Report 1 – Developing a base case to assess the relative costs of nuclear power in the NEM

14 November 2024

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1 Summary

1.1 Two reports

This report is the first of two reports to help inform the debate about the economics of the inclusion of nuclear power in the National Electricity Market (NEM).

Presently, the Australian Energy Market Operator's (AEMO) plans for supplying all of Australia's existing electricity demands and a very large increase in electricity demand necessitated by a forced electrification of Australia's energy total usage are largely based on just three main supply technologies – wind, solar and energy storage.

The objective of this report is to explain the basis of the modelling approach used to assess the inclusion of nuclear, broadly along the lines of the plans stated by the Federal Coalition.

The aim of the modelling and analysis presented in this first report is to establish a base case against which we compare, in the second report, the relative costs of including nuclear power in the NEM.

We consider AEMO's preferred approach of relying on just three technologies to supply Australia's energy future as an appropriate base case against which we can compare the economic costs of including nuclear power in the mix of electricity supply options. We consider AEMO's Step Change scenario is an appropriate base case because this is the plan that is approved and being pursued by NEM jurisdictions.

1.2 Funding and direction of work

The work presented in this report and our second report is funded and directed solely by Frontier Economics.

We have consulted with the Federal Coalition through the course of this work to determine more details about their plans to help clarify how we could model the inclusion of nuclear power in the NEM.

We have decided to do this work because of the large amount of ill-informed and misleading cost comparisons being publicly made about nuclear power and we feel Australia deserves better quality analysis and commentary on this important issue. (see for example [1] & [2])

We don't wish to portray the modelling and analysis presented in this and our second report as the last word on this matter. We expect and welcome robust debate on the work we present in both reports, and this is nothing less than Australia deserves.

[1] Rod Sims (2024), "Nuclear discussion must be based on latest economic facts: Sims", The Superpower Institute, Weblink: https://www.superpowerinstitute.com.au/news/nuclear-discussion-must-be-based-on-latest-economic-facts-sims

[2] Institute for Energy Economics and Financial Analysis (2024), Weblink: https://ieefa.org/resources/nuclear-australia-would-increase-household-power-bills

1.3 Scope of modelling and analysis

The modelling focusses on the NEM, which includes Queensland, NSW, Victoria, Tasmania and South Australia. For this study, we do not include Western Australia or Northern Territory in our analysis.

When we compare the outcomes of our modelling with the results of the ISP we don't include the DSP+USE, REZ Augmentation and Flow Path Augmentation costs. Similar to AEMO, for comparison purposes, we do not model the costs of consumer energy resources (CER) but note that these costs are large and increasing.

AEMO's latest 2024 ISP results are in July 2023 dollar value terms. We have rebased AEMO's ISP results to be comparable to the Report Modelling, which is based in July 2024 dollar terms.

AEMO's modelling is referred to as least-cost modelling. This conveys the sense that this modelling finds the lowest cost approach of meeting consumers demand for electricity in an unconstrained manner. This is not the case. The least cost modelling solution is found subject to model satisfying a wide array of technical constraints and policy requirements (also specified as modelling constraints). Most notably in the case of AEMO's modelling, the modelling outcome must conform with meeting government emission reduction targets and targets to have a given amount of electricity demand supplied by renewable generation. These constraints also include meeting State renewable targets. The model will minimise costs subject to meeting these types of constraints. The model outcomes are also driven by what is effectively a carbon price known as the Valuing Emission Reductions (see Section 3.2.5) as determined by the Australian Energy Regulator. This carbon price drives a lot of important decisions in the energy sector but its existence and role is not generally understood outside the energy sector.

In this report we, like AEMO, employ a least-cost modelling approach because we are attempting to develop a base case against which we model the effects of applying alternative policy constraints and modelling scenarios to determine whether introducing nuclear power is more or less costly than AEMO's "least cost" options.

1.4 What we modelled

We modelled AEMO's two main scenarios – Step Change and Progressive. We did not model AEMO's third scenario – Green Energy Exports - because it is not considered credible as there are many other countries that are better suited to exporting green energy. Australia is a high-cost economy and while we have abundant renewable energy resources, so do many other lower cost economies.

Step Change is considered by AEMO more likely, by a single percentage point, than the Progressive scenario.

Step Change is forecast by AEMO to increase electricity demand in the NEM from about 180,000 gigawatt hours (GWh) to about 340,000 GWh by 2050. The Progressive scenario forecasts demand increasing over the same period to about 250,000 GWh.

Aside from the demand forecasts, the modelling also adopted the ISP assumptions because we aim to replicate the ISP modelling outcomes as closely as possible. This included:

- Generator costs and technical characteristics of existing and new supply options
- Transmission projects and technical characteristics associated with each scenario

- Coal closure timetable, although we note in the report that AEMO has thousands of megawatts of coal generators closing much earlier than the generators themselves have nominated (see **Figure 3**).
- Jurisdictional renewable schemes and targets.
- The AER's value of emission reduction – that is, the proxy carbon price.
- The 7% weighted average cost of capital used by AEMO.

We have also attempted to determine the costs of transmission projects that are being built, and that have been committed and approved to be built, and that are included in the ISP in the future to support the enormous growth in new supply capacity. We have undertaken this analysis in an effort to determine the relationship between transmission costs and the quantity of generation capacity so we can estimate how much lower transmission costs could be if less capacity is required in a NEM that includes nuclear power.

1.5 Basis of comparison

In this report we compared AEMO's modelling outcomes (noting the differences explained above in Section 1.3) with the Report Modelling in the following ways:

- The net present value (NPV) by scenario over the modelling period with and without the cost of emissions
- The sum of real costs by scenario over the modelling period with and without the cost of emissions
- The annual generation costs by scenario with and without the costs of emissions
- The total capacity that was built by scenario over the modelling period
- The electricity generated by scenario over the modelling period

1.6 Results and conclusions

We found that the Report Modelling matched AEMO's ISP modelling results very closely in terms of the aspects listed above.

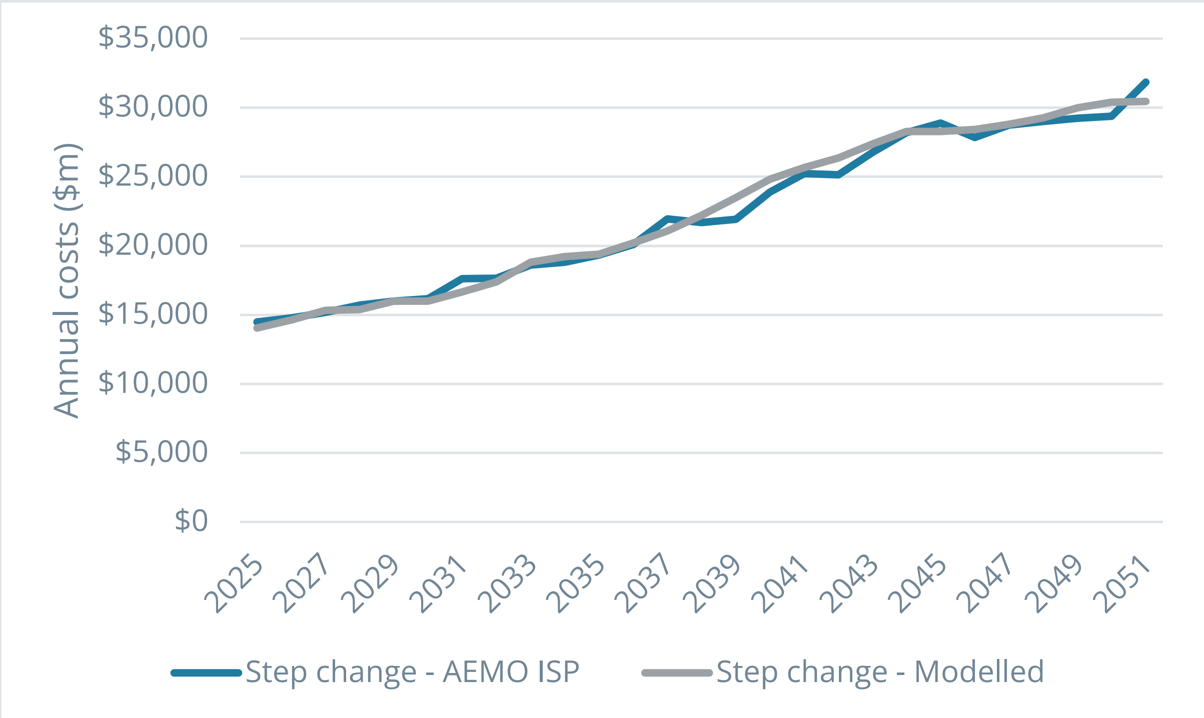
For example, when we compare AEMO's NPV value on equivalent terms to the Report Modelling in the table below, they are about 97% the same.

NPV ($bn)	AEMO ISP 2024 base - generation and emissions costs	Report Modelled 2024 base
Step Change	$245	$237
Progressive	$220	$216

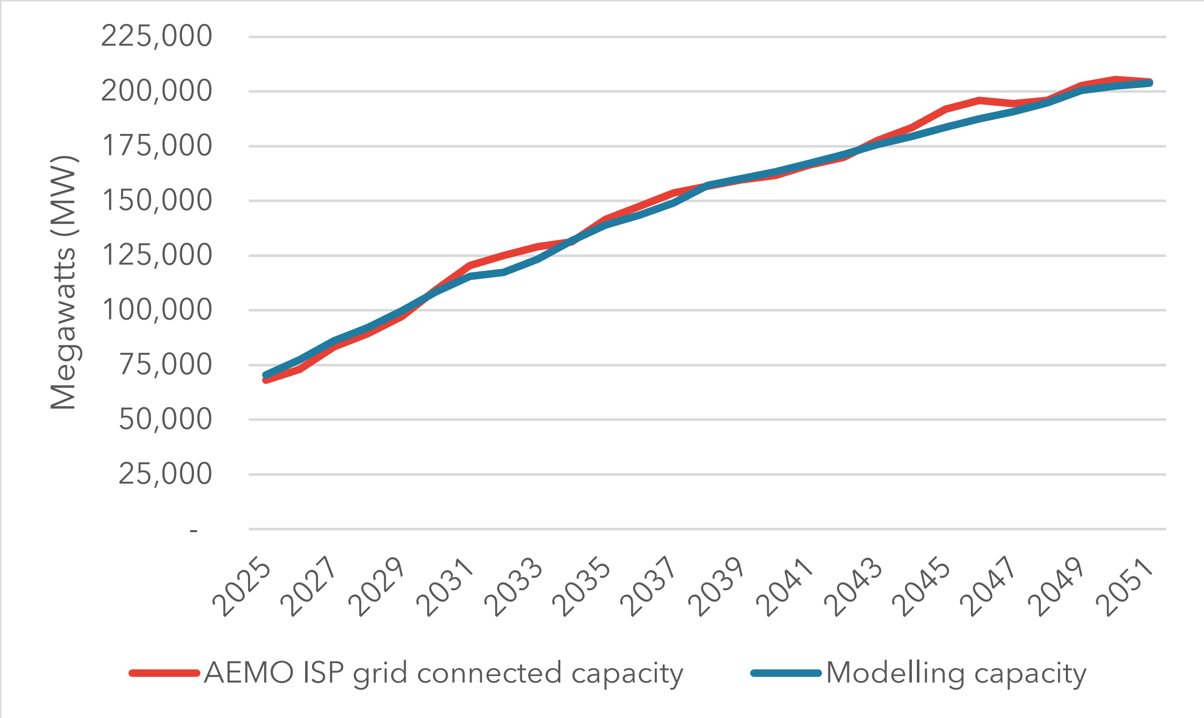
Similarly, when we compare the sum of the real costs over the modelling period to 2050 we find that the Report Modelling is about 91% the same as AEMO's ISP results.

Sum of real costs ($bn)	AEMO ISP 2024 base - generation and emissions costs	Report Modelled 2024 base
Step Change	$671	$608
Progressive	$592	$548

AEMO's Step Change annual costs and the Report Modelling annual costs are shown below and are also very similar.



Similarly, the Report Modelling and AEMO's Step Change modelling also compares well in the figure below.



In summary, the Report Modelling matched AEMO's modelling for both the Step Change and Progressive scenarios well in all aspects. We conclude from this analysis that the Report Modelling provides a reasonable basis for analysing the effect of including nuclear power into the NEM.

In terms of transmission costs, we find that project cost estimates are highly unreliable and show that these estimates tend to exceed their initial project costs by over 100%. We find that, at the very least, currently approved and planned projects are expected to cost $62 bn. The current regulated asset base of the transmission system is about $26 bn.[3] These additional costs will expand the asset base of the transmission networks by about 240%.

We find that, even on these conservative estimates, it takes about $500,000 of transmission costs to support each megawatt of new supply option. One implication of this is that to the extent that the required electricity supply capacity is significantly less with the introduction of nuclear power in the NEM, there is likely to be significant transmission cost savings. This will be considered in the second report.

It is worth noting that the costs of AEMO's preferred Step Change scenario, which does not include the costs of consumer energy resources, is the sum of the real costs of the electricity supply options of $580 bn plus the $62 bn in transmission costs – or a **total of $642 bn**. This is likely to be an underestimate of the costs given the propensity for project costs, and particularly transmission projects, to blowout and because we do not believe that we have captured all the likely transmission project costs.

