AURORA ENERGY RESEARCH

Aurora Energy Research analysis of AEMO's ISP Part 2: economics of coal closures

May 2019

Contents

1 Scope of work

The Australian Energy Market Operator (AEMO) engaged Aurora Energy Research (Aurora) to provide independent, supplementary analysis to the Integrated System Plan (ISP). In Part 1 of that analysis, Aurora analysed the potential benefits additional interconnection might provide to end energy consumers. In Part 2 (summarised in this report), Aurora has provided independent modelling on whether AEMO's coal closure timeline reflects the realities of market-based economic decisions by coal asset owners and whether any coal plants are at risk of closing earlier than AEMO assumes in their ISP neutral scenario.

Coal asset owners face a variety of challenges and decisions when assessing whether to keep their assets operational: from the timings, extent and cost of major refurbishments; to increased cycling costs as renewable penetration grows; to uncertainty regarding future state and federal decarbonisation policy; to commodity price volatility and uncertainty; to shifts in underlying demand; to fundamental shifts in the National Electricity Market (NEM) as new technologies and entrants emerge; amongst others. Fundamentally, these factors drive the underlying profitability of the various coal assets on the NEM. Each asset owner will have a set of views and forecasts that will drive their assessment of when their assets are unlikely to continue to be profitable and therefore when to close them.

In addition to analysing the decisions of any individual coal asset, there are also interactions between the decisions of coal assets. For example, Aurora analysis indicates that, as relatively low marginal cost coal plants exit the system, wholesale prices in the NEM are likely to rise, even as more very low marginal cost renewables enter the NEM over time. These wholesale price increases create more inframarginal rent and hence increased profitability for those coal assets that remain on the system. As such, when one coal plant exits there is often an uptick in profitability for the remaining coal assets on the system. In addition, coal asset owners often own a range of assets and decisions to close some assets also impact the profitability of the broader portfolio.

Given this context, AEMO requested Aurora analyse the economics of each coal asset on the system to assess whether any coal assets are at risk of closing earlier than AEMO estimates and so create potential adequacy of dispatchable supply challenges in the short-run. **This document provides a concise summary of the results of that analysis.** Aurora's analysis focuses on quantifying the profitability of each coal asset on the system under AEMO's ISP neutral scenario, as well as quantifying the impact of a set of risks to coal economics to assess which risks might trigger early coal closures. This identification of critical risks and subsequent scenario analysis has been informed by Aurora's work with coal asset owners in both Europe and Australia. All modelling has been undertaken in Aurora's market-based NEM dispatch model (AER-NEM).

Aurora's approach through-out has been focussed on economic modelling. We have not attempted to incorporate 'softer' factors that might trigger earlier or later coal closures on the NEM – for example,

ageing workforces in some NEM coal plants and the subsequent cost of re-training future workforces. Clearly, there is a diverse range of 'softer' factors that may drive earlier coal closures, but are not within the purview of this report.

Consequently, this report does not represent Aurora's in-house view of NEM outcomes, but rather represents an independent view of coal asset economics under ISP assumptions using an alternative model and modelling approach. AEMO's team has been invaluable in helping clarify input assumptions and methodological approaches within the ISP, but all modelled outcomes in this report are a product of Aurora's AER-NEM model. In the scenarios Aurora has used to assess the impact of risks that may trigger early coal closures, Aurora has used its experience in modelling coal asset economics to create scenarios that are both plausible and that may trigger a material reassessment of coal closure dates from asset owners. In these scenarios, we have selectively deviated from the ISP neutral scenario to create bespoke scenarios for this report.

