Integrated System Plan

July 2018

For the National Electricity Market

Important notice

PURPOSE

AEMO has published the Integrated System Plan pursuant to its functions under section 49(2) of the National Electricity Law (which defines AEMO's function as National Transmission Planner) and section 5.20 of the National Electricity Rules and its broader functions to maintain and improve power system security.

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Executive summary

This Integrated System Plan (ISP) is a cost-based engineering optimisation plan by the Australian Energy Market Operator (AEMO) that forecasts the overall transmission system requirements for the National Electricity Market (NEM) over the next 20 years.

ISP modelling incorporated a range of plausible scenarios to identify future demand for power from the system and likely market response. For the latter, the modelling applied technology-neutral analysis to identify the required level and likely fuel type of supply investments required to meet future needs. The ISP model used cost-based economic analysis, and integrated system security and reliability considerations, as well as expressed Commonwealth and State Government policies, to identify the transmission investments that will be necessary to support the long-term interests of consumers for safe, secure, reliable electricity, at the least cost, across a range of plausible futures.

AEMO's scenario analysis findings are largely constant, and provide the foundation for a robust, least-cost path for the NEM to adapt to and accommodate the rapid and transformative changes occurring in the energy sector.

The ISP confirms numerous observations about the radical changes occurring in both the demand requirements and supply mix in the NEM. In contrast to the history of this sector, overall economic and population growth, and associated growth in demand for power, does not result in increased requirements for supply from the power system. Rather, the demand for power on the grid is flattening, due to the growth of rooftop photovoltaic (PV) and increasing use of local storage, as well as overall increases in energy efficiency.

At the same time as demand from the power system is flattening, existing supply sources, particularly thermal resources, are ageing and approaching the end of their technical lives. These resources must be replaced at a time and at the locations required to continue to support a reliable and secure power system and to meet consumer demand for affordable power that also meets public policy requirements.

It is in this context that the ISP has modelled and outlined targeted investment portfolios that can minimise total resource costs, support consumer value, and provide system access to the least-cost supply resources over the next 20 years to facilitate the smooth transition of Australia's evolving power system.

The result of this modelling and engineering analysis is the identification of those investments in the power grid that can best unlock the value of existing and new resources in the system, at the lowest cost, while also delivering energy reliably to consumers.

Background to the ISP

The comprehensive and transformational changes occurring throughout the energy sector are well documented. In previous decades, the Australian and worldwide power industries have experienced structural change through regulatory liberalisation, the formation of competitive markets, and incremental improvements in supply efficiency.

In the current period, the changes are far more comprehensive and fundamental. The industry is now experiencing the simultaneous effects and benefits of digitalisation, ageing infrastructure, a markedly and rapidly changing cost structure in both supply and storage, flattened and even negative demand growth, the impacts of climate change, cyber security concerns, and a profound change in consumer preferences and expectations for the industry.

These changes collectively are impacting the production, transmission, and consumption of power at an unprecedented rate. What is not changing, however, are the essential need for cost-effective and reliable power for the overall economic welfare of society, the capital-intensive nature of the industry, and the physical requirements governing the complex and integrated characteristics of the power system.

Whenever an industry undergoes the level of transformative change the power industry is experiencing, a level of disruption is to be expected. However, when that change occurs in an essential industry such as energy, neither economic nor physical failure, even for a short time period, is an acceptable outcome. In this circumstance, it is essential to have independent engineering and evidence-based planning around forecastable changes across the spectrum of the supply and demand equation and consumer and investor preferences.

By providing a forecast plan of a likely range of outcomes, this ISP helps identify the desirability of proactive policy, regulatory, and market reforms in the public interest. Collectively, these actions can simultaneously identify required and likely investments, provide pathways for orderly retirements and investment in new resources that can best meet established and new policy and economic objectives, and enable broad innovation through the removal of existing and emerging barriers to entry and competition. As a result, the transition can occur in a much more orderly manner, reduce the risk of failure from uncontrollable and unplanned events, and help ensure the public interest in reliable, affordable energy is met, in the context of government energy policies, including emission standards.

As the national transmission planner, AEMO is required to review and publish advice on the development of the transmission grid across the NEM, to provide a national strategic perspective for transmission planning and coordination, and to publish an annual 20-year outlook for NEM transmission planning, the National Transmission Network Development Plan (NTNDP). This ISP and associated material meet these responsibilities and fulfil the requirements of the NTNDP.

In October 2016, the Council of Australian Governments (COAG) energy ministers agreed to establish the Independent Review into the Future Security of the National Electricity Market, chaired by Dr Alan Finkel AO, Australia's Chief Scientist. The "Finkel Review" provided a *Blueprint for the Future* Security of the NEM[1], with recommendations to deliver a smooth transition for the changing power system, and for energy consumers across the NEM. The Blueprint highlighted the need for better system planning as one of the three pillars required to achieve the following:

> *Enhanced system planning will ensure that security is preserved, and costs managed, in each region as the generation mix evolves. Network planning will ensure that new renewable energy resource regions can be economically accessed.*
>
> Independent Review of the National Electricity Market (Finkel Review)

The Finkel Review's planning recommendations were agreed to by COAG energy ministers and this, as the first ISP, is an important step in enhancing system planning and fulfils specific recommendations in the Blueprint.

The Finkel Review also outlined the extensive technological and economic changes facing the NEM, and understood the scale of transition needed. But these changes are not only in the future. AEMO's experience clearly shows change is underway now and evident in trends in both consumer behaviour and investor interest. Integrated system planning is particularly important in this context and at this stage in the transformation of the national power system.

AEMO has developed the ISP based on its own experience as the system and market operator and planner, as well as through extensive consultation with stakeholders, input from expert consultants, and collaboration with transmission network service providers (TNSPs). The ISP has been developed through rigorous modelling and analysis, using established engineering, cost, and system security models and analytic frameworks, and internal and external reviews to help further validate core assumptions and findings.

The National Energy Market and integrated grid

The NEM provides a mechanism for trade in electricity across eastern and south-eastern Australia. It realises multiple benefits for consumers by its ability to take advantage of diversity in both supply and demand, maximising the use of lower-cost resources available at any time, sharing the needs for reserves, and allowing more effective commitment and dispatch of inflexible plant across the larger consumer base. As elaborated in this plan, the benefits of a geographically diverse resource mix and the ability to easily flow energy into and out of regions based on real-time circumstances grow exponentially over the 20-year plan period and into the future. The NEM also supports new investment to meet consumer demand in each region, while the ability to trade across regional boundaries allows more flexibility and choice in the nature and location of investment.

The NEM is underpinned by the integrated grid. The integrated grid in the NEM is one of if not the longest interconnected power system in the world, which hosts the lowest level of proportionate demand. The generation mix across the power system has a growing proportion of supply from variable renewable energy sources (requiring careful management and balancing of the system), an increasing proportion of non-synchronous generation, and a growing proportion of supply from distributed energy resources (DER), primarily rooftop solar PV. This combination of attributes is leading AEMO to become one of the recognised worldwide leaders in the complex operation of large power systems with substantial volumes of variable renewable and distributed generation.

Over the 20-year plan period, AEMO anticipates the retirement of a substantial portion of the NEM's conventional generation fleet. A significant number of coal-fired generators in the NEM have either advised that they are closing or will reach the expected end of technical life in this plan period. Collectively, the generators expected to retire by 2040 produce around 70 terawatt hours (TWh), or 70,000 gigawatt hours (GWh), of energy each year. This is close to one-third of total NEM consumption. In addition to providing critical energy production and dispatchable power, conventional generators have also traditionally been relied on to provide essential grid security services, such as inertia, system strength, and frequency control.

[1] *Independent Review into the Future Security of the National Electricity Market*, June 2017, available at https://www.energy.gov.au/government-priorities/energy-markets/independent-review-future-security-national-electricity-market.

The ISP modelling identifies investment portfolios that can minimise total resource costs and the targeted transmission investment, as well as the development of selected REZs, necessary to achieve the lowest level of replacement investment costs.

To support an orderly transition, ISP analysis demonstrates that, based on projected cost, the least-cost transition plan is to retain existing resources for as long as they can be economically relied on. When these resources retire, the modelling shows that retiring coal plants can be most economically replaced with a portfolio of utility-scale renewable generation, storage, DER, flexible thermal capacity, and transmission.

Within the plan period, under AEMO's Neutral ISP planning scenario, the analysis projects the lowest cost replacement (based on forecasted costs) for this retiring capacity and energy will be a portfolio of resources, including solar (28GW), wind (10.5 GW) and storage (17 GW and 90 GWh), complemented by 500 MW of flexible gas plant and transmission investment. This portfolio in total can produce 90 TWh (net) of energy per annum, more than offsetting the energy lost from retiring coal fired generation.

This ISP reveals how targeted investment in new transmission will minimise the overall cost and support consumer value by making better use of existing plant, including DER, lower fuel and operating costs and operating risk by a more inter-regionally connected system, and provide system access to the least-cost supply resources that can replace the retiring coal plant.

In the NEM, market participants make investments in generation and storage in response to consumer demand and relevant government policies. The underlying assumption in the ISP is that, in an efficient and competitive market, investors will choose the lowest-cost overall solution. When, as we are experiencing in the NEM, the new supply profile is different to the pre-existing one, both by type and location, it is necessary to take a more holistic and integrated approach to determine the regulated transmission investment which will support efficient market investment in generation and storage, and lead to the overall lowest-cost solution. To do otherwise would be to reduce the opportunity for market participants to invest in those resources that can produce the best outcome for consumers.

The investment costs associated with replacing old and retiring infrastructure with new plant, in one of the most capital-intensive industries, are significant and unavoidable. AEMO's modelling shows that the total investment required to replace the retiring generation capacity and meet consumer demand has an NPV cost of between $8 billion and $27 billion, depending on assumptions made around economic growth and rate of industry transformation. This level of capital investment is going to be needed, irrespective of this plan.

However, modelling shows that by spending 8% to 15% of this total capital investment on transmission rather than generation, efficiency gains are achievable. The ISP conservatively projects total system cost savings ranging between $1.2 billion and $2.0 billion with the integrated approach and new transmission investment in the ISP. These forecast savings do not take into account all the market benefits associated with a more robust transmission network, including, for example, the benefits of greater level of competition, increased resilience, and a more flexible and adaptable system. Conversely, ISP modelling projects that a less interconnected network will increase consumer costs and risks, through greater reliance on local gas-powered generation (GPG), reduced benefit from renewable resource diversity and storage diversity, and greater risk of local system failure.

Transmission investment recommended for immediate action in this ISP is estimated to be between $450 million and $650 million. Once spread over the life of the assets, this is equivalent to less than 1% of the annual transmission and distribution investment in the current regulatory cycle ($6.2 billion per year)[2].

Key observations for the future of a successful NEM

Changes in demand for power from the grid:

- The plan demonstrates the transformative impact distributed energy resources (DER), primarily rooftop PV and, increasingly, distributed storage, are having on the power system.
- Economic growth and population growth no longer result in changes in the overall need for power from the grid, due to the counterbalancing impacts of distributed energy at consumers' locations.
- Increases in electric vehicles will impact the uses of power, but over the plan period they are forecast to have a small impact on overall grid-based demand.
- For the power system to provide consumer value, a transition plan that supports the delivery of reliable power at the lowest cost is essential.

[2] Australian Energy Regulator (AER), State of the Energy Market (May 2017), Section 3.7.1 (p. 111), available at https://www.aer.gov.au/publications/state-of-the-energy-market-reports/state-of-the-energy-market-may-2017.

A portfolio approach:

- Maintaining existing coal-fired generation up to the end of its technical life is a key element of a least-cost approach.
- When existing thermal generation reaches the end of its technical life and retires, the most cost-effective replacement of its energy production, based on current cost projections, is a portfolio of utility-scale renewable generation, energy storage, distributed energy resources (DER), flexible thermal capacity including gas-powered generation (GPG), and transmission.
- There is a growing need for energy storage over the next 20 years to increase the flexibility and reliability of supply.
- All scenarios in the ISP project a growing proportion of supply will come from DER. This is consistent with observed trends, where residential, industrial, and commercial consumers are investing in rooftop PV at the highest rate ever, and there is increasing interest in battery storage and load management.

The crucial role of transmission:

- The projected portfolio of new resources involves substantial amounts of geographically dispersed renewable generation, placing a greater reliance on the role of the transmission network. A much larger network footprint with transmission investment will be needed to efficiently connect and share these low fuel cost resources.
- Increased investment in an interconnected grid provides the flexibility, security, and economic efficiency associated with a power system designed to take maximum advantage of existing resources, integrate variable renewable energy, and support efficient competitive alternatives for consumers.
- Transmission investments will also help manage the risk of anticipated but uncontrollable climate effects such as bushfires, droughts (both water and wind), and heatwaves.
- AEMO estimates that the additional transmission investment proposed in the ISP would conservatively deliver savings of around $1.2 billion on a net present value (NPV) [3] basis, compared to the case where no new transmission is built to increase network capabilities between regions (in the modelled Neutral case). The new inter-regional transmission is projected to more than pay for itself through efficient investment in, and use of, generation and storage across the NEM. Other important benefits associated with the plan, but not quantified in the modelling, include benefits arising as a result of enhanced competition and improved power system resilience.
- The value of the identified transmission investment can be quantified by comparing total costs of supply against a 'no new interconnection' option. In the modelled case without a more strongly interconnected grid, consumer demand was projected to be met, but through more costly investment in generation and storage, and greater use of GPG. This analysis projects that without further network development, consumers would pay more for energy.

Renewable energy zones (REZs):

- The ISP has identified a number of highly valued REZs across the NEM with good access to existing transmission capacity. To connect renewable projects beyond the current transmission capacity, further action will be required.
- The ISP considers how to best develop REZs in future that are optimised with necessary transmission developments, identifying indicative timing and staging that will best coordinate REZ developments with identified transmission developments to reduce overall costs.

Distributed energy resources (DER) and inter-regional development:

- The High DER scenario shows the potential for even greater use of DER to lower the total costs to supply, with the NPV of wholesale resource costs reduced by nearly $4 billion, compared to the Neutral case. In this scenario, the projected need for utility-scale investment and intra-regional transmission development to provide access to the incremental REZs is reduced, however it still illustrates the need for greater increased national transmission capacity to take advantage of diversity and better utilise dispatchable resources.
- The analysis in the ISP only addresses wholesale level costs, and further work is required to quantify the overall value of DER to consumers. This will require markets which support efficient integration of DER and

[3] The present value of a future cash flow represents its worth right now. The net present value (NPV) is the sum of the present values of all future cash flows (both positive and negative). The NPV is commonly used in cost-benefit analysis to assess the economic impacts of policies and projects.

changes to the distribution system, including system management tools and market interfaces, to maintain security, reliability, and power quality with increased DER.

Power system requirements:

- Due to the changes in technology, the transformation requires the adoption of new technologies and approaches to provide services needed to operate the power system that are currently provided predominantly by thermal generation.
- The engineering study undertaken of the power system identifies future requirements in voltage control, system strength, frequency management, power system inertia, and dispatchability. These requirements can be met and system security maintained by procuring services from the market, through network services and by the technical standards set for new plant connecting to the grid. Some recommendations are made to manage system strength in the future and to improve the updating of technical standards.

Timing of development plan:

- AEMO looked at various transmission reinforcement options, assessing the costs and time to implement these relative to modelled benefits, to determine the optimum immediate investments and staging of future development.
- The ISP delivers economic benefits under all scenarios. The timing of some elements varies under different assumptions, particularly relating to the rate of change and the progress of proposed major energy storage initiatives.

An integrated pathway for development of the power system

The result of this modelling and engineering analysis is the identification of those investments in the power grid that can best unlock the value of existing and new resources in the system, at the lowest cost, while also delivering energy reliably to consumers.

The modelling is consistent with current experience in the NEM, where new renewable generation is being proposed and commissioned at high rates. Some of this generation is incentivised through the Commonwealth's renewable energy target, and renewable energy schemes in Victoria, Queensland, and the Australian Capital Territory. However, the rate of build and continuing extent of interest in further investment indicates that at least some of the investment is driven by the reducing costs of renewable generation and encouraged by an expectation of future government policy in the National Energy Guarantee to support generation with low emissions.

As a result of the connection of this generation, and the expected connection over the next few years, there is a need to increase the capability of the transmission system, to reduce congestion and provide generators, existing and new, with cost-effective access to markets. The retirement of conventional generation over recent years, and expected retirement of Liddell in 2022, also drive benefits from transmission development to improve the reliability and resilience of the system and to allow the efficient use of existing generation resources.

In the medium term, to the mid-2020s, there is an increasing need for significant levels of energy storage in the portfolio of new energy sources required for continued reliability and security. The transmission grid needs to be developed to support the connection of the generation and storage options with the lowest cost, co-optimising investment in transmission, storage, and generation across the market and optimising the use of all resources.

In the longer term, in the run up to and after the bulk of expected coal retirements in the mid-2030s, the plan shows the need for further transmission to deliver a more integrated and resilient power system. The elements of this plan have been grouped into three phases, based on the timing of the need and the scale and time to construct, taking advantage of any time available to refine each element.

The overall plan delivers economic benefits under all scenarios, although the timing of some elements varies under different assumptions, particularly relating to the rate of change and the progress of proposed major energy storage initiatives.

Group 1: Near-term construction to maximise economic use of existing resources

Immediate action is required to maximise the economic use of existing low-cost generation. Investment is also required to facilitate the development of projected new renewable resources to replace retired and retiring resources, and to provide essential system security.

To enable these benefits, the ISP identifies two relatively minor transmission augmentations that would increase transfer capacity among New South Wales, Victoria and Queensland, providing immediate reliability[4] and economic

[4] In the first week of June 2018, New South Wales experienced reserve shortages due to an unforeseen combination of generation outages coinciding with low wind and solar conditions. A 360 MW increase in New South Wales' import capacity would have resolved these Lack of Reserve (LOR) 2 conditions.

benefits by increasing competitive alternatives to consumers. The transmission is projected to benefit consumers in all regions by making better use of existing investment and creating greater market opportunities for new investment, including any required and planned new local generation capacity in New South Wales.

These minor transmission upgrades will save on total system costs by improving productive efficiencies. In the absence of strong operational demand growth, greater interconnection across the NEM would increase efficient utilisation of existing and committed resources, reducing reliance on higher-cost GPG, allowing coal-fired generators to operate within more efficient ranges, and providing immediate benefits to consumers by relieving network congestion.

In conjunction with these network upgrades, the ISP identifies the need for synchronous condensers in South Australia to supply both system strength and inertia to the region. This is essential now, and will continue to be needed after the RiverLink interconnector (the new South Australia to New South Wales interconnector discussed in Group 2) is developed to allow the most cost-effective use of South Australia's local generation.

The REZs already developing in western Victoria and north-western Victoria warrant transmission investment to improve access to renewable generators in this area. Reducing congestion increases and diversifies the supply of renewable energy to the market, and improves productive efficiency from existing assets.

AEMO recommends that these network investments be progressed as soon as possible, because of the identified benefits they provide immediately, and the support they deliver to achieve the highest consumer economic and system security and reliability benefits over a range of modelled plausible scenarios.

Group 1 – immediate investment in transmission should be undertaken, with completion as soon as practicable, to:

- *Increase transfer capacity between New South Wales, Queensland, and Victoria by 170-460 MW.*
- *Reduce congestion for existing and committed renewable energy developments in western and north-western Victoria.*
- *Remedy system strength in South Australia.*

In the Base plan, these initial transmission developments for Group 1 are costed at between $450 million and $650 million, and the assets will continue to benefit consumers well beyond the 20-year ISP forecast period.

Group 2: Developments in the medium term to enhance trade between regions, provide access to storage, and support extensive development of REZs

The ISP shows that an interconnected energy highway would provide better use of resources across the NEM, through both access to lower-cost resources and realising the benefits of diversity from different resources in different locations with different generation profiles. The additional transmission also facilitates better use of the less flexible thermal (coal- and gas-fired) generation, which through enhanced interconnectivity can more efficiently meet the operational demand net of renewable generation.

The proposed initiatives in Group 2 are of a larger scale and cost than those in Group 1, and require longer lead times to design and develop, however also provide larger benefits if they have timely implementation. Work needs to commence immediately on refining the requirements for the developments identified in Group 2, finalising the design, and establishing implementation processes and plans to support the lowest-cost outcomes for consumers. AEMO notes that the Energy Security Board (ESB) is undertaking a review on how to best integrate the ISP with the regulatory approval processes, and suggests that these type of significant and necessary projects are suitable for consideration in this process.

The analysis in the ISP supports a new interconnection between South Australia and New South Wales (RiverLink). The ISP has identified a range of further expected benefits from RiverLink, which as well as improving resilience for South Australia, would enable connection of large amounts of renewable energy resources from the Riverland to Murray REZ, as well as improving inter-regional trade and competition, especially if linked to developments to support the Snowy 2.0 project in the 2020s and planned augmentation of the Victorian to New South Wales interconnection in Group 3. RiverLink is currently under assessment by ElectraNet as part of the South Australian Energy Transformation Regulated Investment Test (RIT-T)[5].

Other major transmission developments identified in the ISP that are about to commence assessment include the next stage of the Western Victorian transmission upgrades, augmentation of the Queensland – New South Wales interconnection, and a minor augmentation of the existing Victoria – South Australia transfer capacity.

To support the flexibility and system security required of this future energy mix, the ISP shows a strong role for energy storage that can shift renewable energy production at scale and provide firming support as well as system security.

[5] See https://www.electranet.com.au/projects/south-australian-energy-transformation/.

The ISP examines how the Snowy 2.0 and Battery of the Nation proposals fit this need. Specifically, the plan identifies that increases in interstate energy interchange to take advantage of location diversity, coupled with large-scale storage and flexible gas generation, are essential components of a system that relies on significant levels of variable, zero-fuel cost (and hence low marginal cost) renewable energy.

To accomplish this, the model demonstrates the economic value of network investment to efficiently support development of the Snowy 2.0 and Battery of the Nation proposals.

AEMO understands that a final decision to go ahead with the Snowy 2.0 project is likely before the end of 2018. When a final decision is made on the commitment of Snowy 2.0, a new link from Tumut to Bannaby (SnowyLink North) and associated works between Bannaby and Sydney West would provide system benefits. AEMO also understands that there is work being done to progress the Battery of the Nation initiative, which would provide additional pumped hydro storage in Tasmania for use across the NEM. A second interconnector linking Tasmania to the mainland NEM would be needed to support this project.

AEMO will work with project proponents to refine the timing of the commissioning of these projects and requisite transmission investment for energy delivery. The relevant transmission developments are:

- SnowyLink – provides route diversity to harden the grid against extreme climate conditions, and unlocks high quality renewable energy resources, reducing connection costs for new renewable generation needed once the majority of the coal fleet retires. Without this interconnection, AEMO's modelling indicates that more balancing services (such as GPG or energy storage) would be required to address the lack of diversity that arises from concentrating renewable generation in clusters. This link can be delivered in two stages – a northern component (SnowyLink North) connecting Snowy 2.0 to Sydney, followed by a southern component (SnowyLink South) that enhances interconnection between Victoria and New South Wales.
- MarinusLink – facilitates development of Tasmania as either one or multiple REZs. This would be beneficial if further renewable generation development in Tasmania delivers the potential value highlighted by Battery of the Nation studies[6].

Group 2 – action should be taken now, to initiate work on projects for implementation by the mid-2020s which would:

- *Establish new transfer capacity between New South Wales and South Australia of 750 MW (RiverLink).*
- *Increase transfer capacity between Victoria and South Australia by 100 MW.*
- *Increase transfer capacity between Queensland and New South Wales by a further 378 MW (QNI).*
- *Efficiently connect renewable energy sources through maximising the use of the existing network and route selection of the above developments.*
- *Coordinate DER in South Australia.*

AEMO will coordinate work with project proponents on a design for transmission networks to support strategic storage initiatives (Snowy 2.0 and Battery of the Nation).

Group 3: Longer-term developments to support REZs and system reliability and security

In the period from 2030 to 2040, a significant amount of the NEM's coal-fired generation is expected to reach end of technical life and retire. As noted, given the scale of the investment and building time required, it will be important to retain existing coal-fired generators until the end of their technical life to maintain reliability. This approach is also cost-effective, because while existing generators still operate, they can generate at lower costs than new investment. Once these generators retire, a new generation mix based on renewables is projected to be lower-cost than new coal-fired generation.

The ISP provides a coherent pathway to a more strongly interconnected grid by the mid-2030s. At this point, a more strongly interconnected grid will:

- Provide access to a large capacity of conventional generation, renewable generation, and energy storage to meet consumer demand.
- Provide the capacity to best locate and use those resources.
- Take advantage of geographic, time, and resource diversity in renewable resources, and allow more efficient operation of coal-fired generation and GPG.

[6] See https://www.hydro.com.au/clean-energy/battery-of-the-nation.

- Improve reliability and resilience of the system by allowing resources within and across regions to meet consumer demand and promote greater resilience.

It is important to deliver the optimum mix in the portfolio of resources to minimise total cost of supply. While actual investment in generation and storage projects will be driven by market incentives and technology costs at the time, the transmission grid to support this requires planned, regulated investment.

The strategic design and selection of a transmission route is critical. Cost savings are available if interconnectors pass through identified REZs and alleviate the need for intra-regional network extensions to remote locations. A view to future climate risk resilience will also influence route selection, with projected increases in extreme weather events and bushfires increasing the value of route diversity.

The ISP proposes, in Group 3, strengthening interconnection between Victoria and New South Wales (SnowyLink) to improve resource sharing across the NEM and deliver fuel cost savings. This interconnector will also facilitate the efficient connection of new REZs within Victoria and New South Wales.

A number of additional REZs will need to be accessed to unlock the low-cost resources required to replace the energy previously supplied by retiring coal-fired generators. This includes a number of new REZs in New South Wales and Queensland.

There is time to consult on, refine, and finalise initiatives in Group 3, including the selection of preferred REZs and their timing. The refinement of the projects in this group will also include consideration of the timing of transmission development. Given potential increases in risk as generation units age, the planned investments should occur in sufficient time to provide a level of flexibility in the event of unexpected and unrepairable catastrophic plant failure.

Group 3 – in the longer term, to the mid-2030s and beyond, the capability of the grid should be enhanced to:

- *Increase transfer capacity further between New South Wales and Victoria by approximately 1,800 MW (SnowyLink).*
- *Efficiently connect renewable energy sources through additional intra-regional network development.*

Next steps

The 2018 ISP is a first, and very significant, step in adapting the national transmission system to meet current and future needs. The plan is robust and based on rigorous engineering analysis and established analytic frameworks. A program of work is outlined in the ISP to further refine the recommendations for groups 2 and 3 of the plan.

AEMO's modelling confirms that the NEM is at a critical point, and infrastructure planning decisions made over the next two years will shape the future of the east coast energy systems for decades to come. We look forward to collaborating with industry and government to progress developments that can support an affordable, reliable, secure, sustainable, and future-proof energy system for consumers across the NEM.

AEMO will commence consultation on the ISP, including its inputs, methodology, and conclusions. Information supporting this document will be published, and an extended workshop will be held with stakeholders to aid consultation. Further information will become available on key projects, especially related to storage. This information will be reviewed and current trends analysed to confirm or refine findings.

AEMO will work with project proponents and the Australian Energy Regulator (AER) to take the immediate actions recommended – implementing the projects in Group 1 – and will work with project proponents to progress design work on projects in Group 2. AEMO will also work with the ESB and other market bodies to develop a process for the development, approval, and implementation of these Group 2 projects, as well as the criteria used to implement future plans. The COAG Energy Council will also need to identify the actions it would take as part of this process.

This ISP complements the intentions of the National Energy Guarantee, and other market rule and policy changes that have been accepted by the COAG Energy Council through its approval of the Finkel Review as the core foundations of a smooth transition.

The ISP shows that the power system of the future will be substantially different to the power system of today. The ISP modelling optimises outcomes overall and, as such, these are not necessarily the outcomes that would emerge from the current regulatory structure. These issues are most appropriately addressed through a coordinated approach, supported through the ESB. AEMO looks forward to directly collaborating with market bodies through the ESB and market participants to ensure the regulatory and market arrangements are fit to best address the needs of power consumers, today and into the future.

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1. Context for the ISP

The ISP has been developed through rigorous modelling and analysis, using established engineering cost and system security models and analytic frameworks. This report provided the outcomes of that analysis, and includes information previously released under a *National Transmission Network Development Plan* (NTNDP):

- This chapter provides the context for the ISP and why it has been developed.
- Chapter 2 outlines the modelling approach used (refer also Appendix F).
- Chapter 3 outlines the projected mix of energy resources in the National Electricity Market (NEM).
- Chapter 4 outlines AEMO's assessment of renewable energy zones (REZs) in the NEM.
- Chapter 5 outlines power system requirements that must be met.
- Chapter 6 outlines the integrated development plan for the NEM over the next 20 years, including:
  - Developments for near-term construction.
  - Developments to around the mid-2020s that are of a larger scale and cost, are projected to deliver larger benefits, and on which work should also begin immediately to investigate and consult on requirements, designs, and implementation plans.
  - Longer-term developments identified for the later part of the 20-year outlook, on which there is more time to consult, including the selection of preferred REZs and their timing, and planning for transmission developments to support the portfolio of resources and deliver secure, reliable energy at the lowest total costs for consumers.
- Chapter 7 outlines AEMO's proposed next steps.
- Appendices to the report provide more detail:
  - Appendix A provides AEMO's review of REZs.
  - Appendix B provides key climate change projections that are expected to influence future energy infrastructure, supply, and demand in the NEM.
  - Appendix C provides details on AEMO's assessment of system security over the coming five-year period and any new Network Support and Control Ancillary Services (NSCAS) gaps identified.
  - Appendix D provides details on the transmission developments proposed under this plan.
  - Appendix E provides AEMO's responses to submissions received during consultation on the ISP in December 2017.
  - Appendix F provides details on the methodology, approach and assumptions used in the analysis for the ISP.
  - A glossary to terms used in the ISP report and appendices.

AEMO has also provided this additional information on its website:

- ISP Input assumptions workbook[7].
- Interactive map – visual presentation of ISP outcomes[8].
- 2017 Network Flows and Congestion data[9].

[7] AEMO, Integrated System Plan Assumptions Workbook. Available at: https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/Integrated-System-Plan.

[8] AEMO Interactive maps and dashboards. Available at http://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/Interactive-maps-and-dashboards.

[9] AEMO publishes information on congestion within the Congestion Information Resource (CIR). The CIR provides a consolidated source of information relevant to the understanding and management of transmission network congestion (constraint) risk – including information on where to find constraint data, policies, procedures, guidelines, CIR consultations, and education material. Available at: https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Security-and-reliability/Congestion-information.

1.1 AEMO's responsibilities under the National Electricity Law

The National Electricity Law establishes AEMO's role as the 'national transmission planner', giving it the following responsibilities:

> (a) *to prepare, maintain and publish a plan for the development of the national transmission grid (the National Transmission Network Development Plan) in accordance with the Rules;*
>
> (b) *to establish and maintain a database of information relevant to planning the development of the national transmission grid and to make the database available to the public;*
>
> (c) *to keep the national transmission grid under review and provide advice on the development of the grid or projects that could affect the grid;*
>
> (d) *to provide a national strategic perspective for transmission planning and coordination;*
>
> (e) *any other functions conferred on AEMO under this Law or the Rules in its capacity as National Transmission Planner.*
>
> National Electricity Law Part 5, Division 1, 49 (2)

This scope, which took effect when AEMO was formed in 2009, expanded the scope of previous national transmission planning reports. AEMO must have regard to the National Electricity Objective (NEO) in carrying out its national transmission planner functions, and all its activities. The NEO is:

> *…to promote efficient investment in, and efficient operation and use of, electricity services for the long term interests of consumers of electricity with respect to—*
>
> *(a) price, quality, safety, reliability and security of supply of electricity; and*
>
> *(b) the reliability, safety and security of the national electricity system.*
>
> National Electricity Law Part 1, 2, 7

The National Electricity Rules (NER) set out what factors AEMO must take into account in developing the NTNDP, and the minimum content requirements. As part of these requirements, the NTNDP must "consider and assess an appropriate course for the efficient development of the national transmission grid" for a planning horizon of at least 20 years. The work to develop this plan was undertaken under AEMO's powers and functions as the national transmission planner. This report and the accompanying documentation fulfils all the requirements in the Rules of the NTNDP.

1.2 The Finkel Review

In October 2016, Council of Australian Governments (COAG) energy ministers agreed to an independent review of the NEM to take stock of its current security and reliability and provide advice to governments on a coordinated national reform blueprint. The Independent Review into the Future Security of the National Electricity Market was established with Dr Alan Finkel AO, Australia's Chief Scientist, as Chair of the Expert Panel responsible.

The Review provided a *Blueprint for the Future* Security of the NEM[10]. The Blueprint outlined three key pillars to deliver the necessary outcomes:

- Orderly transition to provide certainty and drive investment.
- System planning to inform investment decisions and deliver an innovative, low emission, secure, and reliable power system.
- Stronger governance to drive faster rule changes, overcome challenges, and deliver better outcomes.

In recommending the need for better system planning, the review concluded that:

- Better system planning should see AEMO having a stronger role in planning the future transmission network, including through the development of a NEM-wide integrated grid plan to inform future investment decisions.

[10] Independent Review into the Future Security of the National Electricity Market, June 2017, available at https://www.energy.gov.au/government-priorities/energy-markets/independent-review-future-security-national-electricity-market.

- Significant investment decisions on interconnection between states should be made from a NEM-wide perspective, and in the context of a more distributed and complex energy system. AEMO should develop a list of potential priority projects to enable efficient development of renewable energy zones across the NEM.

This ISP is the initial implementation of the second pillar, improved system planning, as well as a specific recommendation (5.1) in the Finkel Review.

> “ ***Improved system planning***
>
> *5.1 By mid-2018, the Australian Energy Market Operator, supported by transmission network service providers and relevant stakeholders, should develop an integrated grid plan to facilitate the efficient development and connection of renewable energy zones across the National Electricity Market.*
>
> *5.2 By mid-2019, the Australian Energy Market Operator, in consultation with transmission network service providers and consistent with the integrated grid plan, should develop a list of potential priority projects in each region that governments could support if the market is unable to deliver the investment required to enable the development of renewable energy zones. The Australian Energy Market Commission should develop a rigorous framework to evaluate the priority projects, including guidance for governments on the combination of circumstances that would warrant a government intervention to facilitate specific transmission investments.*
>
> *5.3 The COAG Energy Council, in consultation with the Energy Security Board, should review ways in which the Australian Energy Market Operator's role in national transmission planning can be enhanced.*
>
> *Recommendations from the Independent Review of the National Electricity Market (Finkel Review)*

A key element of the Finkel Review recommendations was the need for a system-wide grid plan:

> “ *The introduction of an integrated grid plan will inform investment decisions and ensure security is preserved in each region as the generation mix evolves. This will ensure that we can generate and deliver electricity more efficiently.*
>
> *Recommendations from the Independent Review of the National Electricity Market (Finkel Review)*

2. Development of the ISP

The primary objective of the ISP is to identify a national, strategic plan to support development of the energy system which will deliver safe, reliable, and secure electricity at lowest cost and in the context of government policies.