[3] AER (2024), *State of the energy market*, p70, Weblink: https://www.aer.gov.au/documents/state-energy-market-2024-full-report

2 Introduction

2.1 Background

The Federal Coalition has stated that they would include nuclear power generation into the mix of electricity supply options. The Coalition's proposal has resulted in claims that nuclear would be too expensive and raise costs to consumers.[4 & 5]

This report is the first of two reports that will be published to provide data and analysis of the economics of including nuclear in the NEM. The objective of this first report is to provide a base case cost against which the costs of a NEM that includes nuclear power can be compared.

2.2 Recent nuclear cost comparisons

When comparing the costs of alternative states of the world it is important to establish the base against which an alternate world is being compared. Unless the base case is appropriately established the comparison could result in an incorrect conclusion about the relative costs of the alternative world.

An excellent example of the error that can occur from this mistake can be seen in the recent analysis conducted by the Institute for Energy Economics and Financial Analysis (IEEFA). The authors compared the wholesale electricity costs of current electricity bills, which reflects a combination of coal, gas, oil, wind, solar, hydro and storages and substituted this plant mix with their estimate of nuclear power, implicitly assuming that consumers are suddenly only supplied by one form of electricity.[6] Clearly this approach is wrong as it is not reflective of how any power system works and would not be what would happen in the NEM if nuclear formed part of the plant mix used to economically and reliably meet demand.

Former ACCC Chair, Rod Sims, in his recent attack on nuclear power attempted to compare the costs of a renewable system broadly contemplated by AEMO with nuclear power. The totality of Sims' published analysis is presented below:

> "All studies show that renewable energy is cheaper for Australia than nuclear. Solar and wind can supply power at about $60-80 a megawatt hour, and much cheaper than this in some areas. When this is firmed so that we have 24/7 reliable electricity using pumped hydro, batteries or gas-fired peaking generation, the cost rises to about $110MWh, including additional transmission costs.
>
> This is all known technology and in use in Australia today. All the recently built nuclear plants in the US, UK and the European Union since 2000 have seen nuclear power coming

4 Rod Sims (2024), "Nuclear discussion must be based on latest economic facts: Sims", The Superpower Institute, Weblink: https://www.superpowerinstitute.com.au/news/nuclear-discussion-must-be-based-on-latest-economic-facts-sims

5 Institute for Energy Economics and Financial Analysis (2024), Weblink: https://ieefa.org/resources/nuclear-australia-would-increase-household-power-bills

6 *Op. cit*, Institute for Energy Economics and Financial Analysis p 44-46.

> in at $200-$300MWh, at best, based on running 90 per cent of the time, and that is in countries that already have well established nuclear power industries."[7]

There is a lot wrong with Sims' claims. Firstly, wind and solar power only operates about a third of the time – as compared to nuclear which produces electricity more or less continually - and the pattern of renewable generators are generally correlated – that is, they tend to operate or not operate at the same time. This means that for renewables to generate sufficient electricity to meet demand at all times, a lot more renewable capacity is required to generate surplus electricity for times when renewables don't operate, and then this surplus has to be stored and also require further backups to cover when there are longer term wind and solar droughts. In rough terms, about three times as much renewable capacity is required to produce the same quantity of electricity as a nuclear generator. This is discussed in more detail in Report 2.

It is therefore misleading to compare the capital and operating costs of renewables per megawatt hour with the capital and operating costs per megawatt hour of a nuclear power plant, even if this includes a crude attempt to add in the cost of 'firming'. A more sophisticated approach is necessary to make a valid cost comparison.

The reality is that electricity consumers are supplied by a wide range of electricity supply options, which are often operating at the same time. In this case it is only valid to compare the total costs of the combination of generators – whether it be the renewable system promoted by AEMO or one that also includes nuclear - required to reliably and securely meet demand.

2.3 Appropriate base case

The base case that the IEEFA, Rod Sims and many others should use to compare the costs of including nuclear in the NEM, is the system that is currently planned to be developed without nuclear power. This is available in the Integrated System Plan (ISP) prepared by the Australian Energy Market Operator (AEMO) as this is what is intended to occur in the absence of an alternative.[8]

The ISP includes a number of modelling scenarios that produce system costs for meeting electricity demand for different states of the world, with different probabilities assigned to them. These scenarios fall into three broad categories called Step Change, Progressive and Green Energy Exports. These categories are broadly described below.

Common across each scenario is the computer model used to compare the outcomes – for example, cost, investment, generation – for the different scenarios. The objective function of the computer model is to minimise the economic resource costs of building and operating electricity generation and storage capacity to meet forecast electricity demand. This cost optimisation modelling is undertaken subject to the model solution conforming to a series of 'constraints'. These constraints are things like the system producing certain emissions, or the mix of generation plant conforming to a State renewable scheme, or meeting a minimum level of grid reliability, and ensuring the technical limits of the power system are not breached.

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7 *Op. cit*, Rod Sims (2024), p3.

8 AEMO (2024), 2024 Integrated System Plan (ISP), Weblink: https://aemo.com.au/en/energy-systems/major-publications/integrated-system-plan-isp/2024-integrated-system-plan-isp

2.3.1 Step Change

AEMO consider Step Change 43% likely and presents a world where there is rapid growth in electricity demand accelerated by the assumed electrification of many services currently provided by fossil fuels (mainly coal, gas and oil), and rapid development of wind, solar and energy storages to meet the associated demand growth. It is unclear whether AEMO has any economic relationship between the economic costs of this scenario and demand. As will be shown in this report, AEMO's Step Change scenario involves enormous cost and it is unclear how an economy grows strongly in the face of such significant economic costs.

2.3.2 Progressive

AEMO's Progressive scenario, which AEMO says is just 1 percentage point less likely - 42% likely - than their preferred Step Change world, also reflects a growth in electricity demand due to electrification of services currently provided by fossil fuels and development of wind, solar and energy storage to meet associated demand, albeit not as rapid as in the Step Change scenario.

2.3.3 Green Energy Exports

AEMO also produces another scenario they call the Green Energy Exports scenario. This AEMO scenario represents a world in which there is extremely strong decarbonisation in Australia's industry and the development of a green energy export industry.

It is worth noting that many countries claim they will also be a major green energy exporters. And with Australia's high costs of land, capital and labour, difficult and uncertain planning restrictions, and distance from many high value markets, other countries are better placed to become green energy exporters.

AEMO assigns a 15% chance of this scenario occurring.

2.4 AEMO as a base case

These AEMO ISP scenarios provide an excellent base case against which to compare the costs of an alternative power system with nuclear power included. They are widely agreed and well documented and the assumptions used are mostly clear.

In the remainder of this report, we develop and report on the results of a modelling exercise that replicates, to a high degree, two of the more likely AEMO ISP scenarios – Step Change and Progressive. This modelling of these two scenarios is intended to form the base case against which the Nuclear Alternative scenario is compared.

In a following report, these two ISP scenarios are modified and re-run to compare the costs of a NEM that includes the scale and timing of nuclear power stations across the NEM that broadly aligns with what the Coalition has announced so far.

2.5 Global nuclear power

The International Atomic Energy Agency report that there are 438 nuclear power reactors operational in 32 countries with a combined capacity of around 370,000 megawatts (MW) of generating capacity.[9] The World Nuclear Association report that around 70 new power reactors are under construction totally around 72,000 MW and that another 90 power plants are planned, accounting for a further 90,000 MW.[10] The average size of these newer power plants is around 1,000 MW. They are large scale nuclear reactors. While many of these new reactors are replacing older reactors, there is considerable growth in the development of nuclear power in Asia where electricity demand is rapidly growing.

The oldest operating nuclear power station is the Beznau plant in Switzerland. Beznau has been operating since Christmas Eve 1969, nearly 55 years. While the company operating the Beznau plant had been planning to take the plant out-of-service in 2030 – indicating a 60-year service life – it is now considering extending the plant's life to 2040.[11] In the recent report released by the US Department of Energy on the growth in the development of the US nuclear power industry – *Pathways to Commercial Liftoff* – it was noted that power lives are being extended to 80 years.[12]

If nuclear power was included in the mix of generators it would result in a different mix of electricity generating capacity than planned by AEMO in its ISP preferred scenarios.[13] AEMO prefer an electricity generation system dominated by three technologies – wind, solar and energy storage – to supply a modern Australian economy. However, other states of the world are possible, including the inclusion of nuclear power. These alternative states of the world ought to be investigated rather than being summarily dismissed, especially if based on deeply flawed logic and analysis.

2.6 This report

This report is structured as follows:

- Section 3 summarises the modelling scenarios developed for this project and the key assumptions
- Section 4 presents the key modelling results of generation capacity, network expansion, electricity production and costs and discusses these results.
- Section 5 attempts to determine the costs of transmission projects required to support the energy transition. Most of these costs are treated by AEMO and NEM governments as "sunk", even though the majority of these projects are yet to be developed. As "sunk" projects the costs are largely beyond further consideration and ignored in the reported cost of the transition. Customers and taxpayers will, of course, pay for these projects irrespective of how AEMO classify them.

9 IAEA (2024), Nuclear Power Reactors in the World, Weblink: RDS-2/44 (iaea.org)

10 World Nuclear Association (2024), Weblink: https://world-nuclear.org/information-library/current-and-future-generation/plans-for-new-reactors-worldwide#:~:text=Today%20there%20are%20about%20440,9%25%20of%20the%20world's%20electricity.

11 Anadolu Ajansi (2024), World's oldest nuclear plant in Switzerland being examined to make it operational until 2040, Weblink: https://www.aa.com.tr/en/europe/worlds-oldest-nuclear-plant-in-switzerland-being-examined-to-make-it-operational-until-2040/3177664

12 US Department of Energy (2024), *Pathways to Commercial Liftoff: Advanced Nuclear*, p1, Weblink: https://liftoff.energy.gov/wp-content/uploads/2024/10/LIFTOFF_DOE_AdvNuclear-vX7.pdf

13 AEMO (2024), 2024 Integrated System Plan (ISP), Weblink: https://aemo.com.au/en/energy-systems/major-publications/integrated-system-plan-isp/2024-integrated-system-plan-isp

3 Overview of approach

This section provides an overview of the modelling that we have undertaken to inform our economic assessment of the scenarios that we have modelled.

3.1 Modelling scenarios

The modelling undertaken in this project is a cost optimisation (minimisation) of the NEM generation system from 2025 to 2051. It is important to note that the modelling does not include the costs of any residential behind the meter supply or storage options – so called consumer energy resources. AEMO does not include these substantial costs in the costings for the ISP scenarios.

3.2 Key assumptions

3.2.1 Electricity sector model inputs

The key electricity sector model inputs are:

- Electricity demand
- Existing electricity supply
- Options for new electricity supply
- Existing electricity transmission and options for new electricity transmission
- Existing carbon reduction and renewables policies
- The weighted cost of capital (WACC)

Each of these input assumptions are briefly discussed below. More detail of the modelling assumptions are available in AEMO's ISP.

Electricity demand

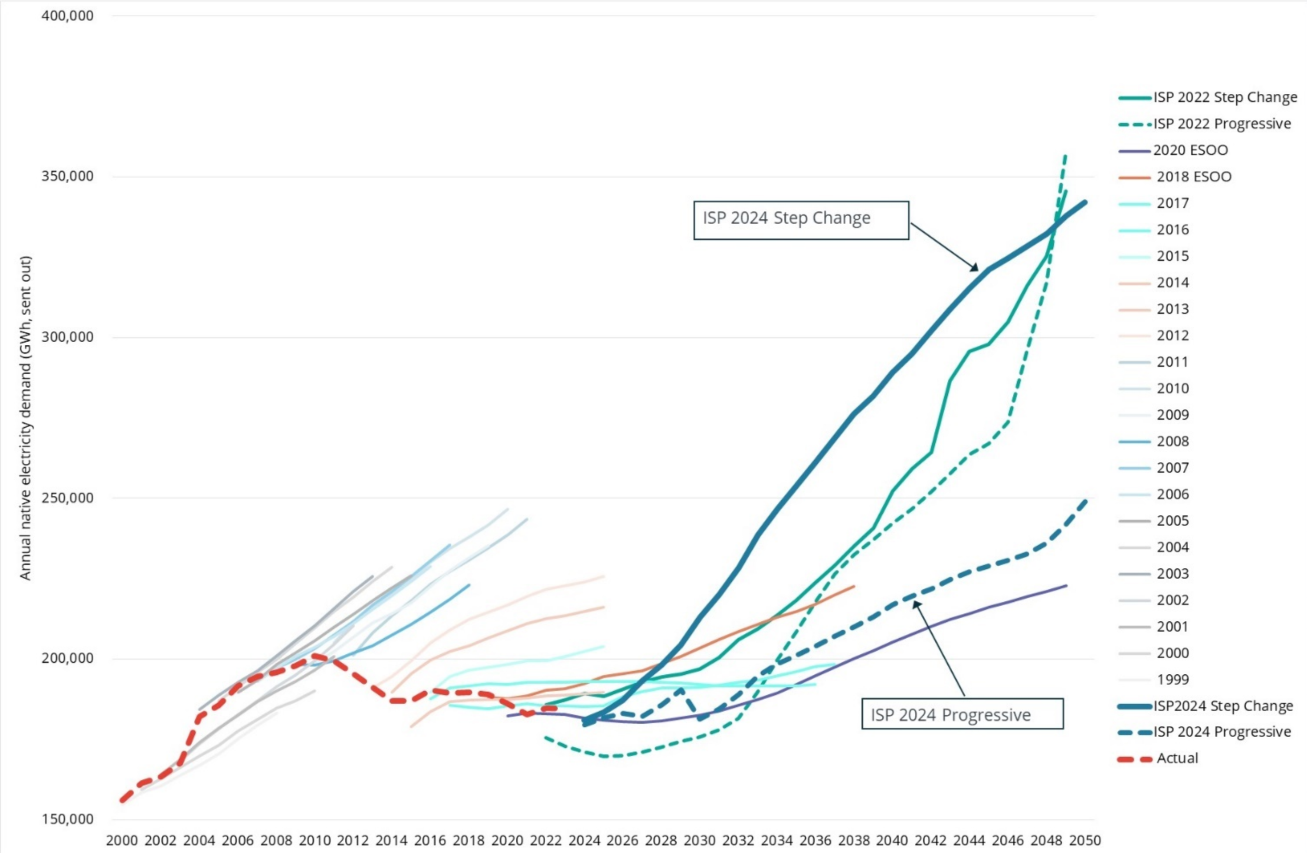
Demand for electricity is based on AEMO's Step Change and Progressive demand forecasts from AEMO's 2024 ISP. These forecasts are shown in teal in **Figure 1** – Step Change is shown in solid teal and Progressive in the dashed teal. Actual demand is shown as the red dashed line. Note that the vertical access of **Figure 1** starts at 150,000 GWh.

