frontier economics

Report 2 - Economic analysis of including nuclear power in the NEM

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1 Summary

1.1 Two reports

This is the second report in this series on modelling the economics of including nuclear in the National Electricity Market. The objective of the first report, *Report 1 – Developing the base case to assess the relative costs of nuclear power in the NEM*, was to establish a proper basis for comparing the cost impacts of nuclear power.

Many commentators simply and erroneously compared the cost of a renewable generator (wind or solar) plus the costs of back-up generation to the capacity and operating costs of a nuclear power station. Such a crude assessment is an incorrect and misleading basis of comparison because it does not account for the fact that much more renewable capacity is required to produce the same amount of electricity compared to a nuclear power station. Nor does it account for the requirement to store surplus electricity from renewable sources as well as the back-up generation. Such simple comparisons also neglect to take into account the enormous amount of investment required to connect renewable generators located in areas where there is presently no or inadequate transmission network capacity. There is also an enormous cost to rural and regional Australians who have to bear a disproportionate burden of the energy transition – first with the loss of jobs in the coal generation sector and now they have to bear the loss of amenity from living with wind and solar farms in their community and extensive new and augmented transmission networks across their land. Consideration of these externalities is beyond the scope of this report but they deserve to be considered as this loss of amenity is a legitimate economic cost.

As argued in Report 1, a more appropriate basis of comparison is the *total cost of a power system* – generators, storages, and transmission – to reliably and securely meet demand. AEMO prepares an Integrated System Plan (ISP) every two years that provides this information. AEMO produces scenarios that they consider most appropriately meets the requirements of Australian consumers for the next quarter century. These scenarios also constrain the model to produce outcomes that are consistent with the Federal Government's 82% target as well as the array of State based targets as set out in Table 1 of *Report 1* (p 18). The ISP therefore provides an excellent base case against which a scenario that includes nuclear capacity, which AEMO does not analyse, can be used to estimate the cost differences between AEMO's preferred energy future with a future that includes nuclear power.

Report 1 described a modelling exercise that compared the modelling outcomes undertaken for this report with AEMO's ISP results. The aim of the modelling exercise set out in Report 1 was to show the extent to which the report modelling replicated AEMO's ISP modelling. If the report modelling adequately replicated AEMO's ISP modelling we could use this model to compare, on a consistent basis, different modelling scenarios, including where nuclear is used in the NEM.

We found that the report modelling replicated AEMO's ISP modelling closely. This result meant that the report modelling would provide a good basis for comparing the modelling outcomes of AEMO's preferred energy transition with one that included nuclear power.

1.2 Funding and direction of work

The work undertaken for this 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.

The modelling approach and assumptions do not necessarily reflect the Federal Coalition's view about how nuclear power would be included in the National Electricity Market (NEM). All assumptions used in this modelling exercise are Frontier Economics' and we fully directed, controlled all the work contained in this report.

1.3 Scope of modelling and analysis

1.3.1 Focus on NEM

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 but can see no good reason why the nature of the results and conclusions found in this NEM based study would not also apply to Western Australia. The Northern Territory electricity system is too small to accommodate a large-scale reactor, so this region would likely continue to be served by a combination of thermal and renewable generation to meet demand.

1.3.2 Costs not included

When we compare the outcomes of our modelling with the results of the ISP we exclude the following costs from both alternatives:

- DSP+USE (Demand Side Participation + Unserved Energy)
- REZ augmentation
- Flow path augmentation

The modelling achieves the reliability target so there are no unserved energy costs (USE) for scenarios which include nuclear energy.

Like AEMO, we do not model the costs of consumer energy resources (CER) or the costs to consumers of switching their appliances and equipment from gas to electricity.

In this report we do include an analysis of transmission costs, but not low voltage distribution costs.

1.3.3 Dollar terms

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.

1.3.4 Scenarios modelled

We model two of the three scenarios that AEMO model in their ISP – the so-called Step Change and Progressive scenarios. AEMO also produces a third scenario in the ISP called Green Energy Exports, which we don't model.[1]

AEMO consider the Step Change the most likely outcome 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. 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.

As noted above, 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. AEMO assigns a 15% chance of their Green Energy Exports scenario occurring. Due to the improbability of this scenario the Green Energy Exporter case is not modelled in this report.

It is worth noting that many countries claim they will also be major green energy exporters. With Australia's high costs of land, capital and labour, difficult and uncertain planning provisions, and distances from many high value markets, other countries are probably better placed to become green energy exporters. Australia has many other strengths it can take advantage of in the future energy market.

As part of discussions to help inform our comparative modelling exercise, the Federal Coalition confirmed that they consider the demand forecast embodied in the Progressive scenario is more consistent with their view of the most likely transition of the electricity market. This contrasts to the Federal Labor Government's pursuit of the Step Change scenario. This difference has significant implications for how government policy supports the orderly transition of the electricity system. For example, to support a Step Change world, as compared to the Progressive scenario, much more land will be required to support many more wind and solar farms. Also, much more transmission will have to be rolled out across rural and regional Australia to allow a larger number of wind and solar farms to transmit their electricity to across the land to supply the main sources of demand in Australian cities. The required land and transmission inputs will need to be provided in advance to give investors certainty. This means that a larger amount of money will have to be spent in advance to facilitate the development of a larger number of wind and solar farms under Step Change.

To help understand the cost differences between the Federal Labor Government's Step Change approach and the Progressive scenario, which is more consistent with the Federal Coalition's view of the likely transition, a comparison of the modelled costs between these two scenarios shows that a Progressive future which includes nuclear power is 44% cheaper than the Step Change future as envisaged by the Federal Labor Government, which involves meeting demand with mainly renewables and energy storages. To achieve these cost savings, it will be important to

[1] AEMO (2024), Integrated System Plan for the National Electricity Market, A roadmap for the energy transition, Weblink: https://aemo.com.au/-/media/files/major-publications/isp/2024/2024-integrated-system-plan-isp.pdf?la=en, p9.

plan for a system that includes nuclear as soon as possible, especially as this relates to the transmission system.

A comparison of modelled costs across the different scenarios is summarised in Section 1.5.1 and detailed in Section 0 of this report.

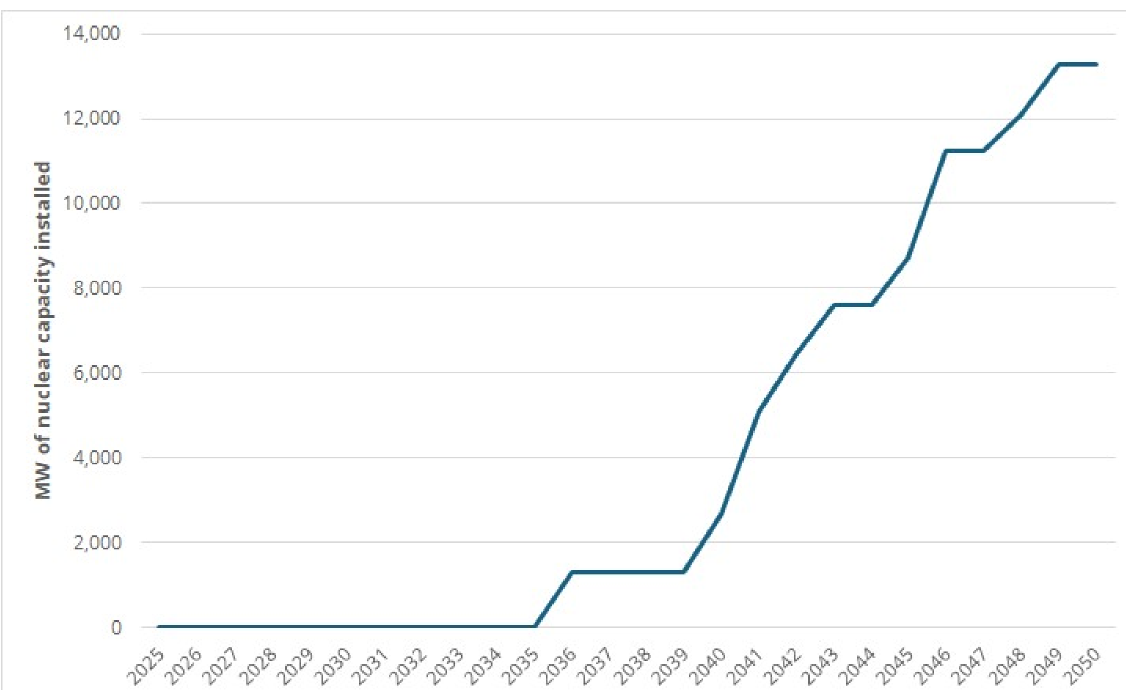
1.4 Key assumptions

Based on an extensive review of the literature, we have made the following modelling assumptions about nuclear power:

- Capital costs are $10,000 per kilowatt of capacity
- Capital costs improve 1% per year based on conservative learning rates for repeated commissioning of a technology type
- Variable costs of $30 per megawatt hour, which covers fuel, fixed and variable (non-fuel), operating and maintenance costs, network costs and decommissioning costs.

The pattern of commissioning of nuclear capacity is a model input and occurs from 2036 onwards across the NEM regions that currently have large coal fired generators that nuclear power stations progressively replace. The regions where nuclear power stations are assumed to be commissioned are NSW, Queensland and Victoria. In total, just over 13,000 MW of nuclear power capacity is assumed to be commissioned across these three jurisdictions. The assumed pattern of NEM nuclear generator commissionings is shown in **Figure 1** and, for the purposes of the modelling exercise, new nuclear generation capacity was commissioned as coal generators were decommissioned.

Figure 1: Assumed pattern of NEM nuclear generator commissionings



In the report modelling, some existing coal fired generators in the NEM are maintained beyond AEMO's early closure dates to ensure that there is sufficient generation capacity to meet the system reliability requirements. The delay to early closure of coal affects about 65% of current coal generation fleet in the NEM. The difference in the average rate of emissions between AEMO's early closure of coal and the report modelling for Step Change and progressive scenarios is shown in Section 4.4. The report modelling ensured that the net-zero target was met by 2050 and, in fact, it achieves a lower rate of average emissions faster than AEMO's approach and maintains a lower rate of emissions thereafter.

As noted on page 15 of Report 1, AEMO's assumed coal closure timetable is well in advance of the closure dates announced by the generators. If coal generators are closed according to the dates announced by the owners there will not be much of a difference in the emissions under these conditions as compared to the report modelling. A comparison of the closure dates announced by the generators and the closures assumed in the report modelling is shown in **Figure 2**.

Figure 2: Comparison of closures assumed for modelling and generator announced closures

Source: AEMO and Frontier Economics

If the recent experience with the extension of the operational lives of Yallourn and Eraring power stations was repeated with other power stations, potentially, the emissions in report modelling may be less than actual emissions over the modelling period.

In any case, extended coal plant operations could be avoided to an extent if gas prices were lowered to allow existing gas generators to displace the highest cost large-scale generators such as Gladstone and Eraring. These coal generators pay relatively high prices for their coal as their fuel is shipped from inland to these generators which are located near major coal export terminals where the coal can just as easily be exported.

While the Coalition has confirmed that a key objective of their energy policy is to reduce gas prices, the likely impact of gas price reductions has not been modelled.

1.5 Results and conclusions

1.5.1 Costs

The results of the report modelling shows that including nuclear in the NEM results in substantial costs savings compared to AEMO's approach of using mainly renewables and energy storage to meet Australia's growing electricity demand. The figure below summarises our findings of the sum of annual costs of the scenarios for the period from 2025 to 2051, including the impact of different transmission costs.

AEMO's preferred Step Change energy future is, by far, the most expensive scenario modelled, with the combined generation and transmission costs of $595 billion.[2] As noted above, these costs do not include Western Australia, the Northern Territory, consumer energy resources or distribution costs.

For AEMO's Step Change scenario, using nuclear power, the total NEM system costs can be reduced by about $150 billion from $594 billion to $446 billion, or about $5.5 billion per annum. The inclusion of nuclear power in the NEM in the Step Change scenario is 25% cheaper than AEMO's renewables and storage approach.

For AEMO's Progressive scenario, using nuclear power, the total NEM system costs can be reduced by $106 billion from $437 billion to $331 billion, or about $4 billion per annum. The inclusion of nuclear power in the NEM in the Progressive scenario is also 25% cheaper than AEMO's renewables and storage approach.

