# Aurora Energy Research analysis of AEMO's ISP Part 1: benefits of interconnection

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# 1 Scope of work

**The Australian Energy Market Operator (AEMO) engaged Aurora Energy Research (Aurora) to provide independent, supplementary analysis to the Integrated System Plan (ISP) – in particular, to focus on the potential benefits additional interconnection might provide to end energy consumers.** The 2018 ISP is a cost-based optimisation plan prepared by AEMO to identify least-cost pathways for the Australian National Electricity Market (NEM) in the period to 2040**.** In practice, the NEM operates as a market – albeit a regulated one – which need not operate or evolve along least-cost principles. Aurora's analysis bridges the gap between least-cost-optimal modelling outcomes and the realities of market behaviour to provide an independent view on the benefits of additional interconnection between regions outlined in the ISP.

**AEMO forecasts material system cost savings from future investment in additional interconnection capacity between regions.**[1] AEMO expects profound supply and demand changes to 2040 as new generation and storage technologies emerge and mature, and as demand changes with additional rooftop solar, electric vehicles and behind-the-meter batteries. The Australian east coast's relatively long and thin grid may benefit from additional investment in transmission infrastructure to adapt to this changing supply mix, as well as significant changes in aggregate demand and daily demand shape. The primary purpose of the ISP is to address these shifts and challenges – to map 'least resource cost' and 'least regret' additional investments in transmission infrastructure that would deliver a robust and secure electricity system, while minimising the ultimate cost borne by consumers.

**Aurora has produced an alternative quantification of costs and benefits from the additional interconnector capacity envisaged in the ISP, based on Aurora's market-based NEM dispatch model (AER-NEM) and the ISP's plant cost and capacity mix assumptions.** This document provides a concise summary of the results of this quantification. Aurora's analysis focuses on quantifying ultimate consumer cost savings generated through additional interconnection capacity which are not directly covered under AEMO's modelling approach (which is based on system cost minimisation). Aurora has modelled the price impact on consumers in each region and the extent to which average prices – and therefore consumer costs – are reduced through the additional interconnection mapped out in the ISP.

**Consequently, this report does not represent Aurora's in-house view of NEM outcomes, but rather represents an independent view of benefits generated under ISP interconnection build-out using an alternative model and modelling approach, but with the same input assumptions as the ISP.** AEMO's

[1] The system cost evaluated by AEMO includes supply-side costs such as fuel costs, variable and fixed operations and maintenance costs, as well as investment in generation capacity, intra-regional transmission and inter-regional interconnection

team has been invaluable in helping clarify input assumptions and methodological approaches within the ISP, but all modelled outcomes in this report are a product of Aurora's AER-NEM model.

# 2 Context and modelling methodology

## Additional ISP planned interconnection

Additional transmission investment is a significant source of cost in the power sector and those costs are ultimately borne by the electricity consumers who rely on the NEM for their power. Appropriately, additional inter-price zone interconnection is subject to rigorous regulatory tests to assess whether the costs of building the transmission capacity is exceeded by the benefits brought to the system and end consumers.

Additional interconnection may bring a range of potential benefits to an energy system – for example:

- **Efficient use of generation and subsequent cost reductions** — for example, additional interconnection can decrease the likelihood of renewable economic curtailment in a given region; or can increase the likelihood that the lowest short-run marginal cost power can be delivered to consumers across the NEM; or can provide additional access to renewable zones; or can improve general grid access for renewables and so decrease the carbon intensity of NEM-wide generation
- **Increase in competition in regions** — additional interconnection increases and diversifies sources of potential supply in a region by decreasing the market power of any single supply provider
- **Improvements to security of supply** — in a future NEM system that will be increasingly dependent on the sun and wind to generate electricity (driven as much by the economics of competing generation technologies as government policy), additional interconnection can increase security of supply by allowing power to flow from regions with excess renewable generation to areas with a deficit. Spatial aggregation, allowed by additional interconnector, reduces the overall variability of solar and wind output, and thus increases security of supply of the overall system. In addition, additional interconnection also improves security of supply through access to other surplus capacity across regions and increases the diversity of demand

These benefits must then be weighed against the costs associated with new interconnection capacity. AEMO estimates the aggregated cost of additional interconnection proposed within the ISP to be $1.2b on an NPV basis to 2040.

