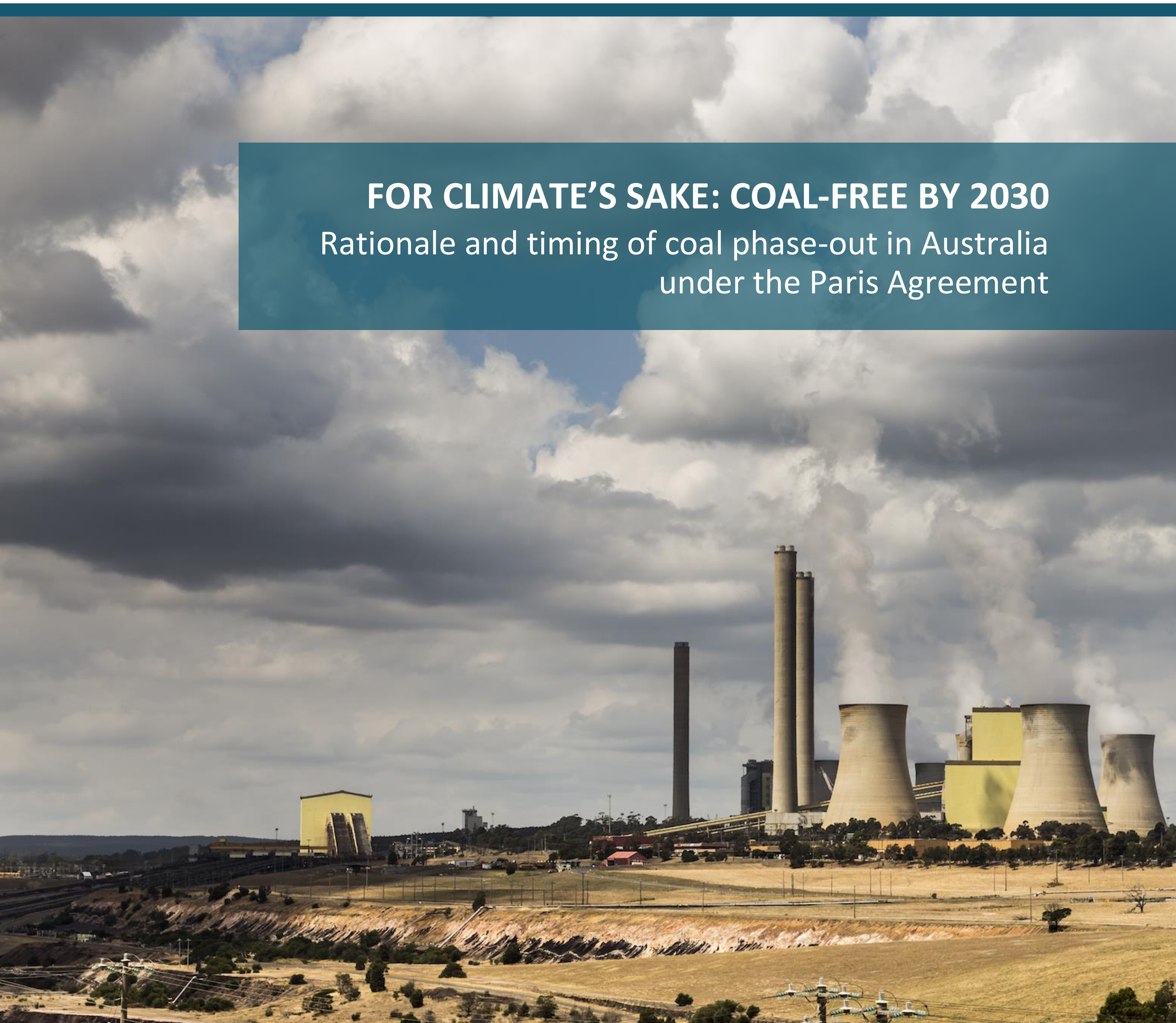
FOR CLIMATE'S SAKE: COAL-FREE BY 2030

Rationale and timing of coal phase-out in Australia under the Paris Agreement



NOVEMBER 2019

FOR CLIMATE'S SAKE: COAL-FREE BY 2030

Rationale and timing of coal phase-out in Australia under the Paris Agreement

Authors

Paola Yanguas Parra
Tina Aboumahboub
Michiel Schaeffer
Alexander Nauels
Ursula Fuentes Hutfilter
Fabio Sferra
Bill Hare
Gaurav Ganti

This document may be cited as:
Climate Analytics (2019). For Climate's Sake: Coal-free by 2030 – Rationale and timing of coal phase-out in Australia under the Paris Agreement

A digital copy of this report along with supporting appendices is available at:
www.climateanalytics.org/publications

This report was funded by the The Sunrise Project.

Cover photo: Daniel L Smith / Shutterstock.com. The Loy Yang Power Station is located on the outskirts of the city of Traralgon, in the Latrobe Valley of south-eastern Victoria and is fed with coal from the open cut mine next to the station.

CONTENTS

EXECUTIVE SUMMARY

Coal is the most carbon intensive fossil fuel and phasing it out and supplanting it with renewable energy is the single most important measure to bring down emissions at the pace and scale needed to curb dangerous climate change. Under the Paris climate accord, Australia and nearly all other governments, regardless of their share of climate-warming carbon emissions, promised to 'do their bit' to reach this goal, and to this end have put forward national emission reduction targets.

Australia needs to steeply decrease coal-based electricity generation in the coming years and phase it out entirely by 2030 in order to 'do its bit.' Coal power generation is responsible for approximately one third of Australia's total emissions. Ridding its electricity of coal is essential for getting Australia on track to meet its national emissions reduction targets and to fulfil its obligations under the Paris Agreement, which sets out to limit global average temperature rise to 1.5°C to avoid the worst of climate impacts.

Last October, the Intergovernmental Panel on Climate Change (IPCC) in its ground-breaking report warned of the increased risks of devastating climate impacts, should global average temperature exceed 1.5°C, emphasising that even half a degree matters.

Why is the 1.5°C limit so important for Australia? Australia can expect to experience a number of significant climate change impacts over the coming decades even under current levels of warming, which will only increase as temperatures rise. Projections show that many parts of southern Australia will have less winter rainfall, with more periods of drought. At the same time, many other parts of Australia will see intense heavy rainfall, causing floods. Periods with high wildfire risk will become more frequent, and the fire season in southern and eastern Australia will become longer. Also, the frequency of high intensity storms will increase. Just half a degree more warming above the 1.5°C limit could mean the demise of nearly all of Australia's coral reefs.

In its report, the IPCC has also shown that it is feasible to limit warming to 1.5°C and outlined pathways for achieving this, at the same time urging that the transformations required for this need to happen very rapidly and carbon emissions need to halve within the next decade. These pathways show that coal needs to be phased out from the global electricity sector by 2040 but that in developed (OECD) countries, including Australia, this needs to happen by 2030.

Australia's coal scorecard is very poor. Its electricity grid is one of the most polluting in the world. Its 19 grid-connected coal power stations supply about 60 per cent of its electricity, which is well above the G20 average of 41 per cent. Australia is the only OECD country in the G20, which relies on coal for more than half of its electricity supply.

Within a decade, around half of Australia's coal power stations will be over 40 years old; some units as old as 60 years. These stations are already technically obsolete and increasingly unreliable: they fail during extreme heat waves, on occasion leading to blackouts. They also have extremely weak air pollution controls and cause substantial adverse health effects.

Also in terms of policies and activities to reduce dependence on coal, Australia is one of the worst performers in the G20 group, and the worst performer among the OECD countries within the G20. Ten stations have closed since 2012, and there are plans to close more stations as they come towards the end of their planned lifetimes. However, if the speed of coal retirements continues at its currently planned slow pace as these policies foresee, Australia's coal plants would emit twice (194%) more than the remaining power sector budget for coal in line with the Paris Agreement.

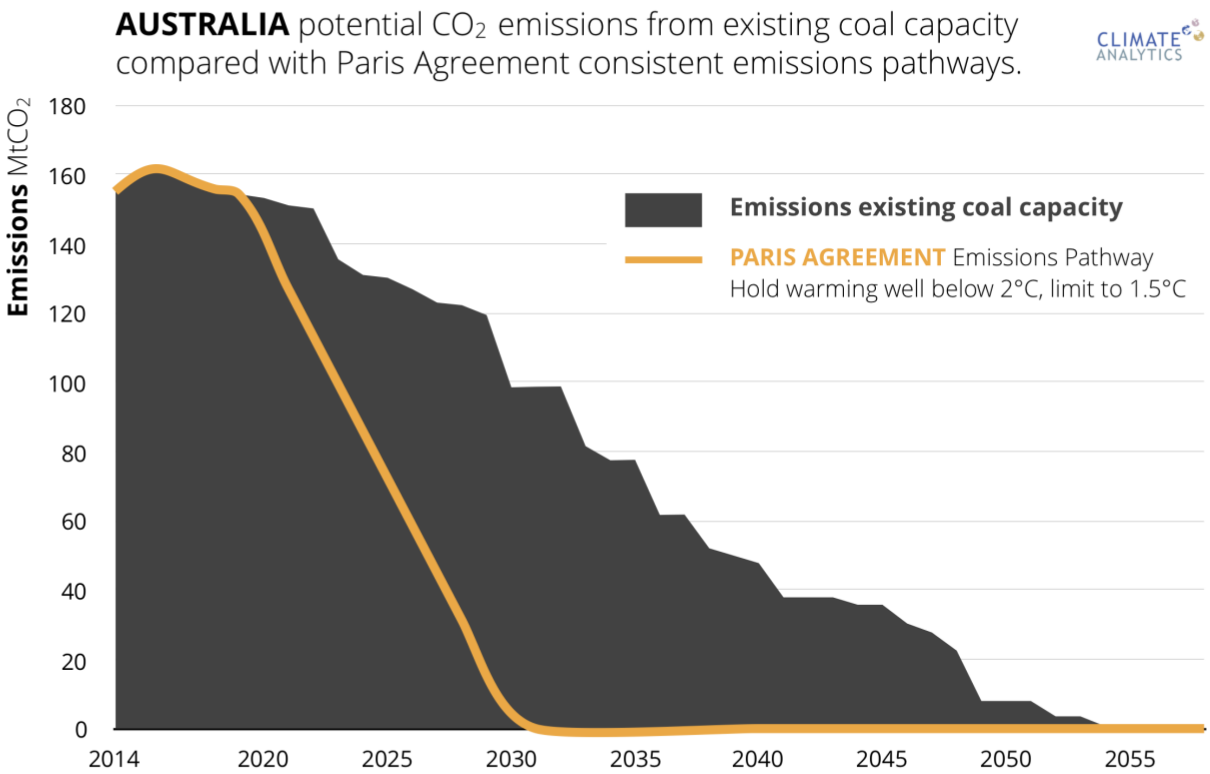


Figure 1 - Coal power plant emissions pathways for Australia. Emissions from operating coal capacity in Australia are calculated based on historical lifetime (44 years) and utilisation rates (62% for hard coal and 82% for lignite), and reported emissions intensities per combustion technology and coal type. Paris Agreement compatible pathway for Australia is a result of the downscaling of the results for the OECD from the IEA ETP B2D scenario to Australia with the SIAMESE model.