A number of features are immediately obvious from **Figure 1**:

- AEMO (and their predecessor, NEMMCO) have a very poor track record at forecasting electricity demand
- AEMO's performance at forecasting demand has not got better through time
- AEMO's demand forecasts have been becoming more extreme as compared to the historic levels of demand in recent years

- AEMO's 2024 Step Change demand forecast is so far from historic trend that it looks incredible. To achieve the growth in electricity demand contemplated by AEMO it would likely require consumers being forced to use more electricity by being banned, by government, from using alternative sources of energy
- AEMO's 2024 Progressive forecast looks to be more credible in the early years but then returns to growth trends that are consistent with AEMO's/NEMMCO's earlier failed forecasts, but this growth reflects the effect on demand from being forced to use electricity and being banned, by government, from using alternative sources of energy.

Figure 1: AEMO demand forecasts 1999 to 2024



Source: AEMO, NEMMCO

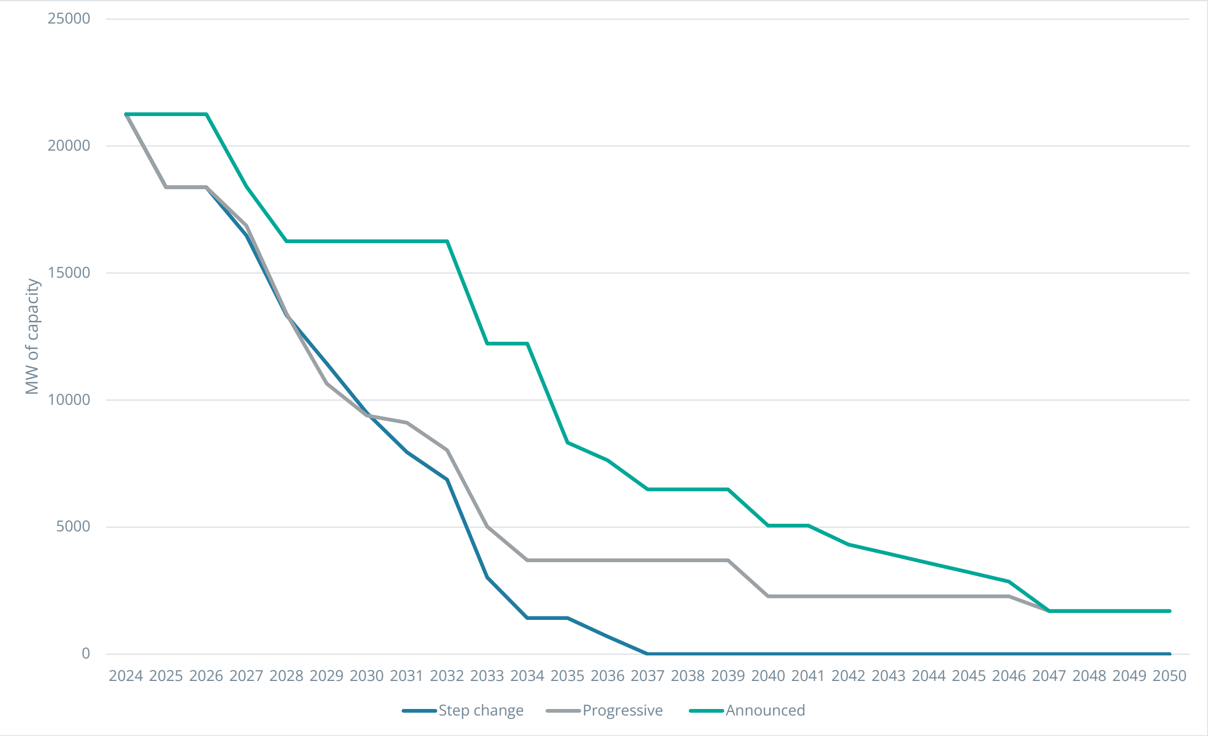
Electricity generation

The base case modelling includes all existing or committed electricity generation, with capacities based on AEMO's generation information or planning documents.

The pattern of plant retirements we use in the modelling conforms with AEMO's ISP assumptions, notably coal closures. AEMO has a different pattern of plant closure for Step Change and Progressive (see **Figure 2**).

It is worth noting that the ISP assumptions are different to the closure dates announced by the generators. The difference between the ISP assumptions for Step Change and Progressive and closure dates announced by the generators are shown in **Figure 2**. As can be seen from **Figure 2** the closure dates announced by the generators are significantly later than what AEMO has assumed in either Step Change or Progressive scenarios. It is also worth noting that already there are delays in closure from the announced closure for two of the largest coal fired generators, Yallourn and Eraring.

Figure 2: Schedule of plant closures

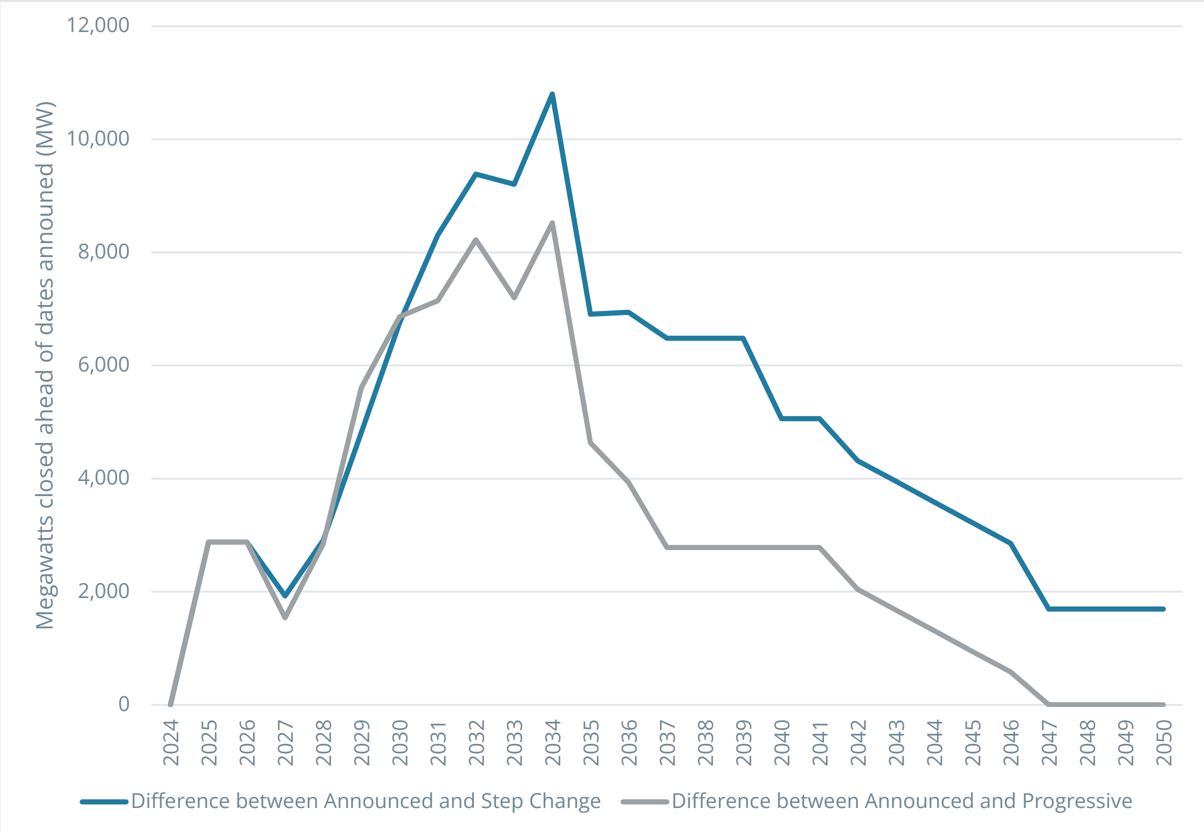


Source: AEMO ISP

The difference in megawatts retired ahead of the retirement dates announced by the generators is shown in **Figure 3** for both Step Change and Progressive. The difference between AEMO's view of coal closures and that of the coal generators peaks in the 2030s with AEMO assuming the closure of thousands of megawatts earlier than currently contemplated by the generators.

It is worth noting that in recent years owners of coal generators that wished to close – Yallourn in Victoria and Eraring in NSW – were contracted by the respective governments to remain.

Figure 3: Megawatts of coal closed by AEMO ahead of generator announced dates (MW)



Source: AEMO ISP and Frontier Economics

3.2.2 Technologies modelled

The modelling includes a range of options for investment in new electricity generation technologies in each NEM jurisdiction. The following electricity supply options were modelled:

- Coal
- Demand side participation (DSP)
- Gas Peakers
- Hydroelectric
- Hydrogen
- Liquid Fuel
- Mid-Merit Gas
- Offshore Wind
- Pumped Hydro
- Solar
- Utility Storage

- Vehicle to Grid - V2G
- Virtual Power Plant - VPP
- Wind
- Nuclear

The assumptions about available generation technologies, capital costs, operating costs, fuel costs and efficiencies of the generators in our model are based on the assumptions from AEMO's 2024 ISP.

For this project AEMO's ISP fuel price assumptions, including gas, have been used. If gas prices were lower in the future than the assumed level, this is likely to place downward pressure on electricity prices, noting that we do not model electricity prices in this project, instead we focus on economic costs. Of course, in a competitive market, if costs are lower then prices are also lower.

3.2.3 Electricity transmission

The modelling includes all existing inter-regional interconnectors in the NEM, with capacities based on the AEMO 2024 ISP.

3.2.4 Existing carbon reduction and renewables policies

There are a number of interacting jurisdictional carbon reduction and renewables policies that currently exist, broadly with targets to 2030 and then further targets post 2030. These policies are summarised in **Table 1**.

When modelling the ISP scenarios, the modelling objective function is set to achieve these targets as well as meet demand, the reliability constraint and conform to the technical limitations of the power system.

Table 1: Carbon reduction and renewable energy targets

Policy	Jurisdiction	Pre 2030	Post 2030
Powering Australia Plan	Commonwealth	82% renewables by 2030	-
Capacity Investment Scheme	Commonwealth	18.4 GW VRE, 6.1 GW dispatchable in 2030	-
Electricity Infrastructure Roadmap	NSW	33.6 TWh of VRE (formulated as availability), 2 GW/16 GWh of LDS	
Queensland Renewable Energy Target	QLD	50% VRE by 2030	70% by 2032, 80% by 2035
Victorian Renewable Energy Target	VIC	50% VRE by 2030	65% by 2032, 95% by 2035
Victorian Offshore Wind Target	VIC	-	1GW by 2031, 2GW by 2032, 4GW by 2035, 9 GW by 2040
Victorian Storage Target	VIC	2.6 GW by 2030	6.3GW by 2035
Tasmanian Renewable Energy Target	TAS	15.75 TWh by 2030	21 TWh by 2040

3.2.5 Valuing emission reductions

The Australian Energy Regulator publishes a carbon price known as Valuing Emission Reductions – VER – expressed as a dollar per tonne. This came into effect in May 2024. The objective of the VER is to set this value at a level to ensure the investments that are considered necessary to achieve the net zero target are economic and, within a cost optimisation modelling framework are built.[14]

The VER is not a price that has to be paid directly by consumers but the investments the VER make appear to be economically cost efficient do have to be paid by consumers and/or taxpayers. In this sense, the VER is, in effect, a carbon price that all consumers pay for through

14 Australian Energy Regulator (2024), *Valuing emission reductions – Final guidance and explanatory statement*, May, Weblink: https://www.aer.gov.au/system/files/2024-05/AER%20-%20Valuing%20emissions%20reduction%20-%20Final%20guidance%20and%20explanatory%20statement%20-%20May%202024.pdf