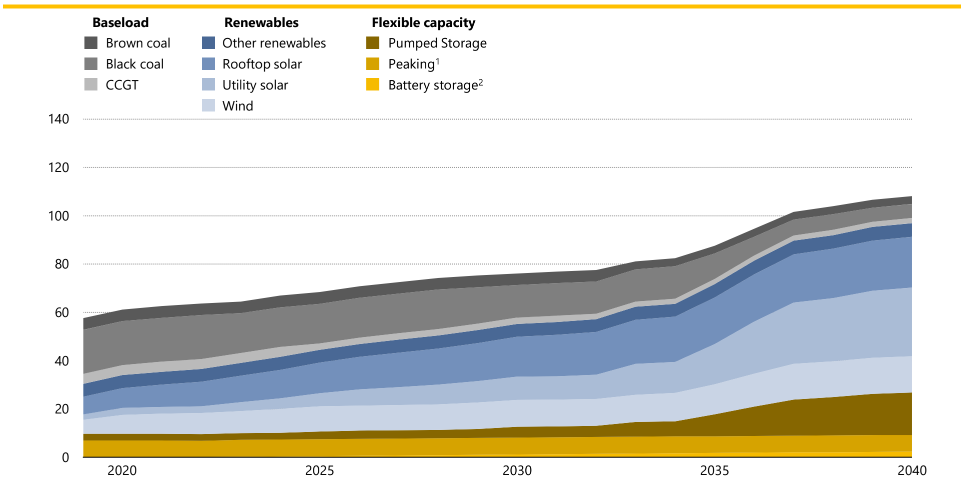
This report compares the costs and the benefits of AEMO's ISP interconnection for Australian energy consumers and market participants based on Aurora's AER-NEM modelling.

## Modelling methodology in comparing AEMO's ISP neutral and neutral counterfactual scenario

For the purposes of this report, Aurora fully replicated the ISP neutral scenario within Aurora's AER-NEM model. Aurora assumed the same plant and interconnector capacity timeline as indicated by AEMO's modelling for each ISP scenario, as well as adopting ISP assumptions concerning electricity demand, generator reliability, and technical and financial settings, including commodity prices.

**Aurora has replicated the capacity mix in the ISP neutral scenario within AER-NEM**

**NEM installed capacity for the neutral scenario,**
Nameplate GW




1) Peaking includes OCGTs, gas and liquid fuel-fired reciprocating engines
2) Aurora has not explicitly model non-aggregated distributed batteries as they are built into the underlying demand profile Aurora has utilised

*Sources*: Aurora Energy Research, AEMO

In terms of additional interconnection, AEMO triages proposed interconnection into 3 groups, and Aurora was asked to model the following specific set of additional interconnectors within each group:

- Group 1: immediate investment in transmission to be undertaken, with completion as soon as practicable.:
  - Increase Victorian transfer capacity to New South Wales by 170MW (2020)
  - Increase Queensland transfer capacity to New South Wales by 190MW (2020)
  - Increase New South Wales transfer capacity to Queensland by 460MW (2020)
- Group 2: action to be taken now, for implementation by the mid-2020s:
  - Establish new transfer capacity between New South Wales and South Australia of 750MW (2022-25)
  - Increase transfer capacity from Queensland to New South Wales by a further 378MW (2023)
- Group 3: – in the longer term, to the mid-2030s and beyond, the capability of the grid should be enhanced:
  - Increase Victoria transfer capacity to New South Wales by 1930 MW (2035)
  - Increase New South Wales transfer capacity to Victoria by 1800 MW (2035)

To estimate the costs and benefits of additional interconnection, Aurora modelled two scenarios:

- 'Neutral scenario' — AEMO's ISP neutral scenario incorporating all generation and storage, as well as additional interconnector capacities. To quote the ISP, the neutral scenario assumes a range of central, or mid-point projections of economic growth, future demand growth and fuel costs. These settings combine to form a central estimate of the transition forecast for the NEM. This includes:
    - Neutral growth outlook for consumption and demand from AEMO's March 2018 electricity demand forecasts, including uptake of distributed energy resources (DER)
    - Moderate growth in DER aggregation, such that aggregated distributed batteries can be treated and operated as virtual power plants, rather than operated to maximise the individual household's benefit
    - Generation expansion affected by central estimates of technology cost reductions
    - Existing market and policy settings
- 'Neutral counterfactual scenario' — an alternative scenario created by AEMO with no additional interconnection between regions and a corresponding alternative capacity mix. AEMO has designed this capacity mix to be least cost while ensuring secure supply based on current transmission capacity between price zones

AEMO's neutral scenario is described in detail in the '2018 Integrated System Plan Modelling Assumptions' document.