It is clear that Australia needs to take rapid and ambitious action to rid its electricity generation system of coal, supplanting it with renewable energy. The Government should create a national plan for an orderly retirement of its ageing coal power plants as soon as possible. In addition to cutting carbon emissions to meet national targets and international obligations, such a plan would provide stakeholders with certainty, facilitating a shift away from the fuel in coal producing regions. Fast action to fully decarbonise electricity generation is a fundamental step for achieving emissions reductions in all other sectors, where electrification plays an important role, and failing to quickly phase out coal from the electricity mix has far reaching implications in terms of feasibility and the cost of reducing greenhouse gas emissions.

At the same time, Australia has a natural comparative advantage in terms of its vast renewable resources, high-level technical and engineering capabilities, infrastructure and proximity to Asian energy markets to develop a carbon free energy system for domestic use and exports of renewable energy. As the world begins to implement the Paris Agreement, the arising global market opportunity for zero carbon energy presents an unprecedented opportunity for Australia to make an orderly and economically beneficial transition.

INTRODUCTION – THE URGENT NEED FOR ACTION TO LIMIT GLOBAL WARMING TO 1.5°C

The Paris Agreement, adopted in December 2015 under the United Nations Framework Convention on Climate Change (UNFCCC) defines the objective of collective action to hold global warming well below 2˚C above pre-industrial levels and pursue efforts to limit it to 1.5˚C (UNFCCC, 2015). The vast majority of countries around the world have signed and ratified the agreement[1], including Australia. While the emissions projections have improved slightly since the adoption of Paris Agreement, global emissions still exceed the level required to meet the Paris Agreement long-term temperature goal. As a result, there is an urgent need for governments to scale up both their climate policies and targets to bring them in line with a pathway to limiting warming to 1.5˚C. Recent estimates show that keeping policies in line with the current Paris Agreement commitments (Nationally Determined Contributions or NDCs) would lead to a global temperature increase of around 3.0°C by 2100, and national policies as they currently stand would lead to a temperature increase of 3.3 °C by 2100 (Climate Action Tracker, 2018), more than doubling the temperature increase agreed by governments under the Paris Agreement.

Achieving the goal of limiting the long-term temperature increase to 1.5°C above pre-industrial levels, as agreed with the Paris Agreement in 2015, instead of the former "below-2°C" goal agreed in the climate negotiations in Cancun in 2011, is of critical importance for Australia. The continent is exposed to numerous climate change-related impacts, such as sea level rise, coral reef loss, and extreme weather events like heatwaves, droughts or floods. All of these impacts are already taking place today and will become much worse in a 2°C warmer world than a 1.5°C warmer world (IPCC, 2018b) (Schleussner, Pfleiderer, & Fischer, 2017). For example, the difference between 1.5°C and 2°C is likely to be decisive if any of Australia's tropical coral reefs are to survive (Schleussner et al., 2016).

Australia can expect to experience a number of significant climate change impacts over the coming decades even under current levels of warming, as the most recent State of the Climate 2018 report (Bureau of Meteorology and CSIRO, 2018) clearly indicates. Current global emissions pathways would lead to further temperature increases, resulting in more frequent heat extremes. The coastal sea level will continue to rise, together with greater warming and acidification of Australia's adjacent oceans. More frequent, intense and longer-lasting marine heatwaves will result in more frequent and severe bleaching events in coral reefs such as the Great Barrier Reef, with the likely extinction of many coral species. Projections show that many parts of Southern Australia will experience less cool season rainfall, with more and longer periods of drought. At the same time, many other parts of Australia are projected to experience more intense heavy rainfall (e.g. eastern Victoria and Tasmania), in particular in the form of short-duration extreme rainfall. Periods with high levels of wildfire risk will increase in frequency, together with a longer fire season in southern and eastern Australia. Also, the frequency of high intensity storms is projected to increase.

Another recent study shows that continued global greenhouse gas emissions increases will lead to greater warming and much higher associated impacts in Australia (King, Karoly, & Henley, 2017). Limiting warming to 1.5°C, relative to 2°C, would reduce substantially the frequency of extreme heat events in Australia and reduce the likelihood of experiencing a variety of high-impact climate extremes that result in loss of life, and economic and environmental damage (King, Karoly, & Henley, 2017)

1 As of November 1st 2019, 197 parties to the convention have signed the agreement, and 187 have also ratified it. See: https://unfccc.int/process/the-paris-agreement/status-of-ratification

The longer Australia experiences a trajectory of continued warming, the more severe these impacts will become. For instance, recent research has shown that delaying Paris Agreement compatible emission reduction efforts by five years would lock in additional 20 cm of long-term sea level rise in 2300 (Mengel, Nauels, Rogelj, & Schleussner, 2018). This highlights the need for immediate action to reduce greenhouse gas emissions at a speed consistent with the Paris Agreement 1.5°C temperature limit, both globally and in Australia.

Meeting this goal means that global emissions from fossil fuels need to peak soon and decline rapidly afterwards. According to the most recent science, summarised in the IPCC Special Report on 1.5°C (SR1.5), achieving this goal requires reaching zero greenhouse gas emissions globally around 2070, with CO_2 emissions declining globally to 45% below 2010 levels by 2030, and reaching zero by around 2050 (IPCC, 2018a)(Climate Analytics, 2019c).

Failure to phase-out fossil fuels from the energy system, including coal, at the necessary speed increases substantially the risk of unprecedented environmental, social and economic damages that the scientific literature has associated with increases in temperature beyond 1.5°C (IPCC, 2018a).

The reality of Australia's climate and energy policy is far from in line with its international commitments under the Paris Agreement and the urgency of action needed to limit warming to 1.5°C. Australia has a target to reduce greenhouse gas emissions by 26 to 28% below 2005 levels by 2030 in its Nationally Determined Contribution (NDC). This target, put forward in 2015, is inconsistent with the global efforts necessary to achieve the Paris Agreement's objectives (Climate Action Tracker, 2019). Additionally, Australia's current climate policies are not even sufficient to reach this inadequate NDC target, as they would lead to an 6-8% greenhouse gas emission increase from 2005 levels by 2030 (excluding the very uncertain land-use emissions**). If all countries followed Australia's approach, this would lead to warming of between 3 and 4°C by the end of the century** (Climate Action Tracker, 2019).

Considering its commitments under the Paris Agreement and its high vulnerability to climate change, Australia urgently needs to implement measures in the short-term to close the large emissions gap between its current emissions trajectories and national targets, and update these targets to benchmarks that are in line with the Paris Agreement. While short-term action is required in all sectors to enable the full decarbonisation of the energy mix required by the Paris Agreement (Kuramochi et al., 2017)(Kriegler et al., 2018), this report focuses on coal-fired power generation for three main reasons:

- Phasing out coal and supplanting it with renewable energy is the single most important measure to bring down emissions at the pace and scale needed to limit warming to 1.5°C. Paris Agreement compatible emissions pathways show the need for a phase out of coal in the power generation sector globally by 2040 and in OECD countries by 2030 (Climate Analytics, 2019b).
- Coal power generation is the single largest contributor to greenhouse gas emissions in Australia, being responsible for approximately one third of its total emissions (Australian Government, 2018). A fast phase-out of coal, the most carbon-intensive fuel, from the Australian power sector therefore plays an essential role in getting Australia on track to meet its national emissions reduction targets and on an emissions trajectory which is in line with the Paris Agreement long-term temperature goal.
- Fast action to fully decarbonise electricity generation is a fundamental step for achieving emissions reductions in all other sectors, where electrification plays an important role, and failing to quickly phase out coal from the electricity mix has far reaching implications in terms of feasibility and the cost of reducing greenhouse gas emissions.

THE ROLE OF COAL IN AUSTRALIA´S ELECTRICITY MIX AND THE NEED FOR ACTION

Australia's electricity system is dominated by centralised, carbon-intensive coal-fired generation. Coal (both brown and black) accounted for approximately 60% of electricity generation across Australia in 2018. Its share of electricity generation is much higher in some states: Queensland, Victoria, and New South Wales (DEE, 2019).

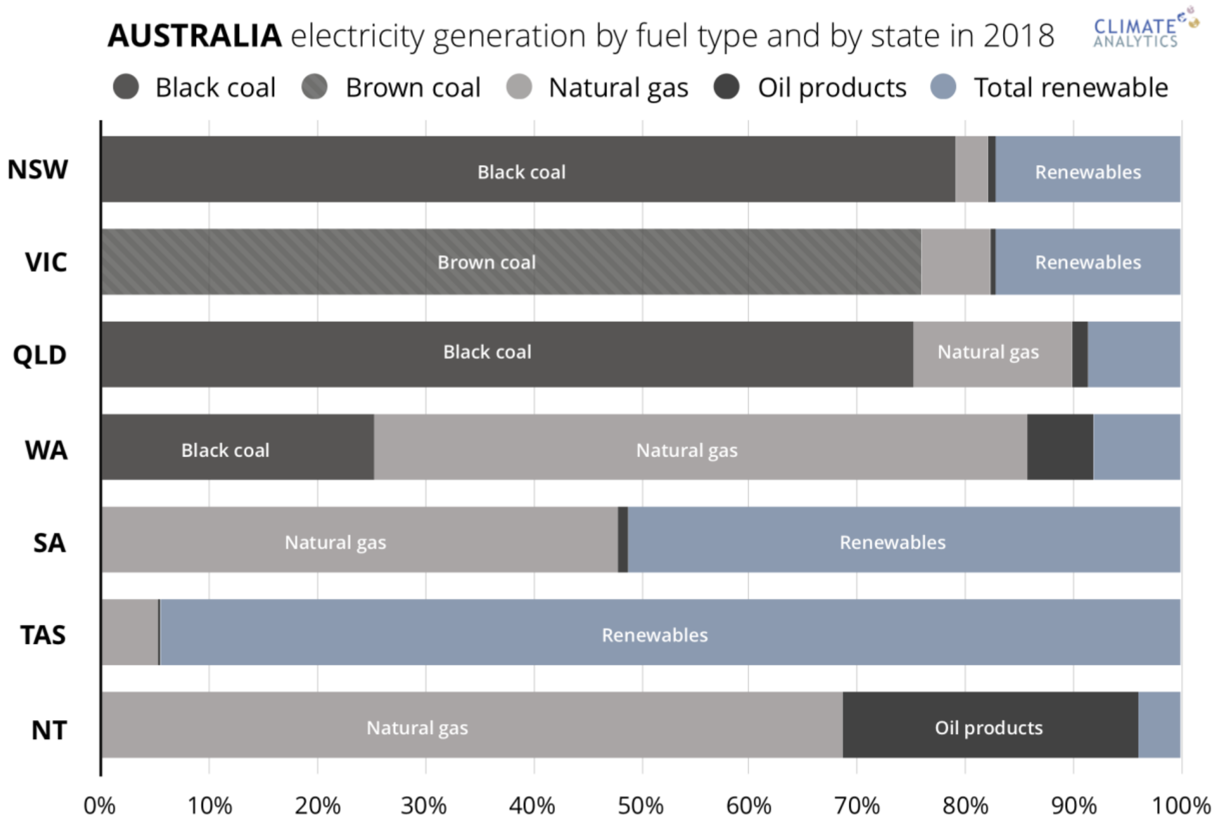


Figure 2 - Electricity generation by fuel type and state in 2018. Source: Department of the Environment and Energy, Australian Energy Statistics, Table O, March 2019