As explained above in Section 1.3.4, the Federal Coalition's view about the energy transition is more consistent with the Progressive scenario including nuclear power, which is 44% cheaper at $331 billion compared to the Federal Labor Government's AEMO's Step Change scenario, which is estimated to cost $594 billion in the report modelling.

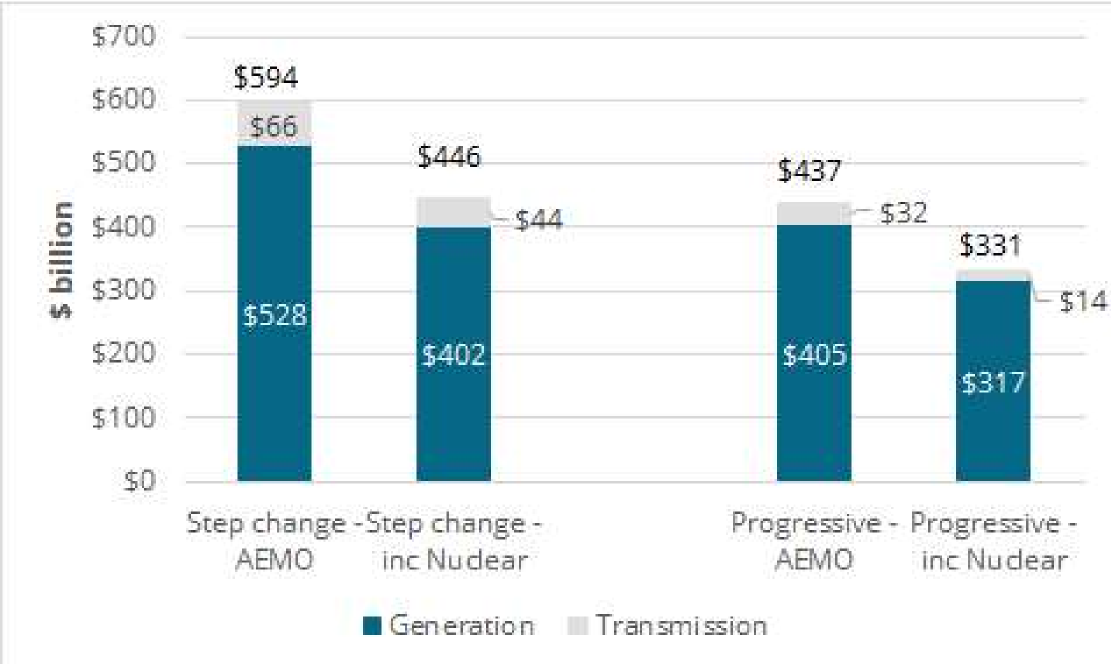
The cost differences between the AEMO cases and the nuclear alternative are so large that the costs of nuclear capacity assumed in the modelling could double on a sustained basis before the costs of AEMO's approach and the nuclear alternative were equivalent. It is very unlikely that the inclusion of nuclear power in the NEM would, in practice, ever be more expensive than AEMO's approach.

It is important to emphasise that aside from not including the costs of Western Australia or the Northern Territory in the report modelling we do not include the costs of consumer energy resources (rooftop solar panels and behind-the-meter batteries) nor the costs of Demand Side Participation nor the costs of upgrades and extensions to the distribution networks, nor the costs to consumers to switching appliances and equipment that use gas to electricity. These costs were

2 In Report 1 on page 8 it was reported that the total costs of AEMO's Step Change ISP costs of $580, which included some REZ and Flow Path augmentation costs, in addition to other transmission projects that are not included in these costs, Demand Side Participation (DSP) and Unserved Energy costs (USE) - see Section 4.6.1 for an explanation of a correction of the reported transmission costs from $62 billion to just over $66 billion. The difference between the total cost estimate of $594 billion reported above is primarily due to the fact that the modelling results presented in this report strip out any costs associated with REZ and Flow Path augmentation, DSP and USE costs – that is, the report modelling focuses on generation costs. For comparison, the report modelling estimated a generation only cost of $528 billion and, on an equivalent basis, the ISP determined a cost of $526 billion. It is important to note that, for the purposes of the analysis presented in this Report 2, the absolute levels of costs are not as important as the relative costs between the options as this report is focussed on the comparative costs of AEMO's renewables only future and one that also includes nuclear power in the NEM. Report 1 was developed to compare AEMO's absolute costs with the report modelling absolute costs.

not accounted for to maintain consistency with the ISP which also does not account for these costs.

These missing costs will be very large and when they are taken into account the total cost of the transition of the electricity sector will be well above a trillion dollars over the next 25-30 years if Australia continues with AEMO's transition plans.



1.5.2 Capacity and energy

While the inclusion of nuclear is often portrayed as being at the exclusion of renewables and storages, the deployment of nuclear in the report modelling was associated with strong growth of renewables and storages in the NEM. Indeed, renewables continue to dominate the provision of electricity to consumers even with nuclear power.

Under the nuclear-inclusive Step Change scenario, wind and solar capacity grows from 24,000 MW in 2025 to 72,000 MW by 2051 when 13,000 MW of nuclear capacity is included in the NEM. Nuclear capacity accounts for just 8% of NEM capacity in this scenario. Wind and solar generate 60% of the electricity under Step Change with nuclear included. By comparison, nuclear power stations generate 29% of electricity.

Under the nuclear-inclusive Progressive scenario, wind and solar grows from 24,000 MW to about 46,000 MW by 2051 with nuclear power included in the NEM. Under this scenario, wind and solar generate about 50% of electricity and nuclear generates 38% of electricity with just 13% of total capacity.

One of the effects of including nuclear power in the NEM is that only about half the amount of gas generation is required as compared to AEMO's approach under Step Change. This is because nuclear power is providing some of the back-up for the system that would otherwise be filled by gas. The effect of halving the demand for gas for gas powered generation will be that more gas is available for industrial gas users. The lower demand for gas powered generation will ease pressure on gas prices for industrial gas users.

1.5.3 Other policy options

Whether Australia chooses AEMO's pathway or the lower cost solution including nuclear power, there will be substantial costs involved in supplying Australia's growing electricity demand in any case.

Some may consider that these costs can be largely avoided by continuing with coal generation. This is not the case. Every coal fired generator that currently exists will reach the end of their operational life during the modelling period to 2051. Indeed, many coal generators are close to the end of their operational lives now. As shown in Section 3.2.1, the assumed pattern of coal closures used in the report modelling is very similar to the announced by the owners. Nuclear power stations are modelled to replace around 65% of existing coal fired generators.

We have not modelled a system where existing coal generators are re-developed and new ones developed, as firstly, it is not a policy of any major Australian political party, and secondly, it is not necessary as it can be easily shown that replacement coal is unlikely to result in lower costs than replacing coal with nuclear power in the NEM. This is because the capital cost for a replacement coal generator with carbon capture and storage - which, realistically, is the only way existing coal generators would be permitted to repower or a new coal fired generator to be built - is, according to the GenCost estimate, about the same as used in the modelling in this report for nuclear power (about $10,000/kW[3]). Using AEMO's ISP assumptions on coal costs per MWh (fuel, variable and fixed O&M), assuming black coal (brown coal is extremely unlikely to be an option), the average cost of coal energy easily exceeds the $30/MWh used in this modelling for nuclear. With the fixed costs of replacement coal being equivalent to nuclear, and having a shorter life than nuclear, and with higher variable costs, replacement coal generation would cost more than nuclear power.

1.5.4 Summary

From an economic cost perspective, the economy is much better off in the Progressive scenario with nuclear power in the energy mix compared to AEMO's preferred Step Change solution using primarily renewables and storages.

The cost difference over the modelling period between AEMO's preferred Step Change system of $594 billion with a Progressive future including nuclear power costing $331 billion is $263 billion, or about $10 billion per annum on average over the modelling period, or 44% cheaper than AEMO's preferred Step Change approach to managing Australia's energy future.

As well as nuclear being cheaper than a power system made up almost entirely of renewables and energy storages, it is also likely to be as economic, or even more economic, as replacing the fleet of existing coal generators that must retire between now and 2050 with new coal generators.

Including nuclear power in the NEM could also help lower the economic costs imposed on rural and regional Australians by avoiding the loss of amenity from having so many wind and solar farms and new and augmented transmission networks on their land.

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3 CSIRO – Paul Graham, Jenny Hayward and James Foster (2024), *GenCost 2023-24*, pp 46-47, Weblink: https://www.csiro.au/-/media/Energy/GenCost/GenCost2023-24Final_20240522.pdf

2 Introduction

2.1 Report 1 – previous report

Frontier Economics recently published a report[4] that described modelling to, as closely as possible, replicate AEMO's Step Change and Progressive Integrated System Plan (ISP) scenarios as presented in their 2024 ISP. [5]

As foreshadowed in Report 1, we would produce a second report that described the modelling of the costs of including nuclear power generation into the NEM.

The objective of our first report was to establish a base case – AEMO's ISP modelling - against which we could compare the economic costs of including nuclear power to AEMO's two main scenarios - Step Change and Progressive.

The ISP produces a wide range of outputs and a key output is the economic cost of the modelling scenarios developed by AEMO. AEMO's modelling seeks to produce the lowest cost mix of electricity supply and storage options given a wide range of constraints. These constraints include a requirement to meet various government policies such as renewable electricity targets. Another constraint is that it must minimise a cost of carbon given an assumed carbon price and carbon budget, even though there is no government policy to have a carbon price. The modelling must also achieve a system that meets the reliability target and develops a system that is secure. The government renewable energy and carbon pricing constraints have an overwhelming influence on the modelled outcome.

AEMO does not model the inclusion of nuclear power in the NEM. The reason given by the CEO of AEMO, Daniel Westerman, at the Clean Energy Summit on 16 July 2024 seems to be that "Even on the most optimistic outlook, nuclear power won't be ready in time for the exit of Australia's coal-fired power stations".[6] That is, AEMO's own assumptions about coal closures, which generates the urgency for replacement generation, prevents their consideration of nuclear power options.

As shown in Report 1, AEMO assume much earlier closure of coal fired generators than the owners of these generators. Moreover, as explained in our first report, in recent times as coal fired generators notify government of their planned closure (e.g. Yallourn and Eraring) State governments have moved to extend their operational life. This most recent occurrence of state government extensions was the announcement by the new Queensland Government to invest $1.4 bn into maintaining the state's coal power fleet[7].

4 Frontier Economics (2024), *Report 1 – Developing the base case*, October, Weblink: https://www.frontier-economics.com.au/wp-content/uploads/2024/11/Report-1-Base-case-report-Nov-14-2024_v2.pdf

5 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

6 Australian Financial Review (2024), "AEMO chief warns no chance of nuclear replacing ageing coal plants", Angela Macdonald-Smith, Weblink: [Paywalled] https://www.afr.com/companies/energy/aemo-chief-warns-no-chance-of-nuclear-replacing-ageing-coal-plants-20240715-p5jtur

7 Renew Economy (2024), "Coalkeeper, Queensland style: LNP commits $1.4 bn, sets utility KPIs, to keep coal generators on line", Giles Parkinson, Weblink: https://reneweconomy.com.au/coalkeeper-queensland-style-lnp-commits-1-4-bn-sets-utility-kpis-to-keep-coal-generators-on-line/

The above suggests that AEMO's reason for not considering the relative economics of nuclear power is unconvincing and their assumed closure dates of coal plants is subject to change. In any case, to the extent that material cost savings can be made by choosing a different mix of technology than assumed by AEMO, Australian consumers should be informed so they can determine whether they wish to pay for AEMO's preferred system, or not.

2.2 Report 2 – this report

This is the second report. In this report we compare the costs of the ISP as calculated using the ISP assumptions modelled in Plexos, the model used by AEMO. We then compare these ISP costs with the costs of an assumed pattern of investment in nuclear capacity starting in 2036. To ensure there is sufficient generating capacity, aside from continuing with investment in renewables and storages, about 65% of the existing coal capacity (mostly the newer coal generators) is kept operating until nuclear capacity is built across each region of the NEM, while continuing the scheduled decommissioning of older coal generators. All other policy constraints are relaxed for the nuclear scenario.

Since the modelling approach automatically replaces life extended coal generators with nuclear capacity when these coal generators permanently close, the model does not assume nuclear capacity replaces coal capacity in South Australia, because there is no longer any coal generation to close. This modelling assumption should not be taken to mean that nuclear capacity should not be installed in South Australia or that the conclusions regarding the relative costs of the different scenarios will be materially different if some of the total installed nuclear capacity was located in South Australia. In fact, a nuclear power station located in South Australia could help improve the otherwise uneconomic EnergyConnect interconnect project that will connect the South Australian and NSW regions directly.