The table below summarises the ISP assumptions adopted for Aurora's analysis and modelled within AER-NEM.

| | Assumptions category | Description | In accordance with ISP |
|---|---|---|---|
| 1 | Installed capacity | ▪ Installed capacity per technology by year | ✓ |
| 2 | Electricity demand | ▪ Aggregate and maximum demand (including daily profile)<br>▪ Drivers of significant demand shifts, including rooftop PV generation, electric vehicles deployment, demand-side participation, battery aggregation | ✓ |
| 3 | Renewable policy | ▪ Renewables capacity<br>▪ AEMO assumes implementation of QRET, VRET and LRET | ✓ |

| | | | |
|---|---|---|---|
| **4** | Interconnector settings | ▪ Installed interconnector capability by year[2] | ✓ |
| **5** | Hydro settings | ▪ Installed pumped hydro by year and hydro inflows | ✓ |
| **6** | Generator reliability settings | ▪ Maximum and firm capacity, seasonal ratings and maintenance characteristics of existing, committed and advanced generators | ✓ |
| **7** | Generator technical and financial settings | ▪ Storage properties<br>▪ Commodity prices (coal, biomass, gas and liquid fuel) and heat rates<br>▪ Plant variable OPEX and auxiliary load | ✓ |
| **8** | Generation constraints[3] | ▪ Minimum load constraints for coal and gas units<br>▪ Minimum capacity factor for select gas units<br>▪ Maximum capacity factor for select units and technology classes | ✓ |

Given these starting assumptions, Aurora estimated the net benefit of additional interconnector capacity using a three-step approach:

- **Step 1:** Major inputs from the ISP neutral scenario and neutral counterfactual scenario are implemented in Aurora's AER-NEM model. The inputs replicated by Aurora are either published or directly provided by AEMO
- **Step 2:** Aurora's AER-NEM model is run for the scenario and its counterfactual. The model runs over the period between 2019 and 2040 at half-hourly resolution, dynamically calculating both dispatch and interconnector flows by region
- **Step 3:** Aurora compares the costs in each scenario and its counterfactual. When generation and investment cost is lower in one scenario relative to its counterfactual, this results in a system cost saving[4]. When electricity price is lower in one scenario relative to its counterfactual, this results in a consumer cost saving

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

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

[4] Because Aurora has replicated the ISP capacity mix and interconnection, investment cost for all scenarios is directly taken from the ISP, instead of being calculated by Aurora

# 3 Results of Aurora analysis

Four key findings emerge from Aurora's quantification of the costs and benefits of additional interconnection as mapped out in AEMO's ISP neutral scenario:

- **Finding 1:** Under AEMO's ISP neutral scenario, Aurora forecasts the net present value of savings to 2040 to be approximately $3.8b when the costs consumers face is quantified
- **Finding 2:** Under alternative scenarios outlined by AEMO in the ISP, Aurora forecasts the net present value of consumer cost savings could range between approximately $1-4b to 2040
- **Finding 3:** Under AEMO's ISP neutral scenario, Aurora forecasts additional interconnectors will deliver approximately $1b in net present value system cost savings to 2040 – consistent with AEMO's estimation of $1.2b in NPV cost savings over the same period
- **Finding 4:** There are a set of other benefits that may be generated from additional interconnection, but that have not been quantified by Aurora — in particular, potential reductions in ancillary service spending, carbon emissions reductions, and price-led shifts in consumption