Regulated transmission investment is best characterised as a "highway system". In a competitive market environment, transmission investment supports the retention and development of supply resources that represent the lowest total system cost, including both transmission and generation investment. By supporting the delivery of energy from the lowest-cost supply options, transmission enables the market to deliver value to consumers through greater competition and the opportunity for lower prices than would otherwise be required. In the next 20 years, there will be a need to make additional investment in the NEM to replace retiring coal plants and address ageing network infrastructure. The challenge is to determine how best to enable the set of regulated and market-based investments that can deliver the requisite energy to consumers at the lowest cost.

The ISP needs to be able to support these expected trends and likely changes that are occurring on the energy system including retirement of existing generation, replacement with a portfolio of resources (utility-scale renewable generation, storage, distributed energy resources (DER), flexible thermal capacity, and transmission, with an orderly, low-cost transition facilitated by maintaining existing generation to end of technical life)[11], and the corresponding need for greater power system flexibility. In this context, an affordable energy system that provides energy security and reliability must be optimised across the entire energy supply chain, from large-scale generation to the consumer level.

The ISP identifies the transmission investments required to achieve that objective. AEMO will work with colleagues at the Energy Security Board (ESB) to identify what policy and regulatory changes are necessary and appropriate to facilitate the transition. AEMO notes, in this regard, that other jurisdictions throughout the Organisation for Economic Co-operation and Development (OECD) have engaged, and are engaging, in similar changes to their regulatory structures as they relate to transmission investment to support the industry in transition.

The development of significant network infrastructure can take multiple years, and will last for many more. All future planning therefore needs to make recommendations, cognisant of future uncertainties. To meet the objective of planning and to be certain that the plan is robust and can readily meet current needs and adapt to possible changes, alternative scenarios must be considered. The goal is to use the scenarios to identify those investments that will provide clear consumer and system benefit under almost any probable future, and simultaneously avoid the risk of poor investment decisions resulting in poor economic outcomes for consumers and investors as well as a less secure, reliable, and resilient integrated power system.

The analysis undertaken for each scenario requires a range of key inputs that can have significant impact on the system requirements. AEMO developed the range of inputs needed based on its own engineering and operations experience, observation of current trends, expert advice, and wide consultation with industry and government, and through robust modelling. These necessary inputs include a range of parameters or assumptions related to:

- The retirement of existing coal-fired generators, as notified by their owners, or when they reach their expected end of technical life.
- Operational demand[12].
- The cost and performance of the various supply options across a broad range of technologies, including thermal generation, storage, and renewable generation from the potential REZs identified.
- A range of potential system investments.
- The policies which will have a direct impact on the development of the power system.

The key inputs and assumptions are discussed in Section 2.3, and the chosen scenarios are described in Section 2.7. The full set of data used in the ISP has been published separately[13].

For this ISP, AEMO has used an integrated energy approach utilising state-of-the-art PLEXOS® software to co-optimise gas and electricity infrastructure investment that meets Australia's future energy needs at lowest cost. The optimisation considers both the value of geographic diversity and the economies of scale associated with clustering

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[11] In this report, AEMO uses the term "portfolio of resources" as shorthand for all the resources modelling identified as delivering energy to meet forecast demand and support reliable, secure power system operation at the lowest total cost.

[12] Operational demand means the electricity used by residential, commercial and large industrial consumers, as supplied by scheduled, semi-scheduled, and significant non-scheduled generating units. For more on definitions, see http://www.aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/EFI/2018/Operational-Consumption-definition---2018-update.pdf.

[13] Available at https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/Integrated-System-Plan.

renewable generation in fewer locations. It takes a systems view that examines the requisite portfolio of generation, storage, and transmission that meets the future needs of the power system and then solves, on an economic cost basis, the resources that might be used to meet these needs.

In effect, it forecasts what future investment is likely in generation and storage, assuming rational investment decisions by market participants based on current information on technology costs and supply requirements. Further, rather than simply assessing incremental investment opportunities, it looks ahead to ensure recommendations made now complement future investment requirements.

As required, AEMO specifically considered the potential value of identified REZs to connect additional resources at low cost. The ISP has analysed the potential value of developing a number of preferred zones of renewable generation to provide an effective, least-cost way to integrate new generation, storage, and transmission development. The proposed transmission development increases the ability of renewable generators to connect without additional action.

System modelling also takes into account the physical requirements of the future power system. In particular, the ISP integrates power system analysis using PSS/E[14] and system strength modelling undertaken in PSCAD[15] as part of AEMO's Power System Frequency Risk Review process. Consequently, the investments identified in the plan also reflect the reliability and security requirements of the integrated grid.

The result of this modelling and engineering analysis is the identification of those investments in the power grid that can best unlock the value of existing and new resources in the system, at the lowest cost, while also delivering energy reliably to consumers, and supporting stable and secure power system operations, in the context of national and state emissions reductions commitments.

The reliability and security of the power system is an imperative, and all scenarios have been modelled in a manner which ensures standards are met. AEMO has also considered a number of risks to the system, and sought to ensure a level of system resilience. In particular, the exposure to climate risks and especially to extreme weather events and bushfires has been considered. AEMO considers that planning for system resilience related to climate effects will be a critical component of planning for the future power system. Further work will be undertaken in this respect and included in future plans.

2.1 Consultation on approach and inputs

AEMO consulted broadly with stakeholders in 2017 on the ISP and its inputs, and undertook two formal stages of consultation early in 2018. The first stage sought feedback on input assumptions, settings, and modelling, including the use of a scenario-based approach. Stakeholders provided a wide range of feedback on AEMO's modelling and scenario assessment for the ISP, which AEMO included in its modelling. In accordance with the requirements of NER 5.20.2(b)(1), in preparing this Plan, AEMO has taken into account the submissions made, and information about submissions and AEMO's responses is included in Appendix E.

In developing the ISP, extensive consultation was undertaken with a wide range of stakeholders. In accordance with NER 5.20.2(b)(3)(i) and (iv), in preparing the ISP, AEMO also worked closely with the jurisdictional Transmission Network Service Providers (TNSPs) so that there was a high degree of alignment between the ISP and their Annual Planning Reports (which needed to be undertaken concurrently) and recent revenue determinations.

2.2 Planning for a range of futures

AEMO has developed timelines and recommendations after analysing a range of plausible scenarios, so the ISP reflects the needs of different possible futures, incorporating expected changes in technology, consumer engagement, and economic growth. In any planning study, it is not possible to explore every potential future, so AEMO consulted widely to select scenarios that were broadly considered the most useful. The chosen scenarios (described in Section 2.7) seek to explore a range of plausible and internally consistent future worlds by varying key uncertainties and dependencies to ensure robustness of any recommendations.

Extensive modelling on the scenarios has been undertaken to build an understanding of how the power system can be expected to develop and to recommend a strategy for the future development of the grid.

Modelling the increasingly complex energy system requires new, innovative techniques. For this ISP, the market modelling approach examined:

[14] Power System Simulator for Engineering (PSS®E or PSS/E) is proprietary software from Siemens used by power system engineers to simulate electrical power systems in steady-state conditions as well as over timescales of a few seconds to tens of seconds. PSS/E modelling is routinely used for large-scale power system studies by AEMO and registered NEM participants.

[15] Power System Computer Aided Design (PSCAD®) is proprietary software from Manitoba Hydro International, an electromagnetic time domain transient (EMT) simulation environment and study tool for modelling and simulating the transient and dynamic behaviour of the power system. PSCAD is the most widely used EMT-type simulation tool, and is extensively used by major power system equipment manufacturers.

- The role that existing generation may continue to have, including hydro, coal-fired, and gas-powered generation (GPG), while emerging low-emissions technologies enter and erode the competitive market share of traditional generators.
- Whether new base load generation such as high efficiency low emissions (HELE) coal-fired generation could help deliver low-cost, reliable, and secure supply as part of a portfolio of resources, recognising the increasing need for synchronous generation to operate flexibly to assist in the management of renewable energy oversupply and variability.
- Gas and electricity system co-dependencies, to consider the capabilities of the gas network to deliver gas for GPG as well as for domestic gas consumers and liquefied natural gas (LNG) exports.
- Diversity across geographic areas as well as generation technologies through detailed resource assessments of variable renewable resources across the NEM, identifying REZs.
- The need for and technical capabilities of energy storage, particularly the capacity for variable renewable energy, supported by storage technologies, to provide energy-replacing solutions for retiring coal generators.
- The role of the transmission network, through co-optimised expansion of the generation mix and the transmission infrastructure required to deliver this new energy. For example, renewable generation can be co-located in REZs to share transmission, and be built in locations where new generation can use major transmission assets that are already operating, being augmented, or being built.
- The impact of DER co-ordination, utilising these resources to meet system needs rather than operating passively.

The outcome for each scenario is a 'least resource cost' solution for that case, constrained to meet all reliability, security, and emissions constraints. See Section 3.1.2 for modelling outcomes and the identification of the projected lowest-cost portfolio of resources.

The ISP modelling and decision-making process are summarised briefly below, and described in greater detail in Appendix F and associated 2018 ISP Assumptions Workbook[16].

2.3 Planning inputs

The principal inputs to the ISP relate to forecast changes in average demand, the timely retirements of existing supply resources, and the economic profile and other attributes of new supply resources, including storage resources. The key inputs in this plan reflect the fundamental changes occurring in the power sector:

- **Demand forecasts** – underlying demand for power (at consumers' power points) is projected to increase, due to population and economic growth. Much of this growth, however, is projected to be met by DER (such as rooftop PV) and energy efficiency. As a result, demand for grid-supplied energy is forecast to remain relatively flat over the outlook period, and load growth is not the primary driver of new investment in this ISP. Local pockets of demand growth are still projected, and will need to be addressed and coordinated within the broader plans (see Section 2.3.2 for more detail on forecast trends in electricity consumption).
- **Schedule of generation retirements** – a schedule outlining when existing generation plant reaches expected end of technical life and retires is a key input to the ISP. The assumed retirement timing of a significant proportion of the coal-fired generation fleet is a dominant driver for future planning of the power system[17]. A significant number of coal-fired generators in the NEM have either advised they are closing, or are expected to reach the end of their technical lives at 50 years of age, during the plan period. This is an important driver of investment in the resources and infrastructure needed to supply consumer demand.
- **Cost projections for supply** – the cost components of conventional generation and the cost and performance of renewable generation and energy storage are key inputs to the ISP. Changes in these input costs are also forecast over the plan period, projecting trends observed over recent years and expected cost reductions over time based on the maturity and potential of the technology. Based on these costs, the delivered cost of energy from wind and solar in combination with storage from pumped hydro and batteries is anticipated to be lower than generation based on new coal or natural gas when the existing coal generators retire. This is an evolving trend from previous plans, but the ISP is AEMO's first plan in which utility-scale solar generation is projected to be lower-cost than wind generation. This change in cost relativities impacts on the generation forecasts, the preferred REZs, and the identified transmission developments.

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[16] AEMO, Integrated System Plan Assumptions Workbook. Available at: https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/Integrated-System-Plan.

[17] The timing of retirements of coal-fired power stations is highly complex and the outcome of a wide range of commercial and financial factors in the market. For the purpose of this ISP, AEMO has assumed retirements of coal-fired generators at either announced retirement times, or a time based on 50 years of operational age of the plant (termed "technical life"). Actual retirement timing could be earlier or later than assumed. See Section 2.4 for details.

- **Transmission development options** – a wide range of potential upgrades to the national transmission grid were designed and costed by AEMO and the TNSPs. These included intra-regional developments to connect REZs and inter-regional developments to reduce impending congestion, take advantage of diversity, and develop and use the lowest-cost generation and storage resources. The identified transmission investments support a wide range of planned and potential supply investments throughout the NEM, and at locations that optimise their value to investors and consumers. In developing these transmission options, AEMO also reviewed a range of risks to the resilience of the system and considered the need to maintain system strength.
- **Policy assumptions** – the scenarios in the ISP were each modelled under policy directives current at time of modelling[18]. The approach was to model the lowest-cost approach in the context of current federal and state government policies. These policies influence the development of the power system. The plan assumes no risk premium on any investment, assuming rather that the National Energy Guarantee removes that risk and supports the technology-neutral approach taken in the ISP.

2.3.1 Policy inputs

The NEM operates in the context of a range of government policies at state and national level. The ISP includes announced federal and state government policies that will affect investment decisions. Inherent in the planning is the assumption that policy certainty will allow efficient, technology-neutral investment decisions to be made, and that the appropriate framework will be in place to deliver the reliability outcomes and sustainability policy context built into this plan.

AEMO has incorporated the Commonwealth government's policy on emissions reductions in the cases analysed, and has also tested the impact of a faster reduction in emissions. AEMO has incorporated the Victorian and Queensland Governments' renewable energy policies in all cases studied.

AEMO uses its published commitment criteria[19] for determining which proposed development projects are included in the modelling. Because the Snowy 2.0 and Tasmanian Battery of the Nation projects do not yet meet these commitment criteria, but are being actively pursued, these projects have been explicitly modelled in a separate scenario, to examine how these large-scale hydro storage investments support the flexibility and system security requirements of the future energy mix. AEMO notes that significant work is underway on these two major storage initiatives, and this work will provide valuable new information to the market. AEMO will continue to work with project proponents on a design for transmission networks to support these storage initiatives.

2.3.2 Consumption

Total NEM electricity consumption is forecast to remain relatively flat over the outlook period in most scenarios, as shown in Figure 1[20].

This forecast reflects projections of greater energy efficiency and growth in distributed generation including rooftop solar PV accompanied by growth in battery storage behind the meter, offsetting drivers for increases in consumption arising from projected productivity growth due to forecast growth in population and the economy.

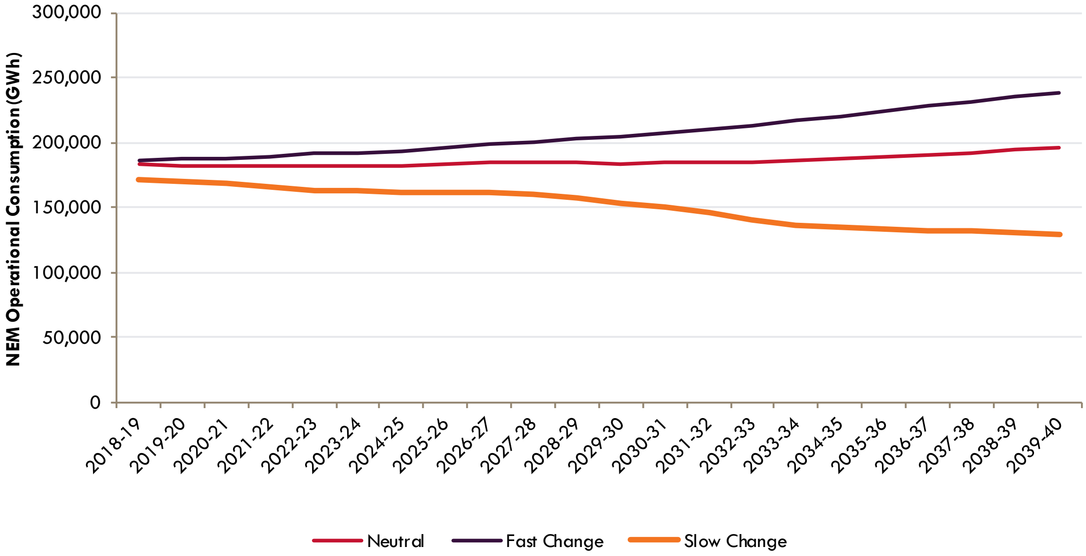
While overall electricity consumption is forecast to remain relatively flat, growth rates are not homogenous across the grid. AEMO's forecasts of individual connection points within regions of the NEM demonstrate that local pockets of demand growth are expected, and will need to be addressed and coordinated within the broader plan. Western Sydney and other city fringe locations are expected to experience greater population growth as our capital cities expand. Further work is required to investigate and incorporate sub-regional demands into future assessments.

[18] AEMO adopts a consistent process across all its major reports to include existing government policies within its modelling. For future ISPs, AEMO will engage with the Energy Security Board on how best to manage current and prospective government policy implications.

[19] Commitment criteria are summarised under the Background information tab in regional spreadsheets on AEMO's Generation Information page. Available at: https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/Generation-information.

[20] In its July 2018 report, *Restoring electricity affordability & Australia's competitive advantage (available at*https://www.accc.gov.au/publications/restoring-electricity-affordability-australias-competitive-advantage), the Australian Competition and Consumer Commission (ACCC) recognised the risk of "dead-weight loss", whereby higher prices resulting from over-investment in networks may drive consumers to make sub-optimal choices about their supply and use of energy. In its consumption forecasts, AEMO has not assumed any dead-weight loss associated with network over-investment, because the least-cost approach adopted in this ISP is designed to avoid this outcome.

Figure 1 Total NEM operational consumption



2.4 Anticipated coal-fired generation retirements

The impending retirements of coal-fired power stations are highly complex and the outcome of a wide range of commercial and financial factors in the market. As a result, the projected timing of retirements is highly uncertain. For the purpose of this ISP, AEMO has assumed retirements of coal-fired generators at either announced retirement times, or a time based on operational age of the plant (termed "technical life") [21]. For black coal-fired power stations, this technical life is assumed to be 50 years in most cases. For Victorian brown coal-fired power stations, the retirement dates broadly align with the 17-year mine rehabilitation guarantee secured by the Victorian Government in June 2018[22].

Figure 2 below identifies the retirements of coal plant across the NEM that were assumed as inputs to the analysis. The retirements are spread across Queensland, New South Wales, and Victoria, with New South Wales the NEM region assumed to have the greatest scale of age-driven retirements.

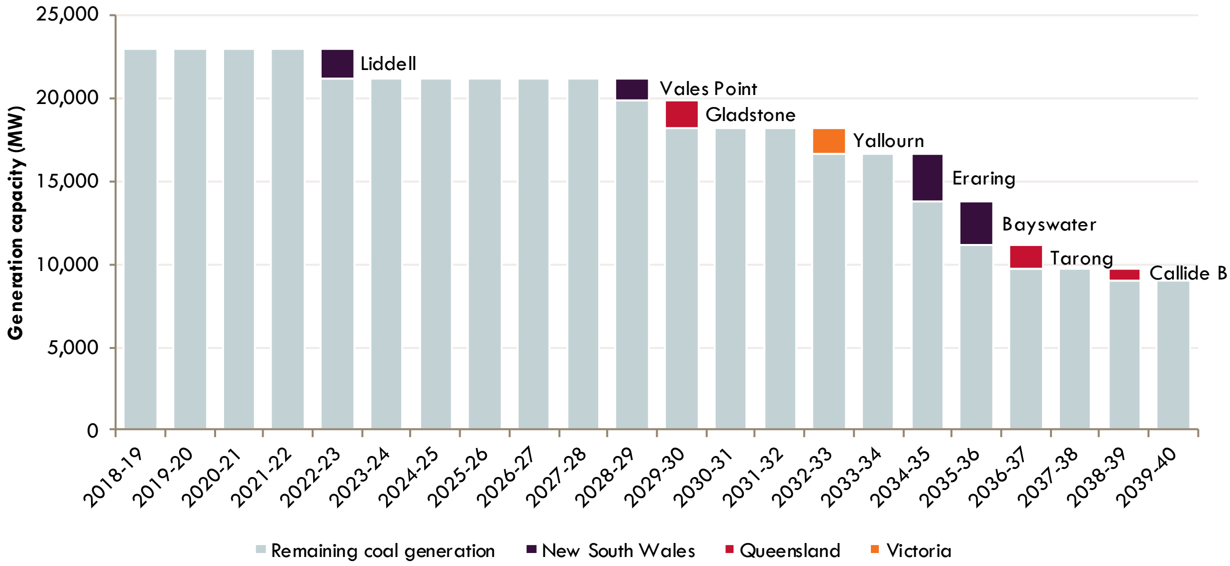
It is assumed that approximately 15 GW of generation (14 GW of coal fired and about 1 GW of GPG) will reach its end of technical life by 2040 and retire. This is projected to result in an overall reduction in the energy generated from coal, with the coal-fired power stations retiring currently generating approximately 70 TWh, equivalent to around one-third of current total NEM consumption.

The modelling allows for earlier retirement of coal- and gas-fired generation on economic grounds, if this decision would deliver lower total system costs. Revenue sufficiency for individual power plant has not been factored into assessing retirement timing. In the development of Group 2 and Group 3, AEMO will further consider revenue sufficiency and the risk of catastrophic early failure of existing generators.

[21] The ISP considers that all generators will need to either be retired or require significant capital investment equivalent to replacement cost at the end of each generator's technical life.

[22] See http://earthresources.vic.gov.au/earth-resources-regulation/information-for-community-and-landholders/mining-and-extractives/latrobe-valley-coal-mines/yallourn-and-loy-yang-rehabilitation.

Figure 2 NEM coal-fired generation fleet operating life to 2040, by 50th year from full operation or announced retirement



2.5 New generation, transmission, and storage options considered

The ISP is, by design, a holistic and technology-neutral approach, integrating existing and new resources on both the supply and demand side, at utility-scale and distributed at consumers' premises, at the lowest overall consumer expense. It takes into consideration a broad set of thermal and renewable generation, transmission, and storage investment opportunities across the NEM in assessing the requisite transmission development to deliver the 'least resource cost' future energy mix. Capital and operating costs for all technologies are provided for reference in the 2018 ISP Assumptions Workbook[23]. The same weighted average cost of capital was applied for all technologies to convert capital costs into an equivalent annual cost stream for assessment.

As has been widely noted, both in the context of emissions policy and due to their falling costs, renewable wind and solar resources are quickly becoming the lowest capital cost resource for supplying energy. Almost 80% of all currently announced, proposed, advanced, or committed projects in the NEM are wind or solar generators[24]. In many jurisdictions, the ideal location of these resources from the perspective of fuel availability is distant from the network required to deliver the energy to consumers and will require transmission development to connect them, and dependent on where they connect, potentially also system strength remediation.

A wide range of potential REZs across the NEM were analysed and the characteristics of the resources in those zones determined. AEMO identified and assessed 34 potential REZs across the NEM through consideration of a mix of resource, technical, and other considerations. In addition to the quality of the renewable resource, AEMO assessed the value of the diversity of renewable generation within the region to generation in other REZs and its correlation to demand. The planning model analysed which mix of plant from which REZs would be the optimum, taking into account the diversity of those resources, their costs, network costs and any storage required for balancing supply and demand.

AEMO has also considered the transmission investment required to develop REZs to provide consumers access to the lowest-cost renewable resources. Modelling also considered the need for specific REZ developments in light of the availability of locations close to the existing network that could be relied on to deliver energy with a reduced level of transmission investment.

AEMO has worked closely with TNSPs to identify an efficient range of potential network upgrades for consideration to provide continued power system reliability and security during the transformation of the NEM.

[23] *Integrated System Plan Assumptions Workbook*. Available at: https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/Integrated-System-Plan.

[24] AEMO, Generation information, March 2018. All generation projects currently operating, withdrawn, committed, and proposed in the NEM are reported by region on AEMO's generation information web page, at http://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/Generation-information.

2.6 Approach to modelling

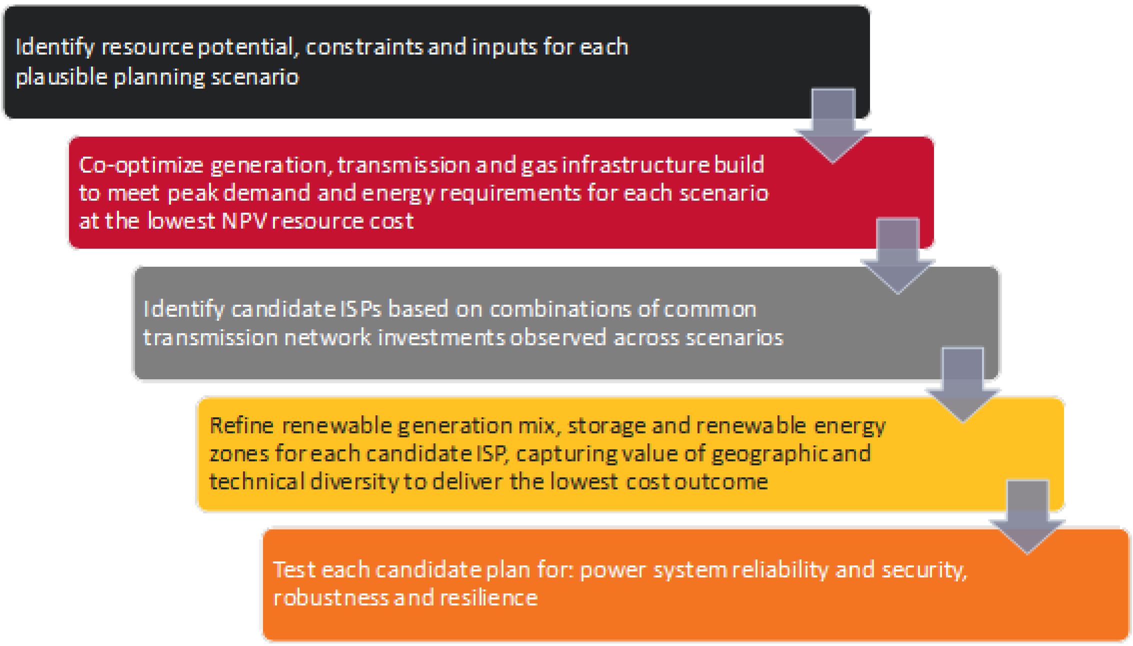
To understand how the power system can be expected to develop and recommend a strategy for the future development of the grid, AEMO conducted extensive cost modelling and cost-benefit analysis applying the inputs outlined above to each of the scenarios discussed.

Modelling the increasingly complex energy ecosystem requires new, innovative techniques. This has required AEMO to adopt a multi-staged modelling approach, with each stage helping to build a more complete analysis of the strengths and weaknesses of various future grid development options. Figure 3 below summarises this approach (the ISP Model). AEMO has published detailed information on the methodology separately (see Appendix F of the ISP). Energy Exemplar's PLEXOS Integrated Energy Model (PLEXOS®) is the key software platform utilised throughout.

The ISP Model sought to find the optimal mix of gas and electricity infrastructure investment and operation which meets the future power system needs at lowest cost for consumers across the NEM. The initial analysis focused on identifying the optimal solution for each scenario and progressively moved to finding the overall plan which was optimal, or close to optimal, across all scenarios.

The modelling approach required extensive computation, because the ISP Model considered a broad set of investment choices in generation, transmission, and storage across regions and zones, through the plan timeframe.

Figure 3 Summary of modelling approach – the ISP Model



The ISP Model took into account:

- Availability of gas reserves, resources and pipeline capacities – these influence the cost and availability of gas and consequently the viability of future GPG to supply electricity consumption in volume.
- Maximum renewable energy potential and constraints in each region – the quality of the renewable resource, potential quality degradation as more generation is co-located, existing spare transmission capacity, and cost to augment the existing capacity all influence the value of a given location and REZ. Where new interconnector routes pass by REZs and effectively encompass the intra-regional transmission augmentation required to access the REZ generation, this value was captured by removing any REZ transmission congestion.
- Diurnal and seasonal weather patterns by REZ – the hour by hour profile of expected output for each renewable generation technology is related to the REZ in which it is located. AEMO used historical weather observations to capture observed solar and wind variability at each REZ, to take account of diversity as an important input to the overall optimisation.
- Minimum synchronous generation constraints – where synchronous generation is required to maintain power system security, constraints have been imposed on the modelling. In turn, these constraints are removed in instances where new interconnector options would alleviate these power system security concerns.

- Levels of DER co-ordination – utilising these resources to meet system needs, rather than operating passively, can make the overall system more efficient, flexible, and affordable. For this initial ISP, the volume of DER and level of DER co-ordination was an input assumption that was varied for each scenario.

The first step of the ISP Model was to find the combination of investments for each scenario that delivers reliable and secure electricity supply at the least cost to consumers. This combination reflects input assumptions and the broad set of investment choices in generation, transmission, and storage identified across regions and zones.

Certain interconnection options and combinations of options were consistently seen to be part of the least-cost solution as each scenario was modelled. Importantly, some interconnector developments were selected by the model under all scenarios, with immediate effect. These interconnector investment decisions common to all scenarios formed the basis for developing a number of "candidate plans". All the candidate plans included both headline interconnection upgrades between NEM regions and a range of smaller upgrades within regions to relieve constraints and support the integration of new generation.

For each candidate plan, and each scenario, the future generation mix was re-evaluated in detailed long-term modelling, assuming that generation and storage investment decisions would be influenced by future grid expansion. The resulting net present value (NPV) of resource costs was used to compare between candidate plans to develop the recommended pathway.

The final step in the ISP Model was hourly modelling of snapshot years, using detailed transmission constraint sets, and considering unit commitment and bidding behaviour. This step was undertaken to verify whether the candidate plans met the reliability and system security requirements.

Cost benefit analysis

Thoughtful development of the transmission network has the potential to deliver cost savings to end consumers by improving efficiency of the existing generation fleet, deferring or reducing the need for new generation and storage investment and reducing the cost of accessing renewable energy resources.

To assess this value in each scenario, the investment and production costs for each candidate plan were compared on an NPV[25] basis against a case with no additional inter-regional transmission developments. In this counterfactual, no new interconnector transmission development is required, although additional transmission is still needed *within* regions to connect new renewable generation and/or storage. Without intra-regional transmission investment to connect new local generation to load centres, the analysis projects there would be insufficient energy accessible to replace the retiring coal fleet.

Key market benefits considered when comparing the recommended pathway against the counter-factual include:

- Capital deferral benefits (transmission and generation).
- Productive efficiency gains through fuel and operating cost savings.

The recommended pathway represents the most efficient plan that would transition the electricity industry to reliable and secure future, taking into account policy settings, at lowest cost to consumers under the majority of scenarios.

Additional unquantified benefits

The modelling undertaken for the ISP focused on minimising the total resource costs. This provides a conservative estimate of the potential benefits of the identified network investment. In addition to lowering the total resource cost, increasing the transfer capacity of the network could also provide:

- Greater operational flexibility to deal with plant outages and weather events. The ISP modelling process only optimised outcomes under 'system normal' conditions.
- A level of resilience against climate change and extreme events (or sudden shocks, such as unplanned coal closures) which can impose high costs on consumers and society.
- More choice and competition.
- Scalability, providing the option to extend or increase capacity over time as the future becomes more certain and the industry transforms.
- Lower costs for ancillary services (services the power system needs to operate securely, such as frequency control services).

It is also important to recognise that the modelling considered resource costs, not prices to consumers. An informed and efficient competitive market should see the lower resource costs reflected in lower consumer prices. Increased transfer

[25] The long-term social discount rate used in the net present value calculation was 7% (in real terms), the same as recommended by New South Wales Treasury: https://www.treasury.nsw.gov.au/sites/default/files/2017-03/TPP17-03%20NSW%20Government%20Guide%20to%20Cost-Benefit%20Analysis%20-%20pdf.pdf.

capacity of the system and a reduction in congestion, or the risk of congestion, should also increase competition, reduce the cost impact of network outages, and result in more efficient pricing.

Consideration has been given to the resilience of the system, and a checklist of additional value from the various alternatives under consideration has been qualitatively assessed. Further work is required to fully understand power system security, market, and regulatory impacts of the ISP, including detailed assessments of future congestion, reverse flow impacts, revenue sufficiency, and future prices to consumers. Some of this future work is further discussed in Chapter 7.

2.7 Detailed scenario descriptions

The ISP was developed around two Neutral cases using a central or median outlook, together with analysis on the impacts of a range of likely futures on investment decisions identified in the plan. This is essential, given the need to plan and recommend investment in an industry in transition where there is a level of inherent uncertainty. The purpose is to provide insights and information on how changes in inputs or policy settings would impact on the type, location, and timing of utility-scale generation and storage and therefore on the most cost-effective development of the transmission system. As such, the scenarios have been selected to test robustness of the plan under a range of factors that may have a material impact on transmission investment.

The scenario themes were developed around variations in operational grid demand, and grid-scale generation capital cost reductions, to ensure the transmission development is robust under a broad range of conditions. Variations in economic and population growth, levels of consumer energy engagement, and deployment of new technologies (such as electric vehicles and battery systems) will impact the volume of energy that needs to be transported across the grid and therefore influence the benefits of transmission development and risks of stranded assets.

The three scenarios developed around the Neutral outlook are therefore intended to provide a plausible range of grid consumption and supply outcomes that drive faster and slower transformative change. Following broad industry consultation, AEMO modified the original scenarios to broaden this range further. For example, an additional scenario was included to test the impact of High DER on utility-scale investment needs, and wider variations in fuel costs and technology cost reductions were covered across the scenarios.

The need to consider broad scenarios was a consistent theme of the consultation feedback AEMO received, and is summarised in AEMO's review of submissions (see Appendix E).

The ISP focuses on seven scenarios/sensitivities:

- Two base cases:
  - Neutral, and Neutral with storage initiatives.
- Three additional scenarios:
  - Slow change, Fast change, and High DER.
- Two additional sensitivities to explore key opportunities or risks:
  - Increased role for gas, and Early exit of coal-fired generation.

The scenarios are summarised in Table 1 below and then described, along with the additional sensitivities.

Note that, on modelled emissions reductions, while the Commonwealth Government has recently clarified that the target to 2030 would be 26%, the original commitment was expressed as a range (26-28% emissions reduction). AEMO modelled the higher 28% level based on earlier consultation with stakeholders[26]. To undertake the ISP modelling, assumptions needed to be made on future emissions levels. All studies except the Fast Change scenario projected a similar trajectory from 2030 as that in the first decade of the plan to 2050. This achieves a reduction of 70% over 2016 emissions by 2050. To test the potential impact on transmission investment of greater reductions, the Fast change scenario assumed emission constraints which were consistent with the Low Emissions Technology Roadmap developed with the Commonwealth Scientific and Industrial Research Organisation (CSIRO)[27]. The enduring policy certainty contemplated by the National Energy Guarantee is assumed to support efficient, technology-neutral investment decisions that achieve targeted emissions levels while maintaining system reliability.

[26] AEMO, *2018 Integrated System Plan Consultation Submissions*, available at https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/Integrated-System-Plan.

[27] Electricity Networks Australia. Electricity Network Transformation Roadmap, available at https://www.energynetworks.com.au/electricity-network-transformation-roadmap.