There are 19 grid-connected[2] coal power stations operating in Australia, mostly old and inefficient. Within a decade, around half of Australia's coal fleet will be over 40 years old, with some units approaching even 60 years. These stations are technically already obsolete and increasingly unreliable: they fail during extreme heatwaves, on occasion leading to blackouts. In addition, stations in Australia have extremely weak air pollution controls and the power stations are associated with substantial adverse health effects, particularly in Sydney (Ewald, 2018).

2 Smaller off-grid plants, with a combined capacity of 202 MW, have also been taken into account on our emissions estimates to provide a complete overview of emissions from coal-based power generation.

Table 1- Australia's grid connected coal power generation plants

Plant	Capacity (MW)	Opening year	Number of units	Combustion technology	Planned retirement	State
Eraring	2,880	1982-84	4	Subcritical	2031	NSW
Bayswater	2,640	1982-84	4	Subcritical	2035	NSW
Liddell	2,000	1971-73	4	Subcritical	2022-23	NSW
Mount Piper	1,400	1993	2	Subcritical	2042	NSW
Vales Point B	1,320	1978	2	Subcritical	2029	NSW
Loy Yang A	2,210	1984-87	4	Subcritical	2048	VIC
Yallourn	1,480	1975, 1982	4	Subcritical	2033	VIC
Loy Yang B	1,070	1993-96	2	Subcritical	2047	VIC
Gladstone	1,680	1976-82	6	Subcritical	2035	QLD
Tarong	1,400	1984-86	2	Subcritical	2037	QLD
Stanwell	1,460	1993-96	4	Subcritical	2043-45	QLD
Callide C	900	2001	2	Supercritical		QLD
Millmerran	852	2002	2	Supercritical		QLD
Kogan Creek	744	2007	1	Supercritical	2042	QLD
Callide B	700	1989	2	Subcritical	2028	QLD
Tarong North	450	2002	1	Supercritical	2037	QLD
Muja	815	1981, 1986	4	Subcritical		WA
Collie	318	1999	1	Subcritical		WA
Bluewaters 1&2	434	2009-10	2	Subcritical		WA
TOTAL	**24,753**		**53**			

Source: own elaboration based on Global Coal Plant Tracker and national sources (e.g. AEMO).

This makes Australia's electricity grid one of the most polluting in the world. A recent report on the coal sector in G20 economies shows that Australia is not only well above the G20 average for coal use in electricity production (62% compared with 41% in 2017), but also the only OECD country in this group which relies on coal for more than half of its electricity supply (Climate Transparency, 2019). The same report awards Australia's policies and activities to reduce dependence on coal with the lowest rating possible, making it one of the worst performers in the G20 group, and the worst performer among the OECD countries within the G20.

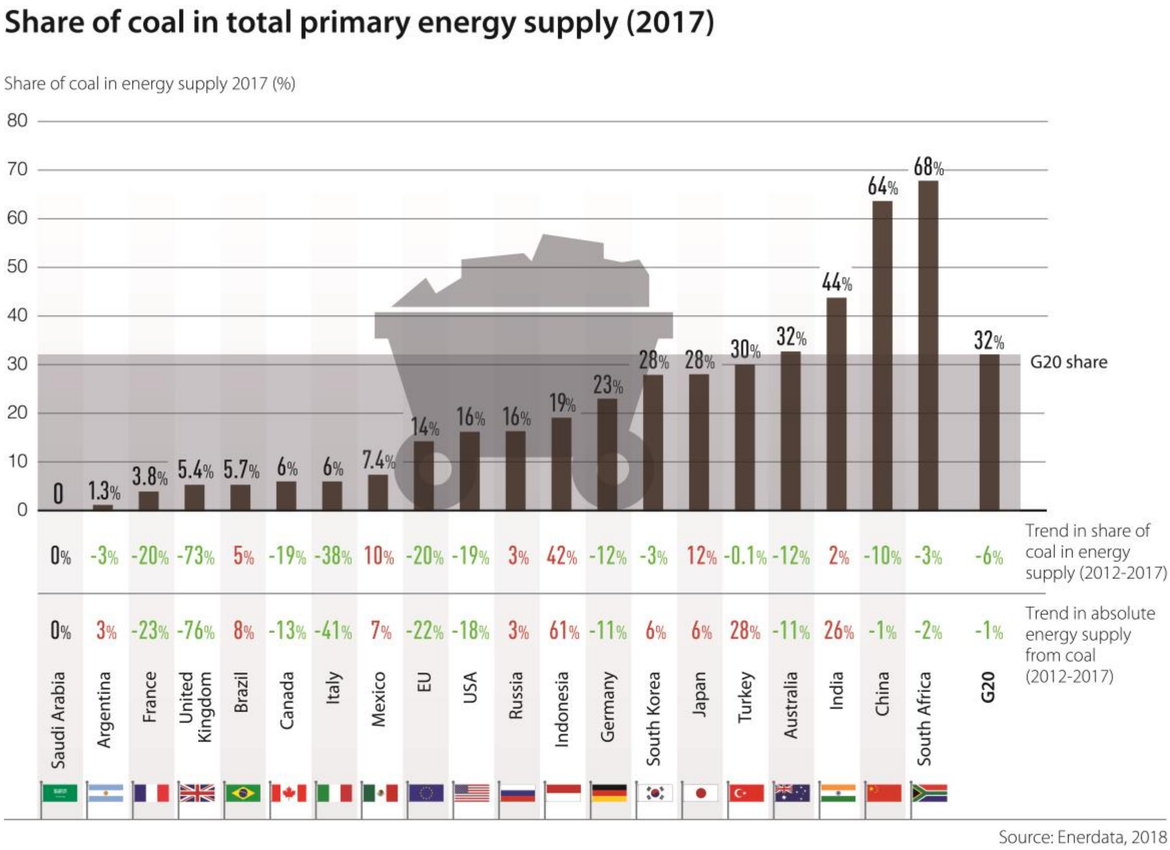


Figure 3 – Share of coal in total primary energy supply across G20 countries. Source: Climate Transparency 2019

Other analyses show that Australia has one of the worst ratings for electricity emissions intensity in the world (Climate Analytics, 2019a). This, together with the high share of coal in electricity production, make Australia's electricity emissions performance in recent decades one of the worst of the world, especially among high-income countries.

A number of different factors have led to the withdrawal of a number of coal-fired generators from the market, including the increasing unreliability of Australian coal plants, lower total electricity demand, increased competition from renewables, volatility of wholesale prices, investor concerns over long-term viability and the high maintenance costs of older stations (Climate Council, 2018; Finkel, 2017). Ten stations have closed since 2012, representing around 5.3 GW of installed capacity, at an average retirement age of 42 years (see Annex 1- Recent coal plant retirements). Also, there are plans to close more stations as they come towards the end of their planned lifetimes (Jotzo, Mazouz, & Wiseman, 2018; Shearer, Ghio, Myllyvirta, Yu, & Nace, 2017).

In addition, the private sector generally regards building new coal power plants as unviable because renewable energy and storage present a cost-competitive alternative (BloombergNEF, 2018; Graham, Hayward, Foster, Story, & Havas, 2018; Morgan, 2017). This is particularly the case in Australia, which has very high potential for electricity from renewable energy, especially from solar and wind sources (AECOM, 2016; Climate Council, 2014; Department of Industry, 2014; Drew, 2015; Prasad, Taylor, & Kay, 2017). This means that the role of coal in Australia's electricity mix will likely continue to decline. However, there is currently no policy to accelerate coal phase out, and no systematic framework to ease the transition in coal-producing regions.

Australia's reliance on coal is expected to continue well beyond 2030 under current policies, with the electricity system projected to generate 29% of total emissions in that year, according to the latest official projections (Department of the Environment and Energy, 2018). These projections have coal still providing just under 50% of electricity generation in 2030, with overall electricity sector emissions only 17% below 2005 levels (Department of the Environment and Energy, 2018). Independent assessments have concluded that Australia’s current policy projections would lead to warming of between 3 and 4°C by the end of the century if all countries followed the same approach (Climate Action Tracker, 2019).

In addition, no strategic approach to the deployment of Australia’s vast renewable energy potential can be found in the federal regulation. On the contrary, the government has scaled back policies aiming at renewables phase-in like the Large-scale Renewable Energy Target (LRET) and the government is not intending to extend this beyond 2020. Instead, it is planning to introduce measures to promote new coal power generation and/or maintain existing generators in the market, including public subsidies (The Australian, 2019; The Guardian, 2018a, 2018b, 2018c).

Based on the characteristics of its coal fleet, the current market conditions, and climate commitments it is clear that Australia needs fast and ambitious action to decarbonise its electricity mix, and a rapid coal phase-out is needed for this task.

This report investigates the implications of the Paris Agreement for coal power stations in Australia, and establishes a science-based pathway for a thermal coal electricity phase out in Australia. This is necessary to draw conclusions relevant for policy development on the timing and scale of coal phase-out and policy capable of dealing with regional structural change and ensuring that regions particularly affected by this change will benefit from a shift to renewable energy.