In all modelling cases presented in this report, the generation system capacity is optimised to ensure the AEMO system reliability criteria is met at least cost. That is, given the modelling assumptions in each scenario, each scenario produces a generation system that meets the reliability standards.

The modelling is based on standard ISP assumptions for AEMO's Step Change and Progressive scenarios. The only difference to these standard assumptions is that we have assumed that the costs of nuclear capacity is $10,000/kW in real terms with a 1% annual learning cost efficiency over the modelling period with a real variable cost of $30/MWh. These costs reflect a reasonable cost in equilibrium (i.e. not the costs associated with a first of a kind) and the learning improvements is a fraction of a reasonable estimate of the expected learning savings based on the experience with other technologies that have experienced rapid growth (e.g. renewables and, historically, nuclear generation in other nations).

On the face of it, the capital costs of nuclear capacity can appear expensive compared to a solar or wind plant (which is about, respectively, $1,800/kW and $2,500/kW) and this simple cost comparison is often used to condemn consideration of nuclear power. However, wind and solar only produce electricity about a third of the time on average and in the Australian NEM these sources of intermittent electricity generation tend to produce electricity at the same time and tend not to be operational at similar times. This means that, broadly, the NEM needs about three times as much wind and solar capacity to produce the same electricity as a generator that can operate on command and, more or less, continuously – that is dispatchable generators. In addition to the large amount of renewable capacity that has to be built and paid for to produce enough electricity, capacity also has to be developed to store electricity at times when there is surplus production from renewables to allow this to be discharged when there is a shortfall of renewable generation (which occurs roughly about half the time). In addition, in a system which is dominated by intermittent renewables, more gas generation will also be needed to produce sufficient electricity to meet the times when there is an extended wind and solar drought and energy stores have been depleted. Moreover, in practice, wind and solar farms are being located over a wide geographic area where there is little to no electricity transmission network. This means that further costs must be expended on the transmission system to support AEMO's renewables plan.

The results of the report modelling can be used to test the proposition that, when considering all the costs involved in building and operating a reliable, secure power *system* that primarily uses renewables and storage, a *system* that incorporates nuclear power might be less expensive. This is potentially the case because nuclear power can reduce the need to:

- build large numbers of wind and solar farms to generate sufficient electricity to meet demand, and
- storages for surplus electricity to cover the, roughly two thirds of the time, intermittent renewable generators don't produce electricity, and
- the backup generation when stored energy is depleted, and
- the costs of a vast expansion of the electricity transmission and distribution network across rural and regional Australia.

To the extent that nuclear generators can be co-located on existing strong transmission lines, this can reduce the need to build such an extensive network across rural and regional Australia and this can mitigate the loss of amenity to Australia's rural and regional communities that are largely bearing the costs of the energy transition.

To achieve these transmission cost savings it is important to plan the transmission network from now incorporating a plan for specific nuclear power stations.

The objective of this project is to compare the overall costs of AEMO's preferred solution to Australia's energy supply to a system that includes nuclear power.

This analysis is being conducted to help inform the debate on Australia's energy transition.

2.3 Report structure

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.

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 any behind the meter supply or storage options. It is assumed that this is likely to be roughly constant across the scenarios.

The objective function of the optimisation model is to minimise the fixed and variable costs of reliably meeting the demand forecast by AEMO in their Step Change and Progressive scenarios. AEMO also produces a third scenario in the ISP called Green Energy Exports.[8] AEMO states that the energy transition will have "… undeniable benefits" including "lower costs".[9] This claim by AEMO is tested in this report.

3.1.1 Step Change

AEMO consider their Step Change scenario most likely at 43% likelihood. This scenario foreshadows a world where there is rapid growth in electricity demand caused 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.

3.1.2 Progressive

AEMO's Progressive scenario, which AEMO says is just 1 percentage point less likely – i.e. 42% likely - than their preferred Step Change scenario, 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.

3.1.3 Green Energy Exports

AEMO's Green Energy Exports 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 major green energy exporters. With Australia's high costs of land, capital and labour, difficult and uncertain planning provisions, and distances from many high value markets, other countries are probably better placed to become green energy exporters. Australia has many other strengths it can take advantage of in the future energy market.

8 AEMO (2024), Integrated System Plan for the National Electricity Market, A roadmap for the energy transition, Weblink: https://aemo.com.au/-/media/files/major-publications/isp/2024/2024-integrated-system-plan-isp.pdf?la=en, p9.

9 *Op cit*, AEMO (2024), p8.

AEMO assigns a 15% chance of their Green Energy Exports scenario occurring. Due to the improbability of this scenario the Green Energy Exporter case is not modelled in this report.

3.2 Electricity sector model inputs

In Section 3.2 of Report 1 the key modelling inputs and assumptions were described. We have used these same inputs and assumptions in the modelling when we include nuclear power in the NEM with the exception of the differences described below.

3.2.1 Coal retirements

The treatment of coal retirements is explained in Section 1.4 above.

3.2.2 Existing carbon reduction and renewables policies

In Report 1 it was explained that a key driver of the outcomes of AEMO's modelling are the various government schemes to support the growth in renewables (shown in Table 1 of Report) and the inclusion of a carbon price – known as Valuing Emission Reductions – as determined by the Australian Energy Regulator, that rises from about $68/tonne in 2025 (in 2024 dollar terms) to about $420/tonne by 2050 (described in Section 3.2.5 of Report 1). At the time the Gillard government carbon tax was revoked in 2014, the price per tonne was $24.15, or about $35-$40/tonne in current dollar terms.

When modelling the inclusion of nuclear in the NEM, the constraints of these renewable schemes and carbon price are not taken into account. This is not to say that no further renewables are built or emission reductions are achieved. As shown in the remainder of this report, the inclusion of nuclear does not halt the growth in renewables and nor does it arrest of the decline in emissions from the electricity sector over time.

3.2.3 Cost of nuclear power

The modelling assumes a cost of nuclear power of $10,000/kW. This is higher than the CSIRO's recent estimate of the cost of large-scale reactors.[10] This assumption is based on a review of the experience of the costs of developing large scale nuclear reactors, including more recent examples. Further, it is assumed there is an annual cost efficiency improvement in the capital cost of nuclear generators of 1% per annum in these costs from 2024 onwards. This is a conservative estimate based on the literature on the learning cost efficiencies when similar units are developed in sequence.

The capital costs are amortised over a 50-year period, although realistically new nuclear generators will operate for many more years than this and more than twice the life of renewables.

A real variable cost of $30/MWh is also assumed. This is higher than the expected variable cost of nuclear power. This amount is considered sufficient to cover fuel costs, variable and fixed operating and maintenance cost, network costs and decommissioning costs over the life of the power stations.

10 CSIRO (2024), GenCost 2023-24, Final report, May, p33, Weblink: https://www.csiro.au/-/media/Energy/GenCost/GenCost2023-24Final_20240522.pdf

All other cost assumptions used in the modelling are consistent with AEMO's 2024 ISP. This includes AEMO's fuel price assumptions, including gas. If gas prices were lower in the future than the assumed level, this is likely to place downward pressure on electricity prices, noting that electricity prices are not modelled in this project, instead we focus on economic costs. Of course, in a competitive market, if costs are lower prices are also lower.

4 Modelling results

4.1 Result categories

In this section eight types of modelling outputs are presented in the following order:

- Generating capacity (as measured by megawatts - MW) mix from 2025 to 2051 for AEMO's Base case Step Change and Progressive scenarios and these are compared to the Nuclear alternative for the Step Change and Progressive cases.
- Electricity production (as measured by gigawatt hours - GWh) mix from 2025 to 2051 for AEMO's Base case Step Change and Progressive scenarios and these are compared to the Nuclear alternative for the Step Change and Progressive cases.
- Annual generation costs by scenario (unless otherwise stated, all dollar values are in 2024 terms)
- Sum of the annual real generation, storage and transmission costs by scenario
- Net present value of generation, storage and transmission costs by scenario
- The combined costs of generation and transmission for the different scenarios.

We do not, at this stage, present any results for the prices as this will depend on how the cost of new capacity will be treated in the future. The current NEM price setting mechanism is no longer fit for purpose irrespective of the whether Australia's energy future is with or without nuclear power. The NEM pricing design no longer serves the purposes it was designed to achieve. In particular, NEM prices no longer drives generation investment decisions in the way it was designed to. In practice, governments have supplanted the role of NEM spot prices in deciding new generation investments and generator exits. If governments make uneconomic decisions then taxpayers and/or consumers are forced to pay the costs. Independent/merchant investors don't have taxpayers and consumers to underwrite uneconomic investments like government can and so this class of investor has, more or less, abandoned the NEM. This desertion of merchant investors then means that government will always have to underwrite, in some form or another, new generation investment.

For the moment, the current spot pricing arrangements still send valuable signals to generators and storages as to when to supply the market or absorb excess supply day-to-day. However, alternative pricing arrangements can achieve the same outcome and, at the same time, almost immediately lower prices for all customers.

Due to its dysfunction, it is inevitable that the current NEM pricing mechanism will be reformed in the near future – or at least ought to be reformed - so it makes little sense attempting to forecast prices for the next 25 years at this stage. For the purposes of this report it is sufficient to consider the relative economic costs of the proposals to determine, directionally, choice of power system configuration. As we noted in Report 1, in a well-functioning and well-regulated electricity market, prices should reflect the cost to supply electricity. It is expected that a lower cost, competitive power system will deliver a lower price than a more costly power system.

4.2 Generating capacity

In this section the results of the cost optimisation modelling are presented and explained. There are two sub-sections to this Section 4.2:

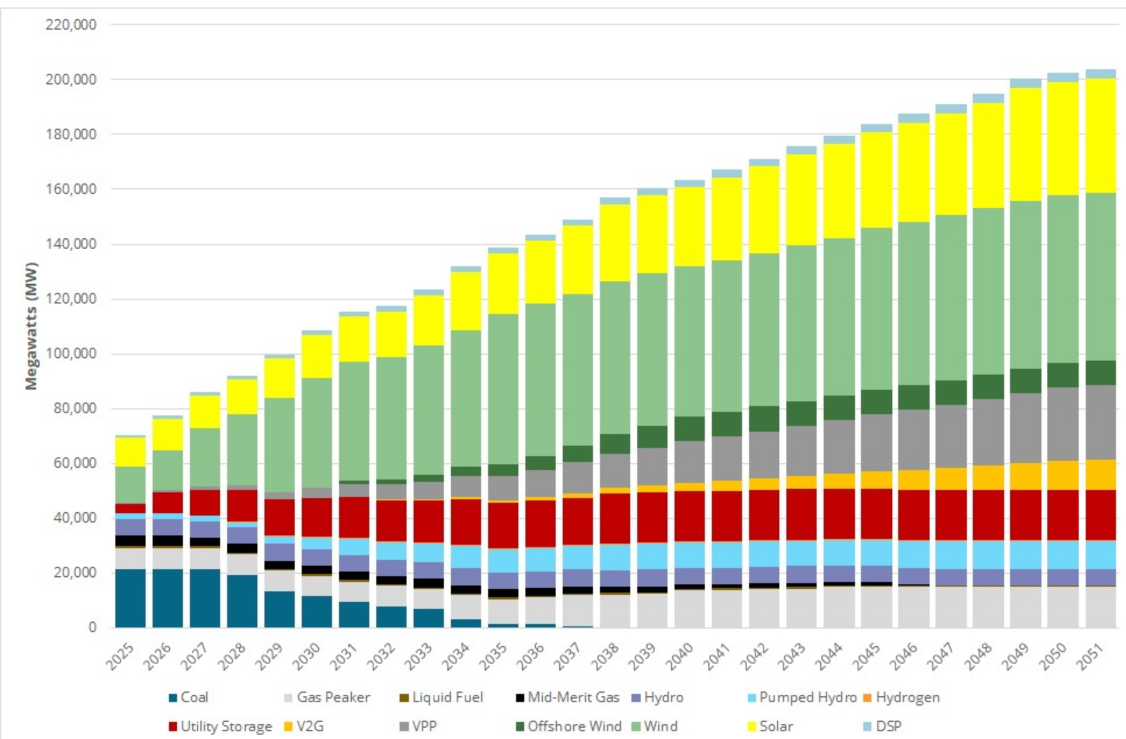
- In Section 4.2.1 the capacity mix from 2025 to 2051 for the modelled Step Change scenario is presented.
- In Section 4.2.2 the capacity mix from 2025 to 2051 for the Progressive scenario is presented.