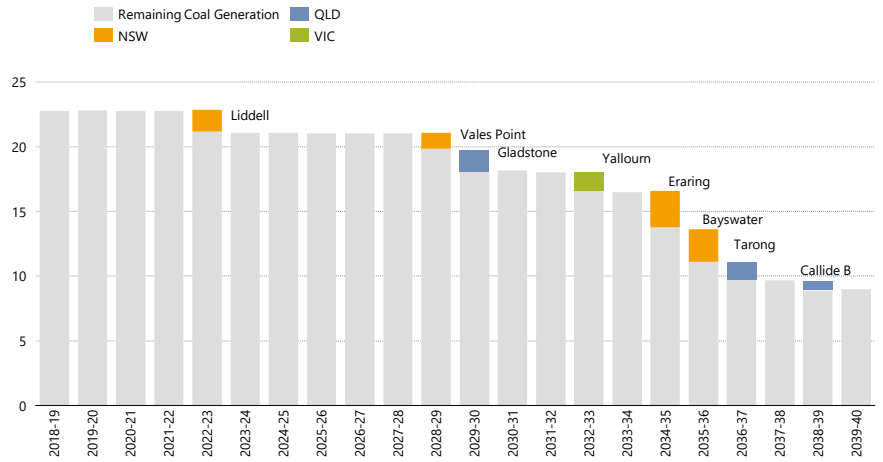
2 Context and modelling methodology

AEMO coal closure timeline within the ISP

In analysing AEMO's coal closure timeline, Aurora has analysed whether there is sufficient revenue for coal assets in the NEM to reach the retirement years AEMO has estimated in the ISP neutral scenario. These retirement years are mapped out below to 2040.

AEMO estimates 61% of coal capacity will close in the NEM between 2020 and 2040

Coal capacity in NEM in AEMO ISP neutral scenario,
Nameplate GW



Source: Aurora Energy Research, AEMO

To quote the ISP, 'AEMO has assumed retirements of coal-fired generators at either announced retirement times, or a time based on operational age of the plant (termed 'technical life'). For black coal-fired power stations, this technical life is assumed to be 50 years in most cases. For Victorian brown coal-fired power stations, the retirement dates broadly align with the 17-year mine rehabilitation guarantee secured by the Victorian Government in June, 2018.'

Again, to quote the ISP, 'It is assumed that approximately 15GW of [coal] generation will reach its end of technical life by 2040 and retire. This is projected to result in an overall reduction in the energy generated

from coal, with the coal-fired power stations retiring currently generating approximately 70TWh, equivalent to around one-third of current total NEM consumption… Revenue sufficiency for individual power plant has not been factored into assessing retirement timing.'

Aurora's analysis into each coal asset has been conducted 'outside-in' and has used AEMO ISP data. Coal asset owners will have insights and data on actual maintenance schedules and costs, as well as contracted coal costs, that are not publicly available. As such, AEMO's assumptions, particularly around the timing and cost of major refurbishments, represent an informed, but understandably limited view of internal operations, cost structures and decision-making.

In addition, when modelling AEMO's ISP neutral scenario, neither AEMO nor Aurora has assumed significant shifts in federal or state coal or decarbonisation policies. Direct policy intervention from future federal or state governments – whether through direct coal closures, carbon pricing or emissions intensity schemes, or through significant government-supported renewable procurement programs beyond those already announced – may significantly alter coal asset economics.

Modelling methodology in analysing risks to AEMO coal closure timelines

For the purposes of this report, Aurora fully replicated the starting point of the ISP neutral scenario within Aurora's AER-NEM model. Aurora assumed the same initial plant and interconnector capacity timeline as indicated by AEMO's modelling for each ISP scenario as well as adopting ISP assumptions concerning electricity demand, generator reliability, and technical and financial settings, including commodity prices. Given the ISP neutral scenario capacity mix is a starting point, additional new capacity development (ranging from renewables to flexible operating assets) and retirement of existing coal plants is enabled in the Aurora AER-NEM model, and investment and retirement decisions are made based on lifetime asset profitability.

AEMO's neutral scenario is described in detail in the '2018 Integrated System Plan Modelling Assumptions' document. The table below summarises the ISP assumptions adopted for Aurora's Part 2 analysis and modelled within AER-NEM.