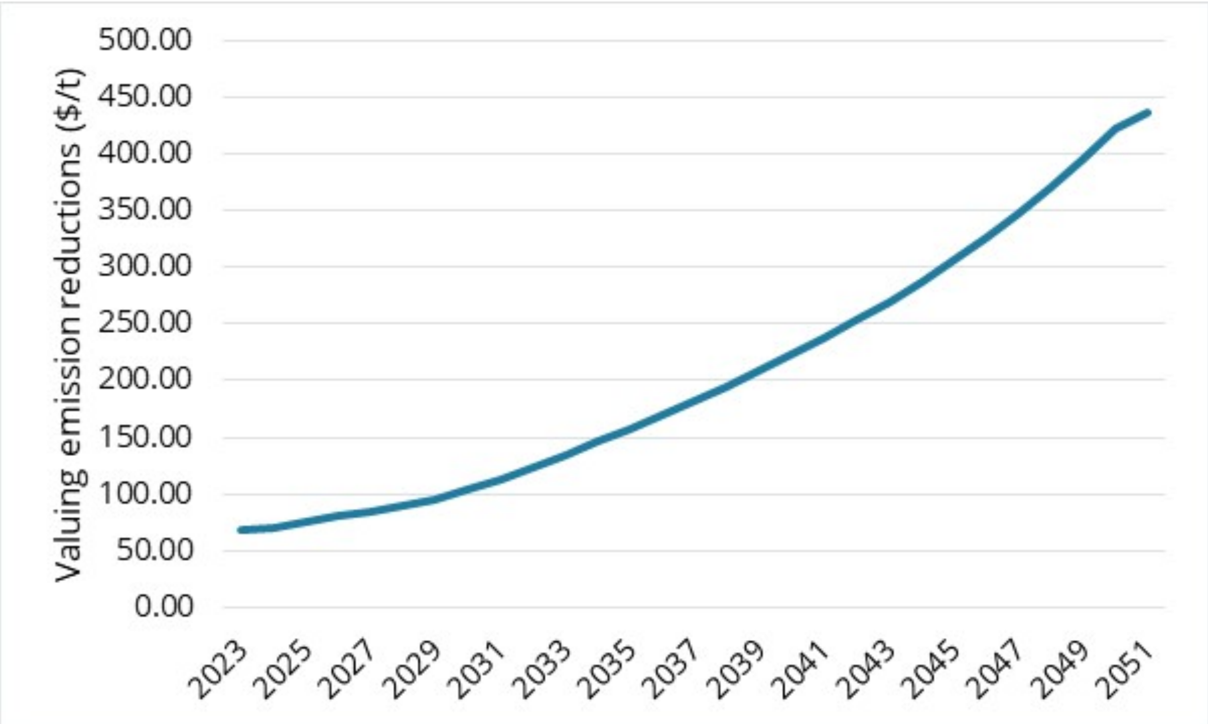
the economic costs caused by the use of the VER in planning the energy system even though no government has agreed to or legislated an explicit carbon price.

The VER came into effect when NEM jurisdictions decided to change the National Electricity Law to include an explicit objective in the National Electricity Objective, National Gas Objective and National Retail Objective that any Rules had to have regard to the achievement of emission targets set by NEM jurisdictions.[15]

The AER's 2024 dollar based VER is presented **Figure 4**. The price of carbon rises from nearly $70/tonne to nearly $420/tonne by 2050.

Compared to explicit carbon price that Australia did have in the form of the Gillard Government carbon tax of $24.15/tonne when it was revoked from 1 July 2014 onwards, the 2024 value of the VER of just under $70/tonne is about twice what the 2024 dollar value would be of the Gillard carbon tax at the time it was abolished.

Figure 4: AER's valuing emission reductions



Source: Australian Energy Regulator (2024), Valuing emission reductions – Final guidance and explanatory statement, May, Weblink: https://www.aer.gov.au/system/files/2024-05/AER%20-%20Valuing%20emissions%20reduction%20-%20Final%20guidance%20and%20explanatory%20statement%20-%20May%202024.pdf . Rebased to 2024 dollars

3.2.6 The WACC

The modelling used a real WACC of 7%.

15 Op Cit, Australian Energy Regulator (2024), p1.

4 Results

In this section the results of modelling the ISP's Step Change and Progressive scenarios are presented. The following results are presented:

- Net present value costs (NPV) – see Section 4.1
- Sum of the real costs – see Section 0
- Annualised costs – see Section 4.3
- Mix of generation capacity used to meet demand – see Section 4.4
- Generation of electricity by technology – see Section 4.5
- Conclusions as to whether the modelling provides a reasonable replication of AEMO's ISP modelling to be used to assess the cost impacts of including nuclear power as an alternative to AEMO's ISP approach – see Section 4.6.

In all cases, the results of AEMO's ISP modelling and 'report modelling' are compared. There are key differences in the scope of costs being modelled, which are explained below.

In addition to the generation modelling, a separate analysis of the high voltage transmission costs is provided in Section 5 as a significant proportion of these costs are excluded from the ISP assessment because they are deemed to be already committed, although not yet developed.

The energy transition is also likely to involve significant costs in the low voltage distribution sector and consumer energy resources (CER). No assessment is made of the costs of the low voltage distribution sector or the CER.

4.1 Net present value of generation

The ISP presents the NPV of the Step Change and Progressive scenarios for a range of cases. AEMO's optimal development path (ODP) is the CDP14 case, so this is used as the base case against which the modelling is compared.

The NPV is typically used to compare the costs and benefits of alternative projects where the economic cost and benefits occur over time and at different times. The use of the NPV puts these different cash flows on an equivalent basis in terms of time and allows a direct comparison of project costs and benefits.

AEMO report a range of NPV costs in their ISP summary, including the following broad cost categories:

1. Generator capital
2. Fixed operating and maintenance costs (FOM)
3. Fuel
4. Variable operating and maintenance costs (VOM)
5. Demand side participation and unserved energy (DSP+USE)
6. REZ augmentation

7. Flow path augmentation
8. Emissions cost

For this modelling exercise costs 1 to 4 and 8 are the relevant and material costs. Network costs will, however, be separately reported in Section 5.

AEMO's latest 2024 ISP has its costs based in July 2023 dollars. To ensure the modelling is up-to-date this modelling sets the costs in July 2024 dollars terms. To ensure AEMO's NPV values and the modelling are comparable and up-to-date, all costs have been rebased to July 2024 dollar terms.

4.1.1 NPV including the cost of emissions

In **Table 2** a comparison of the NPVs for the period from 2025 to 2051 is presented when the costs of emissions are included for both the Step Change and Progressive scenarios.

Data column 1: The first data column shows the NPV as presented by AEMO in the 2024 ISP for CDP14 - $242 bn for Step Change scenario and $216 bn for the Progressive scenario. These costs are based in 2023 dollars.

Data column 2: Given the modelling in this report focusses on grid generation the generation and related emissions costs (based on the Valuing Emission Reduction – VER – estimates), the second data column shows, in 2023 dollar value terms, the generation and emission costs reported by AEMO in their 2024 ISP. The data in this column **does not include AEMO's costs for for DSP+USE, REZ augmentation and Flow path augmentation**.

For Step Change this is $225 bn and for Progressive the combined cost of generation and emissions is $202 bn. These costs account for about 92% of the full costs reported by AEMO.

Data column 3: The data in data column 2 are in 2023 dollar terms. The 2024 rebased dollar values are presented data column 3. The generation and emission costs for the Step Change scenario is $245 bn in 2024 dollar terms while the Progressive value on the same basis is $220 bn.

Data column 4: The 2024 dollar value of the modelling of the 2024 ISP is shown in data Column 4. The modelling produced a value of $237 bn in 2024 dollar terms for the Step Change scenario (shown in data column 4) compared to AEMO's $245 bn (shown in data column 3). For the Progressive scenario the modelling produced a 2024 dollar value of $216 bn (shown in data column 4) compared to AEMO's $220 bn (shown in data column 3).

The similarity of the modelling to AEMO's ISP NPV estimates indicates that the modelling is providing a good representation of AEMO's modelling.

Table 2: Comparison of NPVs of AEMO ISP costs and modelled costs – including cost of emissions

NPV ($bn)	AEMO ISP 2023 base - full cost	AEMO ISP 2023 base - generation and emissions costs	AEMO ISP 2024 base - generation and emissions costs	Modelled 2024 base
Step Change	$242	$225	$245	$237
Progressive	$216	$202	$220	$216

Source: AEMO 2024 ISP and Frontier Economics

4.1.2 NPV excluding the cost of emissions

In **Table 3** the NPVs of the Step Change and Progressive scenarios are presented where the cost of emissions are not included. Aside from the exclusion of the VER based emission costs, the data presented in **Table 3** is the same as presented in **Table 2**. The modelling produces NPV costs that are about 96% of the modelling results by AEMO on an equivalent basis.

Table 3: Comparison of NPVs of AEMO ISP costs and modelled costs – excluding cost of emission

NPV ($bn)	AEMO ISP 2023 base - full cost	AEMO ISP 2023 base - generation costs only	AEMO ISP 2024 base - generation costs only	Modelled 2024 base
Step Change	$242	$182	$198	$190
Progressive	$216	$144	$156	$149

Source: AEMO 2024 ISP and Frontier Economics

Box 1: Government estimates of $122 billion transition cost

In an address to the National Press Club on 17 July 2024, the Hon. Chris Bowen MP stated that AEMO's newly released ISP "… showed we need $122 billion of investment in utility-scale generation, storage, forming and transmission infrastructure to keep the lights on and business going".[1] It is important to explain the basis of this cost estimate.

The Minister's cost estimate can be readily replicated from AEMO's ISP results, but only after carefully interpreting the Minister's media statements on this costing and making the necessary adjustments of costs and ensuring the time over which the Minister has reported the transition costs.

In further media release by the Minister on 26 June, the Hon. Chris Bowen MP said, "The Australian Energy Market Operator (AEMO) has tested 1000 scenarios to ensure the lowest-cost plan that will also meet our growing electricity needs and keep the grid reliable between now and 2050".

There are two important statements from these media releases that help replicate the Minister's AEMO cost estimate. The costs relate to the investment in "…utility-scale generation, storage, forming and transmission infrastructure …" *capacity* and that these are capacity costs are for "…between now and **2050**."

Capacity costs do not include ongoing fuel (Fuel) and other variable operating and maintenance costs (VOM) and do not include the cost of emissions (Emissions cost) as determined by the AER's carbon price (see Section 3.2.5)

Below is a screenshot from the ISP data of AEMO's Net Present Value for the Step Change CDP14 – ODP scenario. ODP refers to the Optimal Development Path. The AEMO Net Present Value (NPV) estimate of $242.453 billion is the capacity cost and operating costs of all existing and new generator as well as demand side participation (DSP), the economic cost of unserved energy (USE) and the emissions costs as determined by the VER, and includes some of the transmission costs – REZ and Flow path augmentation (see comments in Section 5 about how this AEMO cost estimate excludes most of the transmission costs). This NPV is calculated for the period from 2024-25 to 2051-52, to not 2050 as referred to by the Minister.

Real July 2023 dollars ($m)	NPV
Generator capital	$112,302
FOM	$44,082
Fuel	$21,726
VOM	$4,274
DSP+USE	$632
REZ augmentation	$1,714
Flow path augmentation	$15,248
Emissions cost	$42,475
NPV and annual costs	$242,453

*Net present value as at 1 July 2023

If only the generation capacity costs and transmission costs are included – that is, the Generator capital, REZ augmentation and Flow path augmentation costs - as indicated by the Minister to the National Press Club on 17 July, and only these costs to 2050 are included – as suggested by the Minister's 26 June 2024 media release, then the NPV of those costs are $122.818 billion (see recalculated value below), which is consistent with the Minster's claim on transition costs.

Real July 2023 dollars ($m)	NPV
Generator capital	$106,216
FOM	Not included
Fuel	Not included
VOM	Not included
DSP+USE	$509
REZ augmentation	$1,551
Flow path augmentation	$14,542
Emissions cost	Not included
NPV and annual costs	$122,818

*Net present value as at 1 July 2023

AEMO include many other scenarios for their Step Change scenario, but they all produce a similar value to the $122 billion reported by the Minister if similar adjustments are made as described above.

It is important to be clear that the Minister's cost estimate is based on the Net Present Value. Consumers do not pay the Net Present Value, they pay the actual costs. Secondly, the Minister's cost estimate excludes important costs that consumers will also pay for. In the sections below, the sum of the real, and full costs, are shown. We also attempt to make an estimate of the large and growing transmission costs.

Sources: (1) https://minister.dcceew.gov.au/bowen/speeches/speech-national-press-club-canberra-act

(2) https://minister.dcceew.gov.au/bowen/media-releases/massive-economic-benefits-households-and-businesses-reliable-renewable-electricity-grid

4.2 Sum of real costs of generation

To many people the concept of NPV is confusing and they would rather understand the total costs and benefits over time, irrespective of when they occurred. In this section the costs of the AEMO ISP modelling and the modelling undertaken for this project are summed over time and compared between the Step Change and Progressive scenarios, with and without the costs of emissions.

4.2.1 Sum of costs including the costs of emissions

The sum of real costs, including the costs of emissions according to the VER values, are presented in **Table 4**.

The sum of AEMO's real costs over the period from 2024/25 to 2050/51 is $660bn for Step Change and $580bn for the Progressive scenario.

Since the modelling presented in this report focusses on the generation and emissions and not CER, DSP or network (network costs are separately considered in Section 5 below) the relevant AEMO costs are $604bn for Step Change and $533bn for Progressive. Rebased, these costs are, respectively, $671bn and $592bn. By comparison, the corresponding modelled sum of real costs on the rebased value are $608bn and $548bn, which are close to AEMO's values.