4.2.1 Step change

AEMO's Base case Step Change scenario assumes both rapid economic growth and high electrification (see Figure 3).

Installed generation capacity rises from about 71,000 MW (71 GW) to about 203,000 MW (203 GW) by 2051 – an increase in generating capacity of 2.8 times. This implies a compound annual growth rate (CAGR) of 4.17%. That is, capacity would have to increase by 4.17% on average year-on-year to meet the forecast demand under AEMO's Base case Step Change scenario using primarily wind, solar and storages (utility scale storages and virtual power plant – VPP – and pumped hydro). The modelling indicates that gas peaking capacity would need to double from 2025 levels of about 8,000 MW to nearly 15,000 MW over the modelling period.

Figure 3: AEMO Base case – Step Change – MW capacity installed from 2025 to 2051



In **Table 1** some summary statistics of the data underlying **Figure 3** is provided. The share of total capacity of the main supply technologies are presented for either end of the modelling period – 2025 and 2051. The compound average growth rate (CAGR) is also shown for each technology. In the main the CAGR covers the period from 2025 to 2051 but for some technologies the period is shorter as some technologies do not feature until after 2025 (e.g. off-shore wind) and some technologies disappear before 2050 (e.g. coal). In these cases the CAGR reflect a shorter period than the modelling period. Also, the CAGR is calculated from the beginning and end points of the series. In some cases the series shows year-to-year negative and positive growth.

Table 1: AEMO Base case – Step Change – capacity shares and average rate of change in MW capacity installed from 2025 to 2051

	2025		2051		CAGR
	GW	%	GW	%	
Coal	21,297	30%	-	0%	-24.9%
DSP	970	1%	3,418	2%	5.0%
Gas Peaker	7,781	11%	14,926	7%	2.5%
Hydro	6,068	9%	6,068	3%	0.0%
Hydrogen	-	0%	400	0%	2.8%
Liquid Fuel	688	1%	552	0%	-0.8%
Mid-Merit Gas	4,047	6%	-	0%	-10.2%
Offshore Wind	-	0%	9,000	4%	11.6%
Pumped Hydro	1,870	3%	10,160	5%	6.7%
Solar	10,747	15%	41,640	20%	5.3%
Utility Storage	3,642	5%	18,427	9%	6.4%
V2G	-	0%	10,702	5%	28.6%
VPP	458	1%	27,452	13%	7.1%
Wind	12,868	18%	61,112	30%	6.2%

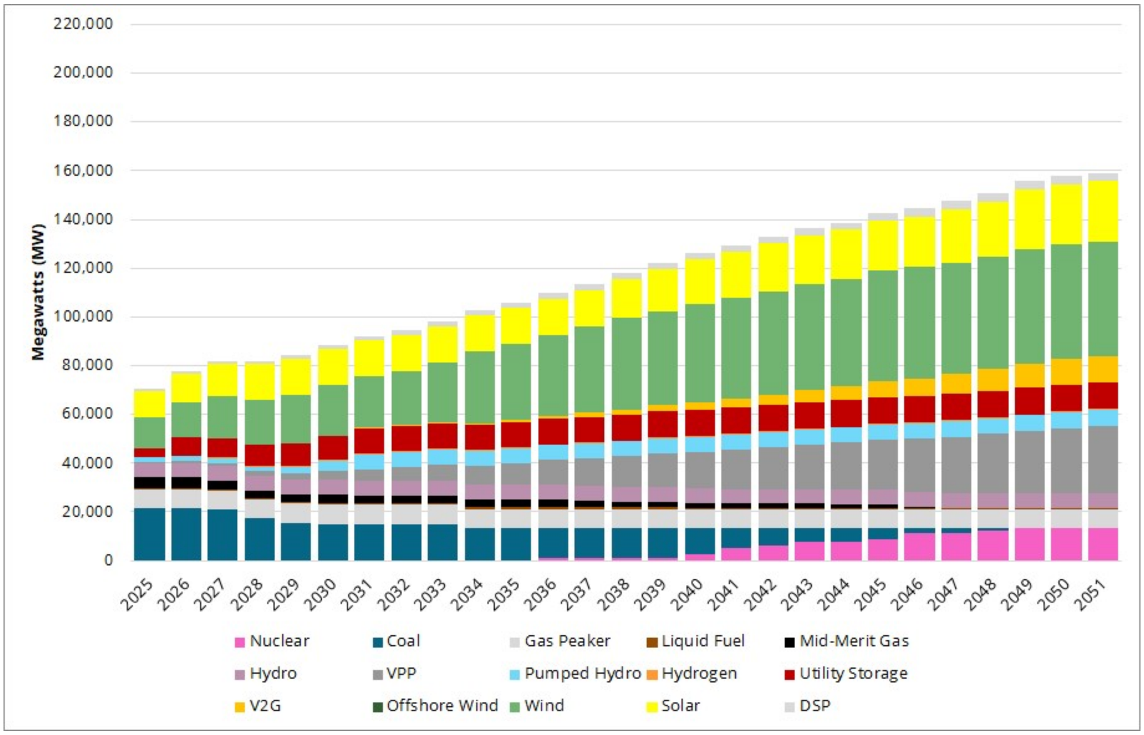
The results of the capacity modelling for the Nuclear alternative Step Change scenario are presented in Figure 4. This figure is presented with the same vertical axis scale as Figure 3 for ease of comparison of the two cases.

It can be clearly seen that in the Nuclear alternative Step Change scenario that by 2051 the total capacity is considerably less than in the AEMO Base case Step Change scenario. In the Nuclear

Step Change case the total installed capacity by 2051 is 159,000 MW compared to 203,000 MW in the AEMO Base case Step Change scenario – a difference of 44,000 MW of generating capacity. To put this into perspective, this difference in capacity represents about 60% of the current installed capacity in the NEM, which is considerable. To achieve this level of capacity by 2051 the required CAGR in capacity is about 3.2%.

The key reason there is such a large difference in required generation capacity to meet, more or less, the same demand as in AEMO's Base case Step Change scenario is because there is 13,000 MW of nuclear capacity that is running at base load. This compares to AEMO's preferred world where wind and solar capacity operates about a third of the time and this means that large amounts of capacity is required to be installed to generate enough surplus electricity to be stored and then discharged when renewable generators cannot produce electricity. Of course, there needs to be capacity to store surplus electricity and there needs to be additional gas peaking generators to operate when storages are depleted and demand still has to be met.

Figure 4: Nuclear alternative – Step Change – MW capacity installed from 2025 to 2051



Aside from requiring less generation capacity to be installed to meet AEMO's forecast for rapid and continuous growth in demand, less transmission capacity will be needed as fewer generators are required. To achieve these cost savings it will be important to plan for a system that includes nuclear as soon as possible. These cost saving should be taken into account when comparing the costs of AEMO's preferred system dominated by renewables and storages. The approach used to determine an estimate of this cost impact is presented in Section 4.6.1.

The 13,000 MW of nuclear capacity and the assumed profile of commissionings is shown in pink in Figure 4. By 2051 nuclear capacity accounts for just over 8% of total capacity.

Under the Nuclear alternative Step Change scenario investment in renewables continues with wind generation capacity increasing from about 13,000 MW in 2025 to 47,000 MW in 2051, which represents a CAGR of over 5%. Similarly, solar increases from around 11,000 MW to about 25,000 MW – a CAGR of around 3.3%. new capacity in energy storages in the form of utility and VPP capacity also continues. Pumped hydro capacity rises from 1,870 MW to around 6,700 MW, and V2G capacity experiences a very large rise from close to zero to about 11,000 MW. Gas peakers remain at about 8,000 MW over the modelling period.

In summary, the Nuclear alternative Step Change scenario can be characterised as a system that is dominated by renewables and energy storage with nuclear providing base load capacity to ensure system security and reliability, and some gas for backup and peaking purposes.

Table 2 provides summary statistics for the data presented in **Figure 4**, including the capacity shares by technology type in 2025 and 2051 and the associated CAGRs.

Table 2: Nuclear alternative – Step Change – capacity shares and average rate of change in MW capacity installed from 2025 to 2051

	2025		2051		CAGR
	GW	%	GW	%	
Coal	21,297	30%	-	0%	-11.9%
DSP	970	1%	3,418	2%	5.0%
Gas Peaker	7,781	11%	7,733	5%	0.0%
Hydro	6,068	9%	6,068	4%	0.0%
Hydrogen	-	0%	400	0%	2.8%
Liquid Fuel	688	1%	552	0%	-0.8%
Mid-Merit Gas	4,291	6%	-	0%	-8.5%
Nuclear	-	0%	13,281	8%	16.6%
Offshore Wind		n.a.	-	n.a.	n.a.
Pumped Hydro	1,870	3%	6,723	4%	5.0%
Solar	10,747	15%	24,821	16%	3.3%
Utility Storage	3,642	5%	10,865	7%	4.3%
V2G	-	0%	10,702	7%	28.6%
VPP	458	1%	27,452	17%	17.0%
Wind	12,868	18%	47,025	30%	5.1%

4.2.2 Progressive

The capacity quantity for different technologies under AEMO's Progressive scenario, which AEMO estimate precisely to be 1% less likely than their Step Change scenario, is presented in Figure 5.

Total capacity grows from about 70,000 MW to 133,000 MW, which reflects a CAGR of about 2.5%. There is a difference of 70,000 MW of capacity required between AEMO's Step Change and Progressive scenarios.

As can be seen in Figure 5 under AEMO's Progressive scenario, new capacity is predictably dominated by wind, solar and storages. Gas capacity continues to feature in AEMO's Progressive scenario well into the 2050's as does coal.

Figure 5: AEMO Base case – Progressive – MW capacity installed from 2025 to 2051

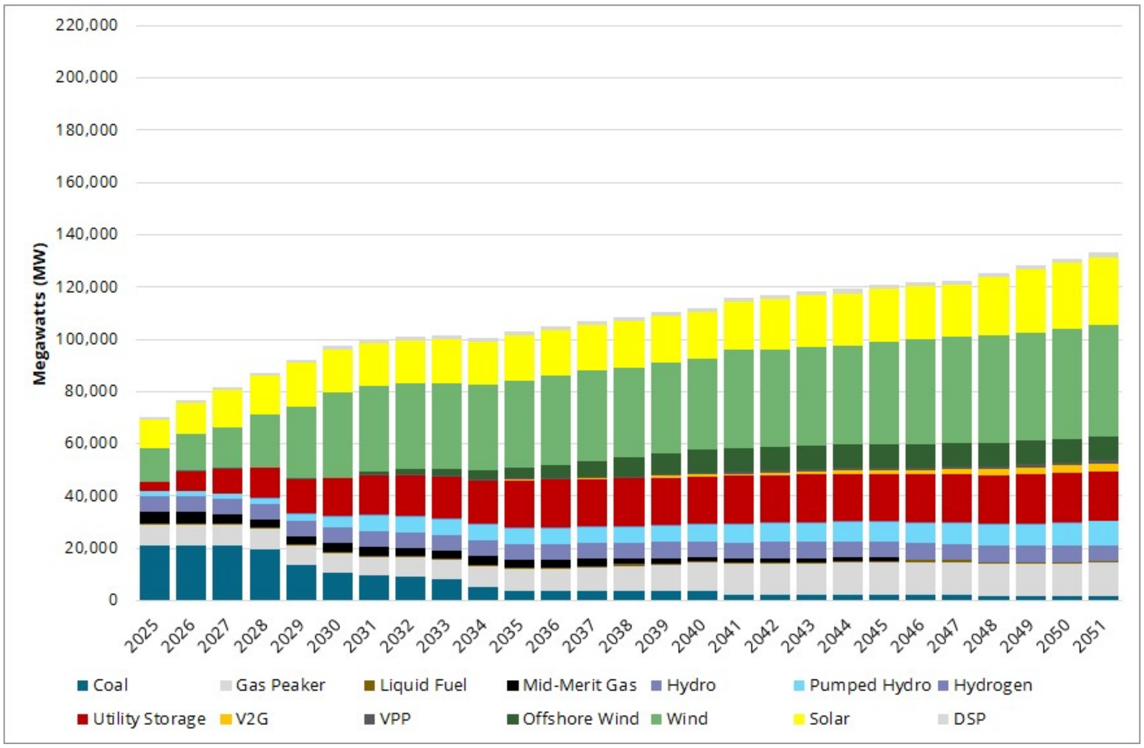


Table 3 provides summary statistics for the data presented in **Figure 5**, including the capacity shares by technology type in 2025 and 2051 and the associated CAGRs.