	Assumptions category	Description	In accordance with ISP
1	Installed capacity	▪ Initial installed capacity per technology	✓
		▪ Capacity additions / retirement allowed based on asset profitability	✗

2	Electricity demand	▪ Aggregate and maximum demand (including daily profile) ▪ Drivers of significant demand shifts, including rooftop PV generation, electric vehicles deployment, demand-side participation, battery aggregation	✓
3	Renewable policy	▪ Renewables capacity ▪ AEMO assumes implementation of QRET, VRET and LRET	✓
4	Interconnector settings	▪ Installed interconnector capability by year[1]	✓
5	Hydro settings	▪ Installed pumped hydro by year and hydro inflows	✓
6	Generator reliability settings	▪ Maximum and firm capacity, seasonal ratings and maintenance characteristics of existing, committed and advanced generators	✓
7	Generator technical and financial settings	▪ Storage properties ▪ Commodity prices (coal, biomass, gas and liquid fuel) and heat rates ▪ Plant variable OPEX and auxiliary load	✓
8	Generation constraints[2]	▪ Minimum load constraints for coal and gas units ▪ Minimum capacity factor for select gas units ▪ Maximum capacity factor for select units and technology classes	✓

While the vast majority of assumptions are consistent with those in the ISP neutral scenario, the key difference under Aurora's modelling is the approach to mothballing, retirement and further investment decisions over-and-above the capacity outlined under the ISP neutral scenario. The ISP was based on establishing the mix of technologies which met the demand at the lowest possible resource cost. In the modelling summarised in this report, Aurora have modelled expected energy market prices and subsequently plant-level revenues. Further additions to capacity and coal plant closures are then driven by market revenues and profitability.

Given these starting assumptions, Aurora estimated the economics of coal assets on the NEM using a four-step approach:

[1] AEMO and Aurora apply different methodologies to model constraints on interconnector to 2040. Aurora did not fully replicate AEMO's approach to dynamic application of interconnector constraints between price zones

[2] Aurora has replicated three types of generation constraints that AEMO imposes in the ISP modelling based on internal analysis on historical generator performance

- **Step 1:** Major inputs from the ISP neutral scenario are implemented in Aurora's AER-NEM model. The inputs replicated by Aurora are either published or directly provided by AEMO
- **Step 2:** Aurora's AER-NEM model is run for the neutral scenario (or other scenarios as required), with additional build/retirement enabled. The model runs over the period between 2019 and 2040 at half-hourly resolution, dynamically calculating both dispatch and interconnector flows by region
- **Step 3:** For each coal asset, Aurora's AER-NEM model dynamically analyses the NPV of costs (including refurbishment costs, fixed and variable operations and maintenance costs, fuel costs, cycling costs, and retirement/ mothballing costs) and compares those with the NPV of future revenues generated by price and volume in the wholesale markets. Where the NPV of costs is close or exceeds the NPV of revenues prior to AEMO's assumed closure date, Aurora flags that asset as a potentially vulnerable plant
- **Step 4:** Aurora analyses a set of plausible scenarios which may adversely affect coal asset economics and trigger early closures to assess how robust coal closure outcomes in AEMO's ISP neutral scenario are to unforeseen shifts in the market

3 Results of Aurora analysis

Four key findings emerge from the Aurora's analysis of AEMO's coal closure timelines:

- **Finding 1:** In AEMO's neutral scenario, Aurora forecasts sufficient revenue such that coal assets are NPV positive and are therefore likely to remain in the NEM for at least as long as AEMO estimates in the ISP
- **Finding 2:** Although all coal assets are forecast to generate sufficient revenue to deliver AEMO's ISP coal closure timeline, there is significant variability in profitability between coal assets and some coal assets are relatively more vulnerable to early closure in Aurora's forecasts
- **Finding 3:** In Aurora's scenario modelling, there are some scenarios in which coal assets may exit earlier than AEMO estimates – lower demand (in line with demand in AEMO's slow change scenario), in particular, represents a significant threat to coal asset returns
- **Finding 4:** Early closure of one coal asset in the NEM improves the profitability of the remaining coal plants on the system – as such, while there are more marginal plants on the system, particularly in some of the scenarios Aurora has examined, once 1-2 coal plants exits, the chances of subsequent closures are diminished