Table 1 High level case settings

Case	Neutral	Neutral with storage initiatives	Slow change	Fast change	High DER
Demand settings					
Economic growth and population outlook	Neutral	Neutral	Weak	Strong	Neutral
Rooftop PV - up to 100 kilowatts (kW)	Neutral	Neutral	Neutral	Neutral	Strong
Non-scheduled PV - from 100 kW to 30 MW	Neutral	Neutral	Neutral	Neutral	Strong
Demand side participation	Neutral	Neutral	Strong	Weak	Strong
Electric vehicle uptake	Neutral	Neutral	Weak	Strong	Neutral
Battery storage installed capacity	Neutral	Neutral	Neutral	Neutral	Strong
Battery storage aggregation by 2050	45%	45%	90%	10%	90%
Renewable/emissions reduction settings*					
Emissions trajectories	28% 2005 - 2030	28% 2005 - 2030	28% 2005 - 2030	52% 2005 - 2030	28% 2005 - 2030
LRET	Yes	Yes	Yes	Yes	Yes
VRET 25% by 2020 and 40% by 2025	Yes	Yes	Yes	Yes	Yes
Queensland Renewables and QRET 50% by 2030	Yes	Yes	Yes	Yes	Yes
Energy efficiency improvement	Neutral	Neutral	Weak	Strong	Neutral
Supply side settings					
Variable renewable energy (wind and utility solar) cost reductions	Neutral	Neutral	Slow	Neutral	Neutral
Storage (pumped hydro, battery, and solar thermal) cost reductions	Neutral	Neutral	Neutral	Rapid	Slow
Gas market settings					
Gas demand - LNG export	Neutral	Neutral	Weak	Strong	Neutral
Gas demand - residential/ commercial/industrial	Neutral	Neutral	Weak	Strong	Neutral
Gas prices	Neutral	Neutral	Weak	Strong	Neutral
Development settings					
Storage developments	Model outcome	Snowy 2.0 2025, Battery of the Nation 2033	Model outcome	Model outcome	Model outcome
Interconnector development settings	Model outcome	Tumut to Bannaby and additional Basslink	Model outcome	Model outcome	Model outcome

* ISP modelling has incorporated explicit emissions constraints to represent this emission reduction.

2.7.1 Neutral case

The Neutral case assumed a range of central, or mid-point projections of economic growth, future demand growth and fuel costs. This includes:

- Neutral growth outlook for consumption and demand from AEMO's March 2018 electricity demand forecasts, including uptake of 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.

These settings combine to form a central estimate of the transition forecast for the NEM.

Table 2 Neutral case settings – summary of assumptions

	Setting	Rationale
Demand settings		
Economic growth	Neutral	Central estimates on broader national and international economic drivers, leading to central estimates for population growth, disposable income, commercial and industrial expansion.
Distributed energy technology uptake	Neutral	Moderate – describing 'neutral' consumer behaviours in a neutral economy. The inputs include: • Rooftop PV systems continue to expand, such that approximately 12% of underlying consumption is provided by rooftop systems by 2030. • Consumer interest in battery storage systems and electric vehicles is moderate over the forecast horizon. • Battery systems provide up to approximately 10% of operational maximum demand by 2030. • Incentives exist to aggregate this storage potential and provide grid support use of these systems, such that 45% of battery systems are coordinated by 2030. • Electric vehicle uptake is moderate, with 10% of the vehicle fleet being electrified by 2030. Vehicle charging is uncoordinated, and primarily occurs overnight.
Renewable energy / emissions reductions settings		
Trajectories	Renewable energy targets, emission reduction trajectories	• All existing announced policies are included, as described by various Governments (LRET, VRET, and QRET). • The NEM is assumed to achieve at least a proportionate share of the Commonwealth Government's emission reduction commitment by 2030, and for emissions to continue on a similar path to 2050.
Supply settings		
Thermal retirements	End of technical life or economic retirements allowed	The modelling approach for the ISP is one of least cost generation expansion to meet consumer needs within the confines of policy, demand and market settings. The model will allow economic based retirements where these lead to reductions in total system costs, accounting for site repatriation costs (an input setting).
Technology costs	CSIRO outlook, AEMO internal	• Technology costs have been selected from current, reputable public forecasts. CSIRO's December 2017 projections* provide a primary reference. • Cost trajectories chosen reflect central estimates of any associated range.

* CSIRO, Electricity generation technology cost projections (2017-2050), December 2017, available at https://publications.csiro.au/rpr/download?pid=csiro:EP178771&dsid=DS2.

2.7.2 Neutral with storage initiatives case

The Neutral with storage initiatives case adopted all scenario settings of the Neutral case, with one key addition. This scenario incorporated the proposed Snowy 2.0 and Battery of the Nation pumped hydro storage projects, and associated augmentations of the transmission network for the projects.

These large pumped hydro schemes provide deep storages (storages able to support prolonged periods of supplying energy at capacity). The case examines the role of storage in supporting variable renewable energy sources as a replacement for retirement of coal-fired generation. The timing of the projects reflects this, with Snowy 2.0 assumed to be developed as soon as possible (in 2025), as a relatively early development to compensate for the retirement of the Liddell Power Station and ahead of projected retirements of coal plant in New South Wales. The Battery of the Nation project is then assumed to be installed by 2033, for projected coal plant retirements in Victoria and before further black coal power stations retire in New South Wales. AEMO will continue to work with project proponents on a design for transmission networks to support these storage initiatives.

The transmission networks will require development to support the full capacity of both projects. The Snowy 2.0 project has been modelled with reinforcement from Snowy 2.0 back to Sydney, while the Battery of the Nation project also includes new interconnection between Tasmania and Victoria. Further explanation of transmission development is outlined in Section 6.3.

2.7.3 Slow change scenario

The Slow change scenario considered 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 case, 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.

2.7.4 Fast change scenario

The Fast change scenario considered 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 check that reliability and security could still be maintained.

Compared to the Neutral case, 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.

2.7.5 High DER scenario

The High DER scenario considered a future where there is a stronger growth in DER, that is, where distributed rooftop PV generation, battery storage, and demand side response at the consumer level are higher than in the Neutral case.

The purpose of this scenario was to examine how increased DER could impact on investment needs for utility-scale generation and storage and transmission, and how this would influence the plans presented in the ISP.

In this modelling, the DER in the system was more tightly managed and integrated into the overall power system. The greater uptake of distributed storage reduced the overall impetus for development of utility-scale storage systems, slowing the cost reductions of these technologies relative to the Neutral scenario.

2.7.6 Increased role for gas sensitivity

The Increased role for gas sensitivity examined a key input – the price of natural gas. In the Neutral cases and most plausible scenarios, while there is development of GPG, its projected future role is limited by the continuation of relatively high gas prices assumed. This is a major change from previous planning, which often showed gas playing an important part in transition. As a result, AEMO considered whether GPG could have a greater role in the supply mix if gas reduced significantly in price from current expectations (around $8-10 a gigajoule [GJ]) to around $6/GJ.

This sensitivity explored the potential implications on investment pathways if significant quantities of gas was to be made available at a much lower price. This creates stronger drivers for GPG development, which also reduce the need for development of renewable generation and storage technologies

Additionally, this sensitivity included consideration of the gas market infrastructure required to meet the needs of increased gas consumption, along with providing an assessment of how increased GPG, located at optimal places within the electricity network, could defer the timing for new interconnection or regional transmission augmentation.

2.7.7 Early exit of coal-fired generation sensitivity

The retirement of coal-fired generation is a key driver of investment needs in this plan. This sensitivity tested the impacts on the identified investment plans of potentially catastrophic failures to plant resulting in unplanned early retirements of coal-fired generation in New South Wales or Victoria. Even if the three-year notice of closure rule change proposal currently before the Australian Energy Market Commission (AEMC) is accepted, the power system will remain exposed to these unplanned events. Bringing forward the timing of identified transmission development, as well as strategic storage, should be considered as potential pre-emptive measures to increase power system resilience against such events. This is an important consideration given the long lead times for transmission development.

3. Projected energy resource mix

Key observations

- ISP modelling projects a profound transition of the NEM over the next two decades, with:
  - The energy mix transforming from one dominated by coal-fired generation to one with portfolios comprising large amounts of technologically and geographically diverse variable renewable generation sources, supported by increased transmission and energy storage solutions.
  - A need to retain existing coal-fired generation while planning for orderly replacement on retirement.
  - A strong role for energy storage that can shift renewable energy production and provide capacity firming[28] support during peak load conditions to support the dispatchability of this future energy mix.
  - An increasing need, with greater renewable energy penetration, for synchronous generation to operate with greater flexibility, responding to renewable intermittency. This will affect the operation of coal-fired generation, gas-powered generation (GPG), hydro-electric, and storage technologies, and may influence network solutions. GPG, for example, is expected to produce less energy overall, but continue to provide a reliability and security role to complement variable renewable energy. Renewable energy will erode in the next decade the need for GPG to operate during the day, but GPG production is forecast to recover to near existing levels in the second decade as coal retirements increase.
  - Coal-fired generation retirements and increasing development of large- and small-scale renewable generators expected to contribute to reductions in emissions.
  - The potential for significant savings through greater use of DER, where those resources are well integrated and coordinated in the power system. For example, greater use of DER could reduce reliance on regional utility-scale renewable energy developments and the associated need to strengthen transmission within a region to support this.
- While increased uptake of consumer-driven DER[29] would slow growth in total grid-generated energy consumption, the modelling projects increasing value for strengthening interconnection between regions to meet an increasingly volatile demand across the NEM and take advantage of diversity of renewables across regions as well as efficiently sharing resources across regions.

This chapter outlines the expected evolution of the generation mix to minimise overall system costs and meet the needs of consumers, for each of the modelled scenarios. Section 3.1 summarises key modelling outcomes and drivers that AEMO observed consistently across different scenarios representing a range of plausible futures.

3.1 Consistent themes across scenarios

Consistent themes in outcomes can be observed across the range of scenarios modelled. These relate to changes impacting energy resource projections since the 2016 NTNDP.

Based on technology cost projections and the whole-of-system modelling undertaken, the key outcomes across scenarios are discussed further in sections 3.1.1 to 3.1.4.

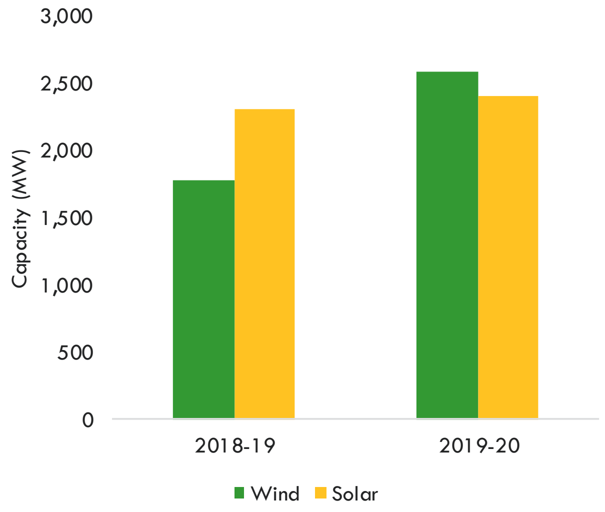
[28] Generation firmness is a measure of the likely energy availability of the resource mix at some time in the future.

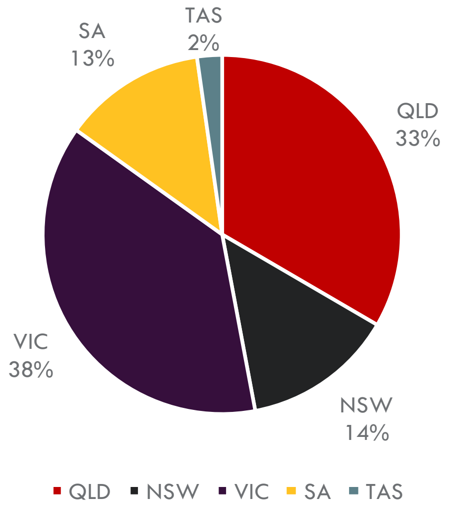
[29] DER can refer to distribution level resources which produce electricity or actively manage consumer demand.

3.1.1 Renewable generator connections will progress at record levels in the short term

Record levels of newly committed renewable generation development in the NEM demonstrate that the NEM is already on a path to wide-scale, fundamental transformation. Around 5 GW of new solar and wind generation projects are in an advanced or committed stage to be operational in the next two years, displacing the energy contribution provided by both gas and coal-fired generation. Figure 4 below shows the currently committed and advanced developments by generation type, year of install, and geographic diversity by 2020[30].

Figure 4 Committed and advanced renewable generation capacity – committed solar and wind capacity to 2020 (MW, left), and committed and advanced solar and wind projects by NEM region (%, right)



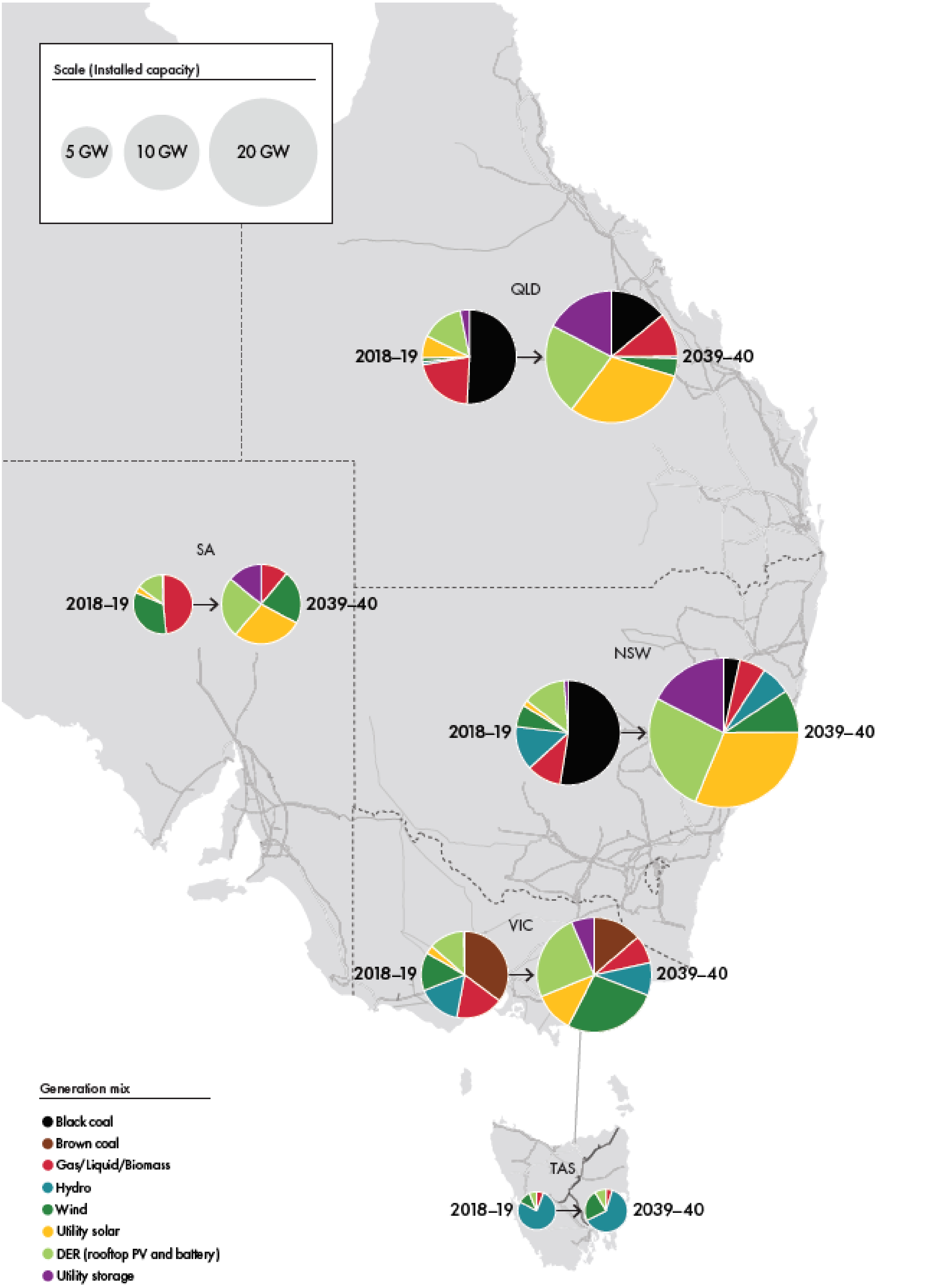


Beyond committed and advanced developments, in the next decade, renewable energy targets at state level (such as the Queensland Renewable Energy Target (QRET) and Victorian VRET) influence the magnitude and location of new renewable energy and influence the transmission requirements to enable these developments.

Figure 5 below demonstrates the geographic and technological diversity of the forecast generation expansion in the Neutral case, showing the change in both distributed and utility-scale resource mix across each NEM region between now and 2040. Strong growth opportunities exist across the NEM, with each of Queensland, Victoria, and New South Wales forecast to expand respective renewable generation capacity by approximately 10 GW or more each by 2040, attributed to replacement of coal-fired generation and other growth drivers.

[30] Committed and advanced generation projects as at December 2017 release of the AEMO Generation Information update, available at: http://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/Generation-information.

Figure 5 Projected change in generation resource mix (installed capacity) by NEM region over the 20-year plan horizon



3.1.2 Portfolio approach required to replace retiring coal-fired generation

The ISP forecasts the NEM evolving from a generation mix dominated by high-utilisation, low-cost thermal coal-fired generation, to a generation mix dominated by zero marginal cost variable renewable generation supported by energy storage, transmission, GPG, and DER.

- Large amounts of grid-connected variable renewable energy sources are projected to be developed across the NEM – between approximately 14 GW and 48 GW by 2040 (depending on the growth in electricity consumption). This diverse development influences the need to develop the transmission system to enable access to these renewable resources, to increase sharing of renewable energy across the NEM and reduce the need for firming technologies.
- Energy security is projected to be supported by new flexible, dispatchable resources at utility scale – between 4 GW and 23 GW by 2040. Utility-scale storage is forecast to provide the majority of new dispatchable capacity in most scenarios, although new flexible gas generators could play a greater role in firming the system if gas prices materially reduce.

During this time, operational consumption (the energy that is to be met by grid delivered generation) is projected to remain relatively flat under neutral economic conditions, as the continued uptake of DER is projected to dampen increases associated with population growth and broader economic growth.

The modelling shows that operating existing coal-fired generation up to the end of its technical life should lead to lower overall system costs, given the relatively high capital cost of new investments relative to the operating costs of existing plant.

AEMO has used projections of reductions in technology costs[31] in its modelling (refer Section 2.7.1). Based on these technology cost projections, the least-cost replacement of energy currently produced by coal is projected to be met through an efficient combination of:

- **Renewable energy** – a mixture of diversely located renewable generation (largely solar and wind), including DER.
- **Energy storage** – to smooth the production of variable renewable energy and provide backup supply and peaking (up to storage capacity).
- **Backup supply and peaking** – GPG to complement renewable energy production.
- **Increased transmission, including interconnection** – facilitating the efficient sharing of renewable energy, storage, and backup and firming services.

The generation mix is therefore expected to be technologically diverse. This technology mix may diversify further in the future than current projections, if forecast technology cost reductions in emerging and maturing technologies increase more rapidly than current expectations.

Coal-fired generators, historically the lowest-cost generation and operated as base load power supplies, are projected to increasingly be operated at lower utilisation levels, as lower marginal cost renewable generation (from grid-connected and distributed sources) displace production from existing coal-fired generation in NEM dispatch (and other generation sources such as GPG).

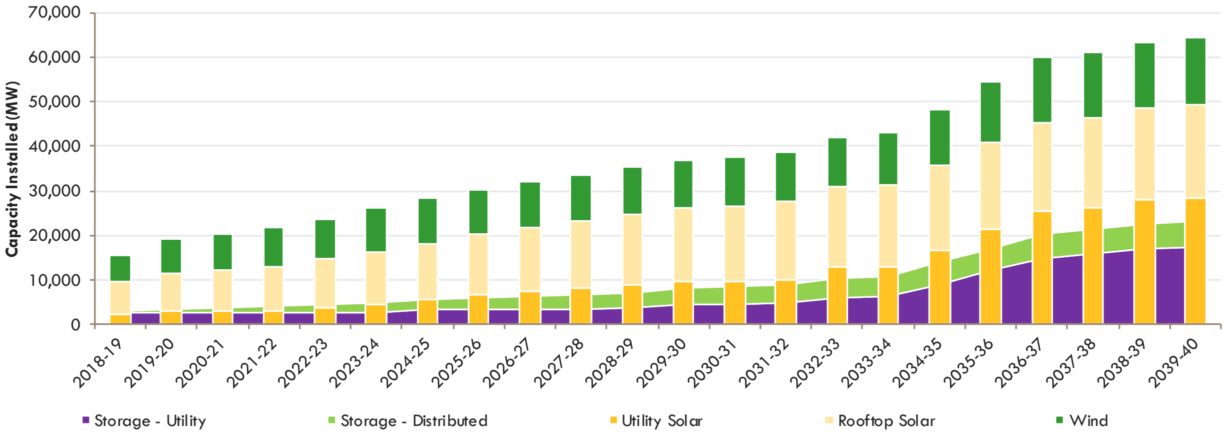
By 2040 under the Neutral scenario, the energy production from retired coal-fired generation is projected to be replaced with about 28 GW of large-scale solar generation and nearly 10.5 GW of wind generation (in addition to the 4.5 GW already installed), complemented by over 17 GW of new and existing storage capacity. Due to resource availability of these generation technologies, this represents a significant increase in installed capacity (as shown in Figure 6 below) for a similar level of generation output.

Typically, these variable renewable generation technologies require a greater land and network footprint than conventional coal-fired generation, and tend to be less variable in aggregate if geographically dispersed. This increases the future value of transmission which facilitates the sharing of surplus low-cost resources across regions, and maximises the value of geographic weather diversity.

This projected resource portfolio provides a lower overall cost to deliver the energy and peak capacity needed than developing new replacement thermal generation, and supports large reductions in emissions (explained further in Section 3.1.4).

[31] Technology costs have been selected from current, reputable public forecasts, and CSIRO's December 2017 projections provide a primary reference. Refer CSIRO, Electricity generation technology cost projections (2017-2050), issued December 2017. Available at: https://publications.csiro.au/rpr/download?pid=csiro:EP178771&dsid=DS2.

Figure 6 Renewable generation development outlook, complemented by utility-scale storage technologies (Neutral case)



The magnitude and depth[32] of storage required in these outcomes will depend on the mix and location of renewable technologies and the flexibility that remains of the existing generation fleet:

- While wind generation is typically available overnight and at higher annual energy contributions than solar generation, solar generation is more predictable during daylight hours.
- The ability for existing portfolio generators to operate flexibly – to ramp up and down as needed given the availability of lower-cost renewable energy – will influence the needs for storage to smooth short-term generator intermittency. A less flexible existing portfolio will require faster control of storage devices, potentially increasing the value of a geographically diverse mix of shallow and deep storages. A more flexible portfolio, with faster operating capabilities, may need less control of storages to provide that flexibility (see Section 5.2.2 for more on flexibility).

While utility-scale storage solutions are expected to become necessary additions to support renewable energy developments and coal-fired generation retirements, consumer-driven distributed storage systems are expected to provide a strong opportunity for demand management, even though the storage itself is relatively shallow. The ISP analysis assumes only a proportion of distributed battery penetration is controlled to manage demand at a grid level, with the remaining capacity operating to the householder's own objective to minimise grid consumption (particularly when paired with a rooftop PV system).

3.1.3 An increasing need for thermal generation to be flexible

Thermal, synchronous generators traditionally have provided baseload generation, operating at all time and some ramping production to meet daily consumer demand patterns. As coal generation retires, and with the development of large amounts of variable renewable energy, there is an increasing need for synchronous generation to operate flexibly to assist in the management of renewable energy oversupply and variability.

While remaining coal generation is expected to continue to provide baseload generation, operating between minimum and maximum load depending on renewable energy and the demand from consumers, the role of GPG is expected to evolve throughout the forecast. Projected future gas prices are expected to reduce the annual volume generated from GPG. Instead, GPG provides a complementary role to variable renewable energy resources, generating at times of low wind or solar availability. No development of new high-utilisation GPG such as combined-cycle gas turbines (CCGT) is expected, based on the development and operational costs modelled, under current gas price assumptions.

Storage technologies are forecast to provide an energy shifting service, smoothing out production throughout the day and through the evening. However, the demand for baseload generation in daylight hours is predicted to decline significantly.

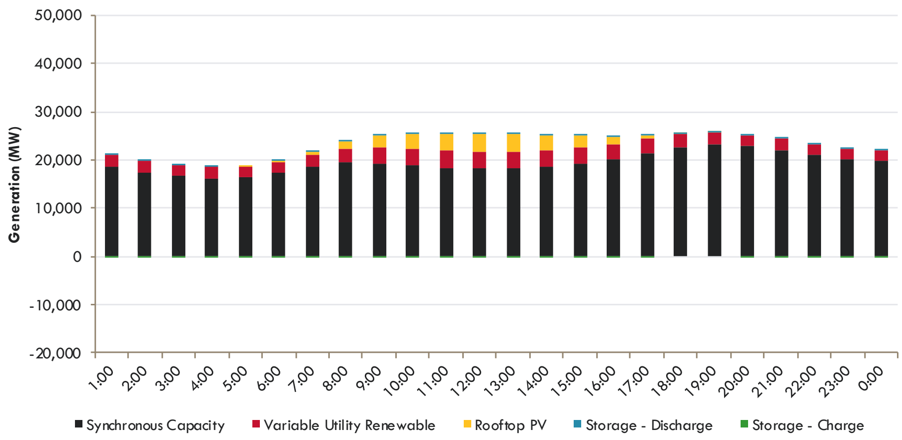
Figure 7 shows the changing average daily output across the horizon of variable renewable energy, storage, and synchronous generation. That is, the generation mix, by hour, averaged across each day in the year. It demonstrates the need for increasing flexibility of synchronous generation, with increased thermal unit cycling[33] (where units shut down on a regular basis – perhaps seasonally) more likely during periods of high renewable generation and/or low underlying demand.

[32] Storage technologies can be referred to as either 'shallow' or 'deep', reflecting the size of the storage and the role that they may play. In the ISP AEMO refers to shallow storages as those that have energy storage shifting capabilities of two hours or less, whereas deep storages refer to those devices with six hours or more.

[33] Cycling refers to regularly operating generators to switch off during times when the generation is not required, and switching on to support higher load times.

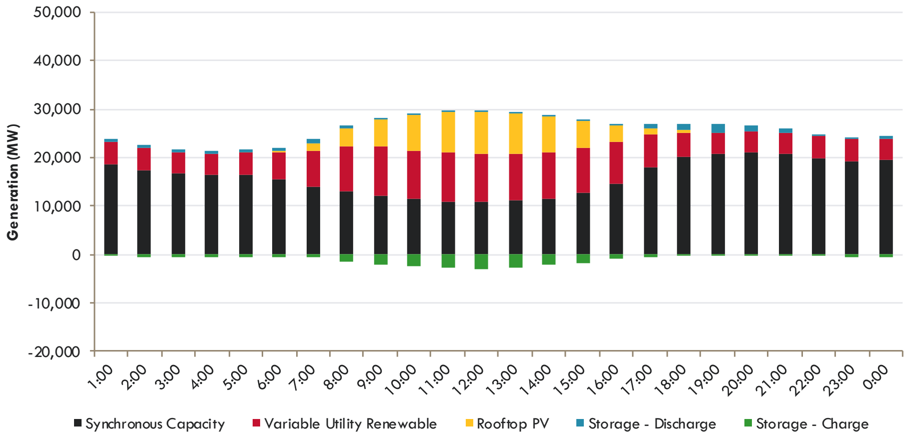
Figure 7 Evolution of the average daily contribution by category across the NEM

Low renewable share



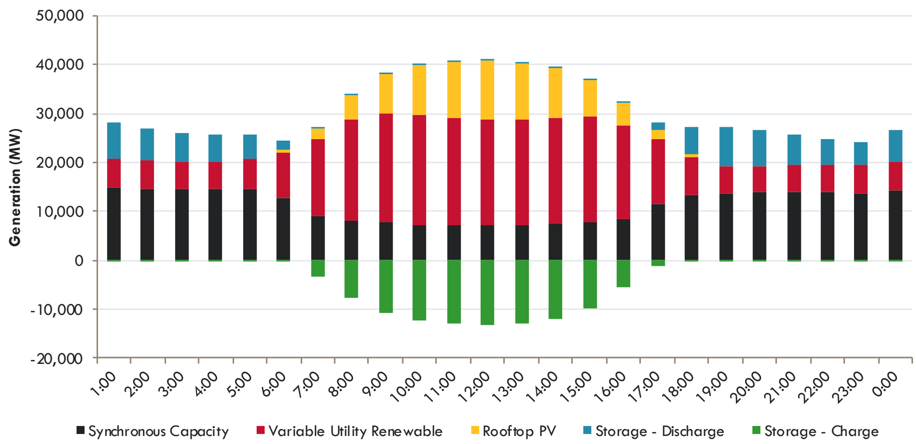
- High operation of synchronous plant, with renewable generation operating as available based on resource.

Medium renewable share



- Increasing role for utility-scale variable renewable energy.
- Emerging energy storage role.
- Reduced need for synchronous plant during high renewable generation times, given higher operational costs.

High renewable share



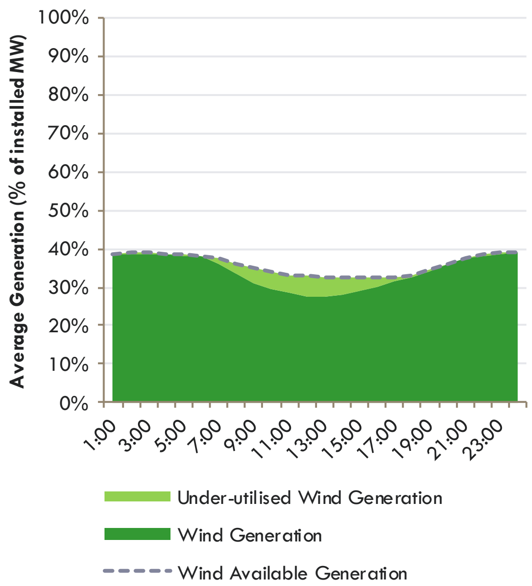
- Large role for energy storage to smooth the production of variable renewable energy.
- Increased flexibility required from synchronous generation to support peak loads and periods of low renewable energy production.

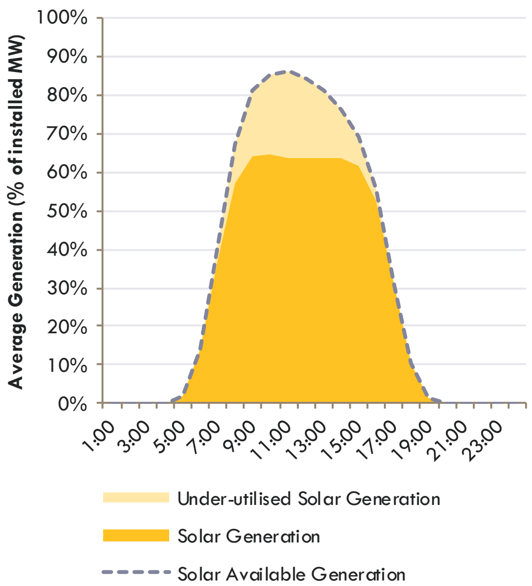
Figure 8 below demonstrates the average generation of wind and utility-scale solar generation, relative to the available resource. It shows that renewable energy may at times be underutilised, which may be due to a number of factors including:

- Congestion within the transmission network.
- Economic decisions of generation portfolios to maintain minimum operation levels of synchronous generators, to avoid the costs associated with cycling.

Greater transmission development or energy storage solutions may allow even greater capture of renewable generation. The operating strategies for energy storage devices to maximise energy shifting, or reserve greater capacity to be available to cater for short-term risks, will influence the overall utilisation of storage.

Figure 8 Average utilisation of utility-scale renewable generation (wind [left] and solar [right], Neutral scenario)





3.1.4 Emissions reductions

The various scenarios were constrained in modelling to achieve the emission reductions set out in the input assumptions (Section 2.3). In the short term, the relevant emissions reductions are delivered, consistent with the National Energy Guarantee. In the longer term, emissions are reduced as new renewable generation replaces energy previously supplied by retiring coal-fired generation, along with the development of increasingly coordinated DER.

3.2 Projected resource mix by scenario

3.2.1 Neutral case, with and without storage initiatives

The future portfolio of resources in the Neutral case (with and without storage initiatives) is expected to include a large share of renewable energy, given the decline of renewable generation costs and the need to replace ageing coal capacity. Initially, these technologies are projected to be developed according to existing commitments, then to meet state renewable energy targets[34], and finally to provide the energy required to replace retiring thermal plant. Given anticipated cost reductions, utility-scale solar is expected to provide the majority of renewable energy developments, with a lesser amount of wind generation providing resource diversity. This renewable energy is complemented with storage solutions and GPG.

Energy storage is projected to smooth renewable energy production, particularly from daytime to evening peak and overnight periods. This energy-shifting role of storage will be essential for generation technologies like solar that are concentrated in the daytime. By the 2030s, as coal-fired generation retires, the cost of even a 1:1 installation of solar with storage backup for capacity firming is projected to be on par with, or lower than, currently projected costs for new entry coal, ignoring any new policy drivers to further limit emissions.

In the next five years, the outlook contains a mix of committed developments and renewable expansions, particularly in Queensland and Victoria. Approximately 300 MW of fast-responding GPG is also projected to be installed by the time the coal-fired Liddell Power Station in New South Wales retires in 2022.

This capacity is forecast to be complemented by additional transmission capacity to share resources between Queensland and Victoria to New South Wales, which (with some capacity being provided through renewable resources) is expected to provide for peak load conditions. More work however is needed to ensure that the reliability standard can be achieved with this mix of generation[35].

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[34] The Clean Energy Regulator has confirmed that there is now enough new renewable energy project capacity under construction or already built to meet the 2020 RET. Source: http://www.cleanenergyregulator.gov.au/RET/About-the-Renewable-Energy-Target/Large-scale-Renewable-Energy-Target-market-data/large-scale-generation-certificate-market-update/large-scale-generation-certificate-market-update-may-2018.