Table 3: AEMO Base case – Progressive – capacity shares and average rate of change in MW capacity installed from 2025 to 2051

	2025		2051		CAGR
	GW	%	GW	%	
Coal	21,297	30%	1,738	1%	-9.2%
DSP	926	1%	1,738	1%	2.4%
Gas Peaker	7,781	11%	12,704	10%	1.9%
Hydro	6,068	9%	6,068	5%	0.0%
Hydrogen	-	0%	400	0%	2.8%
Liquid Fuel	688	1%	552	0%	-0.8%
Mid-Merit Gas	4,047	6%	-	0%	-10.2%
Offshore Wind	-	0%	9,000	7%	11.6%
Pumped Hydro	1,870	3%	9,246	7%	6.3%
Solar	10,747	15%	26,146	20%	3.5%
Utility Storage	3,642	5%	18,800	14%	6.5%
V2G	-	0%	3,066	2%	28.5%
VPP	90	0%	1,239	1%	10.6%
Wind	12,868	18%	42,473	32%	4.7%

The results of the quantity and mix of capacity under the Nuclear alternative Progressive scenario is shown in Figure 6. Total capacity grows from about 70,000 MW to about 99,000 MW, which represents a CAGR of about 1.3%. This is 34,000 MW less generating capacity (133,000 MW minus 99,000 MW) required to meet demand compared to AEMO's Progressive approach.

Under the Nuclear alternative Progressive scenario nuclear capacity accounts for about 13% of total capacity by 2051. Wind capacity doubles from about 13,000 MW 2025 to about 26,000 MW in 2051. Similarly, solar almost doubles over the same period from about 11,000 in 2025 to about 20,000 MW in 2051. Utility storage more than triples over this period from about 3,600 MW to nearly 11,500 MW in 2051.

Figure 6: Nuclear alternative – Progressive – MW capacity installed from 2025 to 2051

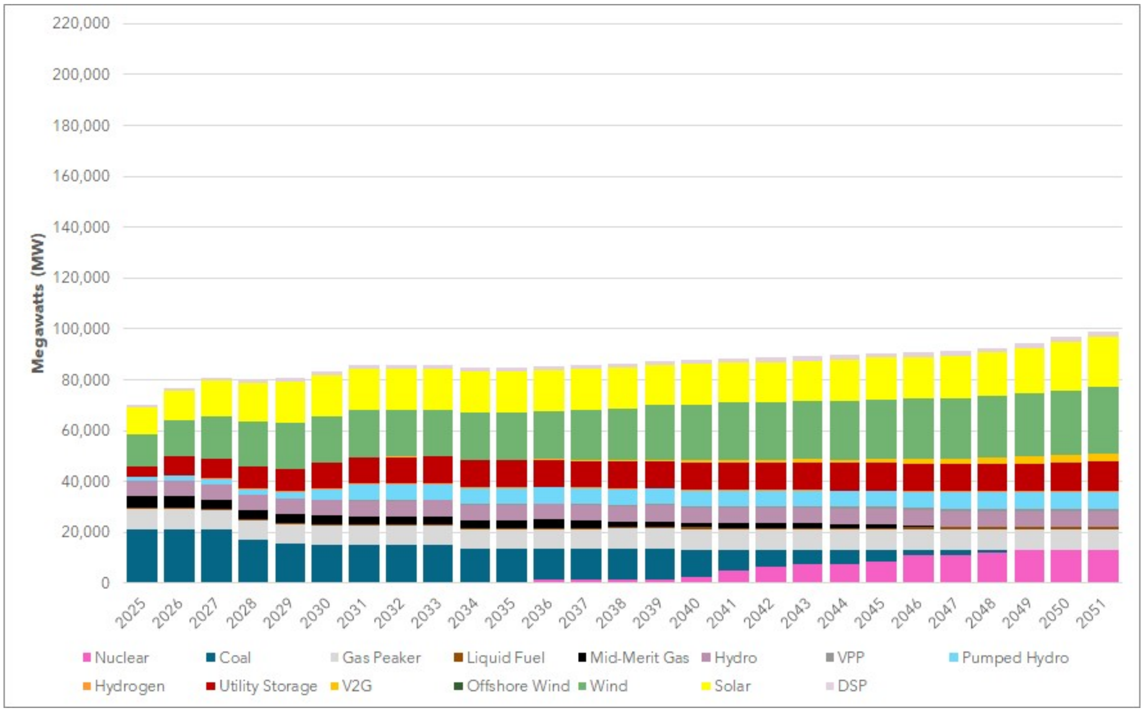


Table 4 provides summary statistics for the data presented in **Figure 6**, including the capacity shares by technology type in 2025 and 2051 and the associated CAGRs.

Table 4: Nuclear alternative – Progressive – capacity shares and average rate of change in MW capacity installed from 2025 to 2051

	2025		2051		CAGR
	GW	%	GW	%	
Coal	21,297	30%	-	0%	-11.9%
DSP	926	1%	1,738	2%	2.4%
Gas Peaker	7,781	11%	8,063	8%	0.1%
Hydro	6,068	9%	6,068	6%	0.0%
Hydrogen	-	0%	400	0%	2.8%
Liquid Fuel	688	1%	552	1%	-0.8%
Mid-Merit Gas	4,291	6%	-	0%	-8.5%
Nuclear	-	0%	13,281	13%	16.6%
Offshore Wind	-	0%	-	0%	n.a.
Pumped Hydro	1,870	3%	6,679	7%	5.0%
Solar	10,747	15%	19,989	20%	2.4%
Utility Storage	3,642	5%	11,403	12%	4.5%
V2G	-	0%	3,066	3%	28.5%
VPP	90	0%	1,239	1%	10.6%
Wind	12,868	18%	26,280	27%	2.8%

4.3 Electricity production and shares

In this section the results of the cost optimisation modelling is presented and explained. There are two sub-sections to this Section 4.3:

- In Section 4.3.1 the electricity production mix from 2025 to 2051 for the Step Change scenario is presented.
- In Section 4.3.2 the electricity production mix from 2025 to 2051 for the Progressive scenario is presented.

4.3.1 Step change

Under AEMO's Base case Step Change scenario, by 2051, electricity production is overwhelmingly from wind generation (59%), followed by solar (24%) with pumped storage coming a distant third source of energy (5% - these facilities are actually net consumer of electricity) - see Figure 7. All other sources of electricity meet just over 10% of demand.

In total, electricity consumption increases from 180,000 GWh to 374,000 GWh, which represents a CAGR of about 2.9%.

Figure 7: AEMO Base case – Step Change – GWh of electricity production from 2025 to 2051

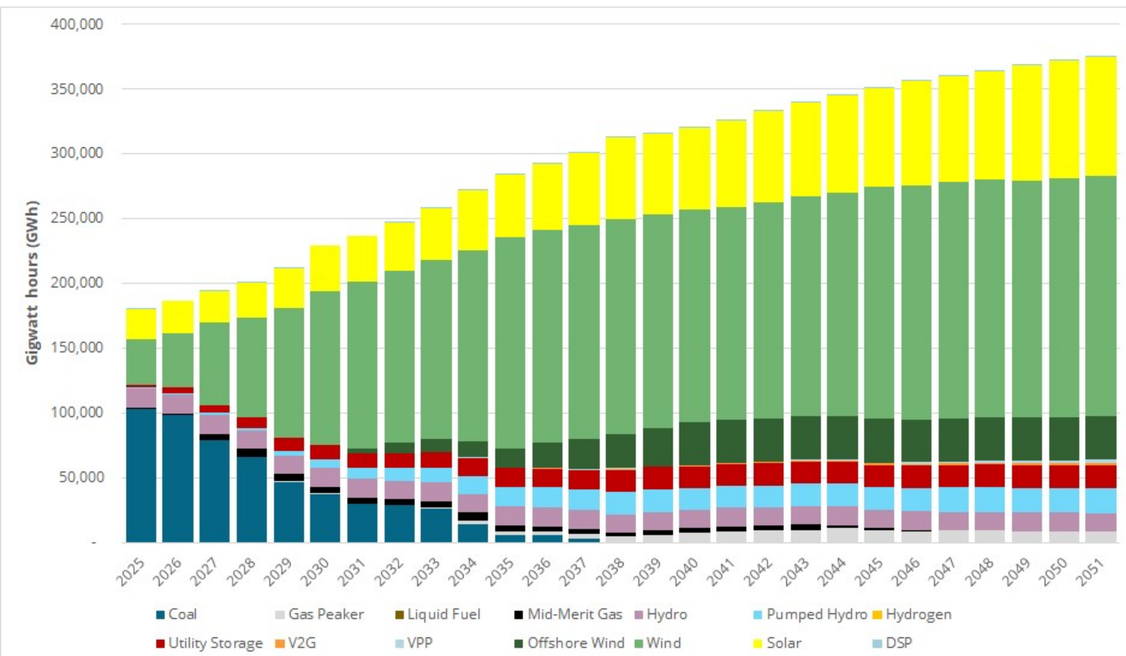


Table 5 provides summary statistics for the data presented in **Figure 7**, including the generation shares by technology type in 2025 and 2051 and the associated CAGRs.

Table 5: AEMO Base case – Step Change – generation shares and average rate of change in GWh from 2025 to 2051

	2025		2051		CAGR
	GWh	%	GWh	%	
Coal	103,090	57%	-	0%	-26.0%
DSP	1	0%	3	0%	5.6%
Gas Peaker	105	0%	8,326	2%	18.3%
Hydro	14,421	8%	14,394	4%	0.0%
Hydrogen	-	0%	18	0%	11.8%
Liquid Fuel	0	0%	6	0%	5.7%
Mid-Merit Gas	1,054	1%	-	0%	-2.8%
Offshore Wind	-	0%	33,445	9%	11.7%
Pumped Hydro	1,384	1%	19,221	5%	10.6%
Solar	23,035	13%	91,435	24%	5.4%
Utility Storage	1,387	1%	17,283	5%	10.2%
V2G	-	0%	2,073	1%	41.1%
VPP	1	0%	2,494	1%	37.8%
Wind	35,414	20%	185,735	50%	6.6%

The level and pattern of electricity production from the different technologies under the Nuclear alternative Step Change case is presented in Figure 8.

It is immediately obvious from this figure that while the total electricity being produced is similar, but about 5% less in the Nuclear alternative than AEMO's Base case, primarily because there are fewer energy losses through the transmission system and storage cycling using nuclear, the base load generators (remaining coal and new nuclear generators) produce more than three times the proportion of capacity they represent of total capacity. For example, by 2051, nuclear accounted for 8% of capacity in the Step Change Nuclear alternative scenario (see Section 4.2.1) but produces nearly 30% of the electricity.

While nuclear is an important source of electricity production in this Step Change scenario, it is not the main source of electricity. The modelling shows that wind is still the major supplier of electricity, meeting about 43% of NEM demand (rising from 35,000 GWh in 2025 to 149,000 GWh in 2051) with solar meeting about 17% of demand (rising from 23,000 GWh in 2025 to 58,000 GWh in 2051).