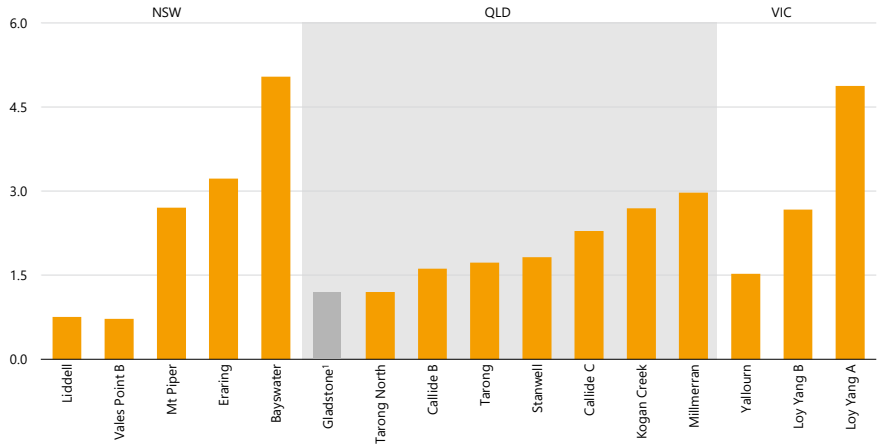
Finding 1

In AEMO's neutral scenario, Aurora forecasts sufficient revenue such that coal assets are NPV positive and are therefore likely to remain in the NEM for at least as long as AEMO estimates in the ISP

Aurora's modelling indicates that each plant generates a positive NPV over its forecast life under the ISP neutral scenario. This would indicate that coal asset owners are likely to continue to run their plants for at least as long as AEMO assume in the ISP, unless there was either a major policy shift from state or federal govt, or future market outcomes deviate significantly from the assumptions in the ISP neutral scenario (e.g., significant shift upwards in coal prices), or an individual plant is subject to an inherently difficult to forecast major failure.

Aurora forecasts all coal assets will have sufficient revenue to remain open in the ISP neutral scenario

NPV of plant profit to 2040 across scenarios until forecast closures dates or 2040 in ISP neutral scenario,
Billion $A



1) Gladstone's NPV is a range estimated based on market-based dispatch and assumed prices for its long-term PPA

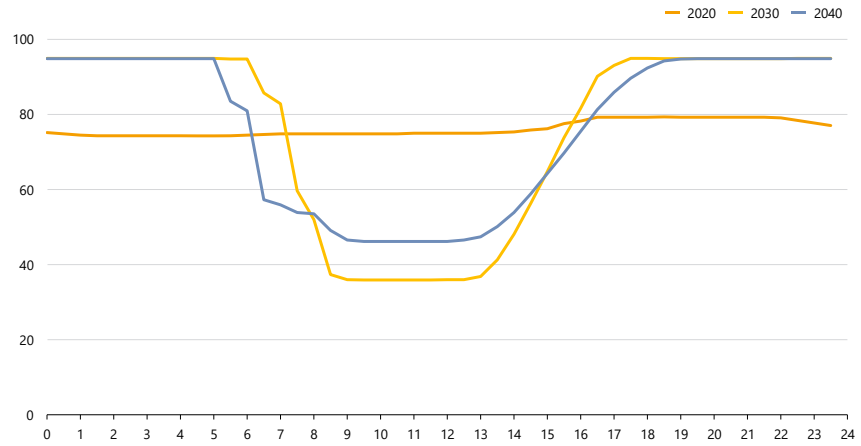
Sources: Aurora Energy Research, AEMO

Evidently, there is significant variability in the remaining profitability of coal plants in the NEM. This is driven both by their underlying cost structure, technical capabilities, and position within the supply stack, but also by the length of time they are assumed to continue to remain open – for example, Liddell is assumed to close in 2022-23 based on announcements by AGL, and therefore has a relatively short future earning period.