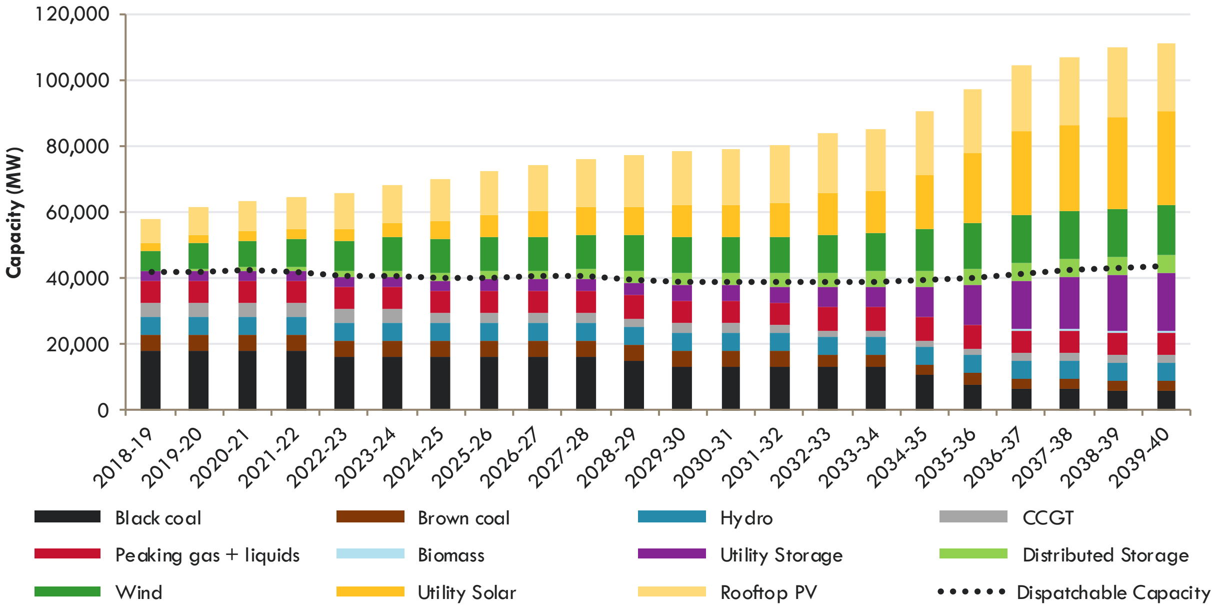
[35] The ISP is not a capacity adequacy assessment, and is not equivalent to the detailed assessments required to project the achievement or not of the Reliability Standard. The *Electricity Statement of Opportunities* (ESOO) fulfils this role.

The modelling considers the value of retirement of coal-fired generation capacity earlier than technical life. The modelling showed that continued operation of existing coal-fired generation was a lower cost outcome, given the sunk nature of capital costs associated with the existing coal-fired generation fleet, and the investment costs of replacing this energy with new resources.

Figure 9 below demonstrates the projected evolution of the generation mix in the NEM to 2040 in the Neutral case, and Figure 10 shows the year-on-year changes in installed capacity:

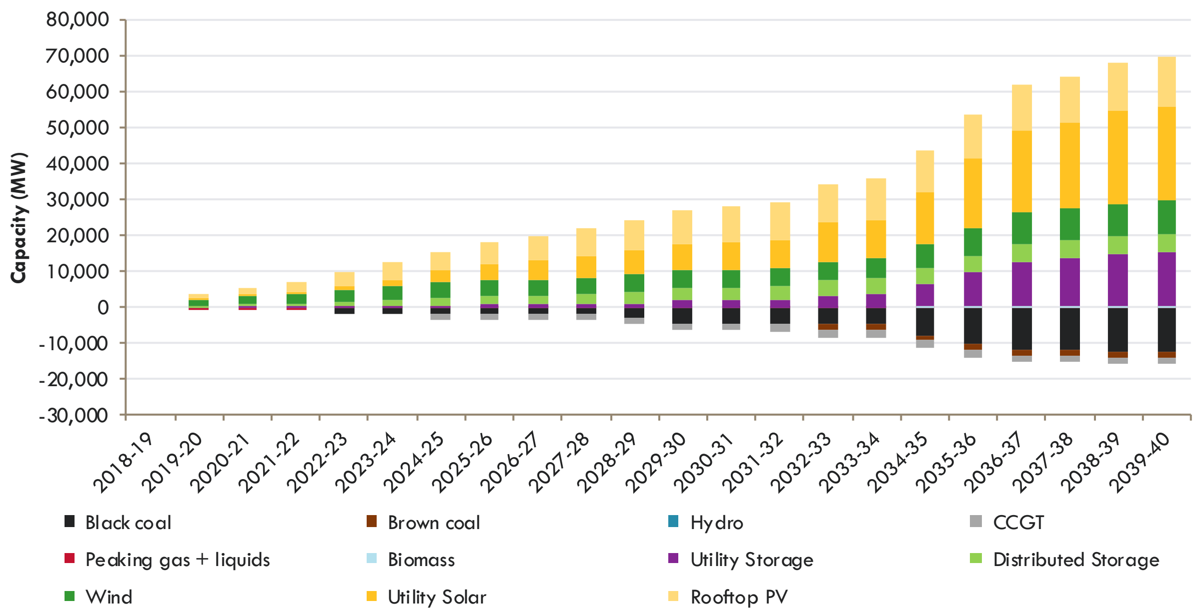
- **To 2030** – delivery of committed renewable generators as well as forecast renewable expansion is projected to meet renewable energy targets, with some GPG, storage, and transmission providing firming support to replace the announced closure of Liddell, as well as projected retirements of the Vales Point (New South Wales) and Gladstone (Queensland) power stations at end of technical life.
- **By 2040** – portfolio development of about 54 GW of new capacity (with an additional 19.2 GW of distributed storage and rooftop PV) is projected to replace 16.4 GW of coal- and gas-fired generation (including about 1.4 GW projected economic withdrawal of GPG).
- The overall capacity of dispatchable generation[36] is projected to remain broadly constant at around 40 GW, although the mix of dispatchable capacity is expected to shift to include greater amounts of storage.

Figure 9 Forecast NEM generation capacity in the Neutral case



[36] Dispatchable capacity in this context refers to generation that is not intermittent, and can theoretically be operated at any level on demand. This includes thermal plant (coal and gas), hydro-electric, biomass, and storage (including the assumed portion of distributed storage that is aggregated). It excludes variable renewable generation – solar and wind generation.

Figure 10 Relative change in installed capacity in the Neutral case, demonstrating the shift from coal to renewable energy



The Neutral case considered storage systems with up to six hours of energy storage, at a capacity that is optimally sized based on the renewable energy developed. Development of deeper storages (such as that offered by pumped hydro) may be more efficient than on-site shallow battery storages, although there will likely exist a role for both shallow and deep storages.

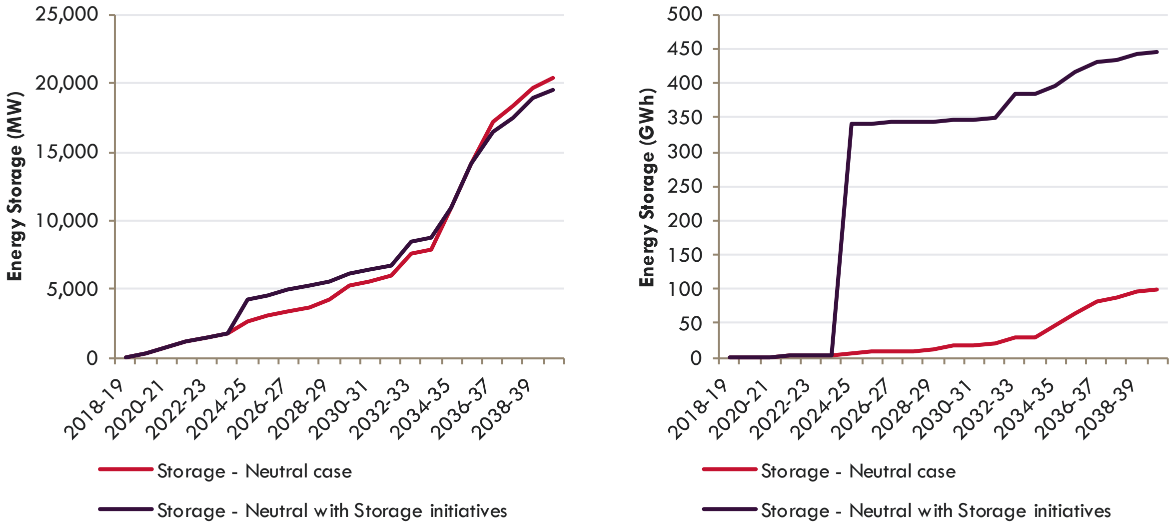
The large initiatives included in the Neutral case with storage – the Snowy 2.0 and Battery of the Nation initiatives – provide large storage capacities (MW) and energy storages (MWh), with Snowy 2.0 providing up to seven days' worth of energy storage, or approximately 350 GWh[37], and the Battery of the Nation project up to 24 hours of storage[38].

Figure 11 demonstrates that, despite the larger size of these initiatives, the overall storage capacity in both Neutral cases is very similar. Figure 11 also clearly demonstrates the significant difference in the volume of energy that can be stored within these initiatives, which will increase the capability of portfolio operators and AEMO to manage short-term risks, rather than just providing a firming and daily energy smoothing service. A more detailed regional breakdown of energy storage across the NEM in both scenarios is provided in Section 5.2.3.

[37] See http://www.snowyhydro.com.au/wp-content/uploads/2017/12/SH1045_SummarySnowy20_web.pdf.

[38] See https://www.hydro.com.au/docs/default-source/clean-energy/battery-of-the-nation/future-state-nem-analysis-full-report.pdf?sfvrsn=25ce928_0.

Figure 11 **New energy storage comparison (capacity [MW, left] and energy [GWh, right]) of the Neutral with storage initiatives case relative to the Neutral case**



The optimal portfolio of resources and transmission in the Neutral case with storage is also very similar. As shown in Figure 12, the earlier development of large, deep storages (Snowy 2.0 and Battery of the Nation), results in:

- Greater utilisation of existing coal-fired capacity (with reduced utilisation of GPG) and deferring some investments in additional solar generation in the 2020s, and
- More technological diversity in the renewable energy generation mix (an increased share for wind generation than the Neutral scenario), with less utility storage capacity in the long term.

In both Neutral cases, the overall increase in installed capacity is projected to result in nearly double the installed generation capacity of the current NEM by 2040, even though operational consumption remains relatively static. Utility-scale storage capacity is forecast to represent approximately 19% of the total transmission-connected capacity installed. By 2040, the NEM generation mix is forecast to include approximately 60 GW of utility-scale variable renewable generation (solar and wind generation) and storage capacity, and 27 GW of distributed storage and rooftop PV capacity.

Figure 12 **Change in generation mix (capacity, MW installed) of the Neutral with storage initiatives case relative to the Neutral case**

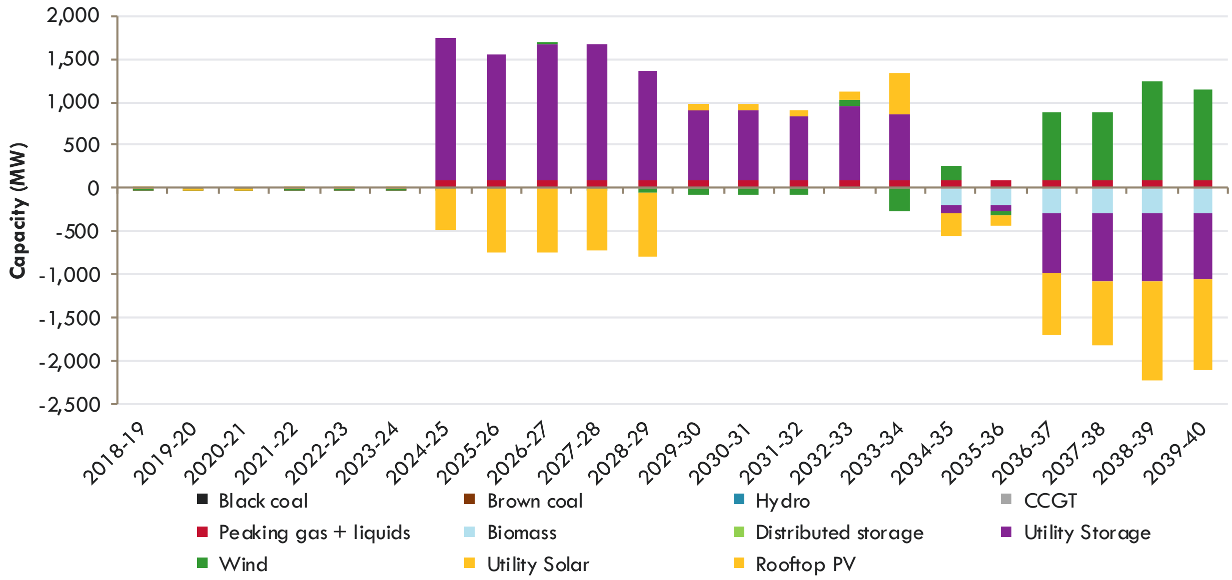
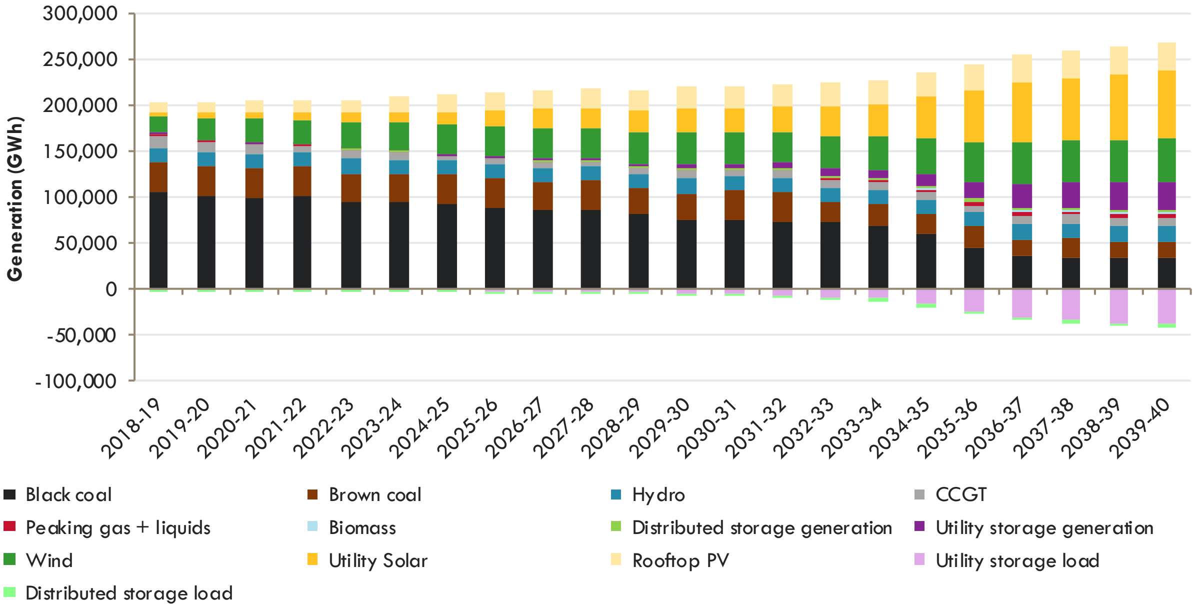


Figure 13 below shows the projected overall energy generation to meet NEM consumer needs in the Neutral case.

The figure includes DER, to demonstrate the portfolio of resources to deliver energy demanded at the power points of consumers ("underlying demand"). It demonstrates that much of the growth in consumer demand is projected to be met through DER, and also highlights the profound change in generation mix over the plan period, with significant reduction in coal-fired generation. As existing generation retires, there is an increased reliance on storage technologies to complement renewable generation. Energy storage charging inefficiency[39] is projected to increase operational consumption after 2030, with greater usage of energy storage devices.

Figure 13 Forecast NEM energy generation in the Neutral scenario



3.2.2 Slow change scenario

The Slow change scenario forecasts the necessary developments with lower economic growth and lower overall grid consumption. It assumes greater capacity of controllable dispatchable residential storage, with both increased aggregation of DER available for load management and a larger future DER resource.

Figure 14 below outlines the projected change in the generation mix under the Slow change scenario, while Figure 15 shows the difference to the Neutral case. While solar and storage are still projected to play a role in this Slow change pathway, their penetration is lower and occurs in later years relative to the Neutral case. Overall, almost 38 GW less capacity is forecast to be needed due to the slower growth conditions, however age-driven coal retirements still result in the need for replacement capacity.

[39] Energy storage devices require energy to 'charge' the technology, and the efficiency of this charging is imperfect. More energy is consumed in pumping water from a lower storage reservoir to an upper storage reservoir than is then available when released from that upper reservoir. This is also the case with battery storage devices. The net energy cost of storage solutions is captured in the modelling.

Figure 14 Projected generation mix (capacity, MW installed) by technology, Slow change scenario

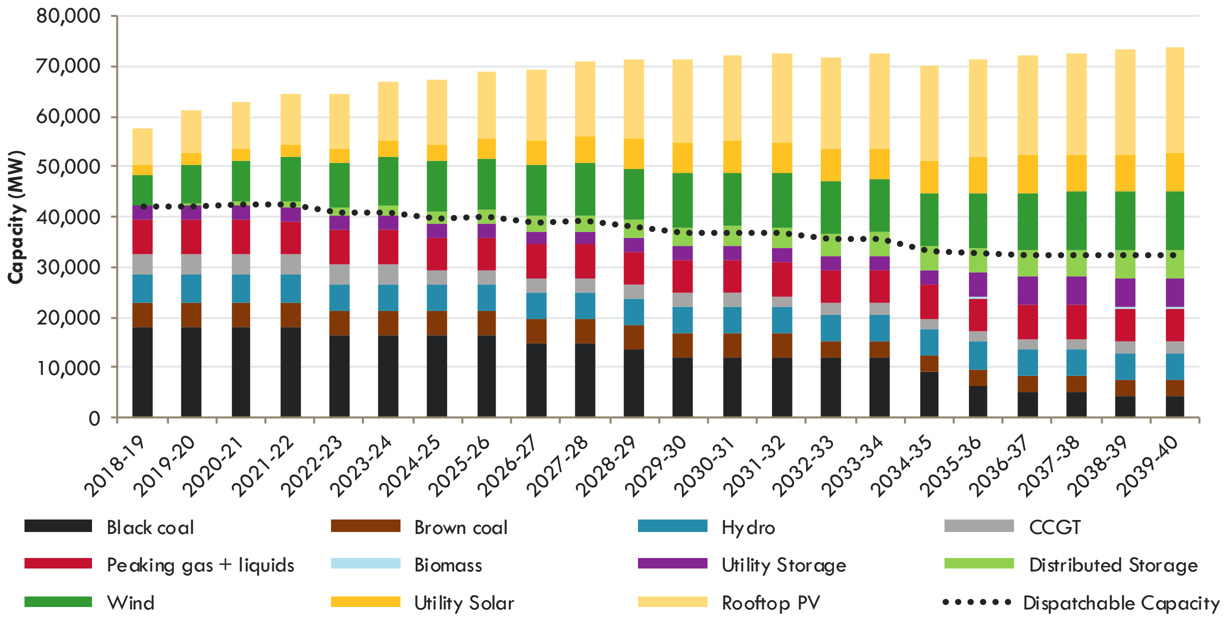
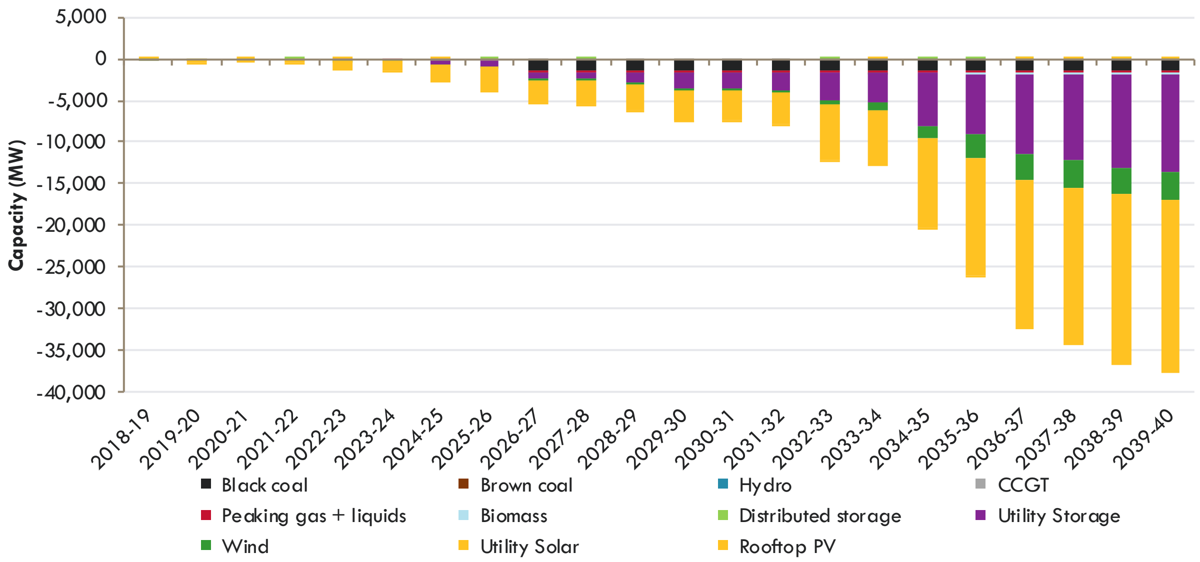


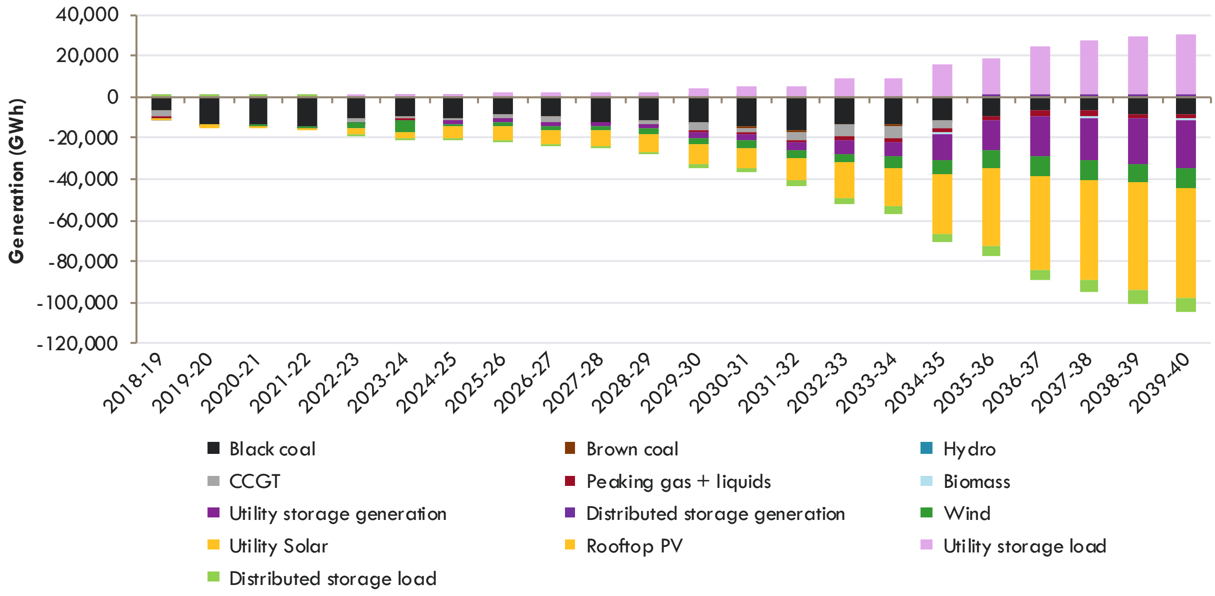
Figure 15 Projected change in generation mix, Slow change scenario relative to Neutral case



Where the change in generation mix is negative, this means that there is less generation capacity in the Slow change scenario compared to the Neutral scenario. The lesser capacity is due to the change in overall energy consumption in the Slow change, resulting in a lesser need for generation.

The impact of assumed slower economic growth has a large impact on projected coal-fired generation across the forecast horizon, as Figure 16 shows. The reduction in coal utilisation may increase the risk of seasonal mothballing or retirement of existing plant, however the modelling has identified that the portfolio of coal-generation can operate feasibly and economically until the scheduled retirements. Further work would be needed to further assess the continued operations or mothballing potential of generators to avoid lower overall utilisations.

Figure 16 Reduced projected generation needed, Slow change scenario relative to Neutral case



3.2.3 Fast change scenario

The Fast change scenario presents a future pathway with forecast higher economic growth and higher overall consumption, and commitment to an increased emissions reduction objective. This future presents a greater need for transformation to meet higher consumption needs, with utility-scale and residential storage technologies projected to reach very high levels. It also considers the impact of deeper emissions abatement ambitions.

In this scenario, the higher forecast consumption results in a much larger NEM than the Neutral scenario – with approximately 50 TWh greater consumption in 2040 in this scenario. This increases the development needs, with greater installations of renewable energy (solar and wind) expected as well as storage. The overall generation mix to provide the energy needs of consumers over the forecast period is shown in Figure 17 below.

Figure 17 Projected generation mix (generation, GWh) by technology, Fast change scenario

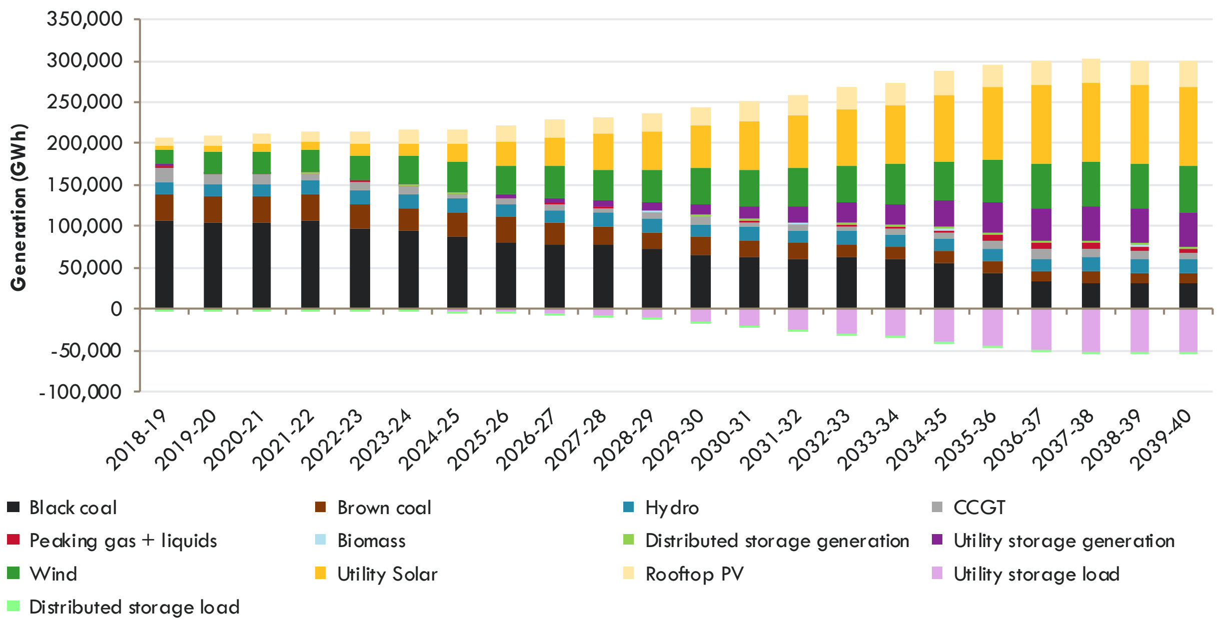


Figure 18 outlines the projected change in the generation capacity installed under this Fast change scenario, showing the large role renewable generation and storage are forecast to have after coal-fired generation is retired.

Figure 18 Projected generation mix (capacity, MW installed) by technology, Fast change scenario

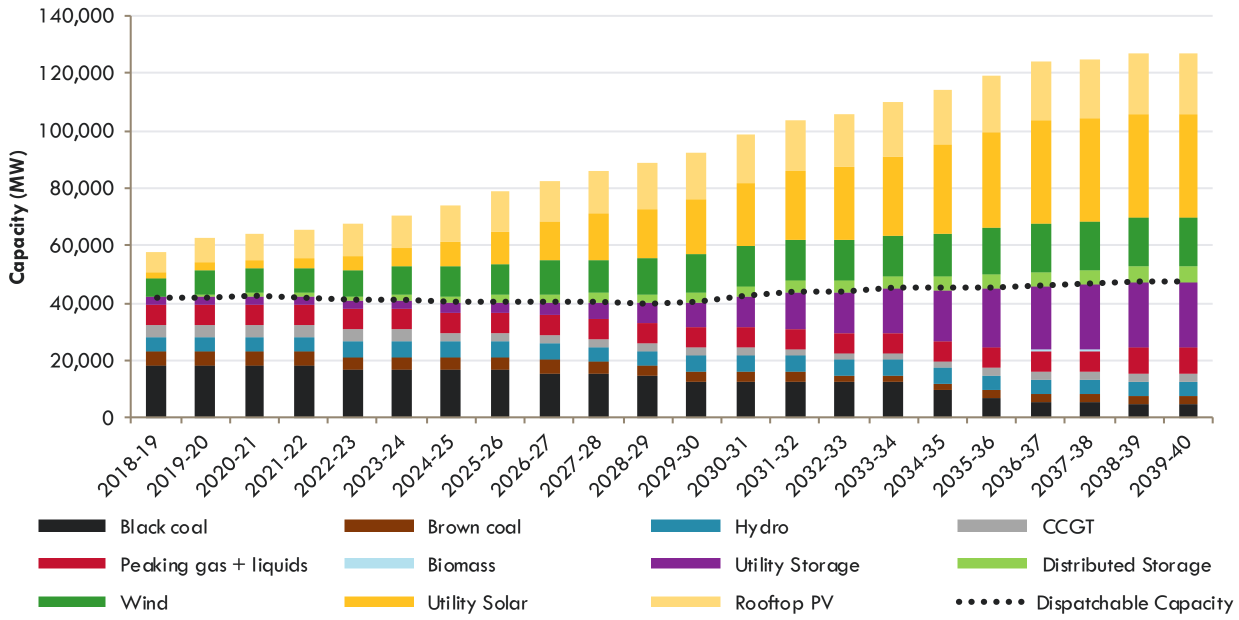
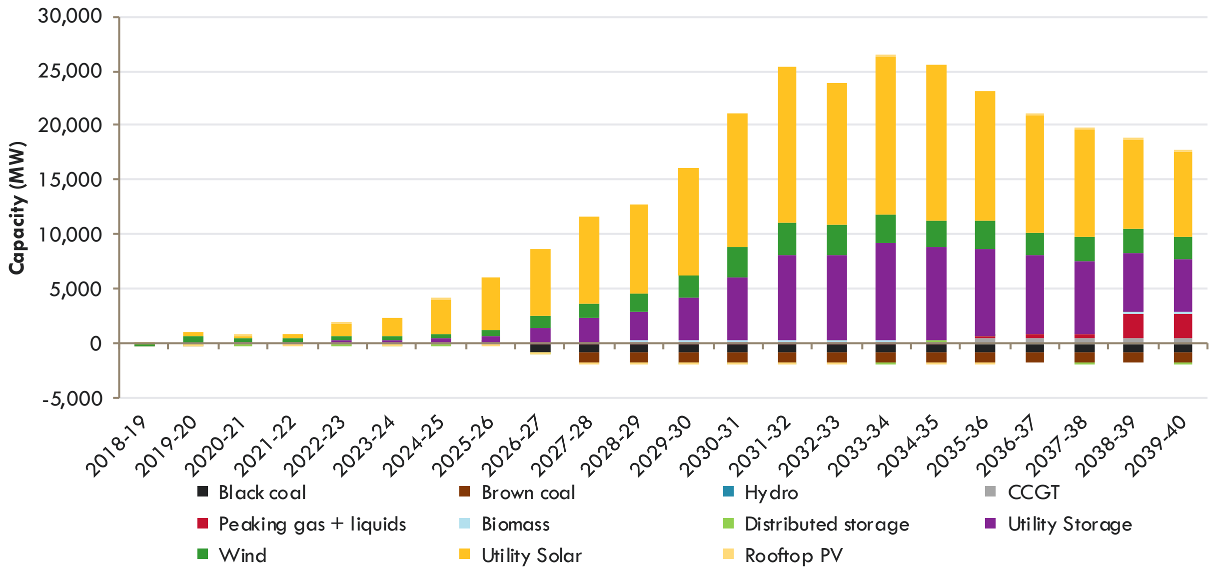


Figure 19 shows the relative developments to the Neutral scenario, and demonstrates that:

- Increased consumption forecasts lead to greater renewable energy developments, with additional storage capacity also.
- Renewable technological diversity increases with increasing consumption, to appropriately balance the storage needs and the costs associated with diurnally concentrated renewable developments, including appropriate transmission access.
- Increased consumption, with greater emissions reduction ambitions, may lead to earlier retirements of some coal-fired generation.

Figure 19 Change in projected generation mix, Fast change scenario relative to Neutral case



3.2.4 High DER case

There has been rapid growth of rooftop solar PV units across the NEM in recent years – from negligible installations in 2008 to an estimated installed capacity across the NEM of over 6 GW (across 1.6 million systems) by March 2018[40]. This growth is assumed to continue as competitive pressures drive cost reductions and further innovation drives new commercial opportunities (either through new technologies or new consumer offerings).

This scenario considers a future where there is a stronger growth in DER, that is, where distributed rooftop PV generation, battery storage, and other demand-based resources at the consumer level are higher than in the Neutral case. The purpose of this scenario is to examine how increased DER could impact on investment needs for utility-scale generation and storage and transmission.

In 2040, rooftop PV generation is projected to reach approximately 31 TWh across the NEM in the Neutral, Slow change, and Fast change scenarios, and nearly 50 TWh in the high DER scenario. This represents between 13% and 22% of forecast total underlying NEM electricity consumption, and is expected to continue to be diversified across each NEM region.

Distributed storage paired with rooftop PV generation would reduce overall grid energy consumption throughout the year, and should reduce demand at peak times where the DER is integrated and its operation optimised for power system requirements. This coordinated dispatchable battery storage could also offset the need for transmission connected large-scale storage capacity. The analysis does not attempt to value DER and identify whether coordinated consumer storages are lower cost than utility-scale storage systems, however, distributed storage does reduce local peak loads, potentially providing network savings at both transmission and distribution level. Further work is required to quantify the potential benefits of this geographically diverse resource and potential distribution network augmentation considerations.

Figure 20 below demonstrates that increased uptake of DER in this scenario is projected to impact the development of large-scale renewable generation and storage alternatives, while it is not expected to shift the investment position of thermal generation required. The figure shows high DER uptake forecast to reduce the overall solar and storage build, with approximately 10 GW of distributed storage and 35 GW of rooftop PV, offsetting approximately 14 GW of transmission-connected wind, solar, and storage technology. The relative capacity difference between the small-scale and utility-scale developments is primarily attributed to the total utilisation of the respective technologies, with utility-scale solar generation expected to make much better use of the solar resource, with optimal orientation, panel tracking systems, and removal of potential sources of shading leading to much higher average generation (or "capacity factor") than small-scale systems.