PARIS AGREEMENT COMPATIBLE PATHWAY FOR COAL IN THE POWER SECTOR

In 2016, Climate Analytics concluded that to meet the Paris Agreement 1.5°C temperature goal, emissions of unabated coal[3] would have to phase out globally by 2050, in China by 2040, and in the OECD and the European Union by 2030 (Climate Analytics, 2016b)[4]. The study was based on an evaluation of energy-economic scenarios from Integrated Assessment Models (IAMs) available at the time. On this basis, Climate Analytics also developed coal phase-out studies for different countries including the European Union, Japan, and Germany (Climate Analytics, 2017) (Climate Analytics, 2018a) (Climate Analytics, 2018b).

More recently, the much larger number and range of 1.5°C compatible scenarios assessed in the IPCC 1.5°C Special Report (SR1.5) extend the scientific basis on the coal phase-out needed to limit warming to 1.5°C (IPCC, 2018a). **Climate Analytics has analysed the scenarios in the IPCC SR1.5 and found that coal needs to be phased out from electricity generation globally by 2040, to get the world on a trajectory compatible with the Paris Agreement** (Climate Analytics, 2019b), which is roughly a decade earlier than previously estimated. For more information on the findings from the IPCC SR1.5 see Annex 2 - IPPCC SR1.5 findings and implications for coal.

The scenarios underpinning IPCC SR1.5 do not provide data at the national level but focus instead on different regions (e.g. the OECD). To draw conclusions on Australian emissions and energy scenarios, we have selected a scenario that characterises well the main features of the set of 1.5°C compatible scenarios: the International Energy Agency's (IEA) Energy Technology Perspectives (ETP) Beyond 2°C scenario (B2DS)[5] (IEA, 2017). This is consistent with our previous work looking at country-level Paris Agreement benchmarks for coal phase-out in Germany (Climate Analytics, 2018a).

The ETP B2DS scenario provides a close analogue to a typical 1.5°C compatible pathway at the global level for the power sector from the IPCC SR1.5 scenario set. For more information on the compatibility of the B2DS with the IPCC SR1.5 scenario set see Annex 3 – B2DS compatibility with IPCC SR1.5. This scenario also contains energy system data on some key countries and regions, including the OECD.

For the OECD, the B2DS scenario has a coal phase out date in the power sector at the 90-95% level some five years later (2035) than the median of the IPCC SR1.5 scenarios (2030). As can be seen in Figure 2, the IEA B2DS OECD trajectory on the use of coal in electricity (without CCS) lies above the median of 1.5°C pathways assessed in SR1.5. Given this context, the 2035 phase out date for coal in the power sector in the OECD in the B2DS scenario appears to be a conservative estimate for a 1.5°C consistent pathway for this region.

3 Coal plants without carbon capture and storage.

4 In this study we assume that a phase-out of coal-fired power plants is achieved whenever emissions are reduced by more than 90% below 2010 levels.

5 The IEA report includes two additional scenarios that are not relevant here: the Reference Technology Scenario (RTS) or baseline scenario, assuming the implementation of present day climate change mitigation commitments (NDCs and other); and the 2°C scenario (2DS) that includes assumptions on additional mitigation action that would result in a 50% chance of keeping anthropogenic global warming below 2°C above pre-industrial levels by 2100.

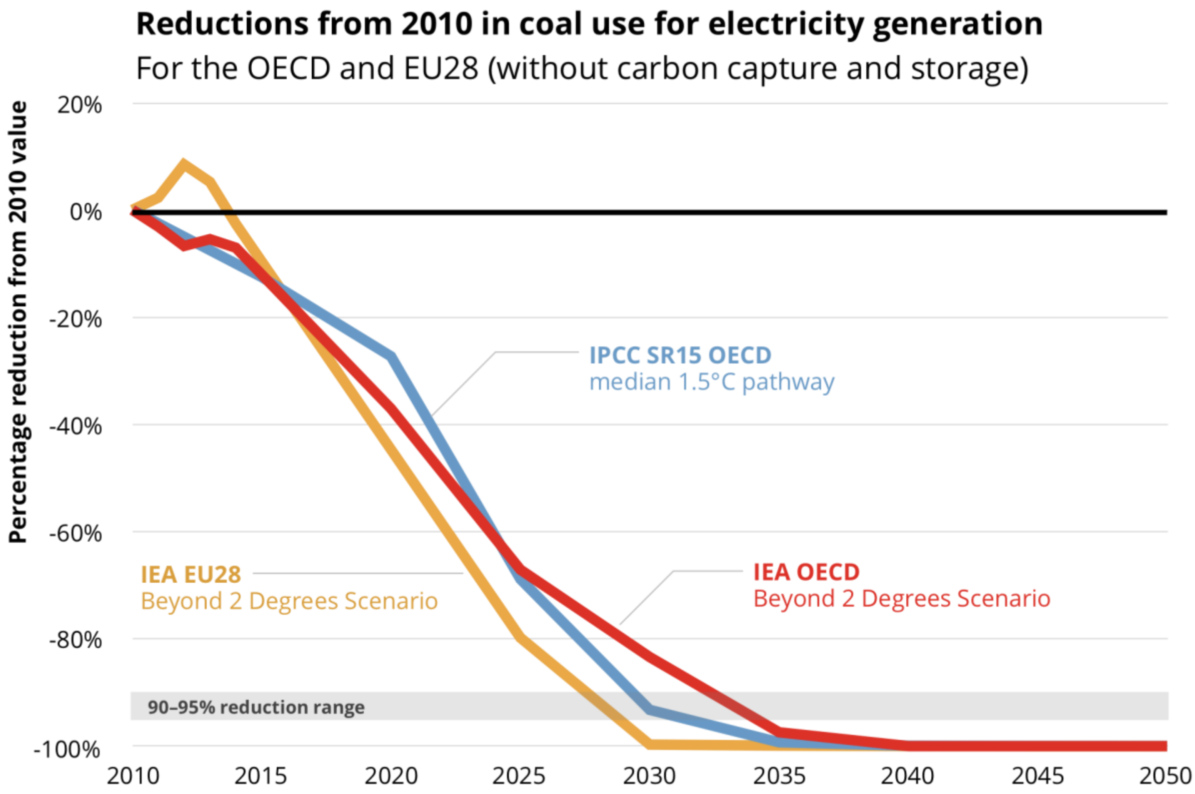


Figure 4 – Reductions below 2010 levels in electricity from coal-fired power plants without CCS
IPCC SR1.5 for 1.5°C compatible pathways (blue line: OECD median) and from the ETP B2DS scenario (EU orange and OECD red line). Sources: IEA (2017); IEA Energy Statistics and Balances 2016 (https://www.iea.org/statistics); SR1.5 scenario database (https://data.ene.iiasa.ac.at/iamc-1.5c-explorer). We have used data from 21 pathways from the SR1.5 database, excluding pathways that have more than 5 GtCO$_2$/yr removals via bioenergy with carbon capture and storage (BECCS) by 2050. This limitation on BECCS is consistent with SR1.5 Summary for Policy Makers (SPM) paragraph C3.2 that specified BECCS potential by 2050 at that level, and not higher, in the context of concerns about the feasibility and sustainability of its large-scale deployment.

To draw conclusions on Australian emissions and energy scenarios, the OECD coal use pathways need to be downscaled to the national level. For this report, we have downscaled the OECD results to Australia by making use of Climate Analytics' SIAMESE model (Simplified Integrated Assessment Model with Energy System Emulator) (Sferra, Krapp, et al., 2018), consistent with other reports looking at national implications of global and regional energy models (Climate Analytics, 2016a, 2017, 2018b, 2018a; Sferra, Schaeffer, & Torres, 2018).

SIAMESE is able to downscale the results of aggregated regions (OECD in this case) to the national level by determining the optimal electricity mix and emission pathways for all countries in the regions, using a welfare maximisation approach that ensures a least-cost approach to achieve emissions reductions that add up to the required regional emissions reductions. For more details on the downscaling methodology and model assumptions see Annex 4 - SIAMESE Model.

There are two main advantages of using SIAMESE instead of other downscaling methodologies, such as applying regional reduction rates to national historical data. Firstly, SIAMESE mimics the structure of energy-economy models like the IEA ETP model, from which the B2DS scenario is derived, and is able to distribute mitigation efforts across countries and sectors under a least-cost scenario which takes into account observed energy consumption, energy mix composition, GDP and population data across different countries in the region. In addition, SIAMESE can take into account specific policies that are in place (e.g. a minimum renewable energy target) and expected energy trends (e.g. nuclear phase-out dates) at the country level, making the results more relevant for national policy discussions.

Given that the IEA B2DS uses 2014 as the last historical year in calibrating its results, we need a two stage approach to derive a Paris Agreement compatible pathway for coal power generation in Australia that reflects accurately the most recent emissions trends:

- First, we use the SIAMESE model to downscale the regional energy mix from the OECD region to Australia, calibrating the model with the officially reported historical electricity generation records from the Australian Energy Statistics until the last historical year of the B2DS scenario (2014). Based on national emissions factors we then derive a Paris Agreement compatible emissions pathway[6] consistent with this energy mix and calculate an emissions budget for coal-based power generation (cumulative emissions 2014 to 2050) for Australia based on this pathway.

- Second, given that observed and expected coal power generation and emissions in Australia as reported by the Australian government for the years 2015-2018 are higher than the levels that Australia would have reached had it followed the Paris Agreement consistent pathway from 2014 (last historical year in the B2DS derived pathway), we modify the emission trajectory so that Australia does not exceed the total emissions budget derived from the original pathway (starting in 2014). Under this approach, to compensate for emissions exceeding the original pathway between 2014-2018, Australia would have to speed-up emissions reductions in coal power generation after 2018, reaching a full phase-out of these emissions by 2030, which is consistent with the median coal phase out pathway of the range of IPCC scenarios consistent with the 1.5 °C limit.

The cost-optimal, Paris Agreement compatible pathway (see Figure 3) shows that coal power plant emissions need to decrease steeply in Australia in the coming years, falling by 27% below 2018 levels by 2025 and then reaching zero by 2030. However, the existing retirement plans in many cases far exceed the 2030 deadline consistent with the Paris Agreement and, in contrast to other OECD countries, the Australian government has no policy for a planned retirement of coal power plants.

We have estimated future CO_2 emissions from operating coal capacity in Australia, under current retirement plans. The key assumptions for this estimate are lifetime and utilisation factors, which are very uncertain in the future. For plants without a planned retirement date, we have assumed a lifetime of 44 years, which is consistent with the average historical retirement age of coal power plants in Australia. It is worth noting that while this lifetime assumption is above the global average retirement age of 40 years, it is a much lower lifetime that the 50 years assumption the AEMO uses in its modelling (AEMO, 2018).

We have also assumed an average utilisation factor of 62% for hard coal and 82% for lignite, which is equal to the 2016 average utilisation factor, according to national reported generation values (Department of the Environment and Energy, 2019). Finally, emissions intensities are estimated based on standard reported values per combustion technology and coal type, around which there is very little uncertainty. We have not assumed any new coal power plants coming online for our estimates.