As part of this forecast, Aurora modelling indicates significant changes to the operation of coal plants on the NEM will unfold through the 2020s. In the future, as significant volumes of renewables enter the system, Aurora forecasts that coal assets (and other dispatchable assets) will be asked to ramp up and down around the lower marginal cost renewable generation profile – particularly around the solar profile that typically delivers power through the middle of the day. This ramping puts upwards pressure on costs as coal plants are typically initially designed to run more flat, 'baseload' profiles. Clearly, there is significant variability in the effective cycling costs of coal plants on the NEM, but, for example, Australia's east coast coal fleet was not initially designed with the flexibility of more recent combined cycle gas turbines (CCGT) which were designed in response to greater system needs for fast ramping around renewable load profiles.

Coal assets will be required to ramp more frequently around renewables generation

Average load factor by time of day for an example NSW coal asset,
Percent



Source: Aurora Energy Research, AEMO

There are additional external factors that have not been included within the analysis given Aurora's use of ISP neutral scenario assumptions, but that have the potential to accelerate coal closure economics. Some of these are relatively less quantifiable in formal modelling, but are significant – for example:

- Increasing difficultly in accessing financing capital as major lenders choose to exit lending or investment in coal
- Ageing workforces in some NEM coal plants and the subsequent cost of re-training future workforces
- Potential health and safety concerns at older coal facilities
- Shifting corporate social and environmental responsibility mandates and increasing public and media pressure for coal divestiture

Finding 2

Although all coal assets are forecast to generate sufficient revenue to deliver AEMO's ISP coal closure timeline, there is significant variability in profitability between coal assets and some coal assets are relatively more vulnerable to early closure in Aurora's forecasts

As outlined in Finding 1, while all coal plants are expected to have revenue sufficient to ensure they remain on the system until AEMO forecasts their closure under the ISP neutral scenario, some plants are relatively more vulnerable to early closure. Aurora's modelling indicates that there is significant variability in the economics of coal plants on the system. In Aurora's analysis, this variability between plants is driven by a range of factors: from coal costs and quality; to the age and efficiency of the plant; to the location of the plant between price zones; to the time and cost of major plant refurbishments; amongst other factors.

In particular, Vales Point B in NSW and Stanwell in Qld are forecast to have periods of potential vulnerability. These plants are forecast to be the most marginal in their respective price zones – i.e., they are forecast to have the highest short-run marginal cost given fuel costs and variable operating and maintenance costs, based on ISP neutral scenario assumptions. Clearly, as renegotiations around fuel contract positions occur, this outlook may change substantially.

While all coal plants are expected to be profitable, Stanwell and Vales Point B have periods of potential vulnerability

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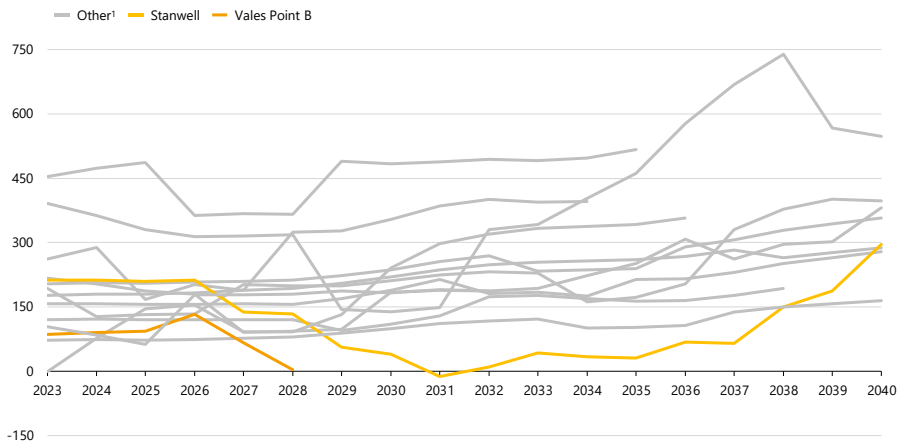
Wholesale electricity market profit until forecast closures dates or 2040 in the ISP neutral scenario[1],
Million $A, real 2017, moving average of previous 3 years