## Finding 1

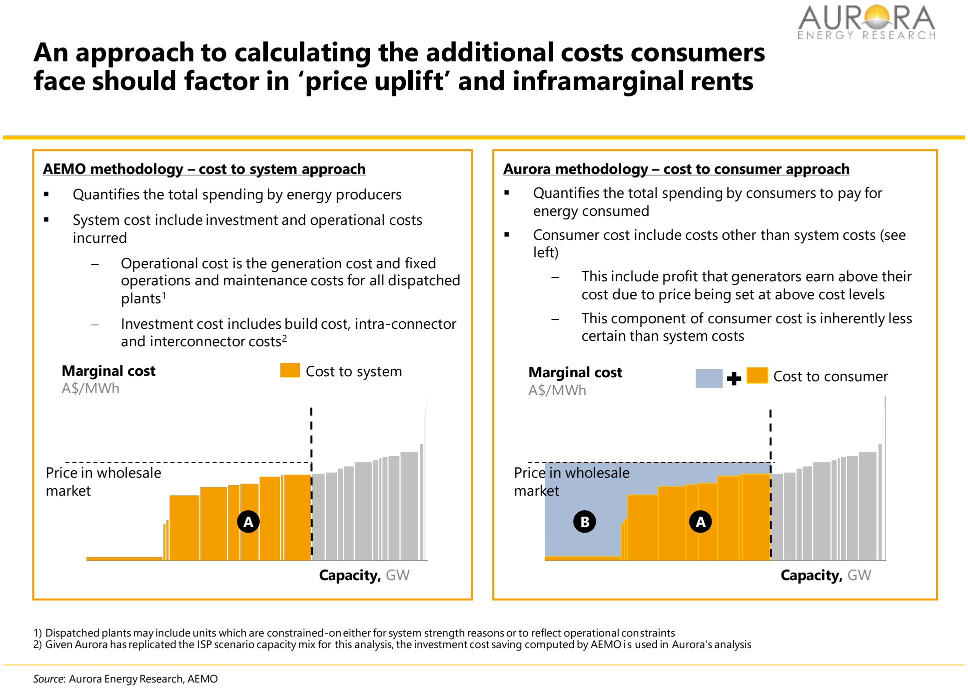
### Under AEMO's ISP neutral scenario, Aurora forecasts the net present value of savings to 2040 to be approximately $3.8b when the costs consumers face is quantified

In AEMO's analysis of the benefits of additional interconnection, AEMO focus on the impact of interconnection on the total cost of generation that is required to meet demand. Savings are generated through the delivery of lower cost power on average across the NEM — fundamentally, a more interconnected system allows for better identification and transfer of lower short-run marginal cost power creating net welfare benefits, and that is captured in AEMO's and Aurora's models. Aurora describes these savings as 'system cost' savings.

However, in the NEM, and all liberalized energy markets that Aurora operates in, the price delivered in the wholesale spot market will on average be higher than the short-run marginal cost of the marginal generation unit – sometimes, significantly higher. This 'price uplift' can be driven by a variety of factors — from ramping and cycling costs to low market competition in parts of the merit order to imperfect foresight from market players. Aurora uses an econometric regression to model this 'price uplift' in each half-hour to 2040.

As an example, on January 24th and 25th 2019, prices in wholesale markets in South Australia and Victoria peaked at over $14,000 per MWh for multiple hours. Clearly, no unit of generation or storage in the NEM has a short-run marginal cost approaching $14,000 per MWh, but when the system is very tight prices may reach very high prices both to incentivize demand and supply responses in the short-run, and to provide a longer-term price signal that new investment in supply may be required.

In addition, consumers will also pay significant inframarginal rent to generation units that have a lower short-run marginal cost than the generation or storage unit on the margin in any given price period.