Our methodology is described in detail in Annex 5 - Estimating CO2 emissions from coal plants.

6 The IEA and SIAMESE models have 2014 as a starting date and provide results for 2025 and 2030. Values between the starting point and these data points are linearly interpolated.

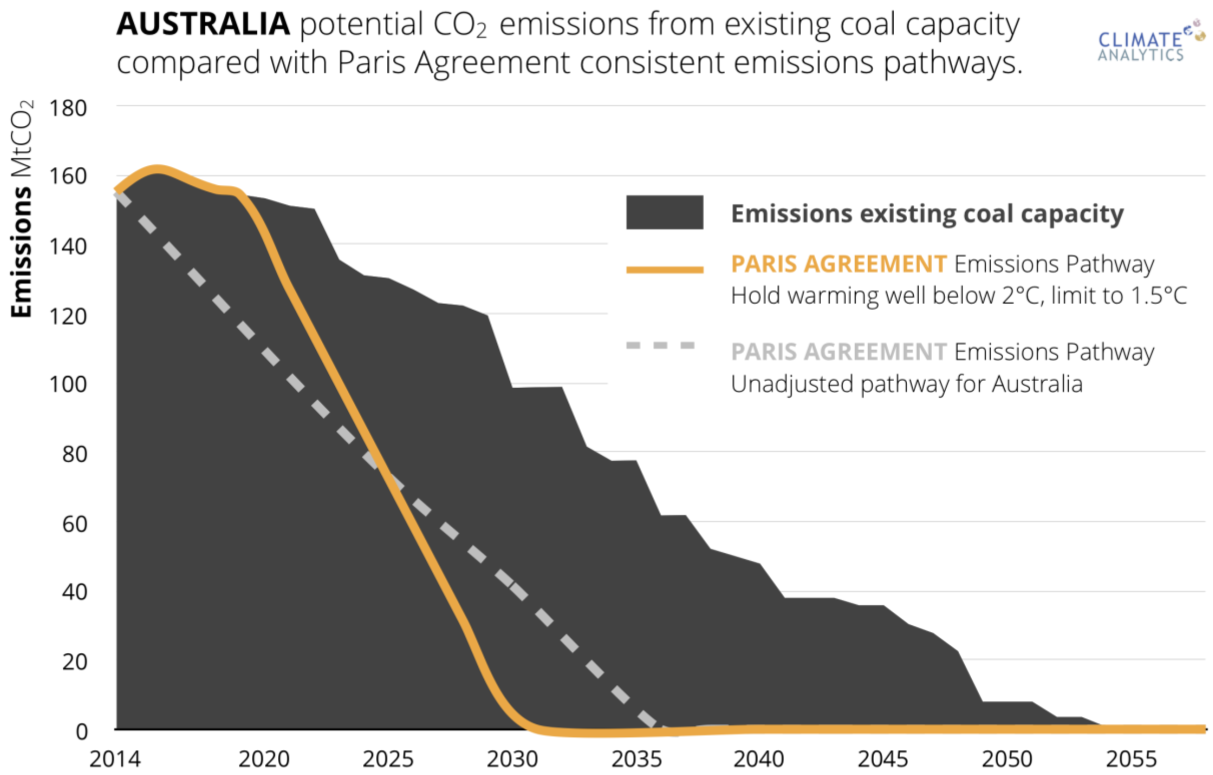


Figure 5 - Coal power plant emissions pathways for Australia. Emissions from operating coal capacity in Australia are calculated based on historical lifetime (44 years) and utilisation rates (62% for hard coal and 82% for lignite), and reported emissions intensities per combustion technology and coal type. The Paris Agreement compatible pathway for Australia is a result of the downscaling of the results for the OECD from the IEA ETP B2D scenario to Australia with the SIAMESE model, taking into account historical emissions until 2018.

Our estimates show that coal-related CO_2 emissions are projected to fall in the following decades even without additional policies due to ageing of the coal fleet and profitability and policy prospects that make refurbishment or opening of new plants unfeasible. **However, if the speed of coal retirements continues at its currently planned pace, Australia's coal plants would emit twice (194%) the remaining power sector budgets for coal in line with the Paris Agreement**, which we estimate by calculating the cumulative emissions consistent with the orange emissions pathway in Figure 5. If the lifetime of existing power plants is extended beyond the assumptions made in this report, or any new power plants come online, this carbon budget will be exceeded by a much larger margin.

In order to achieve the Paris Agreement long-term temperature goal, our results show that Australia will need to retire its operating power plants early and/or dramatically reduce their utilisation rate. Given the urgency of the emissions reductions needed in the power sector, a clear policy signal and structured phase-out plan is needed to provide certainty both for regions affected by this transition, as well as for investors.

This would provide multiple benefits for the general public, Australia's industrial sector, and coal related businesses, workers, owners and investors, who would be better placed to make a sound transition away from coal and plan in advance with investments into renewable capacity to replace retiring coal capacity. A large number of studies has shown that a fast transition to 100% renewable energy is possible in Australia (Blakers, Lu, & Stocks, 2017; Diesendorf, 2018; Gulagi, Bogdanov, & Breyer, 2017; Howard, Hamilton, Diesendorf, & Wiedmann, 2018; Riesz, Elliston, Vithayasrichareon, & MacGill, 2016; Teske, Dominish, Ison, & Maras, 2016).

A delay in phasing out coal from the power sector would have to be compensated for by much more stringent (and costly) emissions reductions in other sectors, or by respectively higher and much more expensive and uncertain negative emissions (removing CO_2 from the atmosphere) in the second half of the century (Luderer et al., 2013; Riahi et al., 2015). Early, ambitious and concerted action to phase-out coal is needed worldwide and in Australia to hedge against the risk that negative emissions technologies will not deliver within the timeframe and at the scale needed (considering the associated technical, sustainability and other challenges).

The longer the world and Australia continue to use coal as currently planned, the higher the cost and the smaller the feasibility of keeping the door open to achieve the Paris Agreement's long-temperature goal.

CONCLUSION

It is clear that Australia needs to take fast and ambitious action to decarbonise its electricity mix, based on the characteristics of its coal fleet, the current market conditions, and climate commitments. For this, a rapid coal phase-out is essential. This report establishes a science-based pathway for a thermal coal electricity phase out in Australia and finds that that coal power plant emissions need to decrease steeply in Australia in the coming years, falling by 27% below 2018 levels by 2025 and then reaching zero by 2030.

Continuing to rely on coal-generated electricity is completely inconsistent with the Paris Agreement, and the discussion should not be on whether coal power plants should close but rather how quickly and orderly these closures will occur, and which policies are needed to help to manage the process. A clear policy signal and structured phase-out plan would provide multiple benefits for the general public, Australia's industrial sector, and coal related businesses, workers, owners and investors, who would be better placed to make a sound transition away from the fossil fuel.

The Australian government should devise a national plan for an orderly retirement of the remaining operating coal power stations by 2030, as soon as possible. Such a plan would provide stakeholders with certainty, facilitating a transition away from the fuel in coal-producing regions. It would also help to give clear signals for investments into renewable energy capacity to replace coal power plants, and avoid a continued flow of investment into unsustainable assets and coal related infrastructure, preventing Australia from becoming locked into a carbon intensive pathway and shouldering expensive stranded assets, while also reducing the cost and complexity of achieving Australia's national mitigation targets and its necessary contribution to the Paris Agreement.

In addition to its contribution to climate change, coal extraction and combustion comes with multiple associated negative effects, including air and water pollution as well as the destruction of whole ecosystems, which are not discussed in this report but have been covered widely in the literature. This is particularly relevant for Australia, which is one of the world's biggest coal producers and relies on an increasingly outdated and polluting coal fleet for electricity generation. A fast phase-out of coal would therefore not only be the most cost-efficient way to put Australia closer to a Paris Agreement compatible emissions pathway but would also offer a range of benefits and opportunities that go beyond emissions reductions, including job opportunities from higher investments into renewable energy and reduced electricity costs.

The longer Australia and the world continue to use coal for power generation, the higher the cost and lower the feasibility of achieving the Paris Agreement's long-temperature goal. Failure to phase-out fossil fuels from the energy system, including coal, at the speed needed increases substantially the likelihood of Australia and the world experiencing the unprecedented environmental, social and economic damage that the scientific literature has associated with increases in temperature beyond 1.5°C.

ANNEX 1- RECENT COAL PLANT RETIREMENTS

Table 2 - Recent coal power plant retirements

Power station	State	Capacity (MW)	Year of Closure	Age at time of closure
Morwell	VIC	189	2014	56
Playford	SA	240	2016	56
Hazelwood	VIC	1,600	2017	53
Anglesea	VIC	150	2015	46
Collinsville	QLD	190	2012	44
Munmorah	NSW	600	2012	43
Swanbank B	QLD	480	2012	42
Wallerawang	NSW	1,000	2014	38
Northern	SA	530	2016	31
Redbank	NSW	144	2014	13
Kwinana -C	WA	400	2015	39

Source: (Climate Council, 2018)

ANNEX 2 - IPPCC SR1.5 FINDINGS AND IMPLICATIONS FOR COAL

The IPCC SR1.5, adopted and published in October 2018, provides the best available science for operationalising the Paris Agreement Long Term Temperature Goal (LTTG) of holding global warming well below 2°C above pre-industrial levels and pursue efforts to limit it to 1.5°C warming. The SR1.5 Summary for Policymakers (SPM) establishes 1.5°C compatible mitigation pathways as being pathways with no-, or limited overshoot. These pathways limit median global warming to 1.5°C throughout the 21st century without exceeding that level ("no-overshoot"), or allow warming to drop below 1.5°C by the end of the century (around 1.3°C warming by 2100) after a brief and limited overshoot of median peak warming below 1.6°C around the 2060s ("low-overshoot"). With a peak warming below 1.6°C these pathways meet several tests with reference to the LTTG.