1) Liddell and Gladstone are not included in this graph, because Liddell is set to close in 2022 and Gladstone's profitability is partially driven by underlying PPA

Source: Aurora Energy Research, AEMO

It is worth noting that vulnerability is not driven primarily by AEMO's forecast cycle of major refurbishments for these assets. The primary driver of declining profitability is increased competition from renewables and increased interconnection which erodes both coal asset load factors and time weighted average wholesale prices.

For Vales Point B, the forecast introduction of the Riverlink interconnector is expected to increase generation competition in NSW from low marginal cost renewables in South Australia.

For Stanwell, assumed rising fuel costs increase its short-run marginal costs and make it the most marginal plant in Queensland (assuming Gladstone continues to operate under the terms of its agreement with Rio Tinto's Boyne Smelter). Aurora modelling indicates that the period of the late 2020s will be a period of relatively low profitability for Stanwell as a result. If it weathers that period, as other plants are forecast to exit in the late 2020s/ early 2030s in the ISP (i.e., Vales Point B and Gladstone), Stanwell is then forecast to take advantage of increased profitability through the 2030s when there is relatively less competition from competing coal plants and higher time-weighted average prices as gas and storage technologies increasingly set the margin.

Finding 3

In Aurora's scenario modelling, there are some scenarios in which coal assets may exit earlier than AEMO estimates – lower demand (in line with demand in AEMO's slow change scenario), in particular, represents a significant threat to coal asset returns

Aurora has worked with a number of coal asset owners globally to help assess coal asset economics over time. Aurora has used this expertise and experience to create scenarios that are both plausible and that may trigger coal asset owners to reassess coal closure dates. In these scenarios, we have selectively deviated from the ISP neutral scenario to create bespoke scenarios for this report.

Aurora modelled the following scenarios:

	Scenario	Change relative to ISP neutral scenario	Details
1	Lower NEM-wide demand	▪ Reduced demand for all five regions to 2050	▪ Demand assumptions from the ISP slow change scenario ▪ Grid consumption in 2040 is 35% lower than that in the ISP neutral scenario
2	Higher renewables build-out	▪ 50% renewable energy target is met in 2030	▪ Additional renewables are built into regions to hit 50% target ▪ Additional renewables are distributed in line with QRET and VRET procurement targets, but also grid availability and constraints
3	Faster technological innovation	▪ Capex reduction for wind, solar, and battery storage decline faster	▪ Lithium-ion battery capex is taken from the ISP fast change scenario

			▪ Onshore wind and solar capex are taken from ISP's 2019 assumptions which are currently under consultation[3]
4	Higher coal fixed operations and maintenance costs	▪ Aging coal plants have higher fixed operation and maintenance cost	▪ Aurora modelled a 6% increase in plant fixed operations and maintenance costs every 5 years from an asset age of 30 years
5	Higher discount rates for future revenues	▪ Coal asset owners apply a higher discount rate to future cash flows	▪ Uncertainty surrounding future state and federal decarbonisation policies leads coal asset owners to view future revenues as more at risk ▪ The ISP neutral scenario discount rate applied is 6% in real terms (pre-tax), which is then increased to 11% for the higher discount rate scenario
6	Lower 'price uplift[4]' in the NEM	▪ 'Price uplift' is reduced over time as additional competition enters the NEM	▪ In this scenario, Aurora capped 'price uplift' and gradually decreased the quantum of 'price uplift' to $5 per MWh by 2040

Each of these scenarios puts downward pressure on coal asset returns.