Table 4: Comparison of sum of real costs of AEMO ISP costs and modelled costs – including costs of emission (2024/25 to 2050/51)

Sum of real costs ($bn)	AEMO ISP 2023 base - full cost	AEMO ISP 2023 base - generation and emissions costs	AEMO ISP 2024 base - generation and emissions costs	Modelled 2024 base
Step Change	$660	$604	$671	$608
Progressive	$580	$533	$592	$548

Source: AEMO 2024 ISP and Frontier Economics

4.2.2 Sum of costs excluding the cost of emissions

The sum of real costs, including the excluding the costs of emissions, are presented in **Table 5**.

The sum of AEMO's real costs over the period from 2024/25 to 2050/51, excluding the cost of emission, is $580bn for Step Change and $451bn for the Progressive scenario.

Since the modelling presented in this report focusses on the generation and emissions and not CER, DSP or network (network costs are separately considered in Section 5 below) the relevant AEMO costs are $525bn for Step Change and $404bn for Progressive. Rebased, these costs are, respectively, $583bn and $449bn. By comparison, the corresponding modelled sum of real costs on the rebased value are $528bn and $405bn, which are close to AEMO's values, but as close as with the cost of emissions.

Table 5: Comparison of sum of real costs of AEMO ISP costs and modelled costs – excluding cost of emissions (2024/25 to 2050/51)

Sum of real costs ($bn)	AEMO ISP 2023 base - full cost	AEMO ISP 2023 base - generation costs only	AEMO ISP 2024 base - generation costs only	Modelled 2024 base
Step Change	$580	$525	$583	$528
Progressive	$451	$404	$449	$405

Source: AEMO 2024 ISP and Frontier Economics

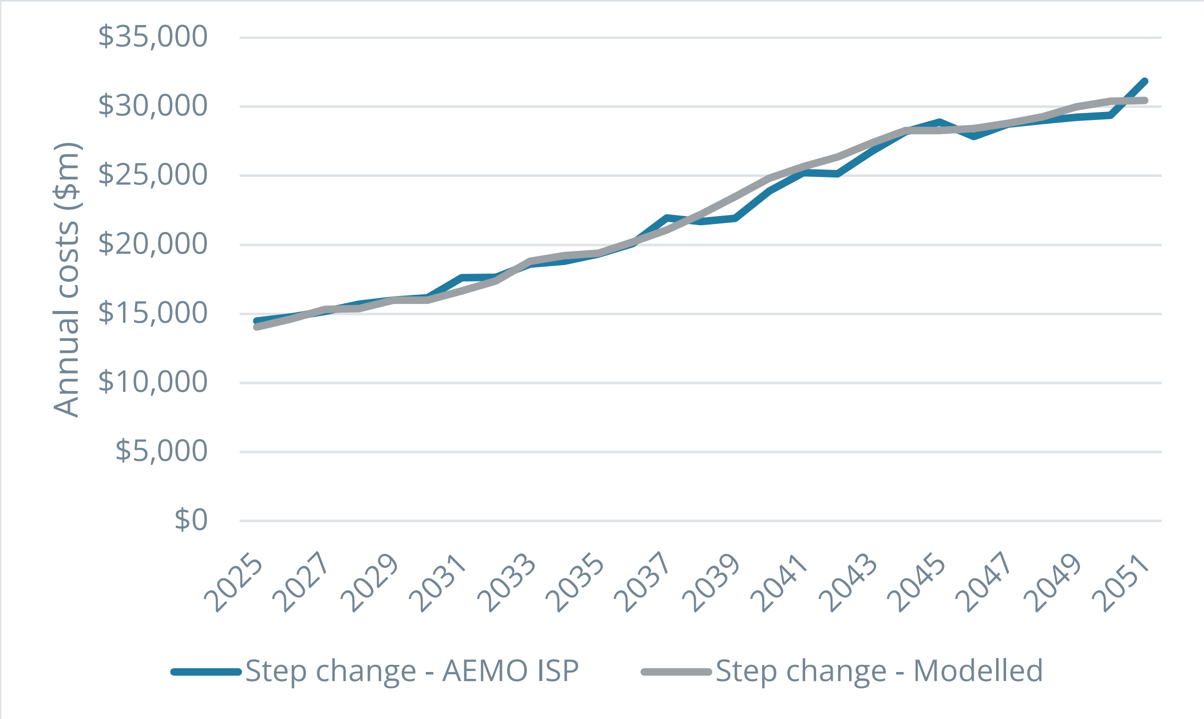
4.3 Annualised costs

AEMO presents the annual costs of their scenarios. In this section AEMO's annual costs for their Step Change and progressive scenarios are compared to the report modelling including and excluding the cost of emissions. These annual costs are compared over time to determine whether the two models follow a similar trajectory in terms of when capacity costs are incurred as this assists in considering the NPV comparison.

4.3.1 Annualised costs including cost of emissions

Figure 5 compares the annual costs of AEMO's modelling for Step Change, including the cost of emissions, with the report's modelling. It is clear that while there are some differences, these are inconsequential. In some years AEMO's costs are higher than the report modelling and vice versa.

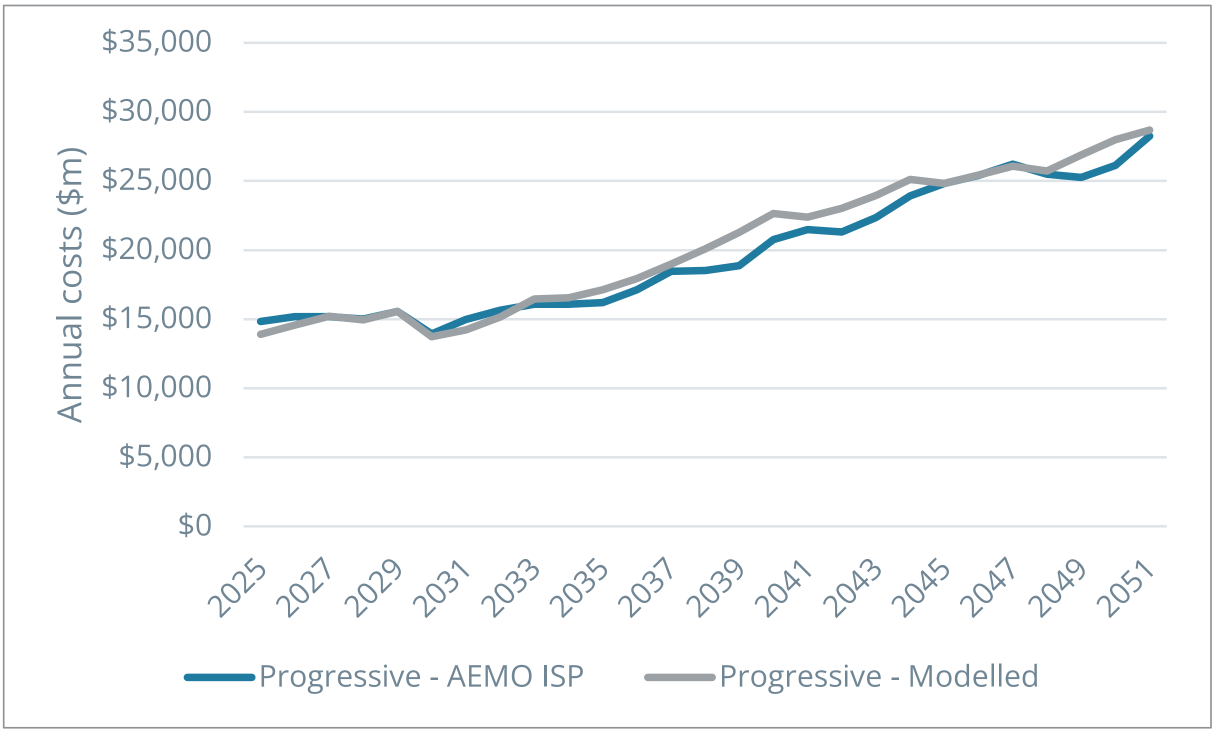
Figure 5: Step Change annual costs including cost of emissions (2024/25 to 2050/51)



Source: AEMO 2024 ISP and Frontier Economics

Figure 6 shows the comparison between AEMO's annual cost modelling, including the cost of emissions, for the Progressive scenario with the annual costs from the report modelling. Like the Step Change results, the report modelling is very similar to AEMO's, although the report modelling produces costs that are somewhat higher than AEMO's modelling from 2035 to 2045.

Figure 6: Progressive annual costs including cost of emissions (2024/25 to 2050/51)

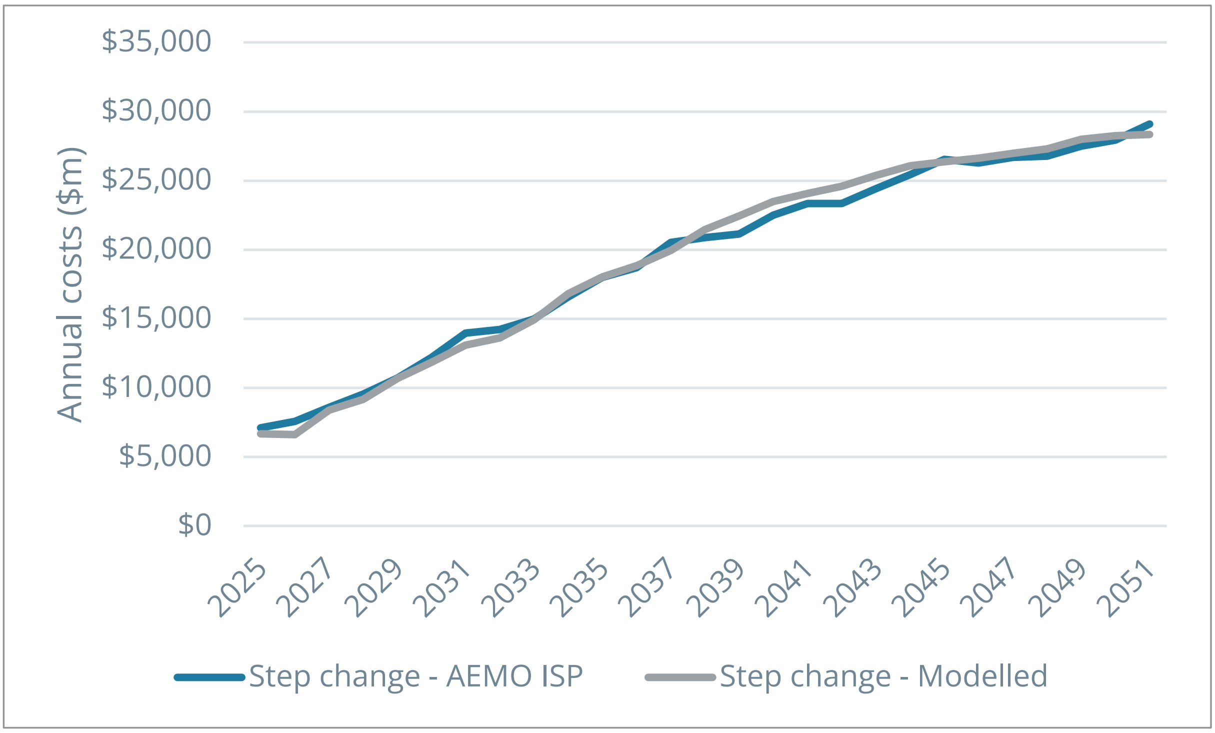


Source: AEMO 2024 ISP and Frontier Economics

4.3.2 Annualised costs excluding cost of emissions

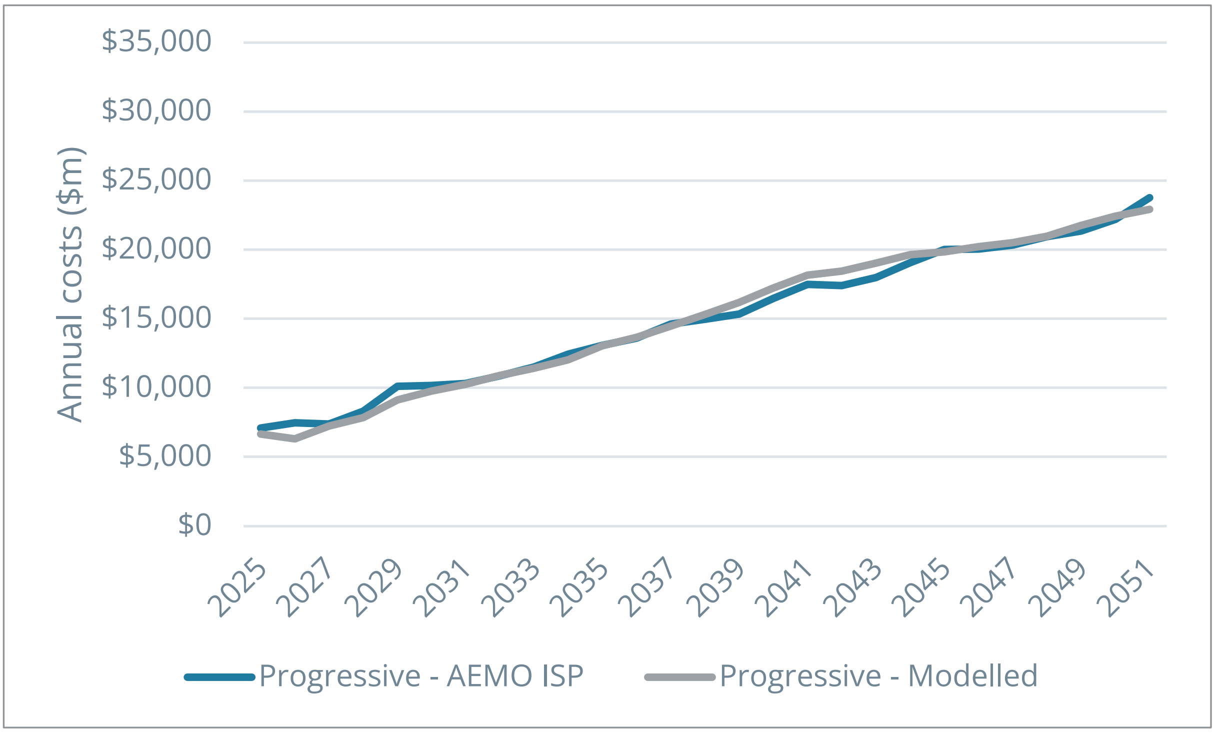
Figure 7 compares the annual costs of AEMO's modelling for Step Change, excluding the cost of emissions, with the report's modelling. Like the annual cost comparisons presented above, the annual costs in this scenario are very similar. The close comparison between AEMO's and report modelling for the Progressive scenario excluding the cost of emissions is also clear in **Figure 8**.