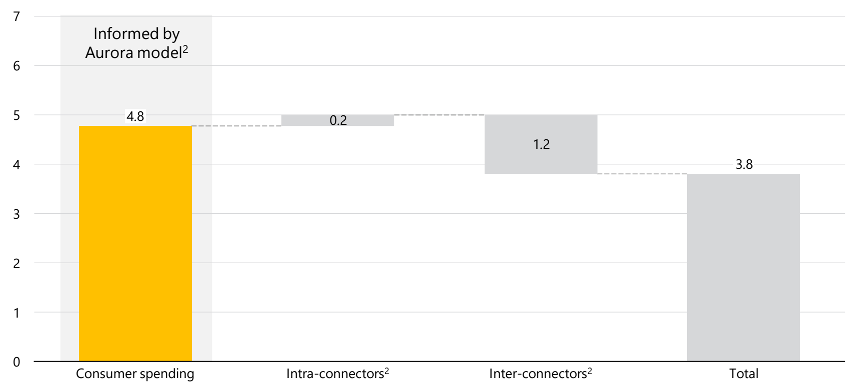

Additional interconnection puts downward pressure on both the cost driven by the short-run marginal cost of the marginal unit ('system cost'), but also price uplift and hence inframarginal rent, which adds to the cost ultimately born by the consumer. Aurora refers to reductions in those total costs (system cost and price uplift) as 'consumer costs'.[5]

[5] While Aurora views 'consumer costs' as a better reflection of the benefits of interconnection than 'system costs', we omit some cost drivers which may also impact ultimate retail bills for customers including, for example: retail margins; or additional costs driven by state or federal renewable auction schemes; or future government support for 'dispatchable' power as proposed in late 2018/ early 2019 by Energy Minister Angus Taylor

When comparing AEMO's neutral scenario against the neutral counterfactual scenario, Aurora modelling finds the net present value consumer cost savings from additional ISP interconnection to be approximately $3.8b from 2019 to 2040.

**The net cost savings additional interconnectors provide is estimated to be $3.8b in consumer costs**

**Net present value of Aurora consumer cost savings for AEMO ISP neutral scenario by 2040[1],**
Billion $A




**Aurora, consumer cost**

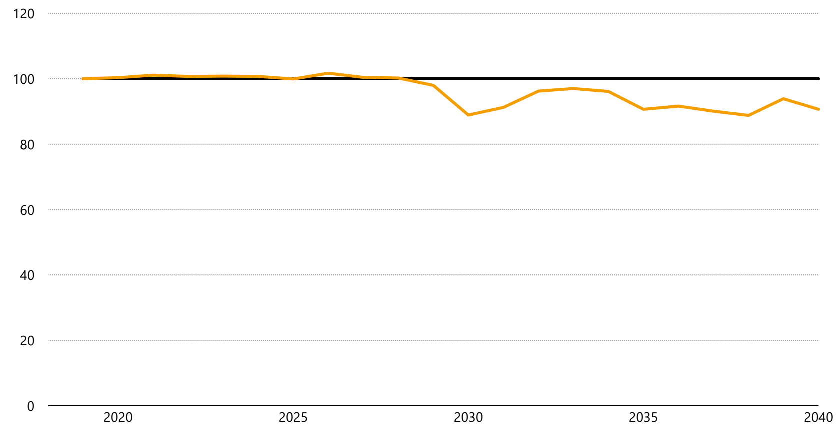
1) A discount rate of 6% is used for all cash flow projections
2) Aurora takes capacity building decision from AEMO's ISP as inputs, therefore, building cost savings are taken from the AEMO ISP study

*Source*: Aurora Energy Research, AEMO

The more efficient delivery of lower short-run marginal cost power and the increased diversification of potential supply to different regions within the NEM creates lower average wholesale market prices, although the price impact will vary by state.

## Additional interconnectors are forecast to decrease average electricity wholesale prices across the NEM

**Time-weighted average wholesale price reductions for ISP neutral scenario,**
Index of 100, relative to counterfactual scenario without additional interconnection, real 2017