With these considerations, the implications for operationalising the Article 4.1 of the Paris Agreement in global emission pathways can be outlined. Article 4.1 of the Paris Agreement is designed to operationalise the LTTG with global emission goals "in order to achieve the long-term temperature goal set out in Art. 2.1" – to peak global emissions "as soon as possible", followed by "rapid reductions thereafter", and to reach a balance between anthropogenic sources and sinks of greenhouse gases emissions in the second half of this century – are to be determined "according to best available science" so as to be consistent with the LTTG. Figure 7 illustrates the PA 1.5°C pathways and the three stages of global transformation and mitigation strategies as outlined in Art. 4.1

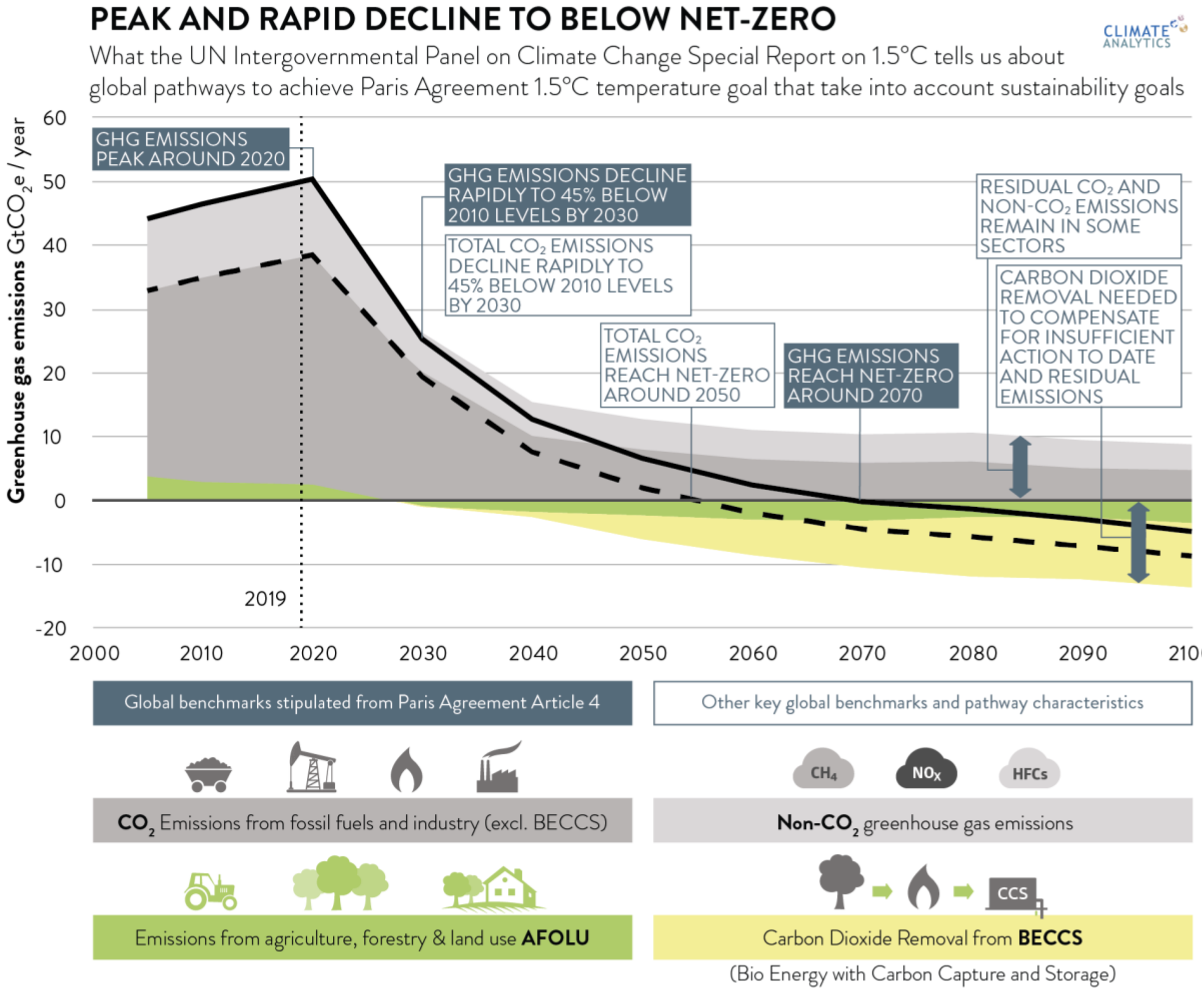


Figure 6 – Emission Benchmarks for Paris Agreement

Article 4.1 for operationalisation of Article 2.1 (dark blue boxes) and global decarbonisation benchmarks (white box). This representative pathway is the median across all 1.5°C-compatible pathways from the IPCC SR15 that reach levels of Carbon Dioxide Removal (CDR) below the upper end of estimates for sustainable, technical and economic potential around 2050 from SR15 in the sector of Agriculture, Forestry and Land-Use (AFOLU), as well as via Bioenergy combined with Carbon Capture and Storage (BECCS). Solid line represents total GHG emissions and dotted line represents total CO_2 emissions.

Following the IPCC SR1.5 SPM assessment of 1.5°C compatible pathways, in this report we define Paris Agreement LTTG-compatible pathways as those that limit global warming to 1.5°C, or below, throughout the 21st century with no or limited (<0.1°C) overshoot. This permits drawing energy-economic data from the 1.5°C compatible pathways in the new set of IAM pathways assessed in the IPCC SR1.5.

Moreover, in the context of defining the broad features of these scenarios it is important to note that the IPCC SR1.5 identified limits based on sustainability and economic constraints on Carbon Dioxide Removal (CDR). These limits were found for BECCS[10] to be below 5 $GtCO_2$/yr globally in 2050 and for AFOLU[11] below 3.6 $GtCO_2$/yr sequestration globally in 2050). Excluding pathways that exceed the BECCS

10 Bioenergy with Carbon Capture and Storage, defined in SR15 glossary as: "Carbon dioxide capture and storage (CCS) technology applied to a bioenergy facility. Note that depending on the total emissions of the BECCS supply chain, carbon dioxide can be removed from the atmosphere."

11 SR15 refers to CDR measures in the Agriculture, Forestry and Other Land Use sector and notes such measure are mainly represented in the models as afforestation and reforestation.

and AFOLU sustainability limits identified in the IPCC SR1.5 implies faster reduction of greenhouse gas emissions by 2030, to be 1-2 $GtCO_2e$/year lower by that time.[12]

Taken together, key global benchmarks and characteristics can now be identified:

- Peaking of greenhouse gas (GHG) emissions and of CO_2 by around 2020
- Rapid decline of GHG and CO_2 emissions by around 45% by 2030 (from 2010)
- Net zero CO_2 emissions by around 2050, negative thereafter
- Net zero GHG emissions by around 2070, negative thereafter
- Net zero AFOLU emissions by around 2030 (between 2025 and 2040) then negative
- Bioenergy with Carbon Capture and Storage (or other negative emission technology) starting to be deployed at scale by around 2040

Applying these criteria to the IPCC SR1.5 mitigation pathways leaves us with 20 scenarios for coal in the power sector that are consistent with the Paris Agreement. We then calculate the median and interquartile range for coal use in the power sector for our filtered subset (in line with IPCC approaches) to derive the benchmark Paris Agreement compatible pathways and find that under Paris Agreement compatible scenarios, unabated coal electricity generation peaks around 2020, decreases steeply afterwards reaching a 80% (62-90%) reduction below 2010 levels by 2030, a 97% (91-99%) reduction by 2040, and reaching nearly zero by 2050.

Figure 8 shows the median and interquartile range for this subset of pathways, and for comparison purposes, for "Below 2°C"pathways [13].

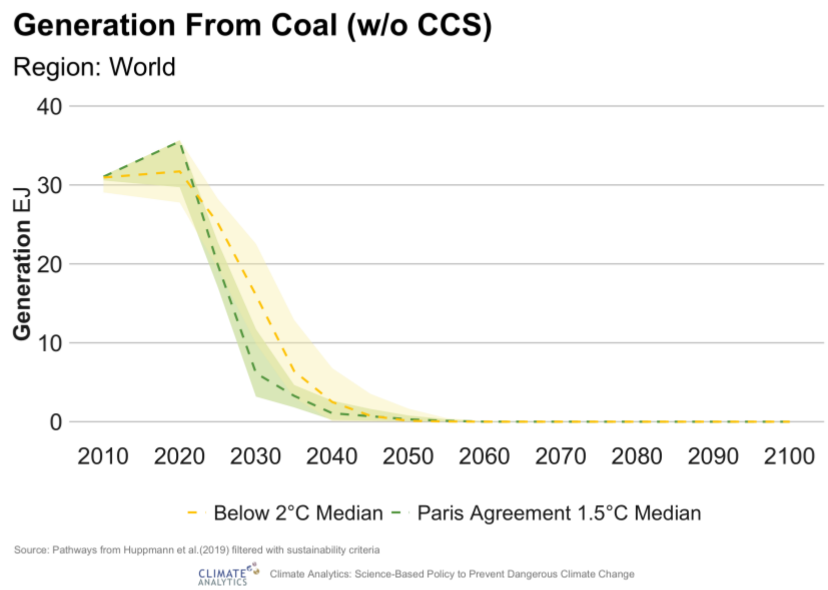


Figure 8 – Generation from coal in Paris Agreement compatible and 'Below 2°C' compatible pathways

12 The resulting 2030 level of 25-30 GtCO2eq/year is numerically the same as reported in SR1.5 SPM, however the latter reports using SAR GWPs for aggregating the various greenhouse gases, while we use AR4 GWPs. Effectively, levels reported in AR4 GWPs represent lower levels for 2030 for the same numerical values, by 1-2 GtCO2e/year at the global level.

13 Defined here as pathways from the IPCC SR1.5 database with high overshoot of the 1.5°C limit or that limit warming to 2°C by the end of the century (which are filtered for the same sustainability criteria as the pathways classified as compatible with Paris Agreement). After applying our filtering criteria, we end up with a total of 55 out of 111 pathways, which are the full sample space of what we hereafter refer to as "below 2°C" pathways.

Given the dramatic differences in the starting conditions for electricity systems and the underlying socioeconomic emissions drivers in different regions of the world, we approach this question looking at regional pathways for the five regions used in most of the models considered by the IPCS SR1.5: OECD, non-OECD Asia, Latin America, Middle East and Africa, Eastern Europe and Former Soviet Union. We define the coal phase-out date as the year in which the underlying pathway for coal use in electricity generation without CCS reaches reductions of 90% or more below 2010 levels (year of calibration of most models with historical data) and find the following regional coal phase-out dates:

Table 3 Comparison of phase-out dates for different regions

Region	Pathways	Phaseout Date	% Reduction of coal generation by 2030 (2010 Baseline)
OECD	12	2031 [2029,2035]	86% [76%,97%]
Non-OECD Asia	12	2037 [2034,2041]	63% [53%,83%]
Latin America	12	2032 [2026,2045]	85% [40%,97%]
Middle East and Africa	19	2034 [2031,2042]	80% [63%,96%]
Eastern Europe and Former Soviet Union	19	2031 [2030,2044]	86% [67%,98%]

ANNEX 3 – B2DS COMPATIBILITY WITH IPCC SR1.5

While nominally the B2DS pathway does not match the Paris Agreement long-term temperature goal and 1.5°C limit, as the IEA report argues it has a peak global warming of 1.75°C above pre-industrial, further examination of the scenario indicates otherwise.