Figure 7: Step Change annual costs excluding cost of emissions (2024/25 to 2050/51)



Source: AEMO 2024 ISP and Frontier Economics

Figure 8: Progressive annual costs excluding cost of emissions (2024/25 to 2050/51)



Source: AEMO 2024 ISP and Frontier Economics

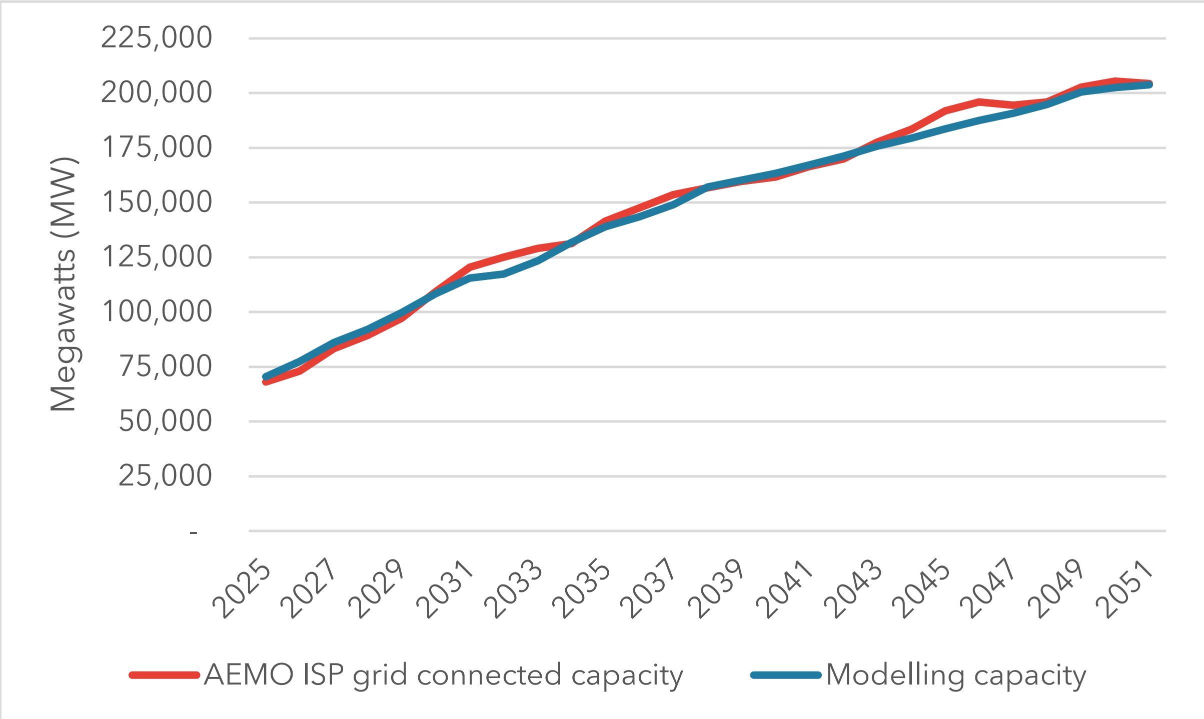
4.4 Generation capacity

In this section AEMO's ISP modelling results are compared to the report modelling results in terms of total electricity supply capacity. Again, the comparison does not include certain supply options not accounted for in the report modelling, such as CER.

4.4.1 Step Change generation capacity

The total capacity each year for AEMO's Step Change scenario is compared with the total capacity on an equivalent basis for the report modelling in **Figure 9**. While there are some small differences in capacity year-on-year, both models invest in the same amount of capacity over the modelling period.

Figure 9: Step Change - AEMO ISP vs modelled capacity (2024/25 to 2050/51)



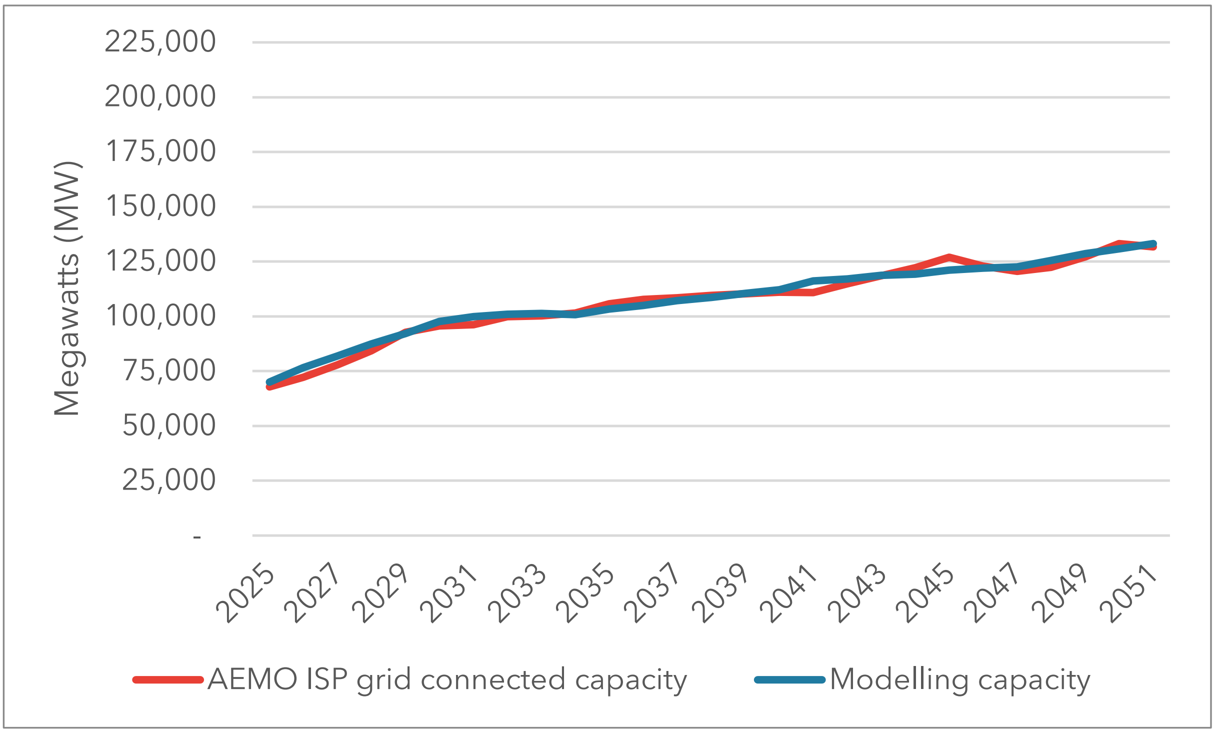
Source: AEMO 2024 ISP and Frontier Economics

4.4.2 Progressive generation capacity

The total capacity each year for AEMO's Progressive scenario is compared with the total capacity on an equivalent basis for the report modelling in **Figure 10**. While there are some small differences in capacity year-on-year, both models invest in the same amount of capacity over the modelling period.

The Progressive scenario results in considerably lower amount of capacity being installed as compared to the Step Change scenario. By 2051 total capacity under the Progressive scenario is about 130,000 MW compared to the Step Change's 205,000 MW. Less transmission investment would be required to support 75,000 MW less capacity.

Figure 10: Progressive - AEMO ISP vs modelled capacity (2024/25 to 2050/51)



Source: AEMO 2024 ISP and Frontier Economics

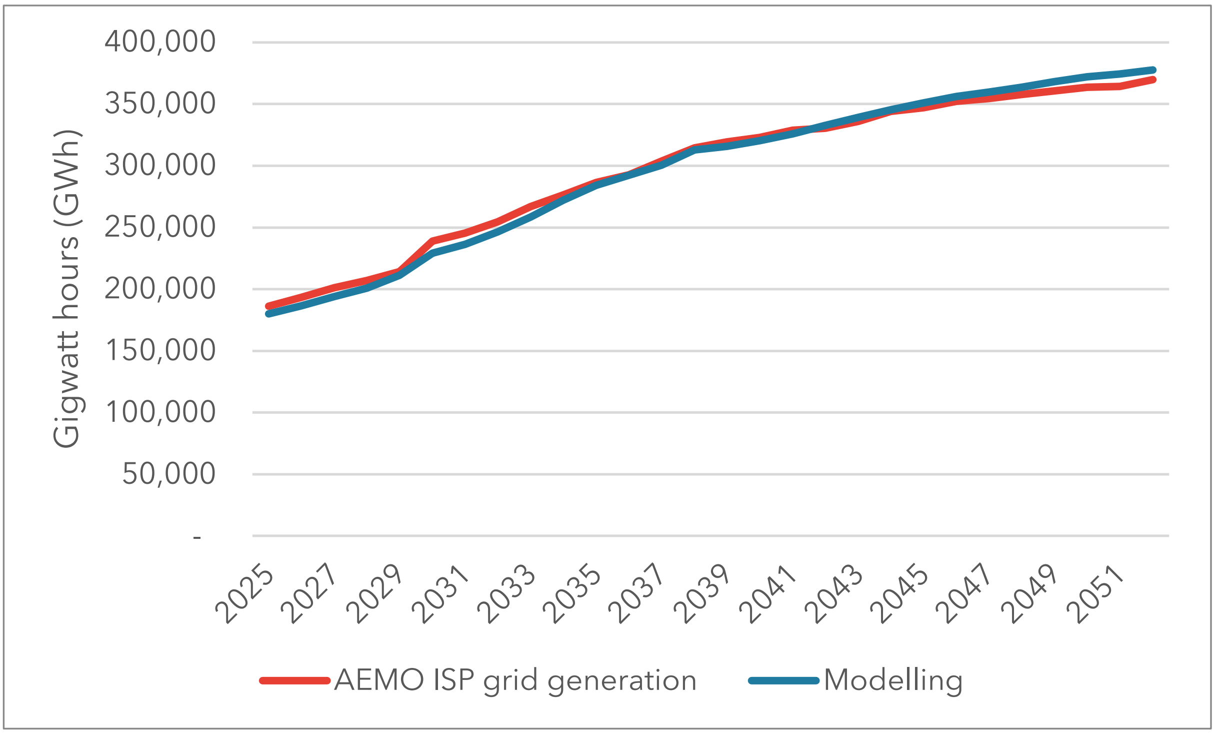
4.5 Electricity generation

In this section AEMO's ISP modelling results are compared to the report modelling results in terms of total electricity generation. As indicated above, this comparison does not include certain supply options not accounted for in the report modelling, such as CER.

4.5.1 Step Change generation

The total generation each year for AEMO's Step Change scenario is compared with the total capacity on an equivalent basis for the report modelling in **Figure 11**. While there are some small differences in capacity year-on-year, the annual generation is very similar for both models over the modelling period.