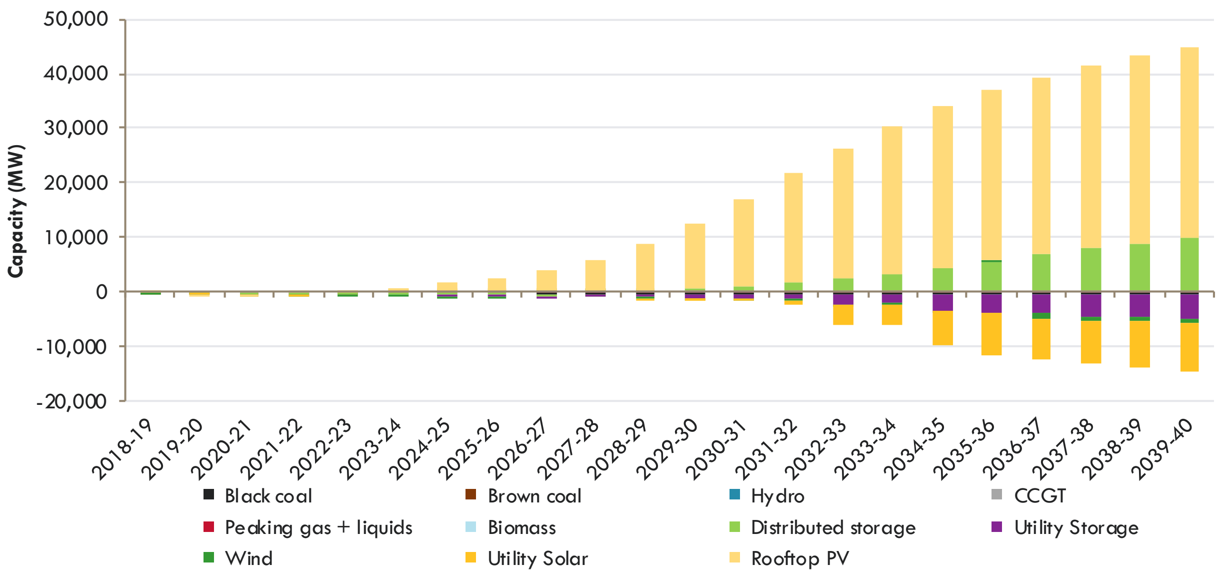
In total energy production terms, the 10 GW of distributed storage and 35 GW of rooftop PV is comparable to the 14 GW of utility-scale developments. In reducing the need for utility-scale renewable generation, the costs associated with connecting these assets within the transmission system can be reduced, delivering a major cost saving to consumers. Efficiency gains associated with lowering overall system losses are also anticipated, as energy is generated at the point of consumption.

Additionally, the modelling captured the consideration of DER "exporting" power into the transmission system. As a general proposition, distribution networks were not designed to facilitate bi-directional flows, and the system management tools to safely and seamlessly integrate DER as a reliable resource on to the system at scale are only now being tested. Investigations will be required to determine how best to assess the ability of the distribution networks to accommodate high levels of price-responsive and bi-directional DER penetration, as well as incorporating these considerations into the cost-benefit analysis outcomes. Substantial work is progressing on this topic through the market bodies, ARENA, and multiple state-based programs. AEMO is also working with Energy Networks Australia (ENA) to identify how best to understand and then address the needs of DER providers.

AEMO considers the resolution of these technological challenges a high priority to address emerging system security challenges and improve overall system efficiency, productivity, and resilience.

[40] AEMO analysis of data from the Clean Energy Regulator.

Figure 20 Projected installed capacity, High DER scenario relative to Neutral case



3.2.5 Increased role for gas sensitivity

The Increased role for gas sensitivity examined the future potential role for GPG if natural gas prices were lower than in the Neutral case. AEMO has not explored the exact price that would drive a much larger role for GPG in detail. Further discussion on the transmission impact of a lower gas price is in Section 6.3.7.

This analysis used natural gas prices centred at $6/GJ (with typical variations associated with delivery charges between regions). These prices are well below current market values and future market price expectations, which under the Neutral case were assumed to be $9/GJ -10/GJ, and represent a lower bound on reasonable future prices.

The purpose of selecting this low gas price was to test the robustness of the plan in a future world with an increased role for GPG, displacing the longer-term development of renewable generation and complementary storage solutions. This is shown in Figure 21 and Figure 22, which demonstrate the impact that an increased GPG forecast has on projected renewable generation development. Total generation in this scenario is lower to deliver the same overall consumption need, as less energy is used in storage systems, which avoids inefficiencies associated with charge and discharge cycles. Increased GPG displaces some of the solar generation and complementary storage solutions originally forecast in the Neutral scenario.

Figure 21 Projected installed capacity, Increased role for gas sensitivity, relative to Neutral case

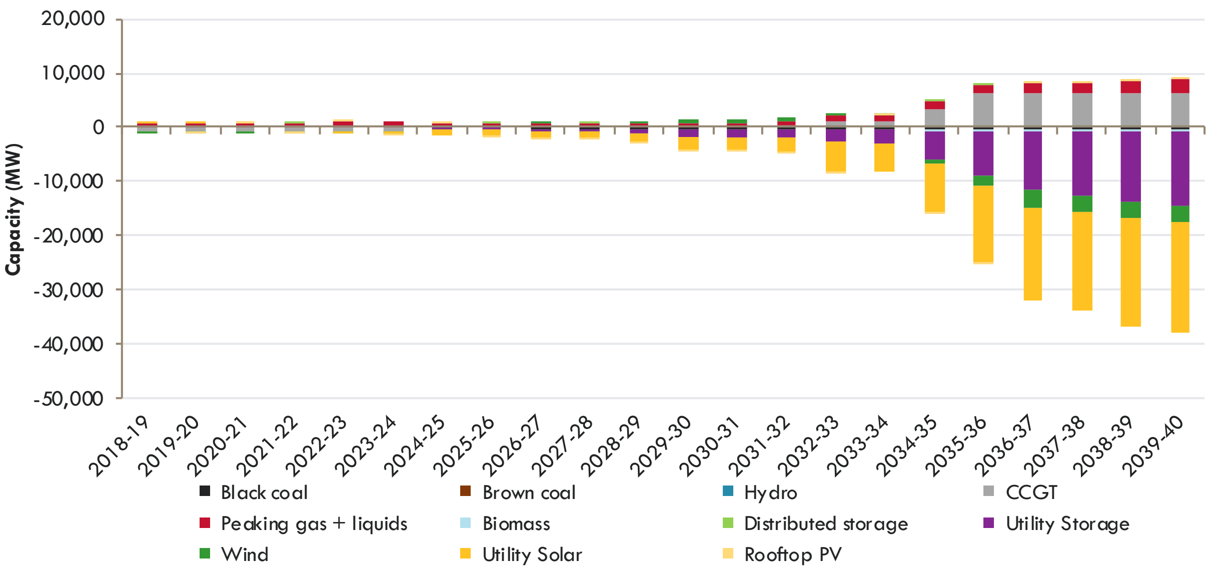
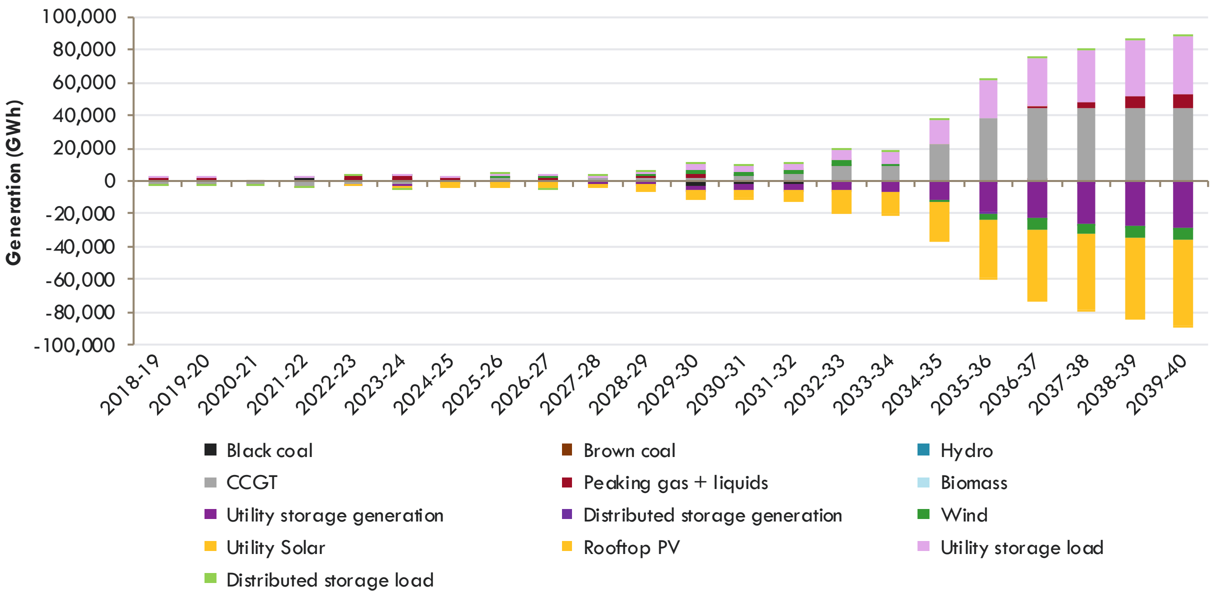


Figure 22 Projected generation impact, Increased role for gas sensitivity, relative to Neutral case



3.2.6 No interconnector development reference

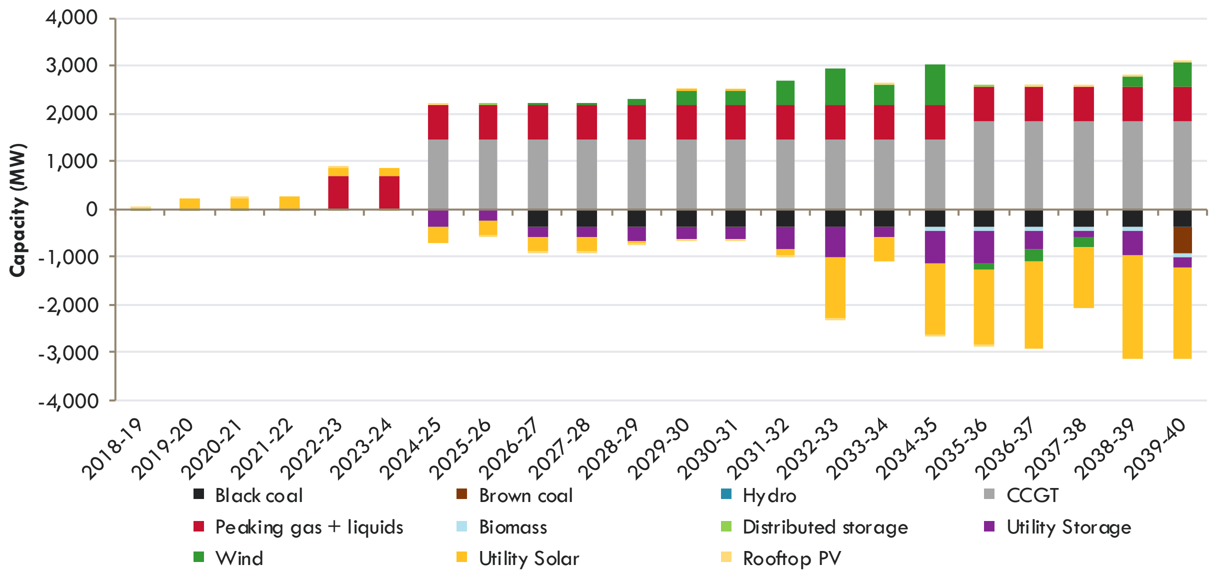
AEMO also modelled the Neutral scenario assuming no interconnector augmentations, to assist in determining the net market benefits of interconnector upgrades on the system. No other assumption differences exist between this case and the Neutral scenario, and transmission developments within a region (intra-regional developments to access renewable resources) still provide benefit to consumers. Without the opportunity to develop inter-regional transmission, the location and preferred generation developments are expected to shift, relative to the Neutral scenario.

This is shown in Figure 23, with the key differences being:

- Reduced contribution from utility-scale solar generation, compared to the Neutral case, as reduced opportunities to smooth concentrated renewable generation between regions increases the value of technical diversity.
- Greater development of GPG (both peaking (open-cycle gas turbine [OCGT]) and mid-merit (CCGT)), despite the higher costs associated with these two generation options in comparison to a utility solar and storage solution.

- Continued operation of existing GPG. The RiverLink interconnector reduces risks associated with power system security in South Australia, leading to lower overall utilisation of GPG in that state. Without the development of the RiverLink interconnector in this scenario, GPG utilisation continues to be much higher than all other scenarios which develop that interconnector. This is shown in Figure 23, which continues to keep in service some existing GPG beyond 2025, after the RiverLink interconnector would be developed in the Neutral scenario. No new CCGT plant is forecast in this scenario until 2036.

Figure 23 Projected installed capacity, no interconnector reference, relative to Neutral case



The 'increased' CCGT capacity for this scenario is due to the continued operation of South Australian GPG in this scenario, relative to the Neutral case, which would allow GPG to mothball or retire due to the introduction of increased interconnection via the RiverLink interconnector.

4. Renewable energy zones

Key observations

- This analysis shows the potential for REZs to provide an effective, least-cost way to integrate new generation, storage, and transmission development, by enabling:
  - Optimisation of the development of REZs with development of supporting transmission network infrastructure, considering the requirements for transporting the energy to load centres, system strength, and optimisation of firming resources, such as storage.
  - More optimal development of investment needs for generation, transmission, system strength, and storage across multiple connecting parties.
  - Realising benefits of scale for capital investment and, in particular, efficiently sizing any network development required.
- AEMO has assessed 34 candidate REZs across the NEM through consideration of a mix of resource, technical, and other engineering considerations. Engagement with traditional owners, residents, broader communities, and local governments will be essential prior to any large-scale development of a REZ.
- The existing transmission network provides the capability to efficiently connect considerable renewable generation. The assessment identifies which REZs are most optimal at present from a range of considerations, in particular the requirements for least-cost integration of REZs into the transmission system. The immediately optimal REZ development areas, supported by existing transmission capacity and system strength and capacity, include:
  - **New South Wales** – Central Tablelands (wind and solar) and Southern Tablelands (wind).
  - **Queensland** – Darling Downs and Fitzroy (wind and solar).
  - **South Australia** – Northern SA (solar) and Mid-North (wind).
  - **Tasmania** – North-West Tasmania (wind).
  - **Victoria** – Moyne (wind).
- To connect renewable projects beyond the current transmission capacity, further action will be required. The assessment considers how to best develop REZ in the future that are optimised with necessary transmission developments, identifying indicative timing and staging that will best coordinate the REZ development with identified transmission developments to reduce overall costs. Optimal areas identified for development in conjunction with the transmission investments in Group 2 include:
  - **New South Wales** – New England (wind and solar), North West NSW (wind and solar), Northern Tablelands (wind and solar) and Murray River (solar).
  - **South Australia** – Riverland (wind and solar).
  - **Victoria** – Western Victoria (wind) and Murray River (solar).
- The Murray River and Western Victoria REZs are experiencing significant committed renewable development, with large amounts of additional generation expected to be operational in the near term. There are currently Regulatory Investment Tests for Transmission (RIT-Ts) underway to assess the transmission developments to support committed renewable developments in these REZ to reduce the cost of congestion and provide consumers with access to low-cost power.
- Modelling shows that many renewable developments contemplated in the 2020s are likely to require some level of system strength remediation for their connection, and from the 2030s onwards most renewable developments would be expected to require system strength remediation. A coordinated approach that allows renewable generators to contribute towards system strength for a REZ will be more economic than developing system strength solutions at individual wind and solar farms.

4.1 Integrating large quantities of renewable generation

Australia is very large, and the NEM is a long and sparsely connected power system, with concentrated load centres that are distant from one another. The current NEM transmission network was primarily designed to connect large centres of thermal and hydro generation to major demand centres some distance away.

There are good wind and solar resources across the NEM regions. AEMO's modelling, across the ISP scenarios, shows that, to replace energy produced by retiring coal-fired generation, between 14 GW and 48 GW of new renewable generation is expected to connect to the NEM by 2040. Currently[41] there is 4.8 GW of variable renewable generation already installed, 3.9 GW committed, and 34.9 GW proposed.

The NEM transmission network will need to develop to efficiently connect and transport large amounts of energy from dispersed renewable generation across the NEM to where consumers want to use it.

Many of the current connection applications are located at the periphery of the transmission network, where access to renewable resources is good but the network is weak, in terms of both capacity and system strength. As the energy sources are less intensive and geographically dispersed, they will require greater transmission to transport their energy to load centres. Developing the transmission network to fully accommodate all the currently proposed renewable generation at sites spread across the NEM would not be economic.

There are also significant implications if a large amount of generation connects to a weak part of the network. To manage power system security issues, generation in those areas will likely be prevented from generating at full capacity unless additional investment was made to remediate the impacts on system strength in the REZ.

However, there are a number of potential REZs across the NEM where high quality renewable resource overlaps with locations where the transmission network is strong and there is good network capacity available. These areas should be prioritised for development to reduce overall costs of integration in the NEM.

Beyond that, development of the requisite transmission to connect large amounts of REZ should be closely coordinated with the identified transmission developments in this plan to integrate the resources into the power system in the most optimal and lowest cost manner.

4.2 Potential renewable energy zones (REZs)

AEMO engaged consultants DNV-GL to assess the resource quality across eastern and south-eastern Australia, to be used by AEMO in identifying possible REZs[42,43]. Information on potential zones with good resource quality were published by AEMO in the December 2017 ISP Consultation Paper[44], and largely supported by stakeholders in feedback (refer to Appendix E for more information).

From this work, AEMO identified 34 potential zones of good renewable resources (REZs) across the NEM, through consideration of a mix of resource, technical, and other considerations, as shown in Figure 24. The quality of the potential REZs was assessed further in the development of the ISP.

The aim in this analysis was to identify the timing, scale, and location of REZs that would minimise the total cost of supply to consumers.

In the ISP, this was achieved in the following process:

1. AEMO engaged consultants DNV-GL to advise on potential candidate REZs, based on a range of criteria.
2. Initial candidates were adjusted after industry workshops and consultation, and used as inputs to the ISP modelling, along with generation and transmission costs associated with each of the candidate zones.
3. The initial outcomes were reviewed, considering additional factors such as transmission development staging, system strength, and network losses, and the process was iterated to optimise the REZ in conjunction with transmission developments and reliability and security requirements.

The process that AEMO used to identify and further assess these REZs is detailed in Appendix F. Additional information regarding the outcomes of REZ assessments is included in Appendix A.

AEMO notes that early recognition of REZs would allow for the range of work needed for implementation and to avoid the costs of poorly planned development. Engagement with traditional owners, residents, broader communities, and local governments will be essential prior to any large-scale development of a REZ. Proponents of new generation connection should conduct their own due diligence, to understand how technical requirements might influence their connection.

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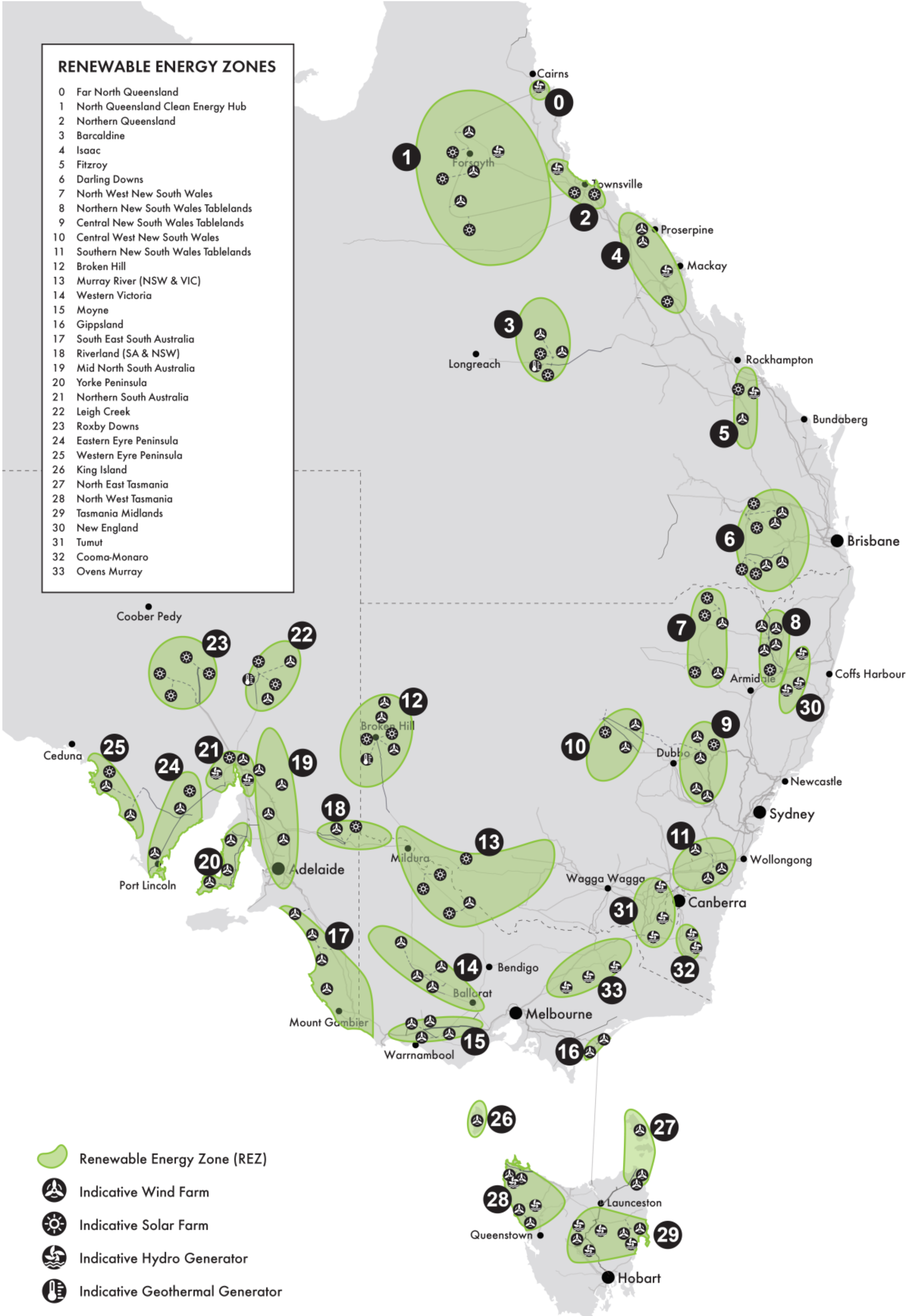
[41] Data is current as at 16 March 2018, AEMO Generation Information Page

[42] Wind resource quality assessment was based on mesoscale wind flow modelling at a height of 150 m above ground level (typical wind turbine height), while Global Horizontal Irradiance (GHI) and Direct Normal Irradiance (DNI) data from the Bureau of Meteorology (BOM) were used to assess solar resource quality.

[43] This work is not intended in any way to replace the specific site assessment of potential wind farm sites by developers.

[44] AEMO, *Integrated System Plan Consultation*, December 2017, available at https://www.aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/ISP/2017/Integrated-System-Plan-Consultation.pdf.

Figure 24 Renewable Energy Zone candidates



4.3 Considerations in the assessment of REZs

4.3.1 Resource quality and diversity

An important consideration for large-scale development of renewables in a concentrated area such as a REZ is the diversity of renewables within the REZ and across the NEM. High diversity (low correlation) between REZs is valuable because it results in a more consistent generation output overall, which requires less energy storage to support the need for firming.

This analysis shows:

- There is high solar energy correlation across the NEM for all REZs.
- Wind resources in Queensland provide the most diversity to wind generation in other areas. Wind generation in Tasmania is somewhat diverse to wind generation on the mainland – particularly Queensland, New South Wales, and South Australia.
- Wind generation within states is generally highly correlated.

There are five REZs that have low or negative correlation with most of the NEM, meaning they will generate electricity at different times to the rest of the NEM. These five REZs are all situated in Queensland, and show good diversity with wind in the other regions of the NEM. These REZs are:

- North Queensland Clean Energy Hub.
- Isaac.
- Fitzroy.
- Darling Downs.
- Barcaldine.

Darling Downs and Fitzroy are considered some of the most strategic REZs in eastern Australia for development in the short to medium term, and hence these are good areas to consider for wind development. Wind development in these areas would allow for the diversification of renewable resources across the NEM, and hence contribute to a firmer resource portfolio across the NEM. Development in these areas would also be impacted less by wind generation in other REZs, as the transmission paths to load centres would be less congested.

4.3.2 Diversity and demand matching

Integrating a large amount of highly correlated variable renewable generation can be more complicated for managing power system reliability than connecting generation whose variations are not correlated. Generation correlation can be influenced by technology, location, and time of day. High levels of correlation – when a lot of nearby variable generation is producing (or not producing) energy at the same time – will increase congestion on the transmission network, and volatility in electricity market dispatch.

There are several key ways to achieve diversity with renewable generation, and improve system efficiency:

- To diversify the type of renewable generation built. For example, wind generation within a REZ is likely to be highly correlated to other wind generation within the same REZ, whereas solar generation is likely to be relatively uncorrelated to wind generation in the same area.
- To diversify the geographical location of where the renewable generation is built. For example, wind generation located in different geographical areas is likely to be less correlated than wind generation within the same geographical area.
- Select REZs where combined output from renewable resources is positively correlated with grid demand.
- Co-develop energy storage and variable renewable generation in the same REZ, to allow the net REZ output to be more correlated with demand or within transmission capacity.

In assessing the REZs for analysis in the ISP, the optimisation considered the correlation of REZ resource with demand.

4.3.3 Transmission development to access a REZ

Transmission connection in the NEM is currently open access. That means, subject to meeting connection standards, a participant is free to connect to any part of the transmission network. Existing generators and generator projects under development in an area face the risk of the network being congested at some future point if further developments exceed the capacity of the transmission network to transport the energy to consumers. Generators may also face restrictions on operation caused by low system strength or be affected by losses without some development of the power system.

If the transmission network required to support a REZ is only designed for known/firmly committed generation projects, the capacity of this network is unlikely to be adequate to handle future generation projects for the REZ. To further exploit the renewable resources in the REZ, additional transmission network will be required.

An incremental approach to augmenting the network risks an overall higher cost of developing the REZ. For example, it is generally less expensive to build one high capacity transmission line than to build one lower capacity transmission line which is later duplicated.

Effective REZ development could reduce these risk to generators if the development of capacity of the transmission network for a REZ is aligned with the likely renewable energy build in the REZ, with a view to both current and future requirements. This highlights the importance of coordinated staging of generation and transmission development that minimises risks of under- and over-utilisation while ensuring reliability and security of the power system is maintained.

Ways to stage a transmission development include, but are not limited to:

- Acquiring strategic easements ahead of their build.
- Building a double circuit tower but stringing a single circuit initially.
- Developing a substation incrementally, but having a footprint that accounts for an ultimate development.

It will be essential in the development of transmission to support REZs that these options are explored, to minimise any stranding risk and maximise option value. In the development of the ISP, AEMO has sought to optimise REZs in conjunction with transmission development to achieve the lowest overall cost of development.

4.3.4 System strength

System strength is a measure of the ability of a power system to remain stable under normal conditions and to return to a steady state condition following a system disturbance[45] (see Section 5.4.3).

Because some types of generation, including most solar and wind generators currently being developed, do not currently provide inherent contribution to system strength, REZs can be susceptible to low system strength conditions. Low system strength can impact the stability and dynamics of generating systems' control systems and the ability of the power system to remain in stable operation. Section 5.4.3 provides detail on REZ that are most susceptible to low system strength.

Based on projections provided in this ISP, many renewable developments contemplated in the 2020s are likely to require some level of system strength remediation for their connection, and from the 2030s onwards most renewable developments would be expected to require system strength remediation. When developing REZs, system strength planning can benefit from economies of scale – coordinated solutions to providing system strength, that generators contribute towards, will be more economic than multiple small-scale solutions developed at each wind or solar farm[46].

As covered in Section 5.4.3, AEMO has published finalised guidelines with regards to system strength and mitigation requirements for new generation connections[47]. TNSPs are also required to maintain minimum fault levels at specified nodes within their networks. Should a shortfall be identified by AEMO, the TNSP must procure system strength services to maintain the fault levels determined by AEMO. AEMO has published methodologies and assessments relating to TNSP responsibilities in maintaining minimum fault levels at specific fault level nodes[48].

4.3.5 Network losses

Network losses occur as power flows through transmission lines and transformers. Increasing the amount of renewable energy connected to the transmission network remote from load centres will increase network losses. As more generation connects in a remote location, the higher the power flow over the connecting lines and on the AC system, and the higher the losses.

In the NEM, transmission network losses are represented through Marginal Loss Factors (MLFs).

Marginal Loss Factors

Energy is lost as it travels through the transmission network, and these losses increase as more generation connects in locations that are distant from load centres. In the NEM, Marginal Loss Factors (MLFs) are applied to market settlements, adjusting payments to reflect the impact of incremental energy transfer losses. MLFs are used to adjust the

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[45] A system disturbance is an unplanned contingency on the power system, such as a high-voltage network fault (i.e. short-circuit) or an unplanned generator or large load disconnection.

[46] Section 4.3.2 of AEMO's 2017 Victorian Annual Planning Report included a worked example that demonstrated the benefits of system strength planning, available at: https://www.aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/VAPR/2017/2017-VICTORIAN-ANNUAL-PLANNING-REPORT.pdf.

[47]AEMO. System Strength Impact Assessment Guidelines, available at http://aemo.com.au/Electricity/National-Electricity-Market-NEM/Security-and-reliability/System-Strength-Impact-Assessment-Guidelines.

[48] AEMO. System Strength Requirements Methodology, 2018 System Strength Requirements & Fault Level Shortfalls, available at: http://aemo.com.au/Electricity/National-Electricity-Market-NEM/Security-and-reliability/System-Security-Market-Frameworks-Review.

price of electricity in a NEM region, relative to the regional reference node[49], in a calculation that aims to recognise the difference between a generator's output and the energy that is actually delivered to consumers. In dispatch and settlement in the NEM, the local price of electricity at a connection point is equal to the regional price multiplied by the MLF. A renewable generator's revenue is directly scaled by its MLF, through both electricity market transactions and any revenue derived from large-scale generation certificates (LGCs) created if accredited under the federal Large-scale Renewable Energy Target (LRET).

Increasing generation within a REZ is likely to increase losses between the REZ and the regional reference node, decreasing the MLFs for the REZ. The MLFs attributable to generators located in some REZs will be more sensitive to change as a result of new connecting generators than other REZs, particularly where they are distant from major load centres and interconnection is relatively weak.

Investors in new generation are concerned about the effect of decreased MLFs on their potential returns, and the uncertainty of how MLFs can vary from one year to the next. Generators in locations that are strongly connected to major load centres have MLFs that are less likely to change over time.

For a generator, an MLF represents the amount of electricity delivered to the regional reference node for a marginal (next MW) increase in generation; for a load, the MLF represents the amount of power that would need to be generated at the regional reference node for a marginal (next MW) increase in demand. In simple terms, a higher MLF is good for a generator's revenue, while a lower MLF is good for a load (as it means it is not paying for energy lost before it reaches the load). Marginal loss factors will change over time, most often decreasing as additional generation connects in an area.

A range of factors affect how much the MLF will change:

- **Transmission and distribution network** – if new generation is added at an electrically distant connection point, the MLF decreases more than if it had been added to a connection point in close proximity to the high-voltage network.
- **Generation profile in the area** – if new generation is only running at the same times other nearby generators are also running, the MLF decreases more. For example, solar generators in an area all produce power at the same time, so adding more of this type of generator will decrease the MLF more than if a different technology generator was added.
- **Load profile in the area** – if new generation mainly produces power at times when there is light load in the area, the decrease in MLF will be greater.
- **Intra-regional and inter-regional flows** – wider trends affecting MLFs include decreasing consumption, increasing distributed generation, changing industrial loads, and retiring generators.

For example, the planned connection of over 1,200 MW of new solar generation in north and central Queensland led to MLFs falling by up to 12% from the 2017-18 financial year to 2018-19.

In addition to new generator connections, a number of other events can cause large changes in power flow across the transmission network, and corresponding large changes in MLF. These include:

- **Retirement of generation** – the retirement of Northern Power Station in South Australia in 2016 caused power flow from Victoria to South Australia to increase, contributing to MLFs in south-east South Australia falling by around 6%. The retirement of Hazelwood Power Station in Victoria in 2017 resulted in increased power flow south from Queensland and New South Wales, contributing to northern New South Wales loss factors reducing around 5%.
- **Change in fuel mix** – the availability of cheap "ramp" gas in Queensland in 2014 and 2015 led to an increase in GPG in southern Queensland. This caused increased power flow from Queensland to New South Wales, contributing to MLFs in northern New South Wales falling by up to 10%.
- **Changes in electrical load** – the closure of the Point Henry Aluminium Smelter in Victoria in 2014 contributed to MLFs in the area falling around 2.5%.

The projected increase in development of renewable generation across the NEM will result in changes to network flow patterns, the network itself where augmentations or new interconnection is undertaken, to network losses as different parts of the network are utilised in different ways, and resultant MLFs will change.

In this analysis, AEMO modelled the transmission system and its losses. AEMO studied each candidate REZ to assess the sensitivity of its MLF to increased renewable generation, based on the existing network. The results are only to be used as a guide to determine how sensitive each proposed REZ would be to changes in MLF.

The studies considered each REZ individually, using network snapshots from the previous 12 months. Various levels of renewable generation were connected in the model to represent the REZ, then an MLF was calculated. The MLFs

[49] The reference point (or designated reference node) for setting a region's wholesale electricity price.

calculated are only indicative as they are not based on applying the full Forward Looking Loss Factor Methodology[50] set out in the Rules and procedures. The studies used existing electrical system strength and the existing generation and load profiles, and AEMO included consideration of some proposed network augmentations.

Effect of energy storage on MLFs

The effect of energy storage on the MLF depends on how well its charging and discharging profiles correlate with the generation profile and load profile. The MLF of a site would improve if the energy storage is charging at times when the generation of the REZ is high and the local area load is low. For example, co-locating a battery with a solar farm could not only assist in shifting the output to times when needed, but could also improve the MLF for the site.

4.4 Outcomes of the ISP development pathways for REZs

The following sections present AEMO's initial assessment of the attributes of the identified REZs within each NEM region. The REZs were assessed according to the defined criteria for assessment[51].

Proponents of new generation connection should conduct their own due diligence, to understand how technical requirements might influence their connection. Engagement with traditional owners, residents, broader communities, and local governments will be essential prior to any large-scale development of a REZ.

Timings presented are indicative only. Importantly, immediate actions identified in this ISP do not lock out opportunities for earlier development of any REZ, if economic in future.