Lower NEM-wide demand, in particular, significantly erodes the value available to coal assets, leading to the potential early exit of Stanwell by the mid-to-late 2020s. Other plants in NSW and QLD are also affected and exit relatively earlier in the 2030s.

While brown coal plants in Victoria also have significantly reduced NPV due in a low demand scenario, it remains profitable to keep them online due to their relatively low marginal cost. The only scenario which may potentially trigger early exit in Victoria is higher renewables build-out. In a scenario where Victoria's

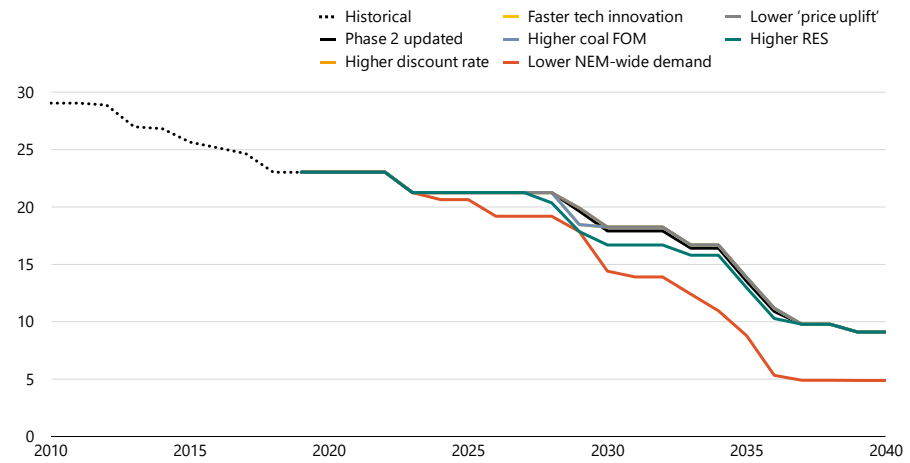
[3] Regional cost differentiation proposed in the 2019 input assumptions is not implemented, to maintain methodological consistency with other inputs from the 2018 input assumptions

[4] In the NEM, and all liberalized energy markets that Aurora operates in, the price delivered in the wholesale spot market will on average be higher than the short-run marginal cost of the marginal generation unit – sometimes, significantly higher. This 'price uplift' can be driven by a variety of factors — from ramping and cycling costs to low market competition in parts of the merit order to imperfect foresight from market players. Aurora uses an econometric regression to model this 'price uplift' in each half-hour to 2040. This 'price uplift' acts as a signal to demand and supply responses in the short-run, and to provide a longer-term price signal that new investment in supply may be required

50% renewable energy target is fully met by 2030, Aurora forecasts increasingly challenging economics for at least 1 unit of Yallourn due to competition from additional in-state renewable generation.

The lower NEM-wide demand sensitivity has the most pronounced impact on the coal capacity timeline