*Source*: Aurora Energy Research

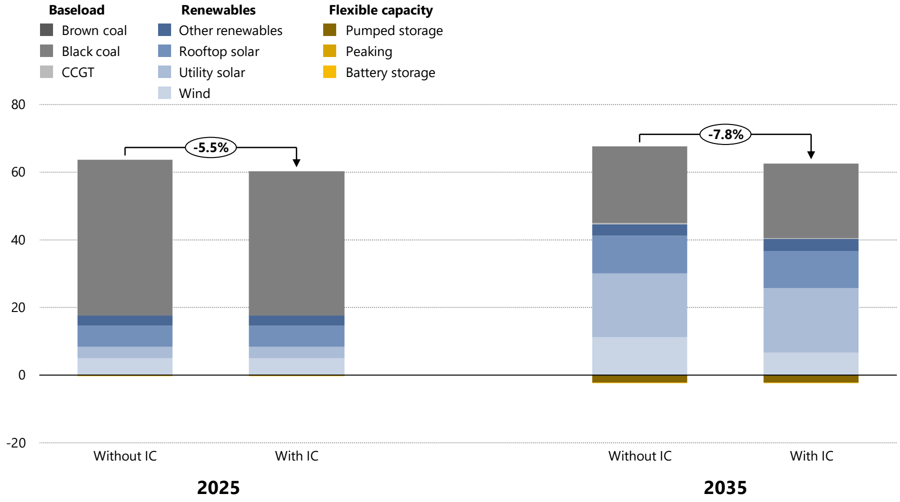
As an example, in NSW in 2025, Aurora forecasts that higher imports of power from neighboring regions reduce the coal-fired generation within NSW that is required to meet NSW demand, relative to the neutral counterfactual scenario with no additional interconnection. This reduces the price of electricity in NSW wholesale markets to 2040 as NSW coal generation has a higher short-run marginal cost relative to generation available elsewhere in the NEM.

In 2035 in NSW, higher imports of power from other regions enables NSW to leverage better natural resource endowment in other regions. Wind and solar farms are built in regions with relatively more resource availability than NSW and then export power into NSW demand centres.

In short, because of changing technology cost dynamics, in 2025 in NSW, additional interconnectors allow relatively more expensive NSW coal, with its relatively higher marginal cost, to be displaced by alternative sources of thermal generation. In 2035 in NSW, the primary effect is building renewables in optimal locations across the NEM. Benefits stem from both cross-correlations of wind and solar production across more dispersed areas and from allowing renewables to build in the areas with the best solar and wind profiles. Both these shifts reduce wholesale power prices in NSW.

## Additional interconnectors allow NSW to meet its demand using resources from other states

**Net generation in NSW,**
TWh

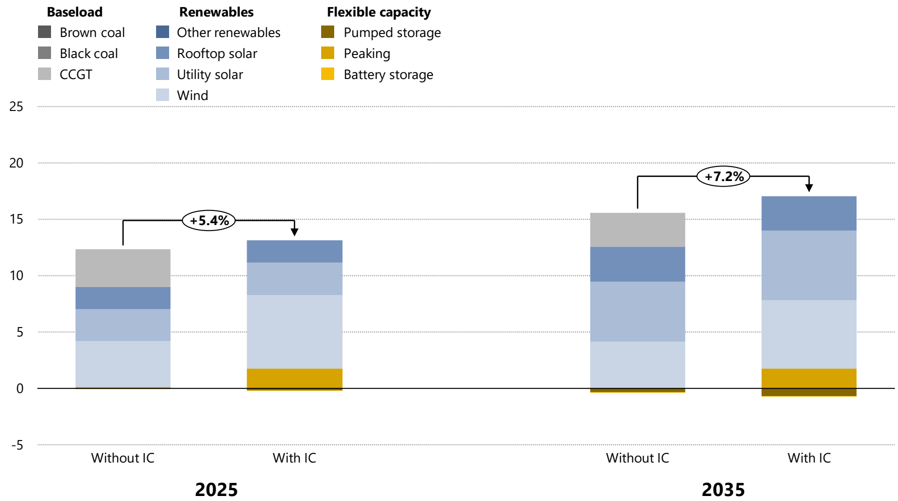



*Source*: Aurora Energy Research

In contrast, in South Australia, Aurora expects additional interconnection to increase export from South Australia to other regions with higher marginal cost generation. In 2025 and 2035, generation by South Australia's local renewable resources is increased relative to the counterfactual case. There are two drivers of increased renewables generation in South Australia within Aurora's AER-NEM model: firstly, additional interconnectors provide a route to market for these resources; secondly, higher interconnectivity with other regions reduces the need to dispatch local gas generation for system strength reasons – system strength can now be maintained through other generation connected via additional interconnection.