Figure 8: Nuclear alternative – Step Change – GWh of electricity production from 2025 to 2051

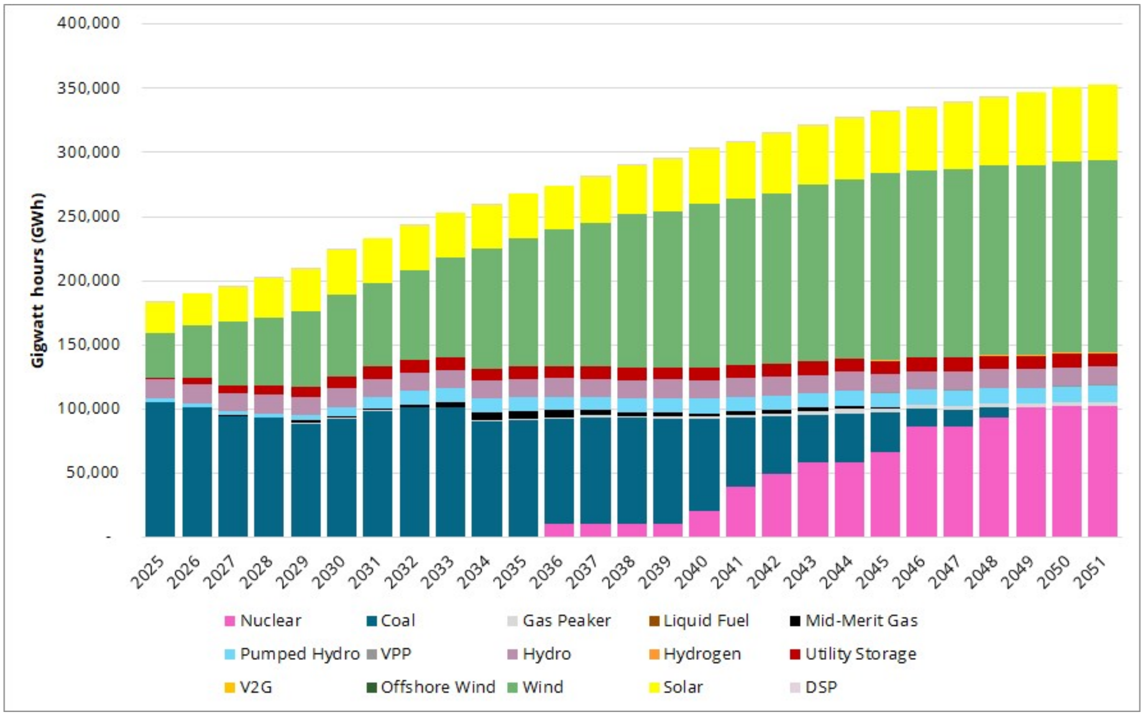


Table 6 provides summary statistics for the data presented in **Figure 8**, including the generation shares by technology type in 2025 and 2051 and the associated CAGRs.

Table 6: Nuclear alternative – Step Change – generation shares and average rate of change in GWh from 2025 to 2051

	2025		2051		CAGR
	GWh	%	GWh	%	
Coal	104,815	57%	-	0%	-10.7%
DSP	1	0%	0	0%	0.9%
Gas Peaker	82	0%	3,194	1%	15.1%
Hydro	14,421	8%	14,414	4%	0.0%
Hydrogen	-	0%	12	0%	7.6%
Liquid Fuel	0	0%	14	0%	7.8%
Mid-Merit Gas	638	0%	-	0%	0.6%
Nuclear	-	0%	102,578	29%	16.6%
Offshore Wind	-	n.a.	-	n.a.	n.a.
Pumped Hydro	2,884	2%	12,404	4%	5.8%
Solar	23,124	13%	58,376	17%	3.6%
Utility Storage	1,462	1%	10,061	3%	7.7%
V2G	-	0%	894	0%	43.1%
VPP	1	0%	733	0%	31.1%
Wind	35,302	19%	149,812	43%	5.7%

4.3.2 Progressive change

The level and pattern of electricity production by technology types under AEMO's Progressive base case scenario is presented in Figure 9. In this scenario, wind accounts for the largest share of electricity production at 59%, followed by solar at 21%. All other sources of electricity supply account for 20%.

Total electricity consumption increases from about 182,000 GWh in 2025 to about 290,000 GWh in 2051, which represents a CAGR of about 1.8%.

Figure 9: AEMO Base case – Progressive – GWh of electricity production from 2025 to 2051

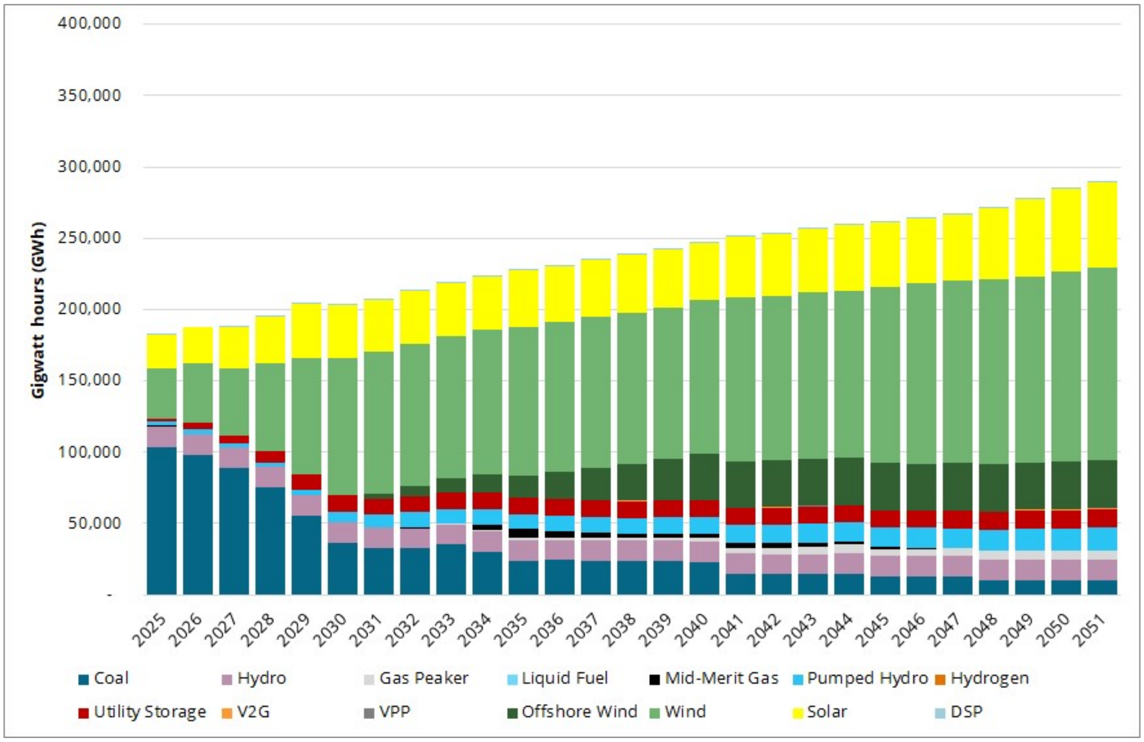


Table 7 provides summary statistics for the data presented in **Figure 9** including the generation shares by technology type in 2025 and 2051 and the associated CAGRs.

The level and pattern of electricity production by technology types under the Nuclear alternative Progressive scenario is presented in **Figure 10**. In this scenario, nuclear accounts for the largest share of electricity production of a single technology in 2051 at 38%, followed by wind at 32% and solar at 17% (which means renewables still accounted for 49% of electricity production). All other sources of electricity supply account for 13%.

Table 8 provides summary statistics for the data presented in **Figure 10** including the generation shares by technology type in 2025 and 2051 and the associated CAGRs.

Table 7: AEMO Base case – Progressive – generation shares and average rate of change in GWh from 2025 to 2051

	2025		2051		CAGR
	GWh	%	GWh	%	
Coal	103,736	57%	10,400	4%	-8.5%
DSP	1	0%	8	0%	10.7%
Gas Peaker	73	0%	6,369	2%	18.7%
Hydro	14,423	8%	14,415	5%	0.0%
Hydrogen	-	0%	13	0%	8.4%
Liquid Fuel	0	0%	13	0%	14.6%
Mid-Merit Gas	589	0%	-	0%	0.0%
Offshore Wind	-	0%	33,520	12%	11.6%
Pumped Hydro	3,110	2%	15,795	5%	6.4%
Solar	23,382	13%	60,309	21%	3.7%
Utility Storage	1,470	1%	12,925	4%	8.7%
V2G	-	0%	642	0%	36.8%
VPP	0	0%	81	0%	15.8%
Wind	35,604	20%	135,002	47%	5.3%

Figure 10: Nuclear alternative – Progressive – GWh of electricity production from 2025 to 2051

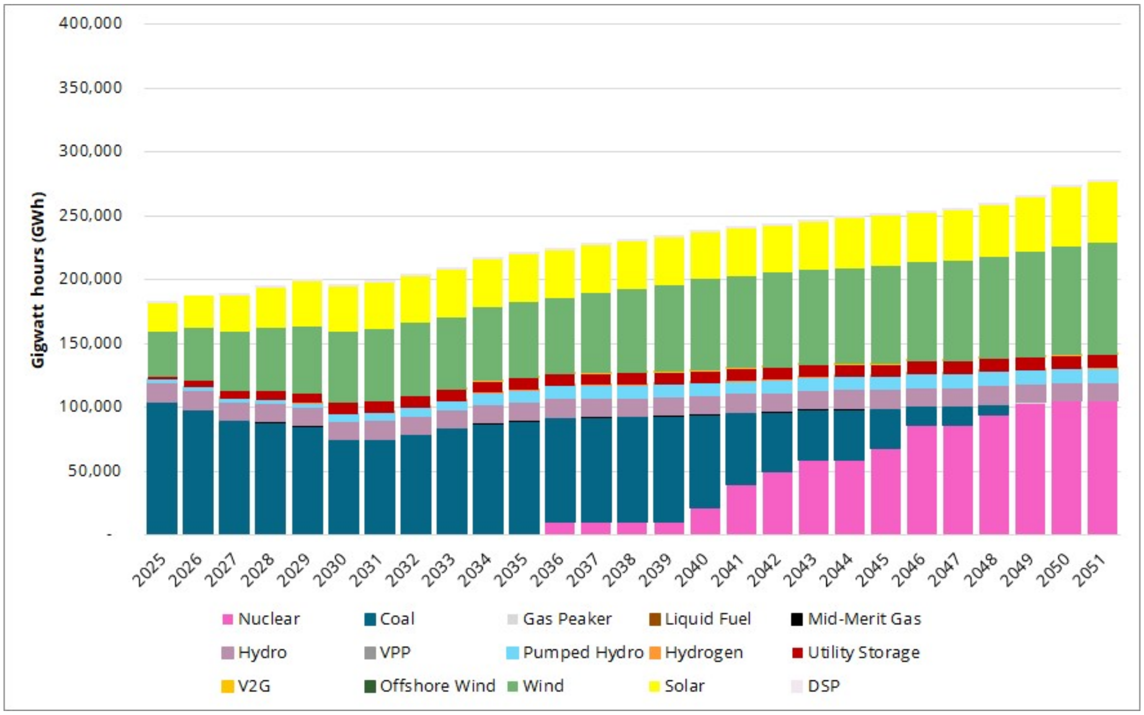


Table 8: Nuclear alternative – Progressive – generation shares and average rate of change in GWh from 2025 to 2051

	2025		2051		CAGR
	GWh	%	GWh	%	
Coal	103,762	57%	-	0%	-10.5%
DSP	1	0%	1	0%	2.5%
Gas Peaker	73	0%	850	0%	9.9%
Hydro	14,423	8%	14,424	5%	0.0%
Hydrogen	-	0%	2	0%	0.5%
Liquid Fuel	0	0%	4	0%	2.7%
Mid-Merit Gas	587	0%	-	0%	-4.4%
Nuclear	-	0%	104,139	38%	16.7%
Offshore Wind	-	n.a.	-	n.a.	n.a.
Pumped Hydro	3,117	2%	11,071	4%	5.0%
Solar	23,465	13%	48,351	17%	2.8%
Utility Storage	1,475	1%	10,749	4%	7.9%
V2G	-	0%	99	0%	34.2%
VPP	0	0%	16	0%	16.4%
Wind	35,521	19%	87,468	32%	3.5%

4.4 Emissions

As indicated in Section 1.4 above, the modelling maintains the operation of about 65% of existing coal generators compared to AEMO's early closure assumption and instead applies an operational life much more consistent with those anticipated by the owners of the coal generators as shown in Figure 2.

The modelled emissions intensity (tonnes per MWh) is shown for each scenario in Figure 11 below. Clearly, if it is assumed that coal will close early and fully replaced with renewables then the modelling will estimate less emissions than if coal is closed later. This is the outcome of the report modelling.

In the nuclear alternative scenarios, emissions continue to fall over the modelling period and achieve lower average emissions in the last few years and maintain this lower level of emissions compared to AEMO's approach. This is mainly because less gas is required to maintain reliability and as there is sufficient nuclear power to provide reliable power supplies.