Historical and forecasted NEM installed coal capacity,
Nameplate GW

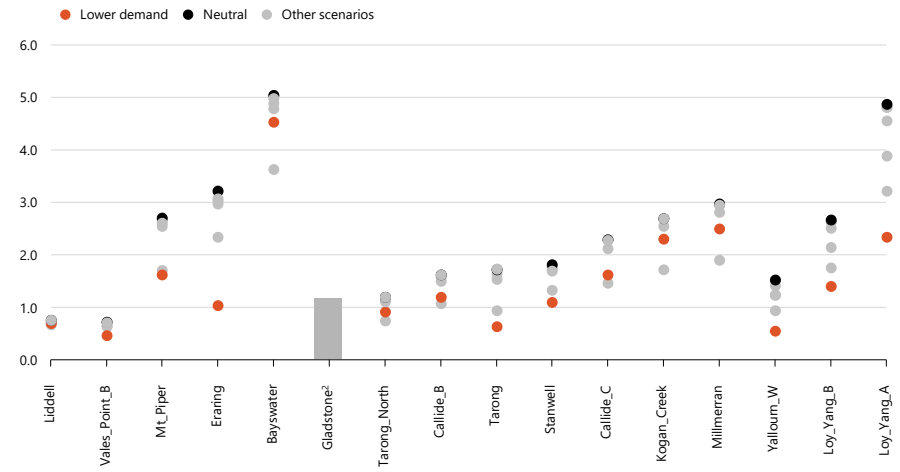


Source: Aurora Energy Research, AEMO

Lower NEM-wide demand does have a pronounced downward impact on almost all coal assets, although the quantum of the impact varies significantly by asset. As an example, when demand is held lower, all coal plants running see their revenue reduced due to lower prices. More expensive plants are impacted more than others, because they also have reduced output given there is less demand to serve. Also, given the persistence of low demand throughout this scenario, a plant that operates until 2040 will be impacted more than a plant exiting by the 2030s.

The lower demand scenario represents a significant threat to coal asset economics

NPV of plant profit to 2040 across scenarios until forecast closures dates or 2040,
Billion $A



1) Gladstone's NPV is a range estimated based on market-based dispatch and assumed prices for its long-term PPA.

Sources: Aurora Energy Research, AEMO

Finding 4

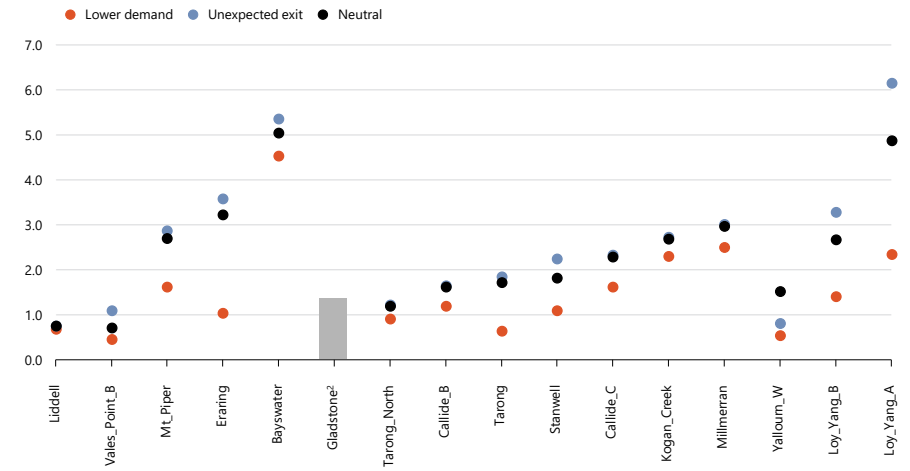
Early closure of one coal asset in the NEM improves the profitability of the remaining coal plants on the system – as such, while there are more marginal plants on the system, particularly in some of the scenarios Aurora has examined, once 1-2 coal plants exits, the chances of subsequent closures are diminished

If one coal asset were to exit the system before AEMO ISP's neutral scenario coal closure timelines, the impact on the economics of the remaining coal assets is likely to be positive. Less competition from other coal assets and higher marginal cost technologies setting prices in the wholesale market more frequently creates a more favourable market for existing coal assets.

Aurora modelled a scenario whereby Yallourn in Victoria exited the market in 2025 (i.e., 7-8 years prior to its closure date as assumed in the ISP neutral scenario). In this scenario, the remaining coal assets on average make higher returns: in Victoria, the potential upside for Loy Yang A and B assets is considerable.

Early exit of one coal plant tends to improve returns for the remaining coal assets on the system

NPV of plant profit to 2040 across scenarios until forecast closures dates or 2040,
Billion $



1) Gladstone's NPV is a range estimated based on market-based dispatch and assumed prices for its long-term PPA.

Sources: Aurora Energy Research, AEMO

As such, the exit of one coal plant is likely to decrease the likelihood of additional coal assets exiting earlier than anticipated in ISP's neutral scenario.

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