## Additional interconnectors allow South Australia to substitute local thermal capacity with a portfolio of renewable and flexible assets

**Net generation in South Australia,**
TWh




*Source*: Aurora Energy Research

## Finding 2

### Under alternative scenarios outlined by AEMO in the ISP, Aurora forecasts the net present value of consumer cost savings could range between approximately $1-4b to 2040

Aurora also analysed additional scenarios aside from the neutral scenario that are laid-out within the ISP. Aurora modelled both the ISP's fast change and slow change scenarios to assess the potential benefits of interconnection within those scenarios. Neutral, fast and slow scenarios all assume the same additional interconnector build-out on the same timeline, but with different demand and capacity build-outs, as well as different commodity price assumptions.

The ISP describes the fast scenario as a future where economic growth is strong, increasing overall discretionary income at a household level, and stronger emission abatement aspirations are economically sustainable. The net effect is higher operational (grid) consumption, a more peaky operational load profile (due to lower demand-based resources and low DER aggregation), and a faster power system transformation, relative to the neutral case. The objective was to test the risks and benefits of candidate transmission plans under a scenario where consumption was higher and more peaky, to assess whether reliability and security could be maintained. Compared to the neutral scenario, this scenario assumed:

- An increase in operational consumption, with higher population and increased productivity
- Higher levels of investment in energy efficiency
- Less coordination of DER and fewer demand-based resources
- Greater uptake of electric vehicles
- Faster overall cost reductions in utility-scale storage technologies
- Stronger domestic and international gas consumption, and higher LNG export volumes

The ISP describes the slow change scenario as a future where economic growth is weak, lowering overall discretionary income at a household level and reducing business investment. The net effect is lower operational (grid) consumption, a smoother operational load profile (due to higher level of demand-based resources and high DER aggregation), and a slower power system transformation, relative to the neutral case. The objective was to test the risks and benefits of candidate transmission plans under a scenario where consumption was lower and smoother, normally considered to reduce the need for development of additional transmission (and some resources). Compared to the neutral scenario, this scenario assumed:

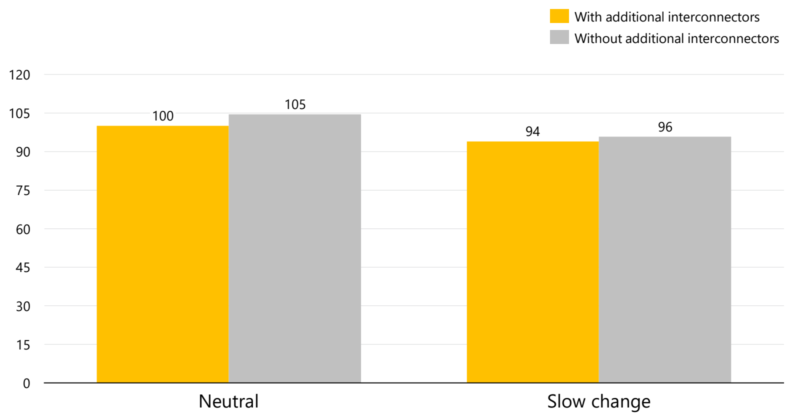
- A decline in operational consumption, with weaker economic growth resulting in some industrial closures
- Lower levels of investment in energy efficiency
- Greater coordination of DER and more demand-based resources
- Slower uptake of electric vehicles
- Slower overall cost reductions in renewable generation technologies
- Weaker domestic and international gas consumption, and lower LNG export volumes

From a consumer cost forecasting perspective, these different scenarios can create material variations in the levels of forecast savings, enabling confidence bands around Aurora's estimates for the neutral scenario. Aurora forecast cost savings of between approximately $1-4b depending on the scenario modelled.

As an example, in the slow change scenario, the primary drivers of lower differences in wholesale prices between the slow change and slow change counterfactual scenario are the economics of thermal generation and lower overall demand. For example, lower gas prices reduce the cost of gas generation at times of peak demand and therefore reduce the benefits of interconnection in providing alternative sources of supply outside of the price zone. In addition, the demand peaks themselves are relatively lower reducing the absolute need for supply outside of the region, as well as price uplift.