Figure 11: Emissions intensity (tonnes per MWh) – 2025 to 2051

Under both Step Change and Progressive scenarios the AEMO-preferred energy mix and the nuclear-inclusive energy mix achieve ultra-low emissions broadly consistent with the definition of 'net-zero'. However, by 2051, the nuclear-inclusive energy mix produces 0.0054 tonnes/MWh and 0.0018 tonnes/MWh less than AEMO's preferred energy mix for the Step Change and Progressive scenarios respectively.

4.5 Generation costs

In this section the results of the cost modelling are described and discussed. Costs are presented in different ways, including annually, the total of the annual costs over the modelling period, and the net present value of costs. In terms of the total annual costs and net present value costs, these are shown with and without a conservative estimate of the transmission costs that was discussed in Section 5 of Report 1.

As explained in Section 4.1 of Report 1 and above in the Summary, the cost modelling presented in this report covers the generation capital cost, fixed operating and maintenance costs, variable (non-fuel) operating and maintenance costs, and fuel costs. Transmission costs are added to generation costs in Section 4.6 below.

To be clear, these costs are reported only for the NEM and does not include Western Australia or the Northern Territory. As previously stated in Section 1.3.1 we do not include Western Australia or Northern Territory in our analysis but can see no good reason why the nature of the results and conclusions found in this NEM based study would not also apply to Western Australia. The

Northern Territory electricity system is too small to accommodate a large-scale reactor, so this region would likely continue to be served by a combination of thermal and renewable generation to meet demand.

The modelling assumes a conservative cost for transmission. In reality, these costs are likely to be much more than the estimates used in this report given the propensity of these project costs to blowout (see Section 5.2.4 of Report 1 for description of the experience of cost blowouts of major transmission projects in the NEM).

It is important to emphasise that aside from not including the costs of Western Australia or the Northern Territory we do not include the costs of consumer energy resources (solar panels and batteries), nor the costs of Demand Side Participation, nor the costs of upgrades and extensions to the distribution networks, nor the costs to consumers to switching appliances and equipment that use gas to electricity. For AEMO's preferred Step Change world these costs will be very large and when they are taken into account the total cost of the transition of the electricity sector will be well above a trillion dollars over the next 25-30 years.

4.5.1 Annual generation costs

A key output of the modelling is the annual (avoidable) resource generation costs – known as the economic costs. It is important to note that these avoidable resource costs do not include the capacity costs of existing generators, just the avoidable costs (i.e. the costs that could be avoided if they shut an existing generator). For existing generators, this cost includes variable operating and maintenance costs, which is dominated by fuel costs (coal, oil and gas). It also includes variable and annual maintenance costs.

The annual generation costs will not reflect the full costs of generation including the cost of capacity until new capacity dominates the system (from about 2040 onwards). The average costs of generation from that point onwards provides a reasonable representation of the long run marginal costs of the overall generation system.[11]

With this important caveat in mind, the annual generation costs are presented in Figure 12. A couple of things are immediately obvious from this figure:

- Costs rise from 2025 to 2051. As explained above, a large part of this apparent rise can be explained by the fact that the avoidable economic costs are presented – we ignore sunk costs. The remainder of the apparent rise in costs is due to demand growing over time and that new capacity has to be developed and operated to meet this growth in demand and existing capacity has to be replaced to ensure the system remains reliable. Specifically, annual economic costs rise from about $6.7 billion in 2025 to around $28 billion in 2051 for Step Change and about $23 billion per annum for Progressive. That is, AEMO's preferred view of the world - Step Change – will cost consumers, in total, nearly 25% more than the Progressive scenario. To put these economic costs into perspective, last financial year (FY 24), the cost of all spot sales in the NEM was over $18 billion for an average spot price of around $100/MWh across the NEM. This price compares to an estimated *average generation system cost* of about $60/MWh for all modelled scenarios from about 2046 onwards. Consumers are paying more for generation than the generation expenses (as distinct from economic costs). In the NEM spot market design, economic costs include the cost of generation capacity scarcity, which is reflected as higher prices at times of greater scarcity of generation capacity. When capacity is scarce, there are fewer substitutes available and generators reflect this through higher bids

11 At the scale efficient level of output long run marginal and long run average costs are equivalent.

that set a higher price. This is a central design feature of the NEM. These higher prices are intended to encourage new investment to take advantage of the higher returns – this form of unregulated investment is called merchant investment. This approach worked well in the NEM until recent times. New generation investment decisions are no longer driven by prices, but rather by government interventions – primarily to meet emission reduction targets. Merchant investors cannot compete or manage the risks of competing with governments, so they instead compete for subsidised government and corporate supported investments. In the meantime, the NEM spot price mechanism is still producing prices that reflect the requirement for investments that are not occurring, and consumers are unnecessarily paying these prices. The NEM arrangements need to be amended to correct this disconnect between the NEM design intent and how the market is working in practice.

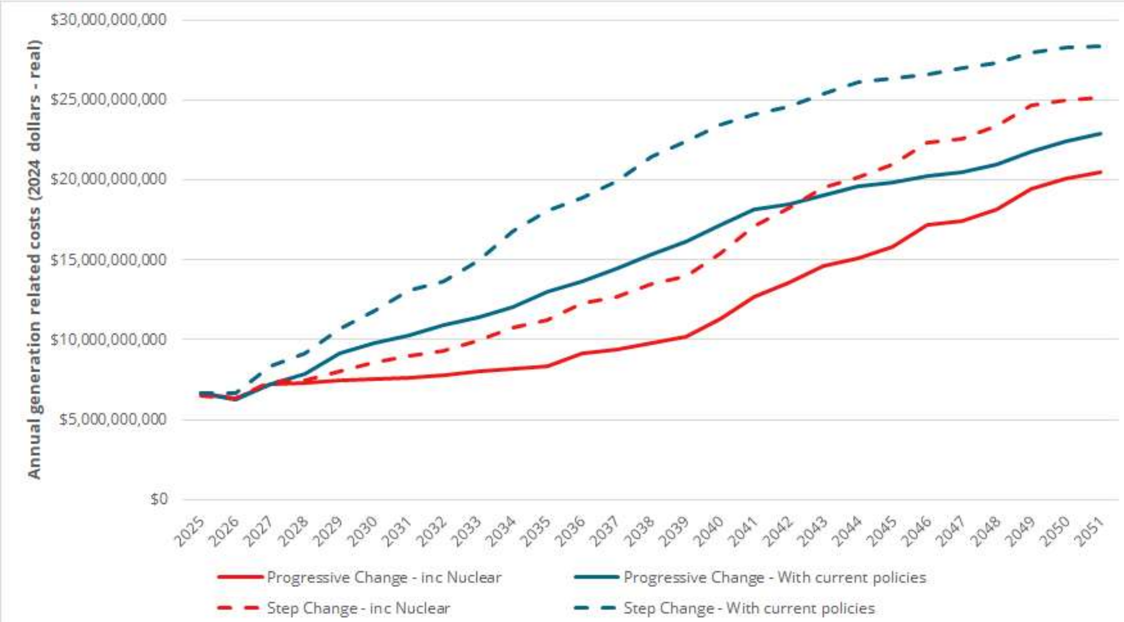
- The annual generation costs of the nuclear scenarios are materially cheaper for either the Step Change or Progressive scenarios and remains that way over time. If prices reflected costs, consumers (or taxpayers) would be considerably better off under the Nuclear alternative than AEMO's preferred approach.

Over the modelling period the total cost differences between AEMO's preferred approach and a system that includes nuclear are substantial. These differences are explained below in Section 4.6.

There are some obvious and important reasons why the Nuclear alternative is cheaper than AEMO's preferred, full renewable, approach:

- The first reason is that, under the Nuclear alternative, where coal plant is maintained to ensure the system remains reliable and secure, the expense of replacing coal fired generation capacity is delayed.
- The second reason is that while nuclear generation is, by itself, expensive, from an overall system cost perspective, it is less expensive than having to build enough renewable generation capacity to produce surplus electricity when the wind is blowing and the sun is shining to be stored and discharged when renewable output is low. Added to the costs of having to overbuild renewable capacity to produce enough energy, is the enormous cost of building capacity to store electricity for times when renewable output is low. In addition, more backup gas power stations will need to be built to produce electricity for extended wind and solar droughts.
- The third reason is that the operational life of wind and solar plants are relatively short and over the modelling period previously developed renewables are being replaced.

Figure 12: Annualised generation costs ($) – real 2024



4.5.2 Sum of real generation costs

In this section the sum of all the real (2024) annual generation economic costs (avoidable capex and opex) are totalled for the Step Change and Progressive cases for both the AEMO Base case and Nuclear alternative.

All figures presented in this Section 4.5.2 and the following Section 4.5.3 are presented on the same vertical scale for ease of comparison.

Step change

In Figure 13 the sum of real costs is presented for the two Step Change scenarios – AEMO's Base case and the Nuclear alternative.

On the left-hand side of Figure 13 the sum of the real generation economic costs of AEMO's preferred Step Change Base case is presented and is estimated to be $528 billion.

On the right-hand side of Figure 13 the sum of the real generation economic costs of Nuclear alternative is presented, and is estimated to be $402 billion, which is about 25% cheaper than AEMO's preferred option. This difference in costs is worth nearly $5 billion per annum on average to consumers/taxpayers.

Figure 13: Sum of real costs from 2025 to 2051 – Step Change

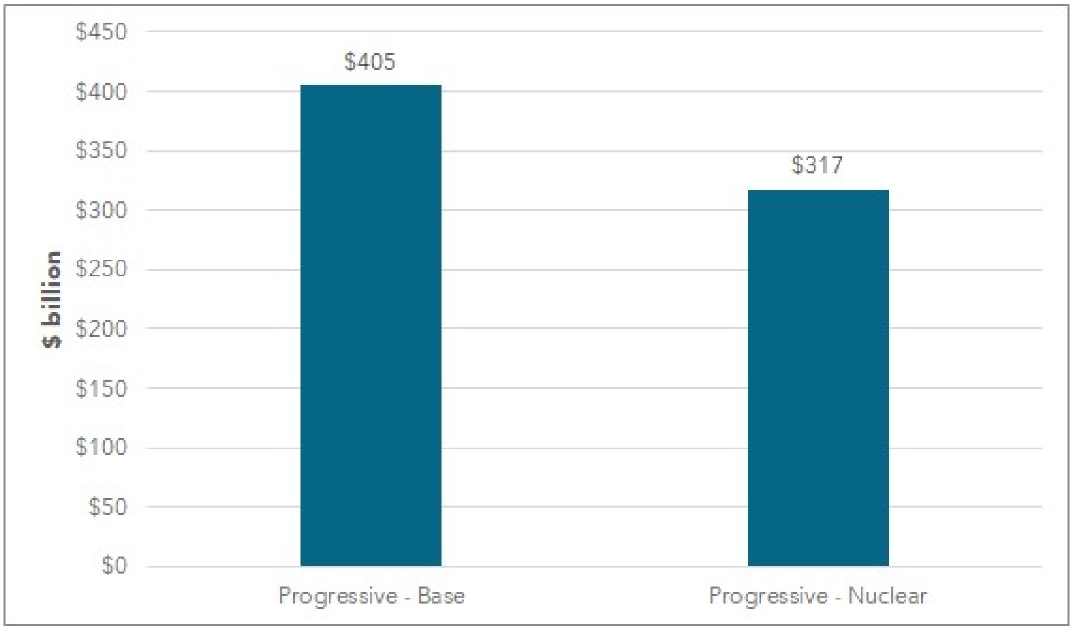
Progressive

In Figure 14 the sum of the economic costs are presented for the two Progressive scenarios – AEMO's Base case and the Nuclear alternative.

On the left-hand side of Figure 14 the sum of the real economic costs of AEMO's Progressive scenario is presented and is estimated to be $405 billion.

On the right-hand side of Figure 14 the sum of the real generation economic costs of Nuclear alternative is presented and is estimated to be $317 billion, which is about 22% cheaper than AEMO's approach and is worth about $3.4 billion per annum to consumers/taxpayers.

Figure 14: Sum of real costs from 2025 to 2051 – Progressive



4.5.3 Net present value of generation costs

In this section the net present value[12] (NPV) of the economic costs are presented for the Step Change and Progressive cases for both the AEMO Base case and Nuclear alternative.

Step change

In Figure 15 the NPV of the economic costs are presented for the two Step Change scenarios – AEMO's Base case and the Nuclear alternative.

On the left-hand side of Figure 15 the NPV of the real generation economic costs of AEMO's preferred Step Change Base case is presented and is estimated to be $190 billion.