4.4.1 New South Wales REZ assessment

AEMO's REZ analysis for New South Wales projected that it will be most efficient to:

- Encourage generation to connect to areas with existing network capacity, such as the Central and Southern NSW Tablelands.
- Increase network capacity in REZs that are aligned with identified interconnector upgrades – such as the RiverLink interconnector proposal with the Murray River REZ, and the New South Wales to Queensland interconnector upgrades with the Northern NSW Tablelands and New England REZs.
- Develop large-scale REZs prior to the closure of Bayswater and Eraring, which at the moment are projected to reach the end of technical life in the early to mid-2030s.

From a total of 11 candidate REZs assessed in New South Wales, three – Northern NSW Tablelands, Central NSW Tablelands, and Murray River – have been identified as areas for consideration of utility-scale generator connections in the short and medium term. Combined, these REZs could support around 3,000-4,000 MW of additional new generation connections following network augmentations (these zones could support in total around 1,300 MW of combined new generation connections without network augmentation).

These REZs align closely with the Potential Priority Energy Zones announced by the New South Wales Government[52,53], with minor differences that are not material to the outcomes.

The Central NSW Tablelands REZ:

- Aligns with the Potential Priority Energy Zone ("Central West") announced by the New South Wales Government.
- Has high quality solar (3,000 MW) and wind (1,600 MW) resource potential.
- Is an example of a REZ where MLFs are resilient to large increases in generation. This is because it is electrically close to Sydney – the main load centre in New South Wales and the regional reference node. Being electrically close to the Sydney means MLFs in this region are relatively resistant to change (see Figure 25).
- Has two 500 kilovolt (kV) and two 330 kV transmission circuits passing through it. The Central Tablelands REZ would be able to support around 1,000 MW of additional generation connections before the transmission network would need major augmentation.

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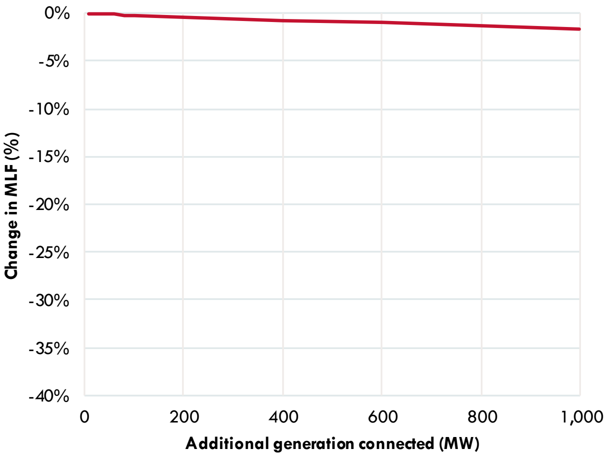
[50] AEMO. Methodology for Calculating Forward-Looking Transmission Loss Factors. Available at: https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Security-and-reliability/Loss-factor-and-regional-boundaries.

[51] The criteria used for this detailed assessment of REZs are defined in Appendix A.

[52] NSW Government. Renewable Energy Hub Knowledge Report. Viewed 4 June 2018. Available at: https://www.resourcesandenergy.nsw.gov.au/data/assets/pdf_file/0006/803751/NSW-Government-Submission-on-Integrated-System-Plan.pdf.

[53] NSW Government. NSW Government Submission on AEMO's Integrated System Plan. Available at: https://www.aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/ISP/2018/Round-2-Submissions/NSW-Government---Submission-on-Integrated-System-Plan.PDF.

Figure 25 MLF resilience for Central New South Wales Tablelands



The Northern NSW Tablelands REZ:

- Aligns with the Potential Priority Energy Zone ("New England") announced by the New South Wales Government.
- Has high quality solar (approximately 1,750 MW) and wind (3,660 MW) resource potential.
- Can only support 300 MW of new renewable generation connections before network augmentations would be required.
- Could support about 2,000 MW of new renewable generation connections following the augmentations proposed between New South Wales and Queensland, and between Bayswater and Northern New South Wales.

The Murray River REZ:

- Aligns with the Potential Priority Energy Zone ("South West") announced by the New South Wales Government.
- Has good solar (approximately 6,000 MW) and wind (9,140 MW) resource potential[54].
- Is not able to support much new renewable energy in the area in the present network, but is linked to, and a part of, the development of RiverLink to provide the network needed to open access to this rich renewable resource area.

While the Southern NSW Tablelands REZ has high quality wind resources available, and is geographically close to Sydney, with MLFs resilient to change and connected to transmission network supporting Sydney by three 330 kV transmission lines and two 500 kV transmission lines, it may, as advised by the New South Wales Government, encounter barriers due to a lack of community support of further development in the area.

Where REZ developments align with major transmission corridors, additional benefits can accrue to provide value for the additional transmission justification, for example:

- The 'medium' Queensland to New South Wales interconnector (QNI) development, proposed for the mid-2020s, would strengthen the network in the Northern New South Wales Tablelands REZ and North Western New South Wales REZ (see Appendix D), opening the way for 1,000 to 1,500 MW of renewable generation development in New South Wales.
- The route for the proposed interconnector between New South Wales and South Australia (RiverLink) goes through the Riverland and Murray River REZs. This link provides economic benefits by increasing the capacity of the network to accommodate renewable energy in these areas (see Appendix D), opening the way for 900 MW to 1,200 MW of renewable generation development in New South Wales.
- The SnowyLink development would improve the connection between the Riverland and Southern New South Wales Tablelands REZs. This would reduce losses in the REZ, along with allowing additional capacity to be added in the REZ (see Appendix D), opening the way for 2,000 MW to 3,000 MW of renewable generation development in New South Wales and Victoria. These benefits would be additional benefits to those estimated in the cost-benefit assessments undertaken for the SnowyLink development.

[54] When combined with the area in Victoria immediately adjacent on the south side of the Murray River.

In the longer term (through the 2030s), AEMO has projected that the establishment of additional REZs may be efficient in New South Wales.

Many of the other REZs identified for longer-term development are also well-aligned with ISP transmission flow path upgrades, including Northern New South Wales Tablelands, North Western New South Wales, Southern New South Wales Tablelands, and Riverland REZs.

The following table outlines the New South Wales REZ candidates, several key metrics, and the modelled indicative timing in the ISP scenarios.

Table 3 New South Wales REZ report card*

REZ Name	Solar quality	Wind quality	Spare Network capacity (MW)	Network losses †	Priority for generator connections	Network upgrade timing				
						Neutral	Neutral with storage	Slow	Fast	High DER
North West NSW	B	D	100	F (B)	3‡	2035	2035	>2040	2029	2037
New England & Northern NSW Tablelands	D	B	300	B	3‡	*Initial upgrades could be considered in conjunction with identified interconnector upgrades (see Appendix D). Subsequent upgrade timing:*				
						2035	2034	>2040	2026	2036
Central NSW Tablelands	D	B	1,000	A	1	>2040	>2040	-	2023	>2040
Central West NSW	C	C	100	E (A)		2037	2039	-	2037	>2040
Southern NSW Tablelands	E	A	1,000	A		2036	2036	>2040	2036	2036
Broken Hill	B	B	100	E		>2040	>2040	>2040	>2040	>2040
Murray River (NSW)	C	C	0	E	2	*Initial upgrades expected in conjunction with RiverLink project (see Appendix D). Subsequent upgrade timings:*				
						2035	2035	-	2035	2037
Riverland (NSW)	C	C	200	E		2033	2032	-	2024	2036
Tumut	N/A	N/A	0	A		-	2025	-	-	-
Cooma-Monaro	N/A	N/A	200	E		-	-	-	-	-

* In this table, a grading system has been used where "A" represents a very high grade, "F" represents a very poor grade, and "B", "C", "D" and "E" represent intermediate grades.
† Scores shown in brackets indicate the result following a major network upgrade.
‡ In the event of a major upgrade of the New South Wales to Queensland interconnector, North West New South Wales is preferred over Northern New South Wales Tablelands. The New England REZ could be developed in conjunction with the Northern New South Wales Tablelands.

4.4.2 Queensland REZ assessment

Renewable generator connections in Queensland are being driven by high quality wind and solar resources, and a state-based renewable energy target.

AEMO assessed seven candidate REZs in Queensland (see Appendix A) and identified two – Darling Downs and Fitzroy – for utility-scale generator connections in the short and medium term.

The Darling Downs REZ:

- Has moderate quality solar and good wind resources, and includes locations where pumped hydro resources could be developed.
- Has a strong network connection with the major load centre in South East Queensland, consisting of multiple 330 kV transmission lines, and sits on the major transmission flow path connecting the New South Wales and Queensland regions. This means there is sufficient capacity in the REZ to connect around 3,000 MW of new generation without needing to augment the regional transmission network.
- Is very resilient to large changes in network losses and MLFs (see Figure 26).

The Fitzroy REZ:

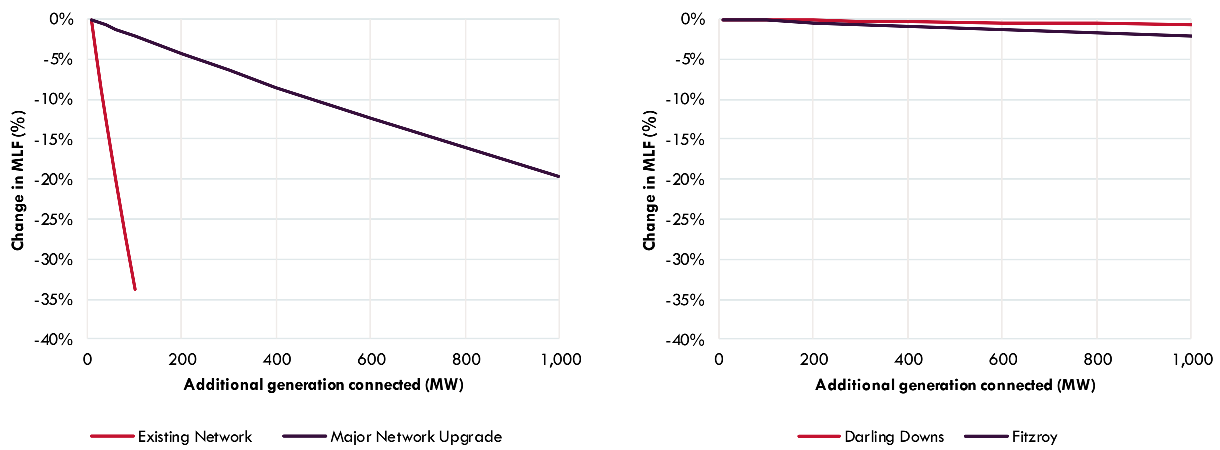
- Has moderate quality solar and good wind resources, and includes locations where pumped hydro resources could be developed.

- Has a stronger connection to the major load centre in Queensland than other candidate REZs (although not as strong as that of the Darling Downs REZ). There is sufficient transmission capacity to connect around 2,000 MW of additional generation without needing to augment the regional transmission network.
- Has more sensitive MLFs than the Darling Downs REZ, but more robust compared to other Queensland REZ candidates.

Analysis of the North Queensland Clean Energy Hub REZ highlighted that:

- Northern Queensland has excellent quality renewable resources. Energy storage projects in this area could support the abundance of correlated solar projects in this locality. However, due to a recent surge in renewable generator connections in this area, and the resulting energy surplus, further large-scale generator connections are unlikely to be efficient in North Queensland until existing thermal generation in Central Queensland starts to retire (currently timed to the 2030s based on power stations reaching the end of technical life).
- The North Queensland Clean Energy Hub REZ is currently only weakly connected to the rest of the NEM by a single 300 km, 132 kV transmission line located inland from Ross to Kidston. As a result, the MLFs in this REZ are not resilient to development of large amounts of new generation in the area. The MLF change in this area is directly proportional to the new generation added in the area – for example, adding just 13 MW of new generation would result in a drop in MLF by 5%.
- Upgrading the network by building a 275 kV line to Kidston would improve loss factor resilience and enable over 200 MW of new generation to be added before the MLF drops by 5%[55]. Figure 26 indicates the resilience of MLFs in the North Queensland Clean Energy Hub, as currently and following transmission upgrade. Due to the geographic and electrical distance between North Queensland and major load centres, transmission losses will be a key consideration for further development in this region.

Figure 26 MLF resilience for North Queensland (left), and Darling Downs and Fitzroy (right)



The following table outlines Queensland REZ candidates, several key metrics, and modelled indicative timing in the ISP scenarios.

[55] Note that this study was for the REZ in isolation and does not consider the further changes in MLF that would occur from new generation also being connected in adjacent REZs.

Table 4 Queensland REZ report card*

REZ name	Solar quality	Wind quality	Spare Network capacity (MW)	Network losses †	Priority for generator connections	Network upgrade timing				
						Neutral	Neutral with Storage	Slow	Fast	High DER
Far North QLD	NA**	NA	700	E						
North QLD Clean Energy Hub	A	A	0	F (E)		-	-	-	2030	-
North QLD	B	B	2,000	D		>2040	>2040	-	>2040	>2040
Barcaldine	A	B	0	F (D)		-	-	-	-	-
Isaac	B	B	2,000	B	3	>2040	>2040	>2040	>2040	>2040
Fitzroy	C	B	2,000	A	2	>2040	>2040	-	>2040	>2040
Darling Downs	C	B	3,000	A	1	>2040	>2040	>2040	>2040	>2040

* In this table, a grading system has been used where "A" represents a very high grade, "F" represents a very poor grade, and "B", "C", "D" and "E" represent intermediate grades.
† Scores shown in brackets indicate the result following a major network upgrade.
** NA – Not applicable

4.4.3 South Australian REZ assessment

Over the past decade, South Australia has seen steady investment in wind farms. The state is capable of meeting, and historically has met, over 120% of its demand from wind generation alone.

Periods of such high penetration of non-synchronous generation present challenges for managing power system security, particularly in relation to maintaining adequate system strength (see Section 5.4.3). The strength of the power system can be low during these periods, due to reduced levels of online conventional synchronous generation.

AEMO assessed nine candidate REZs in South Australia (see Table 5) and identified two – Northern South Australia and Mid-North – for large-scale generator connections in the short and medium term.

The Northern South Australia REZ:

- Has high quality solar resources, and includes locations where pumped hydro resources could be developed.
- Has a strong network connection with the major load centres, consisting of multiple 275 kV transmission lines. This means there is sufficient capacity in the REZ to connect around 1,000 MW of new generation without needing major regional transmission network augmentations.
- Is very resilient to large changes in network losses and MLFs (see Figure 27).

The Mid-North REZ:

- Has moderate quality solar and good wind resources, and includes locations where pumped hydro resources could be developed.
- Has a stronger connection to the major load centres in South Australia than other candidate REZs. There is sufficient transmission capacity to connect around 1,000 MW of additional generation without needing major transmission network augmentations.
- Is very resilient to large changes in network losses and MLFs (see Figure 27).

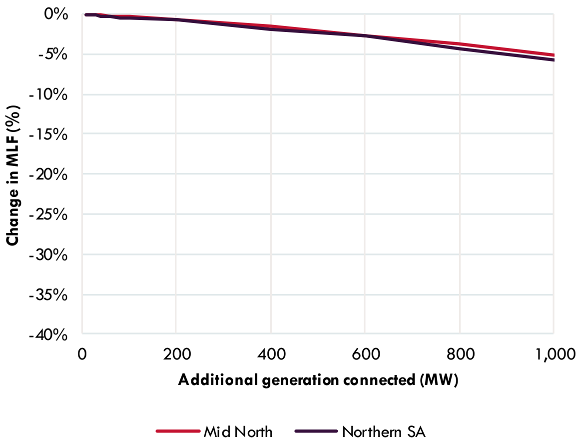
Of the REZ candidates in South Australia, AEMO has identified Roxby Downs for consideration of regional transmission development:

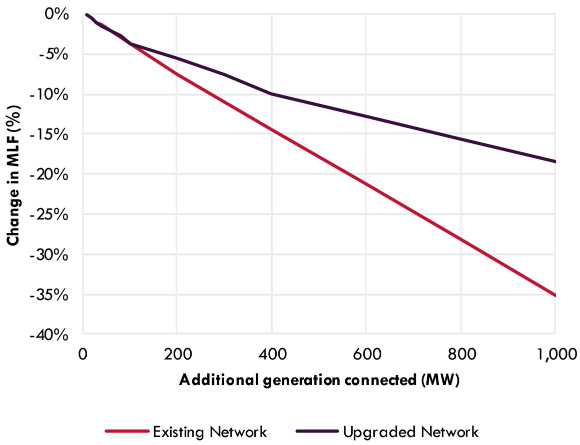
- It has been identified as a priority REZ for solar generation in the medium term.
- It is connected to the shared network by a single-circuit 275 kV transmission line owned by BHP. Recently, OZ Minerals announced that it will establish a new transmission circuit through this area[56]. AEMO recommends that future renewable energy development in Roxby Downs be taken into consideration when considering this transmission line development – for example, by using transmission towers that could accommodate a second circuit at a later date.

[56] OZ Minerals, "OZ Minerals' Power Strategy – Securing current assets, enabling future growth", 9 March 2018, available at https://www.ozminerals.com/uploads/media/180309_OZ_Minerals_power_strategy_ASX_Release.pdf.

- In the longer term, there is spare capacity in the Roxby Downs REZ and planned augmentations would improve MLFs for this REZ, allowing the good solar resource of the REZ to be better exploited. MLF resilience at Roxby Downs is illustrated in Figure 27, including the improvements from a 275 kV network upgrade.

Figure 27 MLF resilience for Mid-North and Northern SA (left), and Roxby Downs (right)





The following table outlines the South Australia REZ candidates, several key metrics, and the modelled indicative timing in the ISP scenarios.

Table 5 South Australia REZ report card*

REZ name	Solar quality	Wind quality	Spare Network capacity (MW)	Network losses †	Priority for generator connections	Network upgrade timing				
						Neutral	Neutral with Storage	Slow	Fast	High DER
South East SA	E	B	500	D		-	>2040	-	>2040	-
Riverland (SA)	C	C	200	E		-	-	-	-	-
Mid North SA	C	B	1,000	C	2	>2040	>2040	-	>2040	>2040
Yorke Peninsula	D	B	50	F (E)		-	-	-	-	-
Northern SA	C	B	1,000	B	1	>2040	>2040	-	2037	>2040
Leigh Creek	A	B	10	F (E)		>2040	>2040	>2040	>2040	>2040
Roxby Downs	A	C	960‡	E (E)	3	2037	2040	>2040	2028	>2040
Eastern Eyre Peninsula	D	B	500₸	F (D)		>2040	>2040	-	>2040	>2040
Western Eyre Peninsula	C	B	0	F (E)		-	-	-	-	-

* In this table, a grading system has been used where "A" represents a very high grade, "F" represents a very poor grade, and "B", "C", "D" and "E" represent intermediate grades.
† Scores shown in brackets indicate the result following a major network upgrade.
‡ Spare network capacity includes a new proposed 275 kV line between Davenport and Mount Gunson.
₸ Spare network capacity includes a proposed replacement of existing 132 kV lines from Cultana to Yadnarie to Port Lincoln with higher rating lines.

4.4.4 Tasmanian REZ assessment

Tasmania is likely to have an energy surplus (that is, Tasmania is projected to be a net exporter of energy) when all the currently committed generator projects in Tasmania proceed to completion. Large-scale development will depend on the development of new high-voltage direct current (HVDC) interconnectors to the mainland (see Appendix D).

AEMO assessed four candidate REZs in Tasmania and identified two for large-scale development of wind farms – North West Tasmania and Tasmania Midlands.

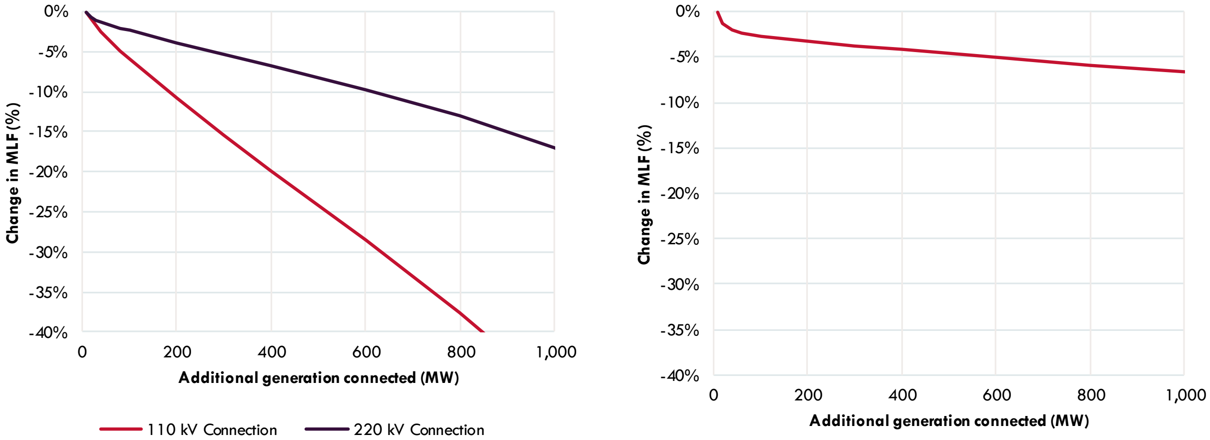
The North West Tasmania REZ:

- Has very high-quality wind resources, and includes locations where pumped hydro resources could be developed.
- Network capacity in this REZ is moderate (approximately 200 MW in the West Coast region), and could be expanded if the MarinusLink project is developed.
- MLFs for generator connections in North West Tasmania are somewhat susceptible to large generation connections – especially for those generators connected through the 110 kV network (see Figure 28).

The Tasmania Midlands REZ:

- Has very high-quality wind resources, and includes locations where pumped hydro resources could be developed.
- Network capacity in this REZ is high (approximately 1,000 MW).
- Is very resilient to changes in MLF due to the geographic and electrical proximity to load centres in Tasmania (see Figure 28).

Figure 28 MLF resilience for North-West Tasmania (left), and Tasmania Midlands (right)



The following table outlines the Tasmania REZ candidates, several key metrics, and the modelled indicative timing in the ISP scenarios.

Table 6 Tasmania REZ report card*

REZ name	Solar quality	Wind quality	Spare Network capacity (MW)	Network losses †	Priority for generator connectio ns	Network upgrade timing				
						Neutral	Neutral with Storage	Slow	Fast	High DER
King Island	E	A	0	N/A		-	-	-	-	-
North East Tasmania	E	A	0	F (C)		-	-	-	-	-
North West Tasmania	E	A	200	E (D)	2‡	>2040	2035	-	2031	-
Tasmania Midlands	E	A	1,000	C	1	>2040	2037	-	>2040	>2040

* In this table, a grading system has been used where "A" represents a very high grade, "F" represents a very poor grade, and "B", "C", "D" and "E" represent intermediate grades.
† Scores shown in brackets indicate the result following a major network upgrade.
‡ If the MarinusLink project is developed, the North West Tasmania REZ becomes favourable due to the proximity to the identified project.

4.4.5 Victorian REZ assessment

Renewable generator connections in Victoria are being driven by high quality wind and solar resources, and a state-based renewable energy target.

AEMO assessed five candidate REZs in Victoria, and recommends one (the Moyne REZ) for large-scale generator connections in the short-term. Proponents of new generation connection should conduct their own due diligence, to understand how technical limitations might influence their connection.

The Moyne REZ:

- Is identified as a short-term priority for wind farm generator connections.
- Can accommodate around 2,000 MW of new generation, and has a strong transmission network connecting it to the major Victorian load centre because it lies on the 500 kV network between Melbourne and the South Australian border.

The Gippsland REZ is also well suited to new generation connection (around 2,000 MW) and MLFs are resilient to change. The onshore renewable resource is of a moderate quality. There is connection interest for around 2,000 MW of off-shore wind power generation in the Gippsland area. Subject to planning approvals and environmental impact assessments, offshore wind farms in this area could be optimal if these can be built economically and with community support.

The generator connection interest in the west and north-west of Victoria already far exceeds the local network capacity. Network augmentation in this area would help alleviate projected network congestion driven by existing and committed generation, and could facilitate the efficient development of renewable energy over the next 20 years.

The analysis has demonstrated that network expansion in the Murray River and Western Victoria REZs is expected to be the most efficient approach.

The Murray River and Western Victoria REZs:

- Have good wind (Western Victoria) and solar (Murray River) resources available.
- Are identified as short-term priority REZ developments. Although there is currently limited capacity to connect new generation, the ISP identifies benefits to upgrading the transmission network in these areas in the short term. The proposed New South Wales to South Australia interconnector (RiverLink) and the major Victoria to New South Wales upgrade (SnowyLink) would aid in the development of these REZs.
- Are being assessed for network development under the Western Victoria Renewable Integration RIT-T[57]. The MLF resilience for Murray River and Western Victoria will depend largely on the preferred solution to this RIT-T. High capacity network options will provide more robust MLFs that will encourage generator connections in the area.

The following table outlines the Victoria REZ candidates, several key metrics, and the modelled indicative timing in the ISP scenarios.

Table 7 Victoria REZ report card*

REZ name	Solar quality	Wind quality	Spare Network capacity (MW)	Network losses	Priority for generator connections	Network upgrade timing				
						Neutral	Neutral with storage	Slow	Fast	High DER
Murray River (VIC)	C	C	300	E	2	2024	2024	2024	2024	2024
Western Victoria	E	A	0	D	3	2025	2024	2025	2020	2025
Moyne	E	B	2,000	C	1	2037	2037	>2040	2032	>2040
Gippsland	E	D	2,000	A		>2040	>2040	>2040	>2040	>2040
Ovens Murray	N/A†	N/A†	300	A		-	-	-	-	-

* In this table, a grading system has been used where "A" represents a very high grade, "F" represents a very poor grade, and "B", "C", "D" and "E" represent intermediate grades.
† The Ovens Murray REZ was identified for potential pumped hydro generation.

[57] AEMO. Western Victoria Renewable Integration RIT-T. Available at: https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/Victorian-transmission-network-service-provider-role/Regulatory-investment-tests-for-transmission.

5. Power system requirements

Key observations

This analysis projects a transition of the NEM over the next two decades to an energy mix with a large amount of technologically and geographically diverse variable renewable generation sources, supported by increased transmission and energy storage solutions.

This transformation requires the adoption of new technologies and approaches to provide the services needed to operate the power system that are currently provided predominantly by thermal generation, including:

- **Voltage control** – Network Service Providers (NSPs) will likely need to install reactive plant to maintain adequate voltage profiles in their networks as minimum demands decline due to the uptake of rooftop PV and energy efficiencies.
- **System strength** – as clusters of non-synchronous generation connect in close proximity, generators will need to offset their impact on system strength and TNSPs will need to ensure a basic level of fault current across their networks. This will drive new system strength investments for generator connections in north Queensland, south-western New South Wales, north-western Victoria, and South Australia.
- **Frequency management** – wind, solar, battery, pumped hydro, and demand-based resources are likely to compete for the provision of a projected increasing need for frequency control ancillary services (FCAS).
- **Power system inertia** – AEMO has identified minimum inertia requirements to operate the power system under rare conditions where the risk of regional network separation is heightened. A minimum inertia requirement has been identified for South Australia, flagging an opportunity to optimise this service with synchronous condensers currently being designed for system strength.
- **Connection standards** – the technical standards applying to new connections need to be kept under review and updated as necessary to ensure security can be maintained as the nature of the power system changes.
- **Dispatchability** – there will be an opportunity for new sources of dispatchable generation. New energy storage developments, at both the utility-scale and aggregated distributed levels, and virtual power plant (VPP) services, such as the one proposed in South Australia, could help support this emerging need.

In preparing the ISP, AEMO has undertaken security-constrained modelling of the power system to assess the resilience and system strength of the resultant plan developments. This section outlines the range of matters considered in developing the ISP. Further work is needed in these areas, and will be undertaken over the next 12 months, to ensure requirements for the ISP are fully understood and implemented.

5.1 Requirements

In March 2018, AEMO published the *Power System Requirements*[58] reference paper, providing a foundation for understanding the technical and operational needs of the power system.

This chapter examines how the fundamental power system requirements, shown in Table 8 below, could be provided as the generation mix transforms over the next two decades.

[58] AEMO, *Power System Requirements*, March 2018, available at https://www.aemo.com.au/Media-Centre/AEMO-publishes-Power-System-Requirements-paper.

Table 8 Power system requirements

	Attribute	Description
Operational prerequisites	Dispatchability of the power system	Ability to manage dispatch and configure power system services to maintain system security and reliability. "Dispatch" refers to the process whereby AEMO issues instructions to generators (and certain loads) to operate at a certain output.
	Predictability of the power system	Ability to: • Measure or derive accurate data on energy demand, power system flows, and generation output across numerous timeframes (real time, hours/days/weeks/years ahead) as key inputs into planning and operational decision-making. • Forecast upcoming power system conditions and have confidence in how the system will perform.
Technical attributes	Resource adequacy and capability	There is a sufficient overall portfolio of energy resources to continuously achieve the real-time balancing of supply and demand.
	Frequency management	Ability to set and maintain system frequency within acceptable limits.
	Voltage management	Ability to maintain voltages on the network within acceptable limits.
	Ability to restore system	Ability to restart and restore the system in the unlikely event of a major supply disruption.

The technical needs of the future power system are delivered through a combination of:

- Power system services, procured from conventional generators and, increasingly, from alternatives including batteries and inverter-based generators.
- Network services.
- The technical performance standards required for new connections to the grid.

The technology to provide many of these power system services from alternatives to conventional generation exists today, and is being demonstrated in the market and through a number of innovative trials underway. Some recent examples that highlight what is happening already in this space include:

- Delivering dispatchable aggregated demand response of 141 MW as part of the Reliability and Emergency Reserve Trader (RERT) provisions and the joint demand response pilot program operated by AEMO and the Australian Renewable Energy Authority (ARENA)[59].
- The Hornsdale Power Reserve Battery Energy Storage System delivering energy arbitrage, reserve energy capacity, network loading ancillary services, and all eight FCAS services, to provide a new competitive source of energy and frequency control in South Australia[60].
- The Dalrymple ESCRI-SA battery project demonstrating how energy storage can strengthen the grid and improve reliability for the lower Yorke Peninsula, by providing FCAS, fast frequency response (FFR), and backup power if connection with the grid is lost[61].
- Demonstrations of wind farms providing FCAS at Hornsdale 2 Wind Farm[62] and Musselroe Wind Farm[63].
- Improving visibility of wind and solar projects through the market participant five-minute self-forecast project, which aims to reduce generation forecast error for variable generation[64].
- Aggregated demand response participation in FCAS markets increasing fivefold since the Ancillary Services Unbundling rule change in 2017, providing new competitive sources of frequency control[65].

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[59] AEMO, *Summer 2017-18 operations review*, May 2018, available at https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Security-and-reliability/Summer-operations-report.

[60] AEMO, *Initial operation of the Hornsdale Power Reserve Battery Energy Storage System*, April 2018, available at https://www.aemo.com.au/Media-Centre/AEMO-Hornsdale-report.

[61] ElectraNet, Dalrymple ESCRA-SA battery project, available at https://www.escri-sa.com.au/.

[62] AEMO. "AEMO and ARENA looking to evolve traditional electricity market", 10 August 2017, available at https://www.aemo.com.au/Media-Centre/AEMO-and-ARENA-looking-to-evolve-traditional-electricity-market.

[63] ARENA, "Tassie wind farm to trial grid stability services", 8 March 2018, available at https://arena.gov.au/news/tassie-wind-farm-trial-grid-stability-services/.

[64] AEMO, Market participant 5-minute self-forecast. Available at https://www.aemo.com.au/Stakeholder-Consultation/Industry-forums-and-working-groups/Other-meetings/Market-Participant-5-Minute-Self-Forecast.

[65] EnerNOC, Submission to the National Energy Guarantee draft design consultation paper. Available at http://www.coagenergycouncil.gov.au/publications/energy-security-board-national-energy-guarantee-consultation-paper.

- Announcement of VPP trials to demonstrate aggregated distributed storage systems as new dispatchable sources of energy, frequency and voltage control services[66,67,68,69].

In developing the ISP, a number of key the technical requirements on the grid have been assessed to ensure the resulting power system will be secure and reliable. Section 5.4 provides further information on the technical attributes required, and outlines some actions which need to be undertaken. Section 5.5 discusses technical standards for plant connecting to the system, and the need to ensure these standards meet both current and evolving future needs and take advantage of future advances in technology.

5.2 Dispatchability and predictability

Dispatchable resources provide the operational levers to manage the power system within its technical limits and continuously match consumer demand with available supply. The dispatchability[70] of a power system refers to the extent to which the output of the overall portfolio of resources in aggregate can be relied on to follow a target, and comprises three key aspects:

- **Controllability** – the ability to manage the output of a sufficient proportion of resources to keep the power system in balance.
- **Firmness** – a measure of the likely energy availability of the resource mix at some time in the future.
- **Flexibility** – a measure of the extent to which aggregate output can be adjusted or committed in or out of service.

The need for dispatchability is closely related to the predictability of the power system. The predictability of the power system relates to the ability to:

- Measure or derive accurate data on energy demand, power system flows, and generation output across numerous timeframes (real time, hours/days/weeks/years ahead) as key inputs into planning and operational decision-making.
- Forecast upcoming power system conditions and have confidence in how the system will perform.

5.2.1 Controllability

As the transition of the power system develops, it is important to consider what firm and flexible resources will deliver reliable power supply in future, and what is the optimal combination of dispatchable and variable resources in the total generation portfolio. Figure 7 in section 3.1.3 shows the projected evolution of the average daily contribution of generation across the NEM, from a mix predominantly of conventionally controllable synchronous generation, to one with portfolios of synchronous and non-synchronous generation and storage.

Figure 29 shows projected annual profiles for the net instantaneous proportion of conventionally controllable resources (that is, resources that are currently classified as scheduled or semi-scheduled) in the aggregate resource mix for the NEM in the Neutral scenario of the NEM.

At times of low demand and high rooftop PV output, the proportion of controllable resources is projected to reduce from about 75% today to as low as 29% by 2038-39. The reduction in dispatchability is primarily due to increasing uptake of distributed rooftop PV.

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66 ARENA, AGL Virtual Power Plant, available at https://arena.gov.au/projects/agl-virtual-power-plant/.