Applying the same climate model evaluation set up as was used in the IPCC SR1.5 and earlier IPCC AR5 the B2DS scenario reaches a peak warming of 1.6°C[16] by 2060 and stays around that level afterwards. In contrast to 1.5°C compatible scenarios, warming does not drop to below 1.5°C after the peak due to IEA's predefined assumption that there would not be global negative CO_2 emissions from the energy sector (IEA, 2017). Allowing net negative CO_2 from the energy sector typical of other 1.5°C compatible pathways means warming would drop to below 1.5°C after the peak at 1.6°C.

As IEA provides only energy-related CO_2 emissions, land-use and non-CO_2 GHG emissions need to be estimated. In its own estimation of the peak warming level the IEA assumed that non-CO_2 GHG would add about 0.35ºC to the CO_2 only warming. For a full climate-model simulation one needs to assume pathways for non-CO_2 emissions and air pollutants. Rogelj et al (2015; 2018) showed that the key difference between 1.5ºC compatible pathways and "likely below 2°C" scenarios is in CO_2 emissions, because the potential to reduce non-CO_2 emissions is seen as essentially the same as "likely below 2°C" scenarios. Non-CO_2 scenario information is available most extensively for "likely below 2°C" scenarios in the public database of IPCC SSP-RCP2.6 scenarios[17]. Consequently, to evaluate the IEA B2DS

16 Global warming through 2100 for the B2DS scenario is projected using the carbon-cycle/climate model MAGICC (Meinshausen, Raper, & Wigley, 2011) in the same configuration used for IPCC's Fifth Assessment Report (IPCC, 2014) and in the IPCC SR1.5.

17 https://tntcat.iiasa.ac.at/SspDb

scenario we used the average of RCP2.6 scenarios (SSP2 representing middle-of-the-road socio-economic and technical developments) to characterize non-CO_2 emissions. In addition, we assumed CO_2 emissions from the land sector also follow the average of these scenarios, reaching largest amounts of annual removals of about -2 $GtCO_2$/yr around 2060, which we note is within the sustainable potential estimated by IPCC SR1.5 at around -3.6 $GtCO_2$/yr by 2050.

Therefore after evaluating the B2DS scenario on a comparable basis with the methods used by the IPCC the B2DS scenario is confirmed to be a suitable analogue to 1.5°C compatible pathways for the period to at least 2060.

ANNEX 4 - SIAMESE MODEL

The **S**implified **I**ntegrated **A**ssessment **M**odel with **E**nergy **S**ystem **E**mulator (SIAMESE) is able to downscale the energy-system characteristics of a particular energy model at the country level, by providing cost-effective scenario in line with a global temperature target. At the same time, SIAMESE can take into account specific policy in place and expected energy trends (e.g. nuclear phase-out dates) at the country level. Therefore, it can provide insights to policy makers on how to realistically improve current policies and pledges in line with the Paris Agreement long-term target.

In this study we downscale the OECD energy consumption results of the ETP/B2D model to Australia. At the base year (2014), the model is calibrated based on observed energy consumption, GDP and population data. In a way, this calibration process sets some preferences regarding the energy mix composition. More precisely, SIAMESE allocates energy consumption in the regions by equalising the marginal utility of energy, under a welfare maximisation approach. Energy prices are endogenous in the model[18] and coincide with the marginal utility of energy.

In terms of the equations, SIAMESE mimics the structure of Integrated Assessment Models, where the economic output (GDP) is a function of capital, labour and energy consumption by using a CES (Constant Elasticity of Substitution) production function.

This version of SIAMESE focuses on downscaling electricity generation from the OECD region of the IEA's ETP model. In terms of gases, SIAMESE focuses on CO_2 emissions only (excluding LULUCF), and does not cover other GHGs such (e.g. CH_4, N_2O etc.).

Given that the outputs of the B2D scenario are only available for the year 2025, 2040, and 2060, it is only possible to downscale the results to Australia for those years. In order to estimate a policy-relevant emissions pathway, we make the following adjustments during our downscaling process:

- For emissions between historical data and target years downscaled, we assume a linear emissions reduction (constant emissions reduction between target years).
- To reflect historical development in CO_2 emissions in Australia, we harmonise the downscaled pathway to the reported CO_2 emissions from coal power plant until the last reported year (2018) and modify the emission trajectory so that the total emissions budget derived from the original pathway (starting in 2014) is not exceeded as a consequence of higher emissions in the first years.

18 SIAMESE determines the energy prices for each fuel, based on energy consumption levels from the MESSAGE model.

ANNEX 5 - ESTIMATING CO_2 EMISSIONS FROM COAL PLANTS

To estimate emissions resulting from currently operating and planned coal power plants in Australia we used the Platts' World Electric Power Plants database (WEPP). This is a global inventory of electric power generating units, which provides information on every known coal-fired power generation unit, including its location, status, investor, capacity, combustion technology[19] and fuel, year of opening and retirement date for officially retired plants. For this analysis we use the information provided in the March 2018 version of the WEPP and contrasted the information in this database with national databases, as well as the Global Coal Plant Tracker database.

The WEPP data used in this report comprise of detailed information per plant concerning the country, its capacity, status and combustion technology, which allows to estimate CO_2 from these plants, using the following formula:

Yearly emissions:

$$Emi_{it} = Cap_i * \frac{1}{eff_i} * lf_{it} * ef_i * \boldsymbol{\phi}$$

with:

$\boldsymbol{Emi_i t}$ are the yearly emissions of plant unit *i* in $MtCO_2$ in a particular year *t*

$\boldsymbol{Cap_i}$ is the Capacity of plant unit *i* in MWel. MWel describes the electrical output of a power plant (unit). About two thirds (actual value depending on the combustion technology) of the energy contained in a coal power plant's fuel is lost while converting it into electricity. The thermal energy released during the conversion is usually not used anymore but gotten rid of via cooling towers or rivers.

$\boldsymbol{eff_i}$ is the conversion efficiency of a power plant unit: How much of the energy contained in the fuel (coal) is converted to electricity. In general, this is higher for modern plants. In the case of Australia, it ranges between 38.2 and 40.5 percent, with an average of 38.5 percent.

$\boldsymbol{lf_{it}}$ is the load factor of the power plant in a particular year t. The load factor is the ratio of the actual power plant output over its theoretical maximum output and is usually calculated over the course of a year. The theoretical maximum output can be calculated by assuming that a power plant runs at its nameplate capacity 24 hours a day, 365 days a year. I.e. a power plant unit with a capacity of 100 MW has a theoretical maximum output of

$$100\ \text{MW}_{\text{el}} * 24 \frac{\text{hours}}{\text{day}} * 365 \frac{\text{days}}{\text{year}} = 876.000\ \text{MWh}.$$

Actual output over a given year is lower since the plant will not always operate at full output – e.g. due to demand and renewable power fluctuations – and has to be taken offline completely for planned maintenance or due to technical restrictions and forced outages. There is large uncertainty about the future utilisation rates of coal power plants in Australia, for our scenario we assume an average utilisation factor of 62% for hard coal and 80% for lignite, which is equal to the average calculated utilisation factor for coal power plants for 2016, according to national reported generation values. Finally, emissions intensities are estimated based on standard reported values per combustion technology and coal type.

19 The database distinguishes between different combustion technologies in the following categories: subcritical, supercritical and ultra-supercritical, ranking from least to most efficient respectively. We do not consider coal fired power plants retrofitted with CCS technology further in our analysis.

$\boldsymbol{ef_i}$ is the emissions factor, which contains information on how much CO_2 is released for a given amount of coal burned. Unit is kg CO_2/TJ. Higher grade coal contains a higher share of carbon, which is converted to CO_2 during combustion. We use emission factors from (IPCC, 2006). Since this source contains only emission factors for pure types of coal, we assumed a 50/50 share for plants that use two different coal grades, e.g. bituminous and sub-bituminous coal.

$\boldsymbol{\phi}$ is a conversion factor to end up with the correct units (Mt CO_2/yr).

Calculating lifetime emissions:

$$Lifetime\ Emi = \sum_{2017}^{\mathrm{T}} \mathrm{Emi}_{\mathrm{it}}$$

with T being the last year the plant unit is in operation, i.e. expected retirement date.

For simplicity, we assume that the shutdown of a given unit happens on 31 December of the respective year. T is calculated for operating power plants or the plants which are planned or under construction as opening year + lifetime. The decisive assumption here is the lifetime. We have assumed a coal plant lifetime of 44 years, which is consistent with the average historical retirement age of coal power plants in Australia – slightly above the global average coal plant retirement age (40 years) that has been assumed in previous reports by Climate Analytics.

We have not assumed any new coal power plants coming online for our estimates. It is important to note that our assumptions regarding the operation year for planned plants do not affect the cumulative emissions estimated presented (used to compare with Paris Agreement carbon budget).

REFERENCES

AECOM. (2016). *CO-LOCATION INVESTIGATION - A study into the potential for co-locating wind and solar farms in Australia*.

AEMO. (2018). Integrated System Plan For the National Electricity Market, (July). Retrieved from https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/Integrated-System-Plan

Australian Government. (2018). Quarterly Update of Australia's National Greenhouse Gas Inventory: June 2018, (September).

Blakers, A., Lu, B., & Stocks, M. (2017). 100 % renewable electricity in Australia, (February).

BloombergNEF. (2018). New Energy Outlook 2018 | Bloomberg New Energy Finance | Bloomberg Finance LP. Retrieved November 23, 2018, from https://about.bnef.com/new-energy-outlook/

Bureau of Meteorology and CSIRO. (2018). *State of the Climate 2018*. Retrieved from http://www.bom.gov.au/state-of-the-climate/

Climate Action Tracker. (2019). Australia. Retrieved October 15, 2019, from http://climateactiontracker.org/countries/australia.html

Climate Action Tracker. (2018). *For the Talanoa dialogue : Input from the Climate Action Tracker*.

Climate Analytics. (2016a). *Implications of the Paris Agreement for Coal Use in the Power Sector*. Berlin. Retrieved from http://climateanalytics.org/publications/2016/implications-of-the-paris-agreement-for-coal-use-in-the-power-sector.html

Climate Analytics. (2016b). *Implications of the Paris Agreement for Coal Use in the Power Sector*. Berlin.

Climate Analytics. (2017). A Stress Test for Coal in Europe under the Paris Agreement.

Climate Analytics. (2018a). Science based coal phase-out pathway for Germany in line with the Paris Agreement 1.5°C warming limit, (October). Retrieved from https://climateanalytics.org/media/germany_coalphaseout_report_climateanalytics_final.pdf

Climate Analytics. (2018b). Science Based Coal Phase - Out Timeline for Japan Implications for Policymakers and Investors, (May).