Figure 11: Step Change - AEMO ISP vs modelled generation (2024/25 to 2050/51)



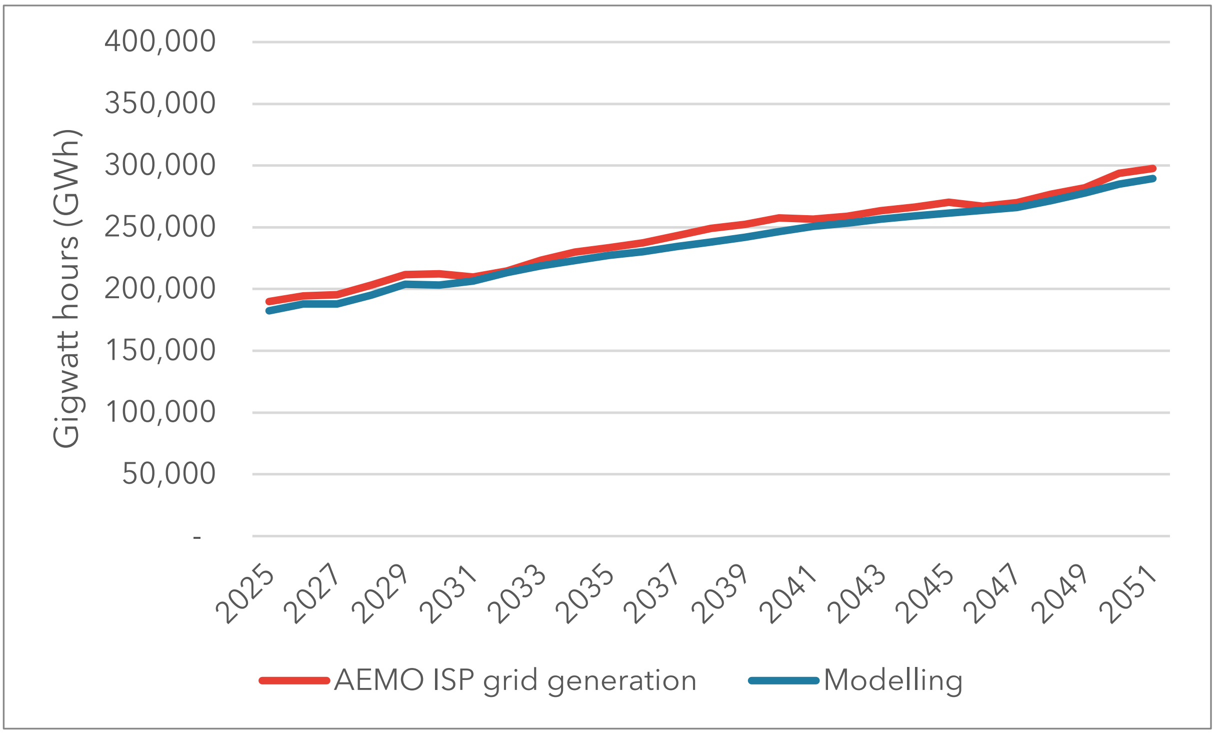
Source: AEMO 2024 ISP and Frontier Economics

4.5.2 Progressive generation

The total generation each year for AEMO's Progressive scenario is compared with the total capacity on an equivalent basis for the report modelling in **Figure 12**. As expected, the results of the two modelling exercises are very similar over the modelling period.

The Progressive scenario results in considerably lower amount of generation. By 2051 annual generation is about 290,000 GWh compared to the Step Change's 375,000 GWh.

Figure 12: Progressive - AEMO ISP vs modelled generation (2024/25 to 2050/51)



Source: AEMO 2024 ISP and Frontier Economics

4.6 Conclusions

The report modelling produces very similar results to AEMO's in terms of capacity levels and generation year-on-year, costs in terms of NPV and sum of real costs for the Step Change and Progressive scenarios and where emissions are included and excluded. These similarities indicated that the report modelling should provide a good basis for comparing the outcomes under AEMO's preferred approach based on using almost solely intermittent renewables and storages, backed up with gas, to meet the needs of consumers in the NEM.

The following report will present an analysis of the cost impacts of introducing nuclear in the mix of NEM generation along the lines as indicated by the Federal Coalition in terms of total quantity of capacity and timing.

5 Transmission costs

5.1 Introduction

An important aspect of the Federal Coalition's proposal to introduce nuclear generation in the plant mix is the consequences for the future costs of high voltage transmission. Depending upon where and when nuclear generators are developed, significant savings could be made in avoided transmission costs.

If the nuclear generators are located near the strong connection points currently serving existing large scale or recently decommissioned coal generator sites, this could save considerable costs associated with configuring and then augmenting over time new REZ zones and flow paths to accommodate renewables as fewer renewables would likely need to be connected to meet demand with base load nuclear in the NEM. The additional economic saving would be lower loss of visual amenity to the rural and regional communities that are bearing the burden of visual pollution from new transmission systems to support AEMO's focus on renewables to meet demand.

The modelling scenarios reported by AEMO in their ISP only include limited costs for REZ and flow path augmentation, usually from the late 2020's onwards. The ISP costs do not include the large scale projects that are so-called commissioned, committed or anticipated as these are treated as sunk costs, even though most have yet to be commenced.[16] These transmission projects are commissioned, committed or anticipated because they are considered necessary to support AEMO's renewable generation and storage projects. At least some of these projects would not be necessary, or necessary at the planned scale and timing if AEMO's preferred approach was not followed and instead nuclear generators were located at or near existing coal fired generator sites.

In the following section the cost of these transmission projects are considered for two reasons. First, the costs of these projects should be added on to the costs of the ISP electricity supply options so that there is transparency of the costs associated with AEMO's preferred approach. Second, the costs of these transmission projects can help inform the costs of connecting and evacuating electricity from the capacity incorporated in the ISP. This information can be used to determine a cost per MW of connected capacity that could be used as a guide of the broad cost savings that could arise from requiring less generation capacity to be connected than incorporated in AEMO's plans. This cost saving is considered in the second report.

5.2 Approach and scope

The analysis of transmission costs was based upon publicly available information including from AEMO, the AER and project proponents.

The scope of analysis included physical measures (easement lengths, type of transmission lines, etc), construction and service timing and the purpose of recent and future projects, with particular interest on the cost estimates of network projects.

16 AEMO (2024), 2024 Integrated System Plan (ISP), pg. 13, Weblink: https://aemo.com.au/en/energy-systems/major-publications/integrated-system-plan-isp/2024-integrated-system-plan-isp

5.2.1 Key sources of data

AEMO's 2024 ISP was used as a database for network projects to be assessed. The actionable and future projects specified in the 2024 edition of the ISP provided a list of network projects to be considered. This includes large scale projects such as Humelink and VNI West. Additionally, to help inform the assessment of transmission costs we have also included Project EnergyConnect, Waratah Super Battery, Central-West Orana REZ and Copperstring 2032. These projects were referred to in previous editions of the ISP and have now been classified as commissioned, committed or anticipated projects rather than actionable or future projects.

Along with the 2024 ISP, the 2020 and 2022 ISPs were also considered to assess how the costs of transmission projects change over time as they develop. This assessment over time helps to evaluate the likelihood that current cost estimated are likely to be accurate.

Fact sheets, reports and updates from proponents and government bodies involved in the construction and development of network projects were also reviewed. Specifically, the documents related to the regulatory investment test for transmission (RIT-T) were reviewed as key sources for updated cost information for projects. The RIT-T is a framework to evaluate the economic and technical efficiency of network investments. The process is overseen by the AER but involves feedback from various groups (stakeholders, registered participants, interested parties) to ensure effective and rational cost-benefit analysis of proposed projects. Submissions to the AER as well as the AER's responses and determinations were utilised to provide more recent cost estimates.

5.2.2 Assumptions and limitations

The majority of the projects considered are still in the planning phase and therefore only a few have undertaken the RIT-T process. Therefore, the ISP figures are used for a significant proportion of the future project cost data. Similarly, accurate physical scopes of projects were difficult to source as the optimal construction paths for projects has not been determined. The ISP documents provided service timing details for projects but most of the future projects are largely undeveloped plans so it is difficult to make firm conclusions on the costs of these projects. Construction times for future projects were also unclear and therefore any findings related to that category were not included.

Any comparison of costs was conducted prioritising the most recent figure first. If figures identified were reported within 6 months of each other, AER cost estimates were prioritised as they are assumed to be the most accurate representation of costs. Where an AER figure was unavailable, the proponent, government and ISP figures were prioritised in that order.

Escalation has been completed using the AER's escalation rates provided within the RIT-T process of various sources. Costs subject to escalation are highlighted in footnotes as well as a comment on the escalation rate applied.

5.2.3 Results

Twenty eight (28) recent, current and future transmission projects where detailed cost data was available was considered. Table 1 presents an overview of the cost data sourced for each of these networks projects. The costs are reported for the most recent ISP data, any recent data provided by the proponent or government bodies that are developing the projects and any AER data available. Key data for these projects are presented in **Table 6**.

Table 6: Transmission projects – summary data

Project	Physical measures	Construction Start	Earliest Feasible Full Service Timing (ISP) [1]	Cost estimate ISP[2]	Proponent/ Government	AER Latest
Project EnergyConnect	~900km of transmission lines	February 22	Stage 1: December 2024 Stage 2: July 2027	$1,990 million (±30%) (2020 ISP)		ElectraNet - $546 million[3] Transgrid - $2,169 million[4]
Waratah Super Battery	800 MW / 1,680 MWh SIPS battery service Augmenting existing transmission lines and substation equipment	May 2023[6]	2025		$1,019 million[7]	
Central-West Orana REZ	~90km of 500kV lines and ~150km of 330kV lines	2024	August 2028	$650 million (±30%) (2020 ISP)	$5,450 million [9]	
CopperString 2032	~850km of new transmission line + ~250km additional transmission to connect new renewable projects	2024[11]	June 2029	$5,000 million	$6,000 million[12]	
HumeLink	~365km of transmission line New or upgraded infrastructure at four substations	2025 [14]	Northern: July 2026 Southern: December 2026	$4,892 million (-5% to +12%)	$4,920 million[15]	$4,900 million[16]
Hunter-Central Coast REZ Network Infrastructure	Upgrades to existing substations and infrastructure		December 2027	$59 million (±50%)	$453 million (±50%)[18]	
Sydney Ring South	~114km 500kV transmission lines New substation and augmentation to existing substations		September 2028	$221 million (±50%)	$1,550 million (-30% to +40%)[20]	
Sydney Ring North (Hunter Transmission Project)	~110km 500kV above ground transmission lines	2026[22]	December 2028	$1,099 million (±50%)		
Gladstone Grid Reinforcement	Establish new substation and ~200km of 500kV of transmission lines	2026[25]	March 2029	$1,492 million (±50%)[26]		

	Upgrading existing lines (~100km)[24]					
Mid North SA REZ Expansion	~130km of 275kV transmission lines[27]	2026 Proposed[28]	July 2029	$389 million (±50%)	$416 million[29]	
Waddamana to Palmerston transfer capability upgrade			July 2029	$201 million (±30%)	$113 million[31]	
Victoria-New South Wales Interconnector West (VNI West)	~205km of transmission lines[33]	Actionable	December 2029	$3,600 million (±30%)	$3,964 million (±30%)[34]	$3,964 million[35]
Project Marinus (Including NWTD)	~255km of undersea HVDC cable + ~90km of underground HVDC cable (NWTD component comprises ~66km new transmission + upgrading ~172km existing[37]		Stage 1: December 2030 Stage 2: December 2032	Stage 1: $3,800 million (±30%) Stage 2: $2,700 million (±30%)	Stage 1: $4,040 million Stage 2: $2,535 million[38]	
New England REZ Network Infrastructure Project		2025 Proposed[40]	Part 1: June 2031 Part 2: June 2033	$3,700 million (±50%)	$4,757 million (±50%)[41]	
Queensland SuperGrid South	~430km of 500kV transmission lines ~60km of 275kV transmission lines[43]	2027[44]	September 31	$3,287 million (±50%)[45]		
Central-West Orana REZ Extension			2030/31	$243 million (±50%)	$906 million (±50%)[47]	
Cooma-Monaro REZ Expansion	~126km of 330kV transmission line + two transformers[49]		2030/31	$512 million (±50%)		
Darling Downs REZ Expansion			2027/28	$28 million (±50%)		
North Queensland Energy Hub Extension	~190km of 275kV transmission[52]		2030/31	$651 million (±30%)		
Facilitating Power to Central Queensland	~18km of 275kV transmission[54]		2030/31	$173 million (±50%)		
Queensland SuperGrid North	~750km of 500kV transmission lines Additional substations[56]		2032/33	$4,184 million (±50%)		

Mid North SA REZ Extension			Option 1a: 2029/30 Option 1b: 2029/30	Option 1a: $350 million (±50%) Option 1b: $70 million (±50%)	
North West Tasmania REZ Expansion			2029/30	$28 million (±30%)	
Central Highlands REZ Extension	~79km of 220kV transmission lines[60]		2032/33	$274 million (±30%)	
Western Victoria Grid Reinforcement			2032/33	$1,140 million (±30%)	
Eastern Victoria Grid Reinforcement			2030/31	$297 million (±50%)	
Queensland - New South Wales Interconnector (QNI Connect)	~600km of transmission lines[64]	2026[65]	March 2033	$2,518 million (±50%)	
Far North Queensland REZ	~300km 275kV transmission line upgrade of existing lines[66]	2021	2024		$40 million[67]

Sources:

[1] Page 61, Table 6 of the AEMO ISP (2024)

[2] Page 61, Table 6 of the AEMO ISP (2024)

[3] Page 1 of the AER - Letter to ElectraNet – Project EnergyConnect Final decision (May 2021) – $17/18 figure escalated to $22/23 using AER escalation factor of 1.1930

[4] Page 1 of the AER - Letter to Transgrid – Project EnergyConnect Final decision (May 2021) – $17/18 figure escalated to $22/23 using AER escalation factor of 1.1930

[5] Available on the Transgrid EnergyConnect project page; available at: EnergyConnect - Australia's Largest Transmission | Transgrid

[6] Found in the project history of the Waratah Super Battery project page; available at: Sydney Ring - Infrastructure Pipeline

[7] Page 48 of the EnergyCo NSW Network Infrastructure Strategy (May 2023)

[8] Available on the EnergyCo project website for the Waratah Super Battery; available at: Waratah Super Battery | EnergyCo (nsw.gov.au)

[9] Page 11 of the EnergyCo CWO REZ public report infrastructure planner recommendation (May 2024), https://www.energyco.nsw.gov.au/sites/default/files/2024-05/cwo-rez-public-report-infrastructure-planner-recommendation-may-2024.pdf