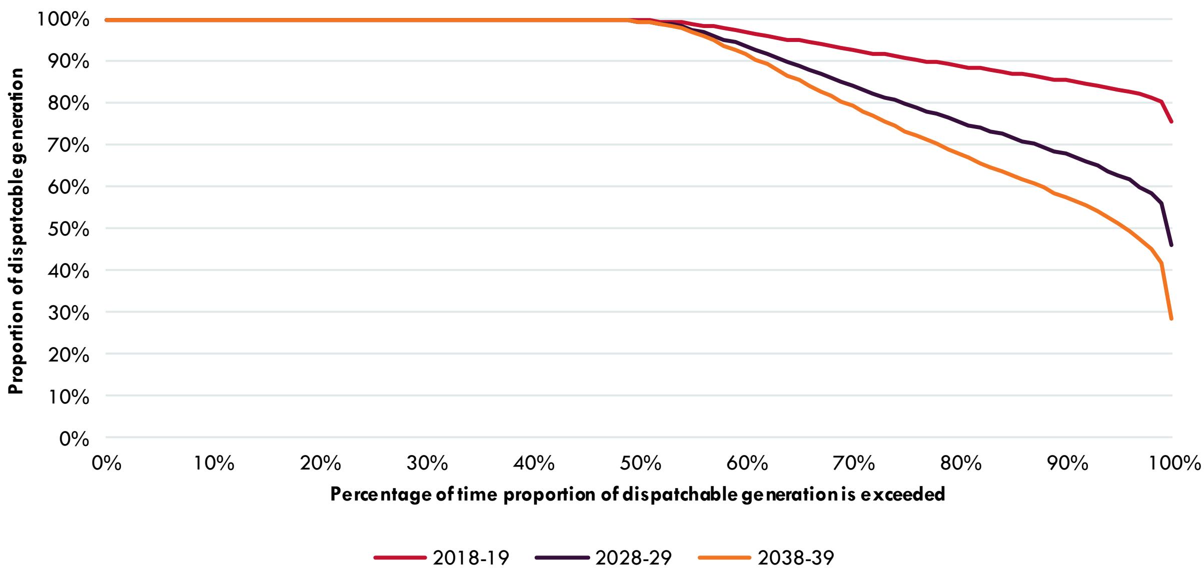
67 ARENA, Simply Energy Virtual Power Plant, available at https://arena.gov.au/projects/simply-energy-virtual-power-plant-vpp/.

68 South Australian Government, Public housing tenants Virtual Power Plant, available at https://www.sa.gov.au/topics/housing/public-and-community-housing/tenants/virtual-power-plant.

69 For information about the CONSORT Bruny Island battery trial, see http://brunybatterytrial.org/.

70 AEMO, *Power System Requirements*, p6, available at https://www.aemo.com.au/-/media/Files/Electricity/NEM/Security_and_Reliability/Power-system-requirements.pdf.

Figure 29 Proportion of conventionally dispatched generation in the NEM, Neutral scenario

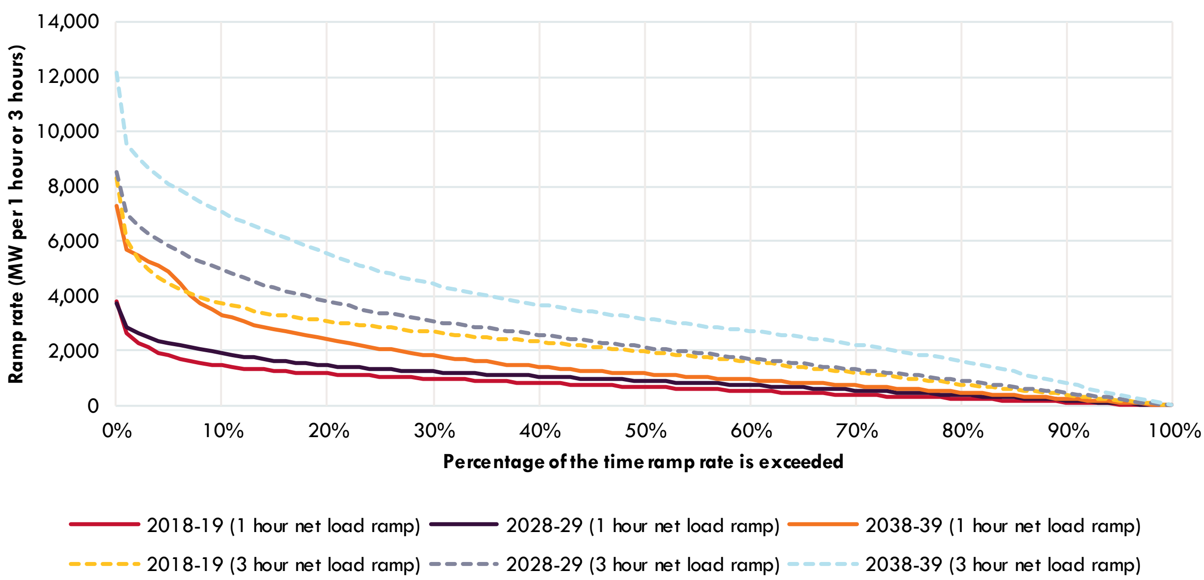


5.2.2 Flexibility

Greater flexibility will be needed in the resource mix to manage the variability associated with increasing penetrations of wind and PV generation. This may drive a need for greater flexibility in the operation of existing baseload generation, and a growing price signal for fast-start generators or batteries (plant that can come online quickly and for short periods). Figure 30 below shows ramp rate duration curves for load less variable generation for South Australia under the Neutral scenario.

Ramp rates are projected to almost double from 2017 to 2025 over the one-hour and three-hour timeframes. Dispatchable resources will have to be more flexible to manage increased variability across multiple dispatch intervals[71].

Figure 30 Projected change in ramp rate over the next 10 years, Neutral scenario



[71] Flexibility within a dispatch interval is considered in Section 5.4.2 on frequency management.

5.2.3 Firmness

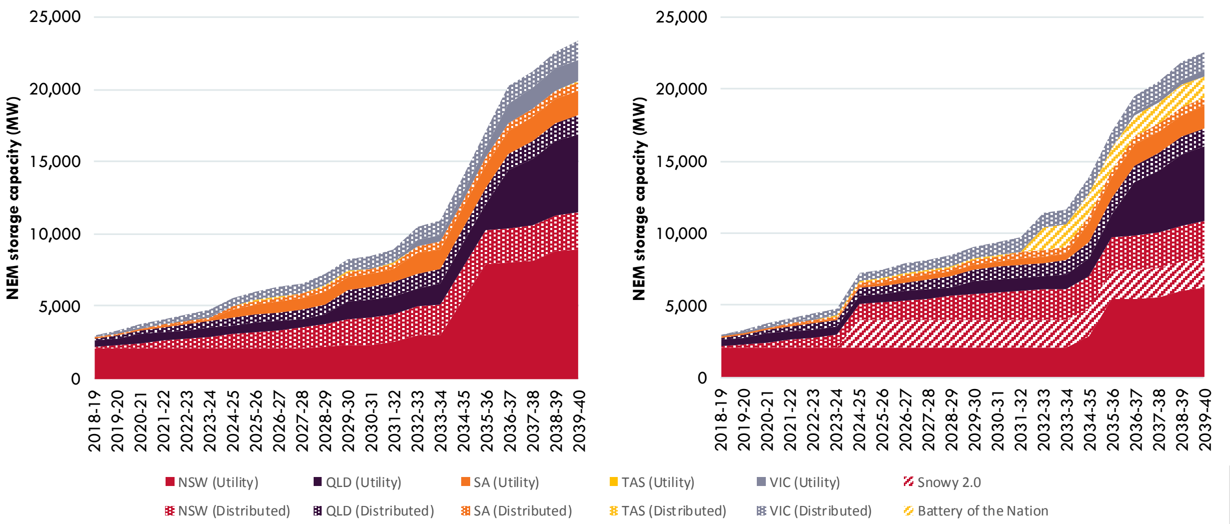
Figure 31 presents the projected development of storage schemes in each of the NEM regions. These schemes are typically located and timed with the projected retirement of thermal coal-fired generation in each of the regions.

Based on power stations reaching the end of technical life, the need for utility-scale storage development begins in the mid-2020s, and rapidly increases by 2035 to 2037 with the expected retirement of coal-fired generators in New South Wales.

In the storage initiatives scenario, the Snowy 2.0 project brings forward the capacity of New South Wales pumped hydro storage, and the Battery of the Nation project results in additional Tasmanian pumped hydro storage.

The connection of new pumped hydro, battery storage (both large-scale and coordinated distributed resources), and fast-start GPG, and further interconnection between regions, will increase the firmness of the generation fleet. However, additional methods of improving dispatchability of the NEM will also need to be developed, including increasing the role of demand-based resources and VPPs.

Figure 31 Projected build of storage for Neutral (left) and Neutral with storage initiatives (right)



5.3 Coordinating DER

There has been rapid growth of DER in the last decade, principally from rooftop PV which passively feeds electricity into the grid. This is projected to continue and be complemented by growth in residential battery storage systems, home energy management systems, and smart appliances, which are examples of active DER that can respond to price or dispatch signals.

Continued development of DER is driven by falling system costs, expected retail price growth, potential tariff reforms (with new opportunities for engaged consumers to benefit from time of use tariffs), and the underlying growth of dwellings. AEMO's modelling forecasts continued uptake of DER, with payback periods for rooftop PV less than seven years for residential systems (up to 10 kilowatts [kW]) and less than five years for commercial systems (10-100 kW).

The growth in DER is expected to present new challenges for grid management, as minimum grid-delivered demand is expected to occur during daylight hours in the next 5 to 10 years, rather than traditional overnight periods when underlying electricity demand is lowest. This is expected to give rise to:

- The need for network planners and operators to effectively integrate these resources into the power system. For example, unless the network is designed for it, high concentrations of passive rooftop PV may otherwise cause voltage variability at the local level, potentially degrading power quality and impacting the lifespan of appliances. At a system level, AEMO will need good visibility of the installation and operation of millions of new DER to continuously optimise supply and demand, and maintain reliability and security.
- Opportunities to deliver a more efficient power system for consumers by delaying or eliminating the need for some network investments and providing competition to utility-scale generators for both energy and system support services, for example by operating aggregated fleets of distributed storage systems.

It will be important to coordinate this DER to realise the potential it could provide to the market and system operations. Enabling DER to respond to both market and network signals could also deliver financial savings to consumers. ENA's 2017 Electricity Network Transformation Roadmap[72], developed with the CSIRO, estimated this potential benefit to be $1.4 billion in avoided network investment and a lowering of household electricity bills by $414 a year. It is, therefore, both economically efficient and necessary for ongoing system security that measures are taken now to enable efficient coordination of DER to participate in the NEM.

In June 2018, AEMO and ENA collaborated to publish a consultation paper (*Open Energy Networks*) on how best to transition to a two-way grid that allows better integration of DER for the benefit of all consumers[73]. This paper outlines some of these challenges and opportunities, and seeks to engage with stakeholders on how best to facilitate large amounts of DER to participate in the energy market frameworks. This partnership is the first of many collaborations that AEMO will undertake as part of a new DER program. The DER program will utilise collaborations and pilot projects to explore and develop sustainable and scalable DER market frameworks and regulatory frameworks, new operational processes, technical standards, and data required to deliver the best outcomes for consumers[74].

The *Open Energy Networks* report included a case study for system security challenges in South Australia, which found:

- From 2021-22, it may be necessary to constrain non-scheduled generation in South Australia in minimum demand periods, if it becomes necessary to reduce flows on interconnectors to zero.
- From 2024-25, it will no longer be possible to reduce flows on interconnectors to zero if required during certain periods. During emergency periods (such as bushfires, severe weather, or forced outages of network components) AEMO must be able to reduce interconnector flows to maintain the power system in a secure state.
- From 2027-28, it will become impossible to maintain flows on the Heywood Interconnector within the required limits during periods where South Australia has a credible risk of separation (planned or unplanned). Planned outages can be scheduled to avoid minimum demand periods, but unplanned outages may occur at any time. This means the South Australian power system will no longer be secure if an unplanned outage occurs at a time of minimum operational demand.
- From 2036-37, it will no longer be possible to maintain flows on the Heywood Interconnector within nominal limits and ±3 hertz a second (Hz/s) Rate of Change of Frequency (RoCoF) limits. Beyond this point, it will become impossible to operate South Australia within secure limits even under system normal conditions, in the absence of intervention.

5.4 Technical attributes

A resilient power system can withstand unexpected disturbances, including generator failures and high impact, low probability events such as interconnector failures. This section discusses the technical attributes of the power system and the essential services needed to maintain them.

5.4.1 Resource adequacy and capability

The provision of resource adequacy as a power system requirement is explored in Chapter 3.

5.4.2 Frequency management

Power system frequency control is achieved by the instantaneous balancing of electricity supply and demand. If electricity supply exceeds demand at an instant in time, power system frequency will increase. Conversely, if electricity demand exceeds supply at an instant in time, power system frequency will decrease. The amount and rate of change of frequency compared to the mismatch in supply-demand depends on the physical characteristics of electrical equipment and control systems.

To operate a power system, the system frequency must be maintained within a close margin around the nominal level of 50 Hertz, and additionally, the RoCoF must remain within tight limits. Failure to do so risks mass disconnection of consumers and equipment, or even potential equipment damage. A standard known as the frequency operating standard (FOS)[75] defines the frequency ranges within which the NEM should operate during normal conditions and following contingency events. These frequency operating standards define the design requirements. AEMO currently procures FCAS via eight co-optimised markets to manage this balancing in the NEM.

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[72] Electricity Networks Australia. Electricity Network Transformation Roadmap, available at https://www.energynetworks.com.au/electricity-network-transformation-roadmap.

[73] AEMO and Energy Networks Australia, 2018. *Open Energy Networks consultation paper*, available at https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/DER-program.

[74] AEMO, *Distributed Energy Resources Program*, available at https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/DER-program.

[75] AEMC, Frequency operating standard, available at https://www.aemc.gov.au/sites/default/files/content/c2716a96-e099-441d-9e46-8ac05d36f5a7/REL0065-The-Frequency-Operating-Standard-stage-one-final-for-publi.pdf.

Additionally, synchronous generators (such as large coal-fired, gas, hydro, and solar thermal generators), are a source of inertia in the power system. The inertia of synchronous generators inherently resists changes in frequency, reducing the RoCoF and allowing time for FCAS to bring frequency within the required range.

Much of the renewable generation currently projected to be developed is non-synchronous and therefore does not provide inertia. As conventional, synchronous, fossil-fuelled generation is replaced with non-synchronous generation, overall system inertia is reduced, increasing the risk of higher RoCoF and frequency disturbances outside the limits specified in the FOS.

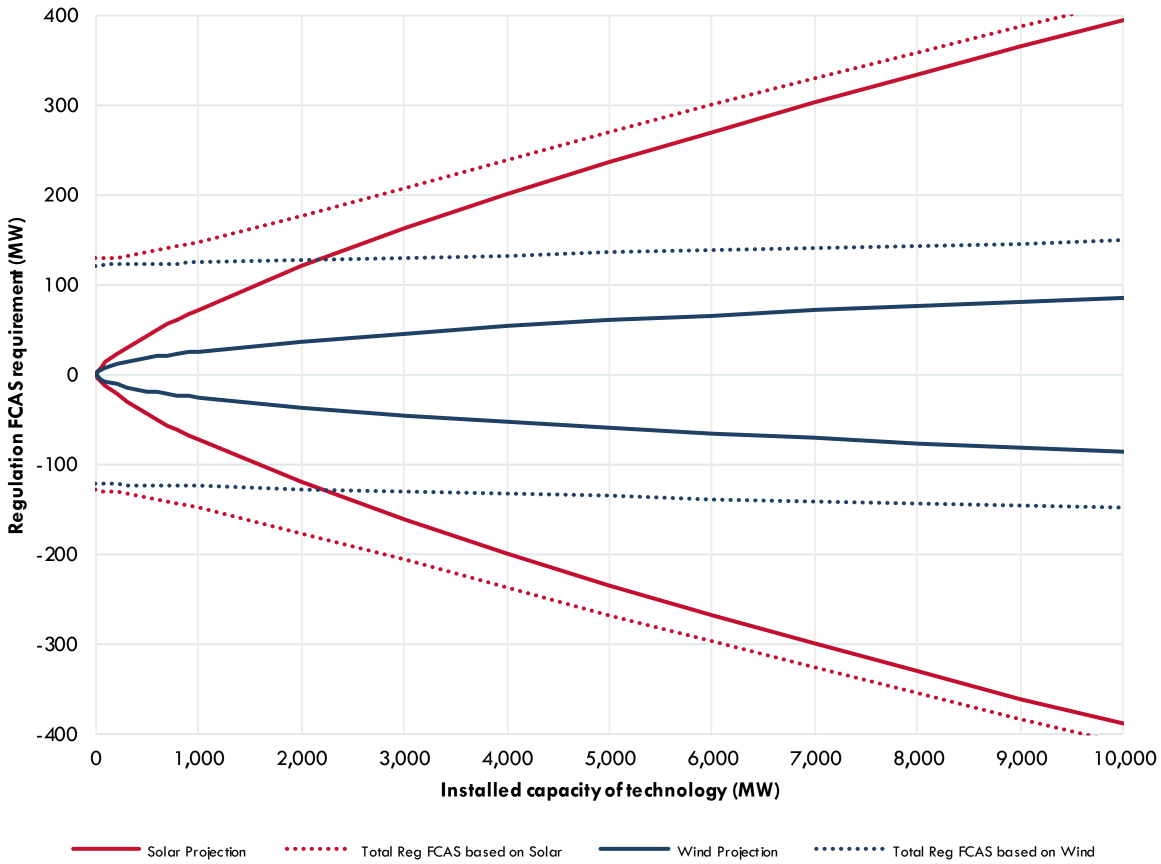
This means opportunities may arise for inertia or inertia-like services:

- Frequency control services will need to be increasingly sourced from non-traditional sources (for example, from battery storage systems, demand-based resources, and renewable generation).
- The need for frequency control services may increase as a result of decreasing inertia, and increasing volatility in the load to be met by dispatchable resources resulting from high penetrations of DER and variable renewable generation, along with changing end-user behaviours.

Sourcing frequency control ancillary services (FCAS)

Analysis by AEMO suggests that the projected major increases in utility-scale solar generation, particularly when clustered in REZ, are expected to drive significant increases in the required amount of frequency control services. Unless resources are commissioned that can provide these services at a lower per unit cost, this is expected to result in increasing ancillary services costs. Figure 32 below draws from analysis conducted under AEMO's Future Power System Security (FPSS) program[76], and shows how the amount of regulation FCAS (one of the key frequency control services) required relates to the penetration of utility-scale solar generation and, to a lesser degree, wind generation.

Figure 32 Projected FCAS requirements for increasing penetration of solar and wind generation



To demonstrate the changing availability of resources that currently offer substantial frequency control services, AEMO has estimated the number of synchronous units of different types that might be expected to be online during

[76] AEMO, *Anticipating and Addressing Security Challenges in an Evolving Power System*, available at https://www.aemo.com.au/-/media/Files/Electricity/NEM/Security_and_Reliability/Reports/2017/FPSS-2017-01-27a.pdf.

the course of a typical day, using data from the Neutral scenario (Figure 33 and Figure 34 below). Synchronous units tend to carry headroom as normal practice, which is one key reason why they have traditionally provided most frequency control services.

The analysis shows that there is likely to be a significant reduction in the number of synchronous units online, particularly during peak sunlight hours in the middle of the day. This suggests a reduction in the availability of frequency control capability during these times, and highlights a growing opportunity for non-traditional providers such as storage technologies and demand-based resources, as well as solar and wind farms. Hornsdale Wind Farm 2, the Hornsdale power reserve, and various demand-side providers are demonstrating that non-traditional sources can provide high quality FCAS capability.

Figure 33 Number of units online during a typical day – Neutral scenario – all units (left), coal units (right)

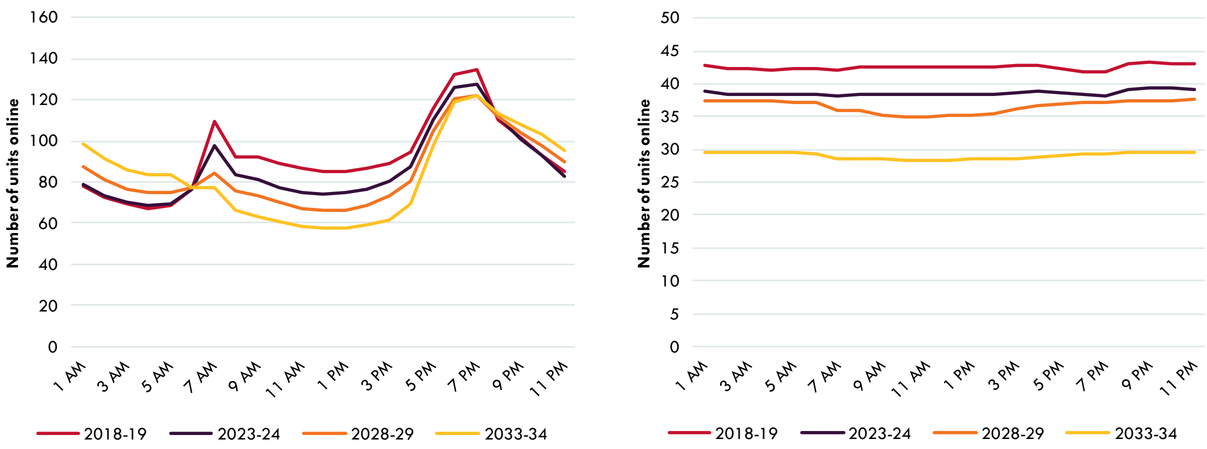
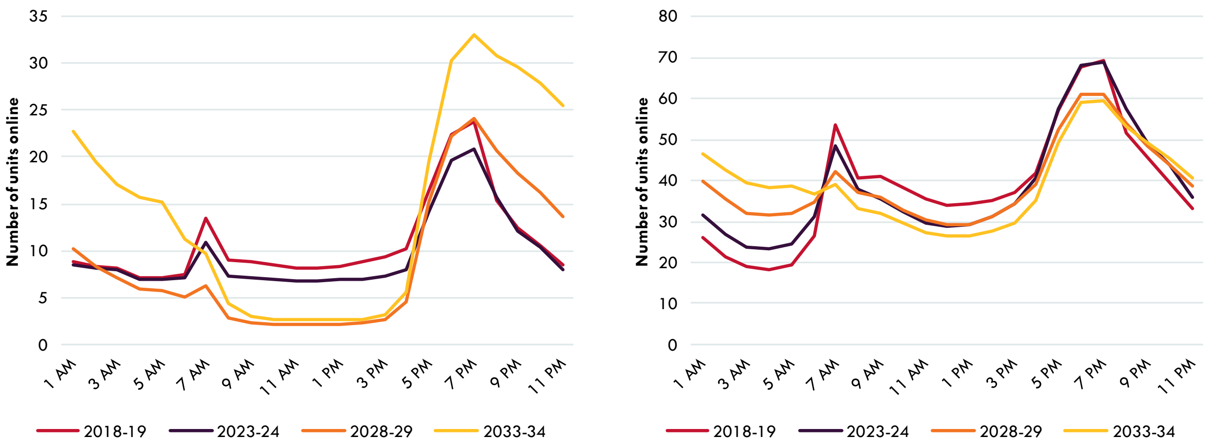


Figure 34 Number of units online during a typical day – Neutral scenario – gas units (left), hydro units (right)



FCAS is usually sourced globally, and the entire mainland is treated as a single frequency area. However, this approach does not work well with weakly interconnected regions and very high penetrations of variable renewable energy resources as it increases unscheduled power flows between regions. These situations require more headroom on interconnector transfer limits. Local challenges are projected to emerge in South Australia and then Queensland. These challenges can be deferred through interconnector upgrades recommended in this ISP.

It is evident that there are emerging opportunities for new FCAS providers and that transmission augmentation particularly between regions will play a significant role in this. To assist with this transition, AEMO has recently conducted two reviews:

- 2018 Power System Frequency Risk Review (PSFRR)[77].
- Inertia Requirements Methodology, 2018 Inertia Requirements and Shortfalls[78].

Additionally, in 2018 AEMO will review the Market Ancillary Service Specification.

The 2018 PSFRR reviewed power system frequency risks associated with non-credible contingency events across the NEM. It made recommendations including modifying two existing emergency frequency control schemes, declaring a protected event in South Australia for certain weather conditions, and an AEMO-Powerlink joint study into managing Queensland over-frequency risk.

The impact of declining inertia

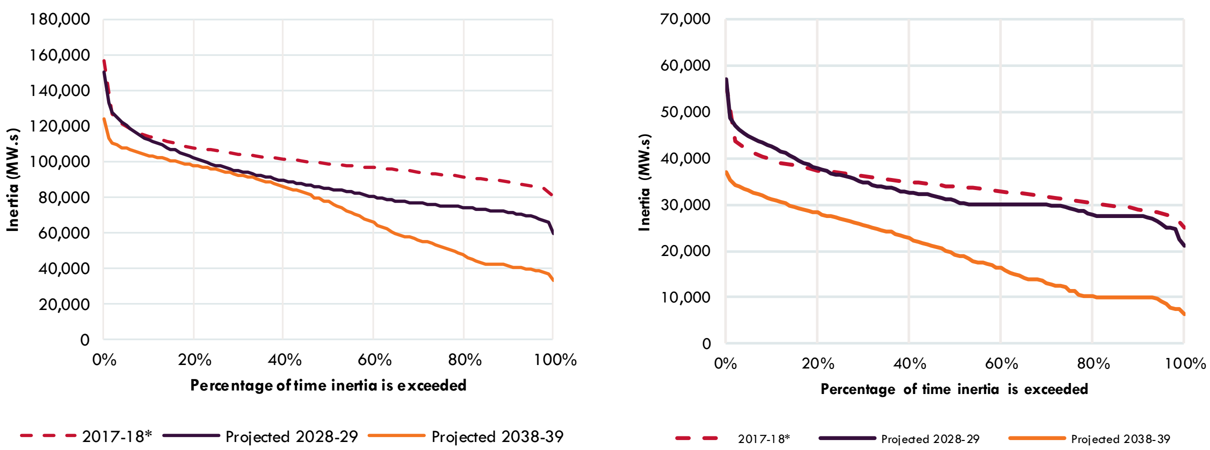
AEMO's report on Inertia Requirements and Shortfalls determined two inertia levels for each NEM region that must be available for dispatch when a region is at credible risk of being islanded:

- The Minimum Threshold Level of Inertia is the minimum level of inertia required to operate an islanded region in a satisfactory operating state.
- The Secure Operating Level of Inertia (SOLI) is the minimum level of inertia required to operate the islanded region in a secure operating state.

The 2018 Inertia Requirements and Shortfalls review found that, under conditions where a region is electrically islanded, or at risk of islanding, there are currently not any shortfalls in any NEM region.

The Neutral with storage initiatives case projects retirement of some synchronous generators in New South Wales, Victoria and Queensland out to 2040. This will reduce the amount of inertia available in these regions. It is important to emphasise that the 2018 SOLI values are subject to change in future years[79], for example, the actual SOLI will be dependent on levels of fast-acting frequency control available in these regions. Figure 35 to Figure 37 provide an indication of the inertia typically online within each region in the NEM.

Figure 35 Inertia projections, Neutral scenario, for the NEM (left) and New South Wales (right)



[77] AEMO. 2018 Power System Frequency Risk Review Final Report, June 2018, available at https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/Power-System-Frequency-Risk-Review.

[78] AEMO. Inertia Requirements, 2018 Inertia Requirements and Shortfalls, available at http://energylive.aemo.com.au/-/media/Files/Electricity/NEM/Security_and_Reliability/System-Security-Market-Frameworks-Review/2018/Inertia_Requirements_Methodology_PUBLISHED.pdf.

[79] AEMO will review inertia requirements and publish inertia shortfalls in future National Transmission Network Development Plans (NTNDPs).

Figure 36 Inertia projections, Neutral scenario, for Queensland (left) and South Australia (right)

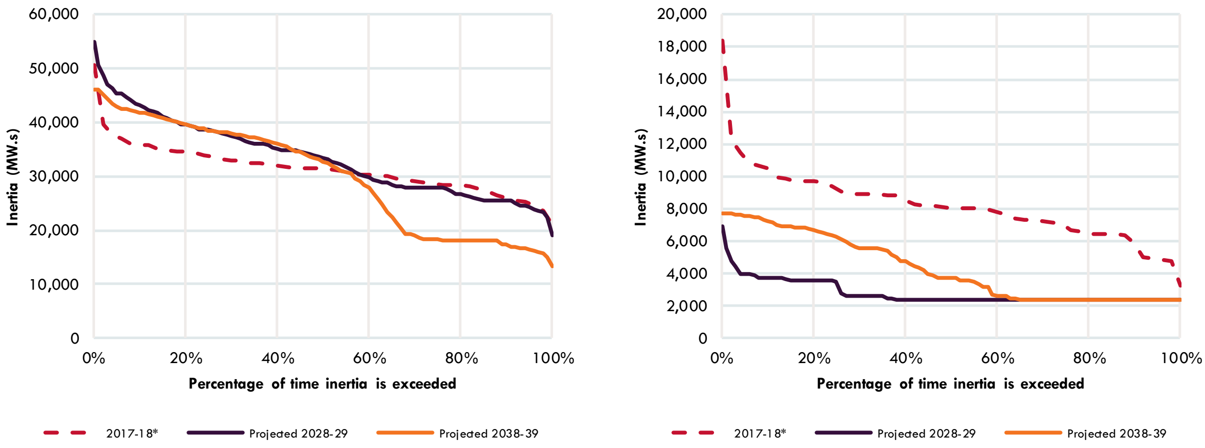
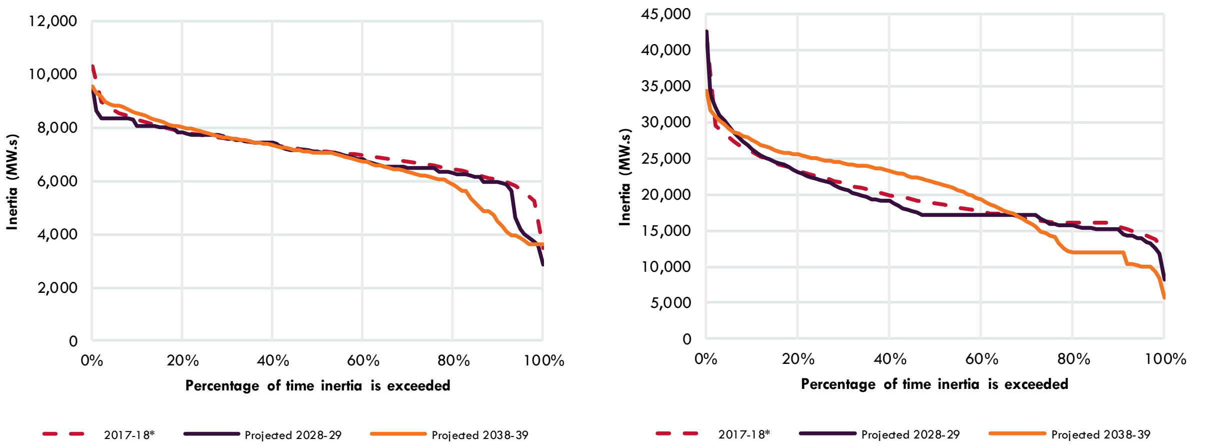


Figure 37 Inertia projections, Neutral scenario, for Tasmania (left) and Victoria (right)



* Historic data for the 2017-18 curves based on the period 1 July 2017 to 1 June 2018.

Before 2028-29, South Australia could require remedial action to maintain appropriate levels of inertia within acceptable requirements. The reduction in typical levels of inertia in the South Australia region is as a result of reduced dispatch of synchronous gas plant due to system strength requirements being met by newly installed synchronous condensers[80], and RiverLink enabling access to lower-cost generation in the New South Wales region. While the inertia available in the South Australian region reduces, it should also be noted that the risk of islanding of the South Australian network will be greatly reduced with RiverLink in place. Remedial actions include, but are not limited to:

- Installation of new inertia from synchronous condensers.
- Contracts to provide inertia from synchronous plant that may otherwise not be economically available to generate.
- Increased availability of fast frequency response (FFR).

The minimum inertia level within a region required to maintain power system security is dependent on the quantity of fast acting frequency control services available, and the speed of these services. Currently, elevated levels of 6-second FCAS are used to compensate for low inertia situations, however as lower levels of inertia are experienced, the 6-second FCAS may no longer be adequate. New services, often termed fast frequency response (FFR), that can deliver response in shorter timeframes, may be required.

5.4.3 Voltage management

Voltage management refers to the ability to maintain voltages on the network within acceptable limits. Traditionally, planning voltage management focussed on providing a combination of slow and fast response voltage control across

[80] ElectraNet, *Strengthening South Australia's Power System*, available at https://www.electranet.com.au/what-we-do/projects/power-system-strength/.

the network. Now, with the increasing penetration of non-synchronous generation (such as wind and solar), planning for system strength has emerged as an important aspect of voltage management. Minimum demands are projected to decrease with increasing rooftop PV uptake and improved energy efficiency. Decreasing minimum demands are projected to drive a need for more reactive plant to maintain acceptable voltage profiles.

System strength

System strength is a measure of the ability of a power system to remain stable under normal conditions and to return to a steady state condition following a system disturbance, and affects the stability and dynamics of generator control systems.

The increasing integration of inverter-based generation in the NEM has additional implications for the engineering design of the future transmission system.

System strength can be considered low in areas with low levels of local synchronous generation, and deteriorates further with high penetration of non-synchronous generation. These systems exhibit deeper voltage dips and slower voltage recovery over a wider area of the network following a fault, switching event, or change in load or generation. Low system strength can lead to different instability problems or adverse interactions. These range from local connection power instability to wider network issues, potentially impacting a range of power system components including synchronous and non-synchronous plant, protection systems, and dynamic reactive devices.

Implications of low system strength

- **Steady state voltage management** – in systems with low system strength, greater deviations in voltages occur due to disturbances. Larger voltage step changes can occur with the switching in/out of reactive devices which could breach system standards. A lack of reactive capability due to reduced synchronous plant online can lead to difficulty in maintaining secure operating voltages. For example, high voltages can occur during light load periods.
- **Voltage dip** – in a weak network area, voltage dips are deeper, more widespread, and can last longer than in a strong network. For example, the transient voltage dip resulting from a short circuit event will be more severe, more widespread, and slower to recover in a weak system than in a strong system. This condition will generally last until the network fault is cleared by protection systems.
- **Fault ride-through** – the ability of generators to maintain stable operation following a fault is an important aspect of power system security. Non-synchronous generation has minimum fault level requirements – if they are not met, then their associated control systems cannot be relied upon to operate in a stable manner. Also, during a network fault, non-synchronous generators tend to reduce their active power generation and supply reactive power. In a weak system, where the impact of the network fault is widespread, a large amount of non-synchronous generation can enter fault ride-through during the brief period before a fault is isolated, resulting in a power imbalance.
- **Power quality** – for the same consumer demand, voltage harmonics and imbalance are higher in weak systems than in strong systems. This can result in large over-voltages lasting for several seconds, potentially exceeding the withstand capability of local generation. Because synchronous generators dampen harmonics and voltage imbalance, displacement of synchronous generators with inverter-connected generation diminishes power quality.
- **Operation of protection** – the trend of decreasing system strength will result in fault current being reduced, which makes it more difficult for protection systems to detect and isolate faults, and can also result in higher likelihood of protection maloperation[81].