## The price reduction impact of additional interconnectors is higher in neutral scenario when compared to slow change

**Average wholesale price for NEM between 2019-2040[1],**
Index of 100, relative to neutral scenario




1) Time weighted average wholesale prices, not discounted

*Source*: Aurora Energy Research

## Finding 3

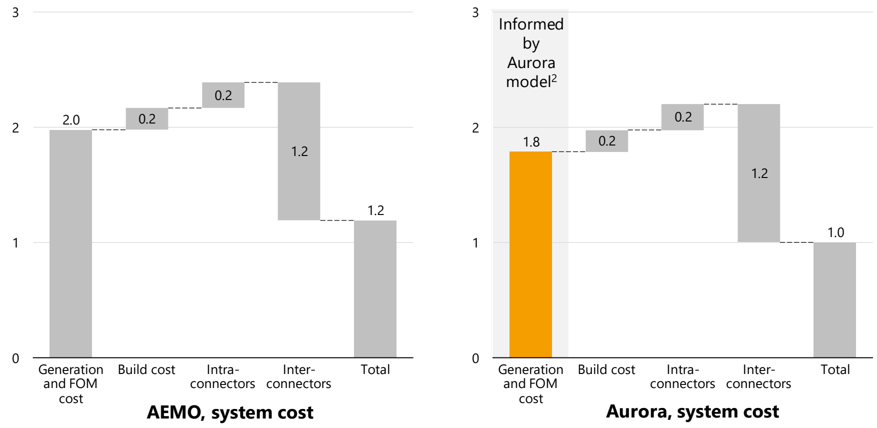
### Under AEMO's ISP neutral scenario, Aurora forecasts additional interconnectors will deliver approximately $1b in net present value system cost savings to 2040 – consistent with AEMO's estimation of $1.2b in NPV cost savings over the same period

While Aurora views the costs faced by the consumer as the most relevant and important metric for assessing the benefits of interconnection and has thus focused on 'consumer costs', Aurora has also analysed the system cost savings created by additional interconnection so as to provide a like-for-like comparison with AEMO's analysis and modelling.

Aurora finds net present value system cost savings from additional ISP interconnection in the neutral scenario to be approximately $1b from 2019 to 2040. The present value spending in the NEM from 2019–2040 on generation costs and fixed operating and maintenance costs is approximately $45b representing a potential saving of 2-3% over the period. AEMO estimates those savings to be $1.2b from 2019 to 2040. In short, Aurora's modelling and AEMO's modelling are closely aligned.

## Aurora's estimate of the net present value of system cost saving is approximately $1b by 2040

**Net present value of system cost savings for AEMO ISP neutral scenario by 2040[1]**
Billion $A




1) A discount rate of 6% is used for all cash flow projections
2) Aurora takes capacity building decision from AEMO's ISP as inputs, therefore, building cost savings are taken from the AEMO ISP study

*Source*: Aurora Energy Research, AEMO

## Finding 4

### There are a set of other benefits that may be generated from additional interconnection, but that have not been quantified by Aurora — in particular, potential reductions in ancillary service spending, carbon emissions reductions, and price-led shifts in consumption

Aurora has focused the quantification of benefits on wholesale market cost savings. There are three additional benefits that Aurora has not quantified but that may materially increase the benefits provided by additional interconnection between price zones:

- **Reductions in costs for ancillary services.** As additional interconnection creates higher competition in NEM wholesale markets and is forecast to reduce consumer costs, that additional interconnection also creates additional competition in FCAS markets. Aurora has not quantified those future benefits in this report as the focus was the much larger wholesale markets which predominantly drives consumer cost outcomes
- **Reductions in carbon emissions**. Additional interconnection can also reduce the carbon intensity of NEM generation by increasing the market access for new and existing renewable generators. Higher interconnector capacity between regions with abundant renewable energy endowment and demand centres allows lower short-run marginal cost power to be exported and used more

efficiently. Higher interconnector capacity that provides transmission capacity through previously unconnected areas can also increase the economic attractiveness of renewable energy projects in these areas

- **Price reductions increasing demand and allowing further productive consumption.** In all the analysis in this report, in reflecting the scenario analysis in the ISP, Aurora has assumed fully inelastic demand in both the short- and the long-run: that power demand remains constant when price falls. In reality, when electricity prices fall, the demand for electricity does increase. The academic literature estimates power elasticities range from -0.1 to -0.5. This means that, beyond reducing cost, price falls increases consumer welfare by enabling further productive consumption

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