[10] Available at the EnergyCo project page for the Central-West Orana Renewable Energy Zone; available at: Central-West Orana Renewable Energy Zone

[11] Available on the PowerLink Queensland Copperstring 2032 project page; available at: CopperString 2032 | Powerlink

[12] Comments made by Deputy Premier Cameron Dick – Flagged a more than 20% rise in costs of the massive Copperstring project, Townsville Bulletin (September 2024)

[13] Available on the state infrastructure page for CopperString 2032; available at: What is CopperString 2032 and why is it important for Queensland's renewable energy future?
[14] Available in the timeline on the Transgrid HumeLink Project page; available at: HumeLink: Connecting Wagga Wagga, Bannaby and Maragle | Transgrid
[15] Page 11 of the Transgrid HumeLink CPA stage 2 A.1 Application (March 2024)
[16] Page 1 of the AER letter to Transgrid RIT-T (August 2023)
[17] Page 1 of the Transgrid HumeLink Project update (February 2023)
[18] Page 39 of the NSW Network Infrastructure Strategy (May 2023) - $20/21 figure escalated to $22/23 using AER escalation factor of 1.1326
[19] Available on the Australia New Zealand Infrastructure Pipeline NSW Hunter-Central Coast REZ project page; NSW Hunter-Central Coast REZ - Infrastructure Pipeline
[20] Page 8 of the Transgrid ISP Preparatory Activities for Sydney Southern Ring (June 2023)
[21] Available on the Sydney Southern Ring project page on the Australia New Zealand Infrastructure Pipeline page; available at: Sydney Southern Ring - Infrastructure Pipeline
[22] Page 11 of the EnergyCo Hunter Transmission Project Update (May 2024)
[23] Hunter transmission project page on the EnergyCo website; available at: Hunter Transmission Project | EnergyCo (nsw.gov.au)
[24] Page 100 of the AEMO Transmission Expansion options report (2023)
[25] Powerlink project page for Calliope river transmission; available at: Calvale to Calliope River Transmission Line Project | Powerlink
[26] Page 100 of the AEMO Transmission Expansion options report (2023); combined Option 1 + Option 2
[27] Page 10 of the Preparatory Activities Mid-North-SA REZ (June 2023)
[28] Page 14 of the Preparatory Activities Mid-North-SA REZ (June 2023)
[29] Page 15 of the Preparatory Activities Mid-North-SA REZ (June 2023)
[30] Page 5 of the Preparatory Activities Mid-North-SA REZ (June 2023
[31] Page 28 of the TasNetworks Revised Proposal Contingent Projects Report (November 2023)
[32] Page 24 of the TasNetworks Revised Proposal Contingent Projects Report (November 2023)
[33] Page 48 of the VNI West PACR Volume 1 (May 2023)
[34] Page 48 of the VNI West PACR Volume 1 (May 2023), escalated from $20/21 dollars to $22/23 dollars using the AER escalation factor of 1.1326
[35] Page 11 of the AER Determination of Transgrid VNI West Stage 1 Early Works Contingent Project (May 2024)
[36] Available on the Transgrid project innovation page for the VNI West; available at: Victoria to NSW Interconnector West | Transgrid
[37] Page 8 & 9 of the AER Marinus Link RIT-T Update (April 2024)
[38] Page 2 of the AER Marinus Link RIT-T Update (April 2024)
[39] Available on the home page of the Marinus Link website; available at: Marinus Link
[40] Page 1 of the NE REZ fact sheet (August 2022)
[41] Page 35 of the EnergyCo NSW Network Infrastructure Strategy (May 2023) - $20/21 figure escalated to $22/23 using AER escalation factor of 1.1326
[42] Available on the EnergyCo New England Transmission Project page; available at: New England Transmission Project | EnergyCo (nsw.gov.au)
[43] Page 52 of the AEMO Transmission Expansion options report (2023)
[44] Page 40 of the QEJP – Queensland Supergrid Infrastructure Blueprint (September 2022)
[45] Page 52 of the AEMO Transmission Expansion options report (2023)
[46] Page 40 of the QEJP – Queensland Supergrid Infrastructure Blueprint (September 2022)

[47] Page 31 of the EnergyCo NSW Network Infrastructure Strategy (May 2023) - $20/21 figure escalated to $22/23 using AER escalation factor of 1.1326
[48] Page 64, Table 7 of the AEMO ISP (2024)
[49] Page 84 of the AEMO Transmission Expansion options report (2023)
[50] Page 64, Table 7 of the AEMO ISP (2024)
[51] Page 64, Table 7 of the AEMO ISP (2024)
[52] Page 92 of the AEMO Transmission Expansion options report (2023)
[53] Page 64, Table 7 of the AEMO ISP (2024)
[54] Page 102 of the AEMO Transmission Expansion options report (2023)
[55] Page 64, Table 7 of the AEMO ISP (2024)
[56] Page 48 of the AEMO Transmission Expansion options report (2023)
[57] Page 40 of the QEJP – Queensland Supergrid Infrastructure Blueprint (September 2022)
[58] Page 64, Table 7 of the AEMO ISP (2024)
[59] Page 64, Table 7 of the AEMO ISP (2024)
[60] Page 123 of the AEMO Transmission Expansion options report (2023)
[61] Page 64, Table 7 of the AEMO ISP (2024)
[62] Page 64, Table 7 of the AEMO ISP (2024)
[63] Page 64, Table 7 of the AEMO ISP (2024)
[64] Available at the QNI Interconnector project page on Australia New Zealand Infrastructure Pipeline; Queensland New South Wales Interconnector - Infrastructure Pipeline
[65] Page 29 & 30 of the Transgrid – ISP Preparatory Activities – QNI Connect (June 2023)
[66] Available at the Kaban Green Power Hub home page; Clean Energy for Queensland (2024)
[67] Available at the AEMO: Powerlink - Notice of consultation developing the Northern QLD REZ (June 2021)

Many of the projects in **Table 6** are considered 'future' projects and therefore have not progressed beyond a preliminary planning stage, therefore detailed cost estimates from the proponents or AER were unavailable. The ISP cost estimates have a wide margin of error - between 30% and 50%.

The costs from **Table 6** are summarised into **Table 7** in terms of a lower, mid and high range of costs. On a mid-range estimate the transmission projects in **Table 6** are estimated to cost about $55 billion. However, it is unclear whether the projects above are exhaustive as the ISP includes costs for REZ and flow path augmentation, but these costs could be partly reflected in **Table 6**.

Table 7: Range of transmission costs

Range	Cost estimate (2024 dollars)
Lower bound cost estimate	$42,928
Mid cost estimate	$54,435
Upper bound cost estimate	$66,103

5.2.4 Risk of cost blowouts

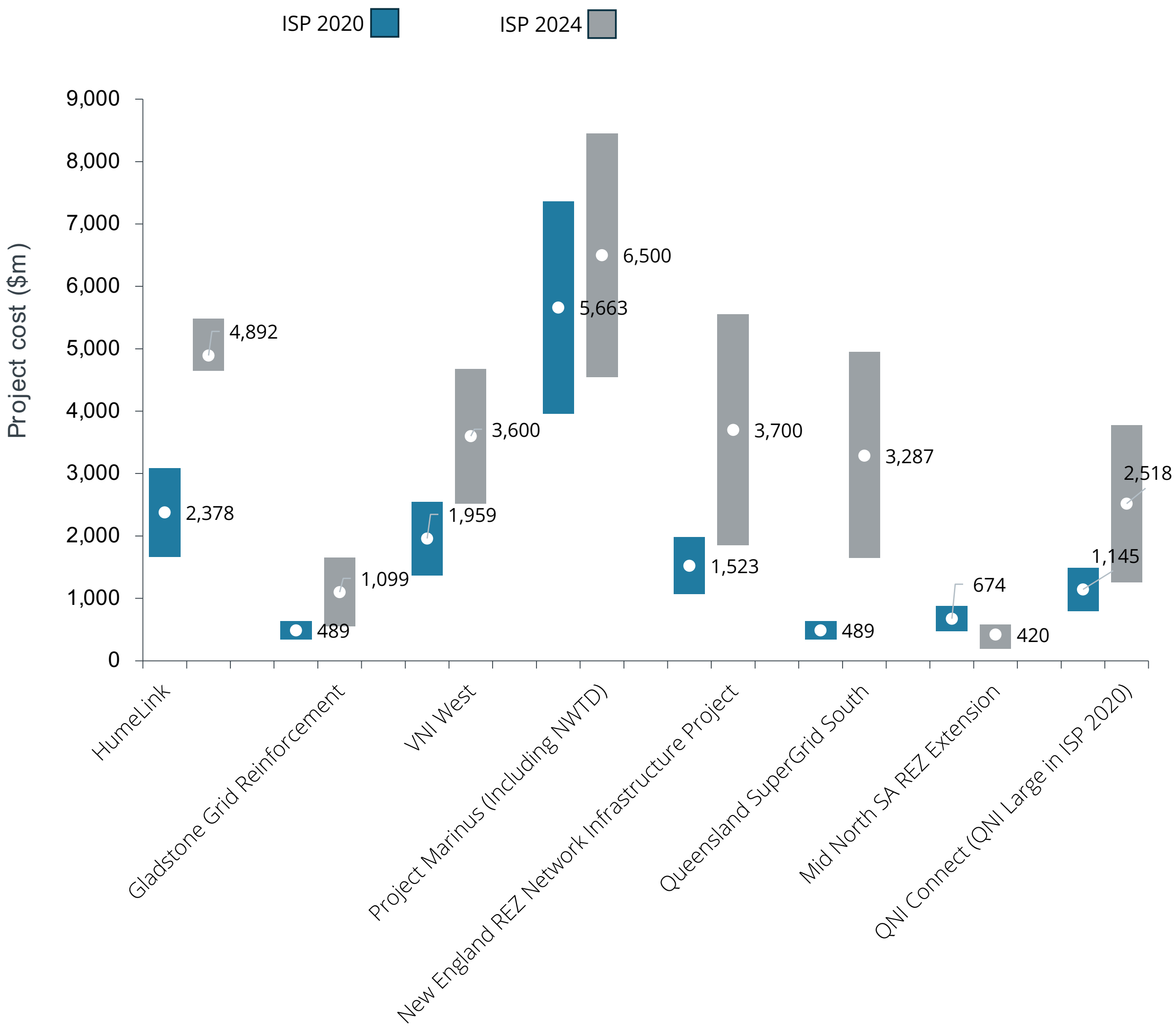
NEM transmission projects are notorious for greatly exceeding their estimated costs. It is doubtful that the estimated upper bound of costs presented in **Table 7** is, in fact, the upper bound.

To assess the likelihood that costs will blowout past existing estimates projects, we have compared cost estimates for projects that appeared in the 2020 and revised costings presented in the 2024 ISP. These projects are shown **Figure 13**. The teal bars show the 2020 ISP cost range – from lower to upper – and the white dot shows the mid estimate. The grey bars show the 2024 ISP cost range – from lower to upper – and the white dot shows the mid estimate.

It is immediately clear that the 2020 ISP cost estimates for the projects presented in **Figure 13** were wildly wrong (except for, to-date, the mid north SAEZ extension) if the updated 2024 ISP estimates are to be accepted. In some cases, the 2024 ISP lower ranges are now higher than the 2020 ISP upper range for the same project (see for example VNI West, Humelink, Gladstone Grid Reinforcement, Queensland SuperGrid South and, almost, New England REZ Network Infrastructure Project).

It should be noted that there have been material changes to a number of these projects resulting in these revised cost estimates, however, assuming a similar outcome for actionable and future projects would suggest significant underestimates for projects included in the 2024 ISP.

Figure 13: Comparison of 2020 ISP and 2024 ISP transmission cost estimates



Source: Frontier Economics based on AEMO ISP and other sources documented in Table 6.

5.2.5 Unit costs of transmission per MW of generation installed

It is unclear how much of the transmission costs presented above accounts for the full additional costs of preparing the NEM to accommodate the generation capacity contemplated under AEMO's preferred approach as indicated by the Step Change scenario. It is likely that additional transmission investment is required.

One approach for determining the incremental transmission cost for each additional MW of installed generation capacity is to divide the total costs of transmission by the expected increase in capacity between now and 2050. As indicated above, the increase in generation capacity under Step Change is about 130,000 MW. This suggests that the transmission cost estimates are likely to be, at least, $500,000 per MW based on the upper estimate of around $62 bn in transmission costs to support AEMO's plan. It is more likely than not that the actual costs will be higher than this as based on past experience transmission projects are typically overbudget and we are unlikely to be including all the transmission costs. To put this $62 bn cost into perspective, an assessment of recent AER post tax revenue models reported that the current total value of regulatory asset base of the NEM transmission businesses is $26 bn. The $62 bn expenditure on transmission will, conservatively, increase the asset base of the networks to $88 bn, which represents an increase of about 240%.

In any case, when considering the costs of the energy transition, it is important to include the costs of transmission transparently with the generation costs rather than treating it as sunk. By way of example, not including the cost of emissions, under AEMO's Step Change, the sum of the real costs of the electricity supply options are $580 bn. At the very least, a further $62 bn should be added to these costs, bringing the total costs of the electricity sector transition to $642 bn, not including the cost of emissions and not including the costs of consumer energy resources.

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