On the right-hand side of Figure 15 the NPV of the generation economic costs of Nuclear alternative is presented and is estimated to be $142 billion, which is about 25% cheaper than AEMO's approach.

12 This uses the WACC value specified in Section **Error! Reference source not found.**.

Figure 15: Net present value of costs from 2025 to 2051 – Step Change

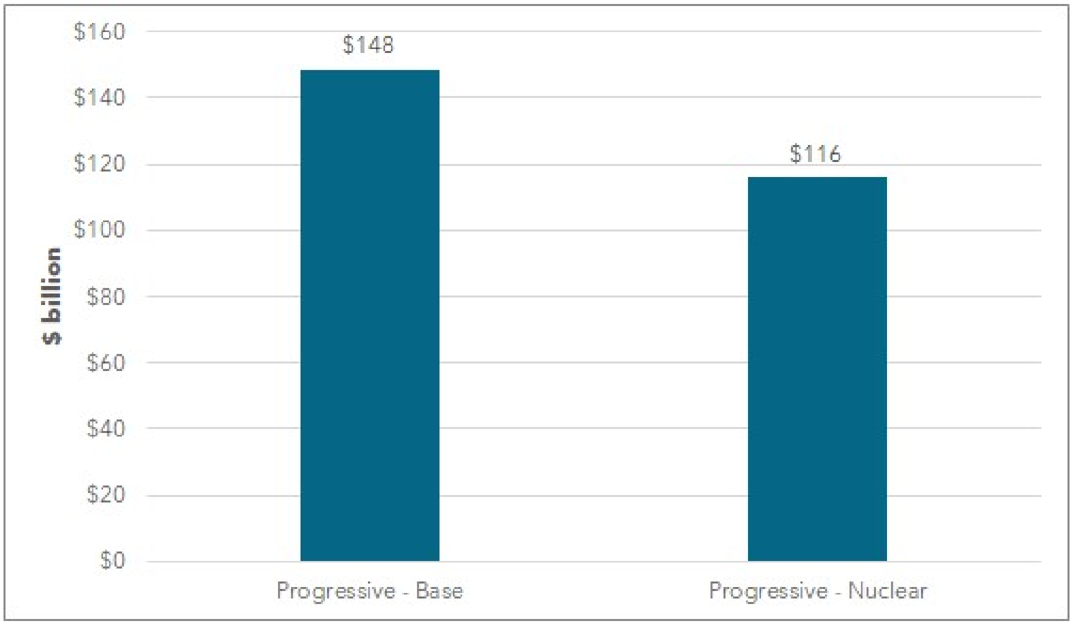
Progressive

In Figure 16 the NPV of the economic costs are presented for the two Progressive scenarios – AEMO's scenario and the Nuclear alternative.

On the left-hand side of Figure 16 the NPV of the real generation economic costs of AEMO's Progressive scenario is presented and is estimated to be $148 billion.

On the right-hand side of Figure 16 the NPV of the generation economic costs of Nuclear alternative is presented and is estimated to be $116 billion, which is about 22% cheaper than AEMO's approach.

Figure 16: Net present value of costs from 2025 to 2051 – Progressive



4.6 Estimate of generation and network costs

In this section the generation and estimate of transmission cost is combined to determine a total system cost estimate of the different scenarios. In the section below the approach used to determine transmission costs, which is then added to generation costs, is explained. Subsequently, the sum of real costs and the NPV costs for the combined costs and generation and transmission costs are separately presented.

4.6.1 Transmission costs

In Section 5.2.5 of Report 1 an approach for estimating the difference in transmission costs for the various scenarios was described. This approach involved deriving an average cost of transmission per MW of capacity installed. This average cost was determined from an estimate of the total transmission costs underway and planned by various network businesses across the NEM. As acknowledged in Report 1 it is very unclear what the totality of transmission costs are likely to be. The only certainty is that transmission costs are rising rapidly and project costs almost always greatly exceed their initial budgeted costs.

The approach set out in Report 1 determined a value of $500,000 of transmission costs per MW of generation capacity installed. That is, there is a linear relationship between transmission costs of installed capacity. It is noteworthy that the REZ network and Flow path augmentation costs in the ISP also tend to rise linearly with capacity.

It is important to note that there is an underestimation in Report 1 with respect to the determination of the estimate of the transmission costs. In Section 5.2.5 of Report it was stated that the transmission costs was estimated to be $62 billion. The updated number, based on the modelling approach, is just over $66 billion.

To determine the total generation and transmission costs the generation costs for each scenario is added to the transmission costs determine by the growth in megawatts of capacity year-on-year multiplied by $500,000, which is the rounded value determined from the analysis in Report 1.

4.6.2 Sum of real costs

The sum of the estimated real costs of the generation and network costs of the different scenarios are presented in Table 9 below.

Table 9: Generation, network and total system costs – sum real $ billion (2025 to 2051)

Scenario		Generation costs ($ billion)	Transmission costs ($ billion)	Total cost ($ billion)
Step change	AEMO base case	$528	$66	$594
	Nuclear alternative	$402	$44	$446
Progressive	AEMO base case	$405	$32	$437
	Nuclear alternative	$317	$14	$331

Overall, the most expensive scenario is AEMO's Step Change Base case with an estimated cost of $594 billion (for NEM only and noting that the transmission cost estimates are conservative). For the same amount of electricity production as AEMO's Step Change scenario, the total costs of the Nuclear alternative is $446 billion, which is about 25% cheaper than AEMO's approach and saves consumers about $150 billion over the period to 2051, or nearly $6 billion per annum.

Considering the Progressive scenario, the total cost of AEMO's approach is $437 billion. By including nuclear power into the energy mix this cost can be reduced to $331 billion, which about 25% cheaper than AEMO's approach. The cost savings from using nuclear in the Progressive case is about $106 billion over the period to 2051, or a saving of about $4 billion per annum.

4.6.3 NPV costs

The NPV of the estimated costs of generation and network of different scenarios are presented in Table 10 below.

Table 10: Generation, network and total system costs – NPV $ billion (2025 to 2051)

Scenario		Generation costs ($ billion)	Transmission costs ($ billion)	Total cost ($ billion)
Step change	AEMO base case	$190	$35	$225
	Nuclear alternative	$142	$21	$163
Progressive	AEMO base case	$148	$17	$166
	Nuclear alternative	$116	$8	$124

The relative costs between the scenarios are the same as for the sum real costs. AEMO's Step Change Base case is, by far, the most expensive scenario (NPV cost of $225 billion), and almost twice that of the Progressive Nuclear alternative scenario (NPV cost of $124 billion).

4.7 Scenario summary comparison

Figure 17 shows the sum of the real cost estimates for generation and transmission, and the total cost for the period from 2025 to 2051. This is a summary of the data shown by scenario and cost type in the sections above.

Similarly, Figure 18 shows the NPV of the real cost estimates for generation and transmission, and the total cost for the period from 2025 to 2051.

Maintaining about 65% of existing coal generation until it can be replaced by nuclear generation, while continuing investing in renewables and storages, results in a much lower cost generation system than promoted by AEMO.

With appropriate reforms of the NEM arrangements these lower costs would be translated into lower prices for consumers and/or lower costs to taxpayers.

All scenarios have been modelled to be equally reliable as the model minimises costs subject to meeting the AEMO reliability target.

From the perspective of consumer costs and prices, consumers are much better off in the Progressive scenario with nuclear power in the energy mix. In fact, the cost difference over the modelling period between AEMO's preferred Step Change system with a Progressive future including nuclear power is about $263 billion, or about $10 billion per annum, on average, over the modelling period. The Progressive scenario including nuclear is 44% cheaper than AEMO's preferred Step Change scenario that primarily relies almost solely on renewables and storages and a web of transmission network across rural and regional Australia to meet our electricity needs.

Figure 17: Comparison of scenarios summary – sum of real costs ($ billion) - 2025 to 2051

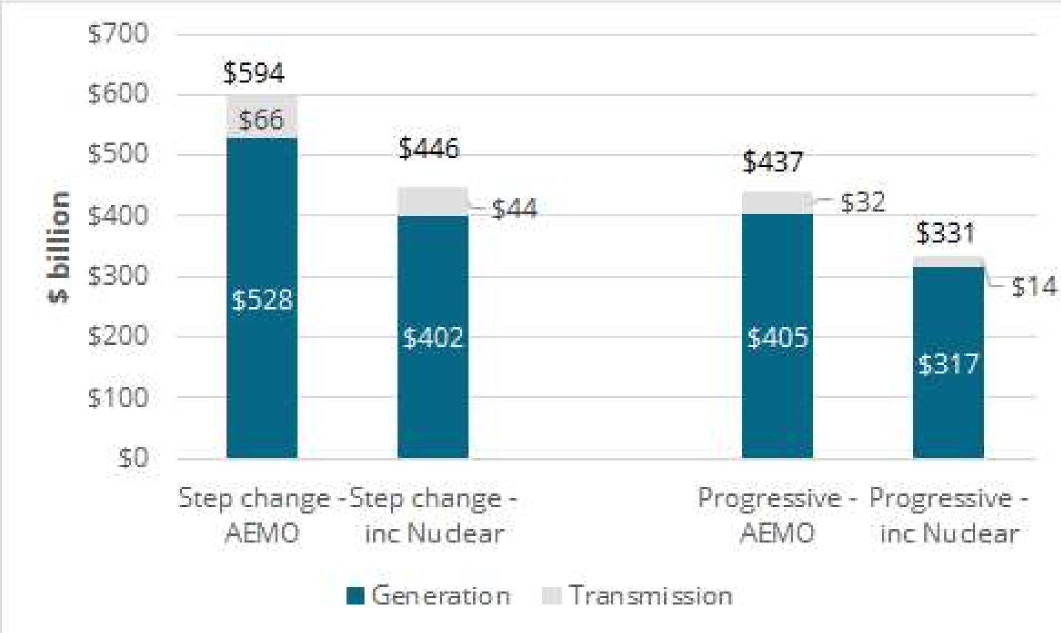
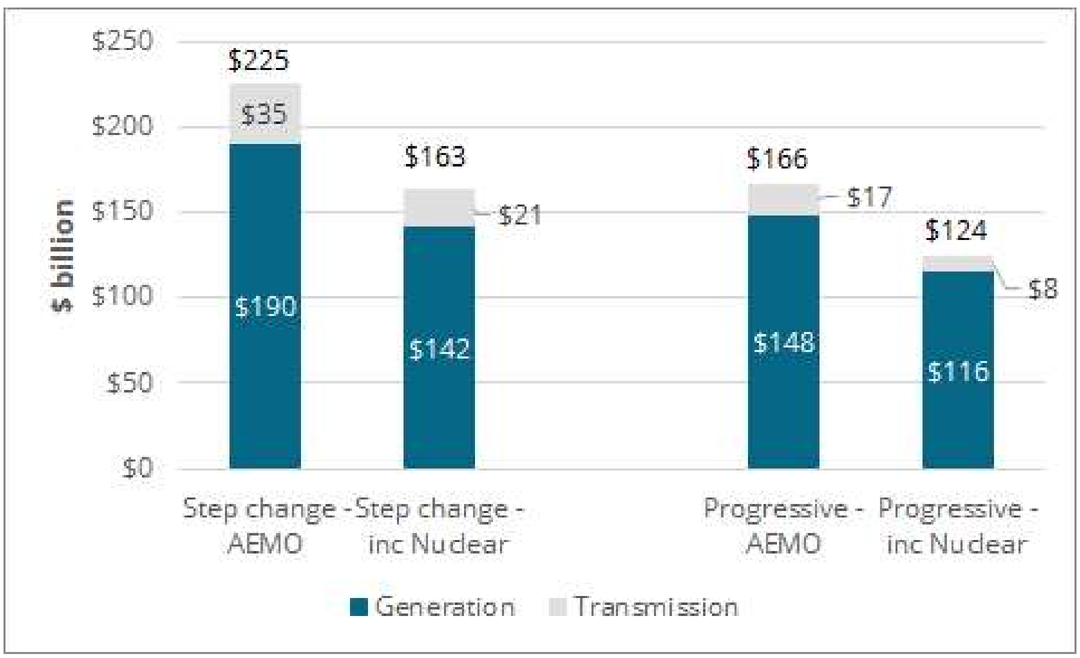


Figure 18: Comparison of scenarios summary – net present value ($ billion) - 2025 to 2051



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