Climate Analytics. (2019a). *Australia's Power Supply. Brown and polluting*.

Climate Analytics. (2019b). *Global and regional coal phase-out requirements of the Paris Agreement: Insights from the IPCC Special Report on 1.5°C*. Retrieved from https://climateanalytics.org/media/report_coal_phase_out_2019.pdf

Climate Analytics. (2019c). Insights from the IPCC Special Report on 1.5°Cfor preparation of long-term strategies.

Climate Council. (2018). *END OF THE LINE: COAL IN AUSTRALIA*. Retrieved from https://www.climatecouncil.org.au/resources/coal-in-australia/

Climate Transparency. (2019). *MANAGING THE PHASE-OUT OF COAL - A COMPARISON OF ACTIONS IN G20*.

ClimateCouncil. (2014). *The Australian Renewable Energy Race: Which States are Winning or Losing?* Retrieved from http://www.climatecouncil.org.au/uploads/ee2523dc632c9b01df11ecc6e3dd2184.pdf

DEE. (2019). *Australian Energy Statistics*. Retrieved from https://www.energy.gov.au/sites/default/files/2019_aes_table_o_march_2019.pdf

Department of Industry. (2014). *Australian Energy Resource Assessment - Second Edition*.

Department of the Environment and Energy. (2018). *Australia's emissions projections 2018*. Retrieved from https://www.environment.gov.au/system/files/resources/128ae060-ac07-4874-857e-dced2ca22347/files/australias-emissions-projections-2018.pdf

Department of the Environment and Energy. (2019). *Australian Energy Statistics, Table O Australian electricity generation, by fuel type, physical units*. Retrieved from https://www.energy.gov.au/sites/default/files/2019_aes_table_o_march_2019.pdf

Diesendorf, M. (2018). *Renewable electricity policy for Australia*. Retrieved from http://www.tai.org.au/sites/default/files/Renewable Electricity Policy for Australia %5BWeb%5D.pdf

Drew, G. (2015). *Zero Carbon Australia. Renewable Energy Superpower*. Retrieved from http://media.bze.org.au/resp/bze_superpower_plan.pdf

Ewald, B. (2018). The health burden of fine particle pollution from electricity generation in NSW, (November), 1–42. Retrieved from http://www.envirojustice.org.au/healthstudynsw/

Finkel, A. (2017). Independent Review into the Future Security of the National Electricity Market. Retrieved March 12, 2018, from https://www.energy.gov.au/publications/independent-review-future-security-national-electricity-market-blueprint-future

Graham, P. W., Hayward, J., Foster, J., Story, O., & Havas, L. (2018). GenCost 2018 Updated projections of electricity generation technology costs, (December). Retrieved from https://publications.csiro.au/rpr/download?pid=csiro:EP189502&dsid=DS1

Gulagi, A., Bogdanov, D., & Breyer, C. (2017). A Cost Optimized Fully Sustainable Power System for Southeast Asia and the Pacific Rim. *Energies*, *10*(5), 583. https://doi.org/10.3390/en10050583

Howard, B. S., Hamilton, N. E., Diesendorf, M., & Wiedmann, T. (2018). Modeling the carbon budget of the Australian electricity sector's transition to renewable energy. *Renewable Energy*, *125*, 712–728. https://doi.org/10.1016/j.renene.2018.02.013

IEA. (2017). *Energy Technology Perspectives 2017*. Retrieved from http://www.iea.org/publications/freepublications/publication/energy-technology-perspectives-2017---executive-summary.html

IPCC. (2006). Stationary Combustion. In H. S. Eggleston, L. Buendia, K. Miwa, T. Ngara, & K. Tanabe (Eds.), *2006 IPCC Guidelines for National Greenhouse Gas Inventories*.

IPCC. (2014). Summary for Policymakers. In Stocker & V. B. and P. M. M. (eds T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia (Eds.), *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

IPCC. (2018a). Global Warming of 1.5°C. Summary for Policymakers, (October 2018).

IPCC. (2018b). GLOBAL WARMING OF 1.5 °C - an IPCC special report on the impacts of global warming of 1.5 °C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat. In *Global Warming of 1.5 C :An IPCC special report on the impacts of global warming of 1.5 C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change,* (Vol. 106, pp. 1323–1330).

Jotzo, F., Mazouz, S., & Wiseman, J. (2018). Coal transitions in Australia. Preparing for the looming domestic coal phase-out and falling export demand.

King, A. D., Karoly, D. J., & Henley, B. J. (2017). Australian climate extremes at 1.5 °C and 2 °C of global warming. *Nature Climate Change*, *7*(May). https://doi.org/10.1038/nclimate3296

Kriegler, E., Bertram, C., Kuramochi, T., Jakob, M., Pehl, M., Stevanović, M., … Edenhofer, O. (2018). Short term policies to keep the door open for Paris climate goals. *Environmental Research Letters*. https://doi.org/https://doi.org/10.1088/1748-9326/aac4f1

Kuramochi, T., Höhne, N., Schaeffer, M., Cantzler, J., Hare, B., Deng, Y., … Blok, K. (2017). Ten key short-term sectoral benchmarks to limit warming to 1.5°C. *Climate Policy*. Retrieved from https://doi.org/10.1080/14693062.2017.1397495

Luderer, G., Pietzcker, R. C., Bertram, C., Kriegler, E., Meinshausen, M., & Edenhofer, O. (2013). Economic mitigation challenges: how further delay closes the door for achieving climate targets. *Environmental Research Letters*, *8*(3), 034033. https://doi.org/10.1088/1748-9326/8/3/034033

Meinshausen, M., Raper, S. C. B., & Wigley, T. M. L. (2011). Emulating coupled atmosphere-ocean and carbon cycle models with a simpler model, MAGICC6 - Part 1: Model description and calibration. *Atmospheric Chemistry and Physics*, *11*(4), 1417–1456. https://doi.org/10.5194/acp-11-1417-2011

Mengel, M., Nauels, A., Rogelj, J., & Schleussner, C.-F. (2018). Committed sea-level rise under the Paris Agreement and the legacy of delayed mitigation action. *Nature Communications*, *9*(1), 601. https://doi.org/10.1038/s41467-018-02985-8

Morgan, E. (2017). Power prices could double with new coal-fired stations: experts. *02.02.2017*. Retrieved from http://www.abc.net.au/news/2017-02-02/coal-power-stations-could-double-the-cost-of-electricity/8234240

Prasad, A. A., Taylor, R. A., & Kay, M. (2017). Assessment of solar and wind resource synergy in Australia. *Applied Energy*, *190*, 354–367. https://doi.org/https://doi.org/10.1016/j.apenergy.2016.12.135

Riahi, K., Kriegler, E., Johnson, N., Bertram, C., den Elzen, M., Eom, J., … Edenhofer, O. (2015). Locked into Copenhagen pledges — Implications of short-term emission targets for the cost and feasibility of long-term climate goals. *Technological Forecasting and Social Change*, *90*, *Part A*, 8–23. https://doi.org/10.1016/j.techfore.2013.09.016

Riesz, J., Elliston, B., Vithayasrichareon, P., & MacGill, I. (2016). 100 % Renewables in Australia: A Research Summary, (March).

Rogelj, J., Luderer, G., Pietzcker, R. C., Kriegler, E., Schaeffer, M., Krey, V., & Riahi, K. (2015). Energy system transformations for limiting end-of-century warming to below 1.5 °C. *Nature Climate Change*, *5*(6), 519–527. https://doi.org/10.1038/nclimate2572

Rogelj, J., Popp, A., Calvin, K. V., Luderer, G., Emmerling, J., Gernaat, D., … Tavoni, M. (2018). Scenarios towards limiting global mean temperature increase below 1.5 °C. *Nature Climate Change*, 1. https://doi.org/10.1038/s41558-018-0091-3

Schleussner, C.-F., Lissner, T. K., Fischer, E. M., Wohland, J., Perrette, M., Golly, A., … Schaeffer, M. (2016). Differential climate impacts for policy relevant limits to global warming: the case of 1.5°C and 2°C. *Earth System Dynamics*, *7*(2), 327–351. https://doi.org/10.5194/esd-7-327-2016

Schleussner, C.-F., Pfleiderer, P., & Fischer, E. M. (2017). In the observational record half a degree matters. *Nature Climate Change*, *7*(7), 460–462. https://doi.org/10.1038/nclimate3320

Sferra, F., Krapp, M., Roming, N., Schaeffer, M., Malik, A., & Hare, W. (2018). Towards optimal 1.5°and 2°C emission pathways for individual countries: a Finland case study. *Energy Policy in Review*, *submitted*.

Sferra, F., Schaeffer, M., & Torres, M. (2018). *Report on Implications of 1.5°C Versus 2°C for Global Transformation Pathways*. Retrieved from https://www.cop21ripples.eu/wp-content/uploads/2018/06/RIPPLES-Deliverable-2-3_2018_06_04_FINALc.pdf

Shearer, C., Ghio, N., Myllyvirta, L., Yu, A., & Nace, T. (2017). *Boom and Bust 2017. Tracking the Global Coal Plant Pipeline*. Coalswarm, Sierra Club, Greenpeace.

Teske, S., Dominish, E., Ison, N., & Maras, K. (2016). 100% Renewable Energy for Australia – Decarbonising Australia's Energy Sector within one Generation.

The Australian. (2019, May 27). Taylor to fast-track 'cleaner' coal plant. Retrieved from https://www.theaustralian.com.au/subscribe/news/1/?sourceCode=TAWEB_WRE170_a&dest=https://www.theaustralian.com.au/nation/politics/rising-minister-angus-taylor-to-fasttrack-cleaner-coal-plant/news-story/fc70ce7b2a34c3088ffae7aff1c11a40&memtype=anonymous&m

The Guardian. (2018a, June 25). Energy minister would welcome new coal-fired power plants. Retrieved from https://www.theguardian.com/australia-news/2018/jun/26/energy-minister-would-welcome-new-coal-fired-power-plant

The Guardian. (2018b, October 23). Coalition could indemnify new coal projects against potential carbon price. Retrieved from https://www.theguardian.com/australia-news/2018/oct/24/coalition-could-indemnify-new-coal-projects-against-potential-carbon-price

The Guardian. (2018c, December 12). Coalition signals it will provide taxpayer support for new and existing coal plants. Retrieved from https://www.theguardian.com/environment/2018/dec/13/coalition-signals-it-will-provide-taxpayer-support-for-new-and-existing-coal-plants

UNFCCC. (2015). FCCC/CP/2015/10/Add.1: Adoption of the Paris Agreement.