The ISP generation outlook for the Neutral scenario to 2040 projects a reduction of around 16 GW of synchronous plant, and the connection of 38 GW of large-scale inverter connected generation, not including rooftop PV. This displacement of synchronous generation is projected to greatly reduce system strength across the NEM, as shown in Figure 38 below. The area of the biggest expected change is where a high concentration of inverter-connected plant such as wind and utility-scale PV is expected. Modelling shows that many renewable developments contemplated in the 2020s are likely to require some level of system strength remediation for their connection, and from the 2030s onwards most renewable developments would be expected to require system strength remediation.

AEMO has performed a high-level assessment to locate areas where system strength is an existing or emerging challenge. An area of the grid is generally considered weak if the short circuit ratio (SCR) drops below three[82]. For this assessment, the weighted[83] SCR was calculated for possible connections to determine network strength.

Figure 38 shows the results of this assessment, for years 2018-19, 2028-29, and 2038-39 of the Neutral scenario.

81 Protection maloperation can result in additional generation tripping during power system disturbances, loss of load due to maloperation of network equipment, and public safety risks if faults are not cleared.

82 Y Zhang, S Huang, J Schmall, J Conto, J Billo, E Rehman, "Evaluating System Strength for Large-Scale Wind Plant Integration", PES General Meeting | Conference & Exposition, 2014 IEEE.

83 Weighted SCR takes into account the interaction between inverter-connected generation on the SCR.

Currently, as the 2018-19 results demonstrate, there is low system strength at the fringes of the grid, particularly in north Queensland, south-west New South Wales (including Broken Hill), north-western Victoria, and South Australia. The SCR in these areas is low due to the relative lack of synchronous generation, and the development of non-synchronous generation (such as wind and solar). The ISP projects further increase of non-synchronous generation and retirement of synchronous generation which could further weaken system strength. The analysis for 2028-29 indicates, that without remediation as part of the development of these zones:

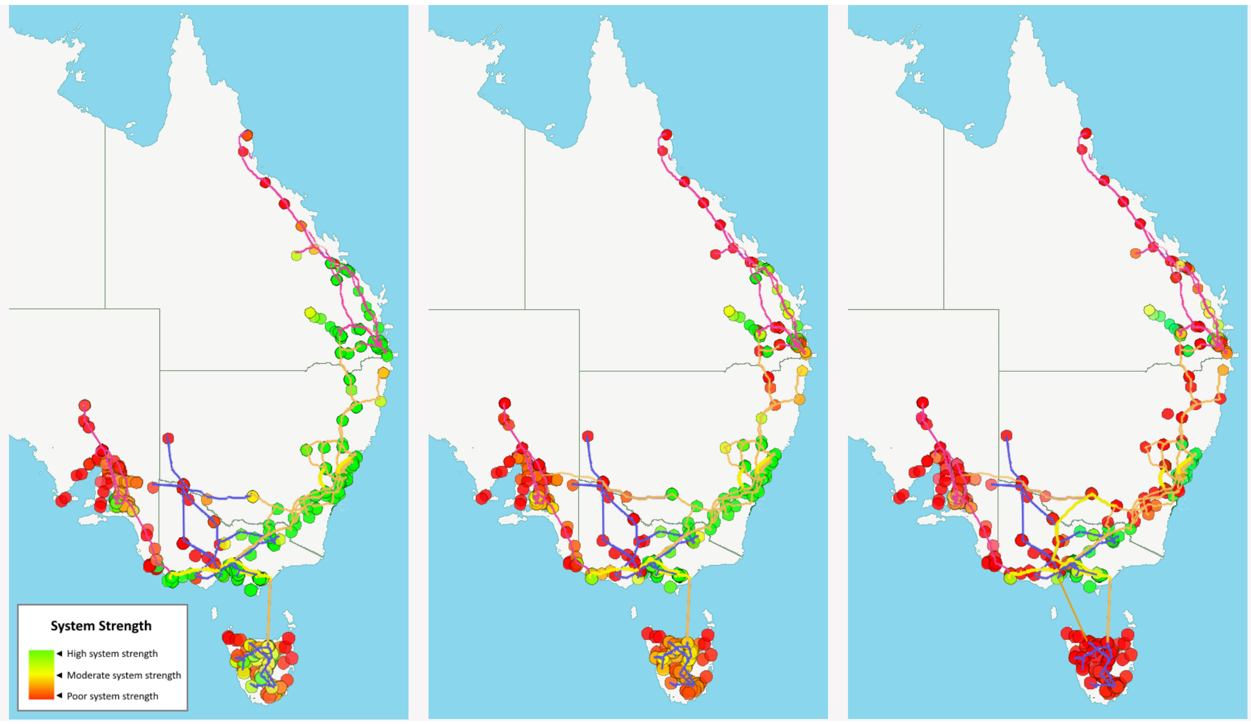
- Retirement of Liddell and Vales Point power stations is projected to decrease system strength in northern NSW, particularly for the North West New South Wales and Northern New South Wales Tableland REZs.
- Development of renewable generation is projected to decrease system strength in the Darling Downs, Moyne, North West Tasmania, and Tasmania Midlands REZs.

System strength is a local phenomenon. Fault currents vary around the grid both by location and by voltage level. Fault levels generally must be supplied locally within an identified weak network. Solutions to improve system strength include synchronous condensers, synchronous generators, and non-synchronous generation with grid-forming converters.

Some combination of these remedial measures will be required as part of the renewable energy development. New non-synchronous generation developments in areas with low system strength are also likely to be required to adopt some of these mitigation strategies.

Following further development of renewable generation and retirement of synchronous generation, most REZs with high quality renewable resources are projected to have low system strength unless remediation steps are taken. System strength remediation is also expected to be needed to allow sufficient renewable generation connection to fulfil the potential of REZs. Clustering of renewable generation in a REZ could provide an important opportunity for the local TNSP to take steps to most efficiently and economically address system strength issues over the development of the REZ area, rather than connection by connection. In the absence of improving system strength across a REZ, renewable generator capabilities and protection design could need to be updated to accommodate further decreases in system strength in some areas of the network.

Figure 38 Projected system strength assessments for 2018-19 (left), 2028-29 (middle), and 2038-39 (right)



Cost of addressing system strength

Since system strength is localised and varies across the network, the exact requirements to improve system strength will depend heavily on the network characteristics at that location. For example, some existing wind farms have been required to install small synchronous condensers to increase local system strength. A coordinated approach that allows renewable generators to contribute towards system strength for a REZ will be more economic than developing system strength solutions at individual wind and solar farms.

As an approximate guide, a 150 MW wind farm connecting in a weak area of the network could require around 30 megavolt amperes reactive (MVAr) of synchronous condenser support, at an approximate cost of $5 million to $10 million. As there are many factors that could influence system strength mitigation requirements and costs, generator proponents should conduct their own due diligence and discuss the topic with the relevant Network Service Provider (NSP) when considering connecting a generator in a low system strength area.

AEMO has published finalised guidelines with regards to system strength and mitigation requirements for new generation connections[84].

TNSPs are also required to maintain minimum fault levels at specified nodes within their networks. Should a shortfall be identified by AEMO, the TNSP must procure system strength services to maintain the fault levels determined by AEMO. AEMO has published methodologies and assessments relating to TNSP responsibilities in maintaining minimum fault levels at specific fault level nodes[85].

Fault level shortfall in South Australia

AEMO identified an NSCAS gap in South Australia for system strength in the 2016 NTNDP[86], and confirmed this gap in subsequent updates in September 2017[87] and October 2017[88]. ElectraNet has elected to treat this NSCAS gap as a 'fault level shortfall' under the transitional arrangements for the AEMC's Managing power system fault levels Rule change determination[89].

Improving system strength in South Australia will improve power system stability and resilience, and enable non-synchronous generation (like wind and solar) to be efficiently dispatched.

Decreasing minimum demand and the increasing reliance on line switching to control high voltages

Operationally, the practice of switching out extra high voltage (EHV) transmission lines for short-term management of over-voltages under low demand conditions is only sparingly used. Inherent risks of EHV line switching involve the operation and life expectancy of circuit breakers, and power system resilience. These are recognised by all TNSPs.

The number of times EHV lines/cables have been switched for voltage control to date has been relatively low in all NEM regions, with the exception in Victoria following the retirement of Hazelwood Power Station, which withdrew a major source of reactive power absorption as well as reducing network loading. Over the over the past 12 months, line switching for voltage control has not been undertaken in New South Wales and Tasmania, has occurred on 10 occasions in Queensland and South Australia, and has occurred on 40 occasions in Victoria. In response, AEMO has already initiated a RIT-T in Victoria to determine the most efficient way to suppress high voltages across the Victorian transmission network[90].

Decreasing minimum demands are projected to continue to drive higher voltages and require additional investment in reactive plant to maintain acceptable voltage profiles and keep voltages below the safe and acceptable levels. TNSPs should identify the long-time reactive power requirements in their regions due to changes of generation mix, and where needed, initiate RIT-Ts to mitigate the relevant risks associated with the potential reactive power shortfalls.

5.4.4 System restoration

AEMO procures system restart ancillary services (SRAS) in each region according to the AEMC Reliability Panel's system restart standard (SRS)[91], through a competitive tender process. This process is designed to procure SRAS at the least-cost combination of submissions, and considers a number of parameters, specifically aggregate reliability, which includes individual (generation system restart equipment) reliability, transmission reliability, strategic location, geographic location, and fuel diversity of SRAS, as well as principles AEMO needs to consider when developing boundaries of sub-networks.

Currently, SRAS services are only supplied by synchronous generators, as they are the only technology that has been proven in providing "grid forming" services in large power systems. Grid forming is the ability of the power system to set and maintain power system characteristics such as voltage and frequency.

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84 AEMO. System Strength Impact Assessment Guidelines, available at http://aemo.com.au/Electricity/National-Electricity-Market-NEM/Security-and-reliability/System-Strength-Impact-Assessment-Guidelines.

85 AEMO. System Strength Requirements Methodology, 2018 System Strength Requirements & Fault Level Shortfalls, available at: http://aemo.com.au/Electricity/National-Electricity-Market-NEM/Security-and-reliability/System-Security-Market-Frameworks-Review.

86 AEMO, 2016 *National Transmission Network Development Plan*, December 2016, available at http://www.aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/NTNDP/2016/Dec/2016-NATIONAL-TRANSMISSION-NETWORK-DEVELOPMENT-PLAN.pdf.

87 Update to the 2016 NTNDP, September 2017, available at https://www.aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/NTNDP/2017/2016-NATIONAL-TRANSMISSION-NETWORK-DEVELOPMENT-PLAN.pdf.

88 Second update to the 2016 NTNDP, October 2017, available at https://www.aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/NTNDP/2017/Second_Update_to_the_2016_NTNDP.pdf.

89 For information and documents about this AEMC Rule change, see http://www.aemc.gov.au/Rule-Changes/Managing-power-system-fault-levels.

90 AEMO, Victorian Reactive Power Support RIT-T, May 2018, available at https://www.aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/Victorian_Transmission/2018/Victorian-reactive-power-support-RIT-T-PSCR.pdf.

91 For information and documents related to this AEMC review, see http://www.aemc.gov.au/Markets-Reviews-Advice/System-Restart-Standard.

As synchronous generators retire, as outlined in Section 3.1.1, the pool of current SRAS providers will shrink without the introduction of new plant capable of proving grid forming services. Critical areas of potential SRAS shortfalls include northern New South Wales and central Queensland. Under the Neutral scenario, by 2036 all major large synchronous generators in northern New South Wales, except the Colongra gas turbines, are projected to be retired, and by 2039, all major large synchronous generators in central Queensland, except Callide C, are projected to be retired.

New system restart services can be provided by pumped hydro synchronous generators which have already demonstrated grid forming capability. SRAS may also be potentially provided by non-synchronous plant, including wind, solar, and batteries, fitted with grid forming inverters. A grid forming inverter essentially gives non-synchronous generators the same characteristics as a synchronous generator except that it does not provide rotating inertia.

5.5 Need for future-focused technical standards

As the penetration of intermittent renewable generation increases, it is critical to ensure the NEM generation fleet is equipped with the capabilities it needs to provide a secure and resilient power supply for the life of the assets.

Any generating unit installed today is likely to remain in service for at least the next 20 years. In future, it will be necessary for the power system to have versatility to maintain a full suite of power system services under diverse conditions, including:

- Increasing periods where less synchronous generation is dispatched.
- Periods where no synchronous generation would be economically dispatched within a region.
- Periods of low, zero, or negative operational demand due to increasing volumes of generation within the distribution network.
- Periods when the supply mix rapidly ramps between synchronous and non-synchronous generation.

In these circumstances, it is necessary and prudent to put in place engineering-led technical standards that have regard to the current and future technical characteristics of the generation mix.

Historically, new connecting synchronous plant inherently delivered the system security services required to support the power system over the lifetime of the asset. This assumption no longer holds true, so performance standards delivered from plant connecting today need to consider foreseeable power system operating scenarios.

Technological improvements over the last decade mean modern plant often includes additional functionality that can help to stabilise the power system, even though most system security services have not been an inherent characteristic of non-synchronous generators in the past. In many cases, it is possible to take advantage of technological developments that provide additional capability at low or zero additional cost.

The current NEM-wide generator technical standards lag behind those applied overseas. More rigorous technical standards apply in South Australia through licence provisions of the Essential Services Commission of South Australia (ESCOSA), and these have not stifled investment in that state. AEMO's rule change proposal to update the NEM's generator technical standards and deliver the capabilities required, both today and into the future, is currently undergoing consultation by the AEMC. Going forward, AEMO will undertake regular reviews of the technical standards and consult with the AEMC on required changes to take advantage of technological advances.

The capabilities of non-synchronous generators are rapidly evolving. The regulatory framework for setting technical standards should be sufficiently flexible to enable the NEM to benefit from modern technical advances. If the technical standards applied at the time of connection are not forward-looking, it may be necessary to put in place more costly alternative solutions in the future, such as additional network infrastructure and/or generator refits.

In the interests of technology neutrality, generator technical standards should apply consistently to all generation types above a given size threshold, unless there are technical reasons why it is unreasonable to apply the standard to a particular technology.

6. Integrated development plan for the NEM power system

Key observations

Immediate needs:

- Immediate low-cost developments have been identified that will reduce impending congestion and provide consumers access to low-cost resources. Without this action, the current rate of connection of new renewable generation will cause congestion and raise security issues in parts of the grid.
- These actions also allow more efficient use and operation of existing generation resources as part of the overall portfolio. Together, these actions will reduce overall costs on any scenario and better support the economic retention of existing resources.

Longer-term needs:

- When existing coal-fired generation reaches the end of its technical life and retires, the most cost-effective replacement, based on current cost projections, is forecast to be a portfolio of utility-scale renewable generation, storage, DER, flexible thermal capacity, and transmission.
- There is a substantial and growing need for energy storage over the plan period to increase the flexibility and firmness of the grid (firmness is a measure of the likely energy availability of the resource mix at some time in the future).

The role of transmission in minimising the cost of supply:

- The transmission network will play a critical role in the transformation of the power system, providing an interconnected energy highway that allows diverse resources to be shared across the NEM more efficiently.
- Increased investment in an interconnected grid provides the flexibility, security, and economic efficiency associated with a power system designed to take maximum advantage of existing resources, integrate variable renewable energy, and support efficient competitive alternatives for consumers.
- The projected portfolio of new resources involves substantial amounts of less energy intensive renewable generation that is geographically dispersed, resulting in a much larger network footprint with transmission investment needed to efficiently connect and share these low fuel cost resources. This will also place a greater reliance on the role of the transmission network.
- Transmission investments will be necessary not only to secure greater geographic diversity of weather dependent resources but also to manage the risk of anticipated but uncontrollable climate effects such as bushfires, droughts (both water and wind) and long duration high heat periods. AEMO will consult and report on the development of a more robust risk management approach to system planning and resilience, including criteria for future investments, in future plans.
- While the modelling of all scenarios showed the need for storage, one scenario implemented Snowy 2.0 in 2025 and Tasmania Hydro pumped storage scheme in 2033 as a specific project path to install large-scale energy storage. These projects require specific transmission development which is shown in the 'Base development plan with storage initiatives'. AEMO will continue to work with project proponents on a design for transmission networks to support these storage initiatives.
- The value of the recommended investment in the grid has been quantified by comparing total costs of supply with the identified transmission against a 'no new interconnection' option. In the modelled case without a more strongly interconnected grid, consumer demand was projected to be met, but through more costly investment in generation and storage, and greater use of GPG. This analysis projects that without further network development, consumers would pay more for energy.

- AEMO estimates that the additional transmission investment proposed in the ISP would deliver net market benefits of around $1.2 billion on a net present value (NPV)[92] basis, compared to the case where no new transmission is built to increase network capabilities between regions (in the modelled Neutral case). The new inter-regional transmission more than pays for itself through efficient investment in, and use of, generation and storage across the NEM. There are other important benefits associated with the plan that are not quantified in the modelling, including benefits arising as a result of enhanced competition and improved power system resilience.
- The benefits of a more strongly connected grid extend beyond NPV savings in resource costs, to include the following:
  - A more interconnected grid supports increased competition across regional boundaries.
  - The analysis also demonstrates that greater interconnection would improve the power system's resilience to be able to manage unexpected events, such as unexpected exits of coal- and gas-powered generation. As a next step, AEMO will do further work to evaluate ways to mitigate against risk of generating plant exiting early due to catastrophic failure. This includes quantifying the benefits of advancing identified longer-term transmission developments in future plans.
  - Transmission investments are also necessary to secure greater geographic diversity on the system and help manage the risk of anticipated but uncontrollable climate effects such as bushfires, droughts (both water and wind), and long duration high heat periods. AEMO will consult and report on the development of a more robust risk management approach to system planning and resilience, including criteria for future investments, in future plans.
- The analysis supports an immediate upgrade of the national network, and a forward plan of efficient network investment over the next 20 years. These investments would provide immediate benefits to consumers by improving reliability and increasing wholesale market competition across the NEM, putting downward pressure on electricity bills.

Renewable energy zones:

- The existing transmission network provides the capability to efficiently connect significant amounts of renewable generation. The ISP has identified a number of highly valued REZ across the NEM with good access to existing transmission capacity. Early development of these zones could minimise costs and more efficiently support the range of work needed for implementation, and AEMO will continue working with project proponents.
- To connect renewable projects beyond the current transmission capacity, further action will be required. The assessment considers how to best develop REZ in the future that are optimised with necessary transmission developments, identifying indicative timing and staging that will best coordinate the REZ development with identified transmission developments to reduce overall costs.
- The Murray River and Western Victoria REZs are experiencing significant committed renewable development, with large amounts of additional generation expected to be operational in the near term. There are currently Regulatory Investment Tests for Transmission (RIT-Ts) underway to assess the transmission developments to support committed renewable developments in these REZ to reduce the cost of congestion and provide consumers with access to low-cost power.

The impact of DER on the development of the integrated grid:

- All scenarios in the ISP project a growing proportion of supply will come from DER. This is consistent with observed trends, where residential, industrial, and commercial consumers are investing in rooftop PV at the highest rate ever, and there is increasing interest in battery storage and load management.
- The High DER scenario shows the potential for even greater use of DER to lower the total costs to supply, with the NPV of wholesale resource costs reduced by nearly $4 billion, compared to the Neutral case. In this scenario, the projected need for utility-scale investment and intra-regional transmission development to provide access to the incremental REZs is reduced, however it still illustrates the need for greater increased national transmission capacity to take advantage of diversity and better utilise dispatchable resources.

[92] The present value of a future cash flow represents its worth right now. The Net Present Value (NPV) is the sum of the present values of all future cash flows (both positive and negative). The NPV is commonly used in cost-benefit analysis to assess the economic impacts of policies and projects.

This chapter assesses and outlines an appropriate course for the efficient development of the power system over the next 20 years, under a range of futures. The overall strategy for development of the power system is a combination of new transmission, storage, and generation, and must:

- Maintain energy security.
- Provide efficient transmission of power from generation hubs to load centres and facilitate competition between generators.
- Balance reliability, generation cost, network cost, and emissions abatement targets.

In developing the ISP, AEMO has considered the latest *Electricity Statement of Opportunities* (ESOO), *Gas Statement of Opportunities* (GSOO), TNSP revenue determinations and Annual Planning Reports, and historical transmission utilisation and performance.

6.1 The need for a strategic plan for transmission

The need for transmission development in the future will be primarily driven by the changing generation mix and retirement of coal-fired generators, rather than by growing demand. As the existing fleet of coal-fired generation reaches end of technical life and retires, the energy it currently provides will need to be replaced by new generation, either within the region from which the generation exited, or from neighbouring regions. Given the relatively lower projected costs assumed in AEMO's modelling[93], this analysis projects that the new replacement generation capacity is likely to be renewable energy.

The replacement generation will comprise a range of technically and geographically diverse variable renewable generation sources. Transmission networks in the NEM, designed for transporting energy from coal- and gas-powered generation centres, would need to transform if they are to support large-scale development of non-synchronous generation in new areas. At the same time, optimisation of the existing assets and any new development requirements will be vital to achieving lower-cost solutions for reliability.

The increase in renewable energy will drive a need for an integrated, portfolio approach incorporating:

- **Interconnection** – to efficiently share resources and services between regions, reducing the need for local reserves and taking advantage of regional supply and demand diversity.
- **Energy storage** – to provide firming capacity and flexibility of supply for regional reliability.
- **Flexible generation** – to support peak demand and provide supply during prolonged periods of low wind or solar energy.

Following consultation[94], the ISP analysis considered a wide range of interconnector upgrade options between NEM regions. The full list of upgrade options developed in conjunction with the TNSPs is outlined in the ISP assumptions[95]. AEMO reviewed each of the upgrade options from a system security perspective, and developed preliminary network constraints to support modelling. The prospective upgrades developed for modelling were also examined for their impacts on the resilience of the grid.

The modelling approach outlined in Figure 3 (Section 2.6) was then applied, to determine which upgrade options were part of the solution which delivered the lowest NPV resource cost. The modelling was constrained to ensure the solution would provide secure and reliable power supply to customers.

This analysis shows that increasing interconnection would be economic under all scenarios considered, in part as it supports the projected development of large amounts of alternative lower-cost energy sources (mainly renewable generation and storage) across the NEM. Additionally, increased interconnection provides the advantages of reduced reliance on localised supplies for reserves, increases transfer capability and therefore trading between regions, and improves competition and market access across region boundaries.

To verify the benefits of proposed inter-regional transmission development, AEMO's analysis compared a future without inter-regional transmission development to a range of efficient transmission development pathways. This analysis projected that without further network development, consumers would pay more for energy.

[93] Refer to Section 2.4 for information on the assumed trajectory of generation technology costs.

[94] AEMO, *Integrated System Plan Consultation*, December 2017, available at https://www.aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/ISP/2017/Integrated-System-Plan-Consultation.pdf.

[95] AEMO, *Integrated System Plan Assumptions Workbook*, June 2018, available at https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/Integrated-System-Plan.

6.2 Planning the transmission system for weather events

Weather has always had a strong influence on the planning of power systems, because weather is a strong driver of peak demands for energy for cooling or heating, and this determines the capacity requirements of transmission, as well as reliability requirements for supply. Power system infrastructure is designed to withstand the extremes of weather, and the capacity of networks to transmit power is designed for managing contingencies and expected ranges of ambient temperatures that the infrastructure will experience.

The power system will need to prepare for increased frequency and scale of more extreme weather-related events[96].

Strategic system planning

With the recent trend of generators connecting on the fringes of the grid, it will be increasingly important to consider the changing climate. For example, generation connecting in areas prone to extreme temperatures may be de-rated during the hottest days of the year, when they are needed most (see Appendix B).

As noted, the NEM is one of the longest power systems in the world, with regions only sparsely connected by major transmission lines.

The analysis in this plan has included a preliminary assessment of the climate risk resilience of the power system, including siting and diversification of generation and transmission corridors. This is an area which has not previously received much attention in Australia, and is seen as particularly relevant given that many assets considered in this analysis will remain in service for 60 to 80 years.

This approach is supported by the AEMC, whose review of extreme weather said that "planning processes should consider the impact of long-term trends in the climate"[97]. Climate change risk has been recognised by the Australian Prudential Regulation Authority (APRA) as "foreseeable, material and actionable now"[98]. Protecting the integrity of energy infrastructure against damage from extreme weather and climate, and future climate change, was also a key recommendation of the Finkel Review[99]. Similarly, Australia's Commonwealth Home Affairs Department has recognised the increased national cost of weather- and climate-related natural disasters in establishing the National Resilience Taskforce to improve Australia's resilience through disaster risk reduction and mitigation reforms[100].

Climate Change in Australia (a partnership between CSIRO and the Bureau of Meteorology [BOM]) currently projects an increase in the frequency and nature of some forms of extreme weather. For example, the frequency, intensity, and duration of heatwaves is projected to increase, and this would likely lead to an intensification of compound extreme events. Details on this are provided in Appendix B.

Extreme weather events can have a significant influence on the reliability of the power system, if not taken into account when designing infrastructure and planning the power system. As the hottest days get hotter, and heatwaves become more prolonged, the risks to supply increase. The combination of more frequent extreme weather-related regional disruption to the network, and the increasing reliance on weather-dependent renewable generation, makes geographic and technical supply diversity much more desirable to mitigate risks of supply interruption.

Planning the grid to withstand more extreme weather events requires a multi-pronged strategy, involving a combination of integrated planning, improved asset design and management, and disaster recovery to address vulnerabilities. This will influence the design, location, and rating of future infrastructure and, more particularly, has strong implications for any future transmission developments.

For example, previous transmission plans have often focused on multiple power lines running side-by-side through wide easements to deliver the lowest-cost option under normal conditions. However, the risks and impacts on supply reliability from more extreme compounded weather-related events, as now projected by BOM and CSIRO for the future in the NEM regions, need to be factored into future planning. Alternate routes offering diversity may provide greater climate risk resilience. The additional costs can be offset by optimal route selection that leverages the ability to provide access to diverse renewable generation sources when selecting a route that passes through prospective rich renewable areas, reducing reliance on any one weather-dependent supply source in one area, while providing better

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[96] This analysis has considered the impacts of long-term climate trends on the design and future planning of the grid using projections made available through the Climate Change in Australia website (https://www.climatechangeinaustralia.gov.au/en/) and close collaboration with the BOM and CSIRO. Historical occurrences of fires in Australia were also provided by LANCE FIRMS operated by the NASA/GSFC/Earth Science Data on NASA's "Earthdata" website96. Details on this analysis and supporting data are provided in Appendix B.

[97] AEMC. *Review of the Effectiveness of NEM Security and Reliability Arrangements in light of Extreme Weather Events*, available at https://www.aemc.gov.au/sites/default/files/content/6bc855c4-b77a-4188-ae56-95fbf0938edb/Final-Report-no-appendices.pdf.

[98] APRA. Speech, "Australia's new horizon: Climate change challenges and prudential risk", 17 February 2017, available at https://www.apra.gov.au/media-centre/speeches/australias-new-horizon-climate-change-challenges-and-prudential-risk.

[99]Department of the Environment and Energy. *Independent review into the Future Security of the National* Electricity *market – the Blueprint at a glance*, available at https://www.energy.gov.au/sites/g/files/net3411/f/independent-review-future-nem-blueprint-recommendations-2017_1.pdf.

[100] Commonwealth Minister for Law Enforcement and Cyber Security, media release, "Reforms to reduce impact of natural disasters in Australia", 10 April 2018, available at http://minister.homeaffairs.gov.au/angustaylor/Pages/reforms-to-reduce-impact-of-natural-disasters-in-australia.aspx.

redundancy in main transmission corridors. AEMO will be undertaking more work with BOM and CSIRO on the potential future risks from projected weather changes, particularly when assessing any transmission developments.

6.3 The 20-year integrated system plan

After studying a range of scenarios in this analysis, AEMO has consistently found strong signals for development of a combination of interconnector upgrades. This consistency demonstrates that AEMO's recommended NEM development plans are expected to be robust to a wide range of uncertainties, including:

- High uptake of DER by consumers.
- Fast and slow change projections, with different rates of economic growth, costs of storage, and gas prices.
- Unexpected early exit of existing generation.

The outcome of this analysis is AEMO's recommendation on two base development plans for the NEM:

1. A Base development plan which was found to be optimal under all scenarios studied.
2. A modified Base plan, Base development with storage initiatives, that accommodates specific proposed energy storage initiatives (Snowy 2.0 and Battery of the Nation)[101], and again is optimal under all scenarios studied.

The ISP projects that these development pathways would deliver the lowest-cost, most reliable power system that supports emissions abatements while meeting the need for system security, reliability, flexibility and resilience. AEMO will expand its analysis of power system resilience in future ISPs.

The development pathway is recommended as delivering economic benefits under all scenarios, although timings and some elements vary under different assumptions, particularly relating to the rate of change and the progress of proposed major storage initiatives. All timings in the plan are indicative only.

ISP modelling indicates a large need for renewable energy and energy storage to replace coal-fired generation as it retires. The ISP considers how recently announced storage initiatives might support this emerging long-term need, although AEMO acknowledges other innovative solutions are also likely to be available over time. Specifically, the ISP network plan can adapt to efficiently support development of the Snowy 2.0 and Tasmanian Battery of the Nation proposals.

The two alternate pathways represent an economic staged grid development, with and without the Snowy 2.0 and Battery of the Nation storage initiatives proceeding. While different, the two pathways share many elements. AEMO understands that a final decision to go ahead with the Snowy 2.0 project is likely before the end of 2018, and this will resolve much of the difference between the two alternate development pathways. When a final decision is made on the commitment of Snowy 2.0, a new link from Tumut to Bannaby ("SnowyLink North") and associated works between Bannaby and Sydney West are projected to provide benefits from the mid-2020s.

In the longer term, in anticipation of significant retirements of coal-fired generation, strengthening interconnection between Victoria and New South Wales (SnowyLink) and between Victoria and Tasmania (MarinusLink) could improve resource sharing across the NEM and deliver fuel cost savings. Both would also facilitate connection of new REZs:

- SnowyLink provides route diversity to harden the grid against future climate change risks, and unlocks high quality renewable energy resources, reducing connection costs for new renewable generation needed once the majority of the coal fleet retires. Without this interconnection, AEMO's modelling indicates that more balancing services (such as GPG or energy storage) would be required to address the lack of diversity that arises from concentrating renewable generation in clusters. This link can be delivered in two stages – a north component ("SnowyLink North") connecting Snowy 2.0 to Sydney, followed by a south component ("SnowyLink South") that enhances interconnection between Victoria and New South Wales (see Appendix D).
- MarinusLink facilitates development of Tasmania as either one or multiple REZs and would be beneficial if further renewable generation development in Tasmania delivers the potential value highlighted by Stage 1 Battery of the Nation studies. While MarinusLink does not form part of the ISP under all scenarios, this assessment is based on preliminary information available to AEMO, and warrants further review as new information is obtained.

AEMO has shown developments in groups 1, 2, and 3, based on based on the timing of the need and the scale and time to construct, taking advantage of any time available to refine each element. Supporting REZ development is a core component of all three groups, throughout the outlook period. See Chapter 4 for more information on REZ assessments.

While indicative timings are provided, based on ISP modelling and assumptions, the timing of requirements and benefits will vary depending on the timing of events in the NEM, particularly when and where coal-fired generation withdraws and new generation and storage resources are built.

[101] The Base with storage initiatives plan assumes Snowy 2.0 is in service in 2025, and MarinusLink in 2033.

While just-in-time investment may be least-cost with perfect foresight, uncertainties around timing of coal-fired generation retirements may be better managed and power system resilience improved by advancing the timing of longer-term grid development. There remains time to refine the projects outlined in the longer term under this plan, although this is limited by the lead times for more extensive proposals. The plan outlines further work, and AEMO will continue to engage with industry, government, and other stakeholders to refine the longer-term plan.

6.3.1 Group 1 – near-term construction to maximise the economic use of existing resources

The NEM is currently experiencing strong growth in the connection of new renewable generation, driven by falling costs and targets set by federal and state governments. This rate of new connections is continuing and will lead to increasing congestion in parts of the power system in the near term, without immediate action.

Immediate action is required to maximise the economic use of existing low-cost generation. Investment is also required to facilitate the development of projected new renewable resources to replace retired and retiring resources, and to provide essential system security.

To enable these benefits, the ISP identifies two relatively minor transmission augmentations that would increase New South Wales' transfer capacity from Victoria and Queensland by 360 MW in total, and transfer capability from New South Wales to Queensland by 460 MW, providing immediate reliability and economic benefits[102] by increasing competitive alternatives to consumers.

The identified transmission developments are projected to benefit consumers in all regions, by making better use of existing investments and creating greater market opportunities for new investment, including any required and planned new local generation capacity in New South Wales.

These minor transmission upgrades will save on total system costs by improving productive efficiencies. In the absence of strong operational demand growth, greater interconnection across the NEM would increase efficient utilisation of existing and committed resources, reducing reliance on higher-cost GPG, allowing coal-fired generators to operate within more efficient ranges, and providing immediate benefits to consumers by relieving network congestion.

In conjunction with these network upgrades, the ISP identifies the need for synchronous condensers in South Australia to supply both system strength and inertia to the region. This is essential now, and will continue to be needed after the proposed RiverLink interconnector (the new South Australia to New South Wales interconnector discussed in Group 2) is developed to allow the most cost-effective use of South Australia's local generation.

The REZs already developing in western Victoria and north-western Victoria warrant transmission investment to improve access to renewable generators in this area. Reducing congestion increases and diversifies the supply of renewable energy to the market, and improves productive efficiency from existing assets.

AEMO recommends that these network investments be progressed as soon as possible, because of the identified benefits they provide immediately, and the support they deliver to achieve the highest consumer economic and system security and reliability benefits over a range of plausible futures as part of a cohesive development pathway.

Group 1 developments are outlined in Figure 39.

Group 1 – immediate investment in transmission should be undertaken, with completion as soon as practicable, to:

- *Increase transfer capacity between Victoria, NSW and Queensland as follows:*
  - *Increase Victorian transfer capacity to New South Wales by 170 MW.*
  - *Increase Queensland transfer capacity to New South Wales by 190 MW.*
  - *Increase New South Wales transfer capacity to Queensland by 460 MW.*
- *Access renewable energy in western and north-western Victoria.*
- *Remedy system strength in South Australia.*

In the Base plan, these initial transmission developments for Group 1 are costed at between $450 million and $650 million, and the assets will continue to benefit consumers well beyond the 20-year ISP forecast period.

[102] In the first week of June 2018, New South Wales experienced reserve shortages due to an unforeseen combination of generation outages coinciding with low wind and solar conditions. A 360 MW increase in New South Wales' import capacity would have resolved these Lack of Reserve (LOR) 2 conditions.

Figure 39 Group 1 integrated development plan map

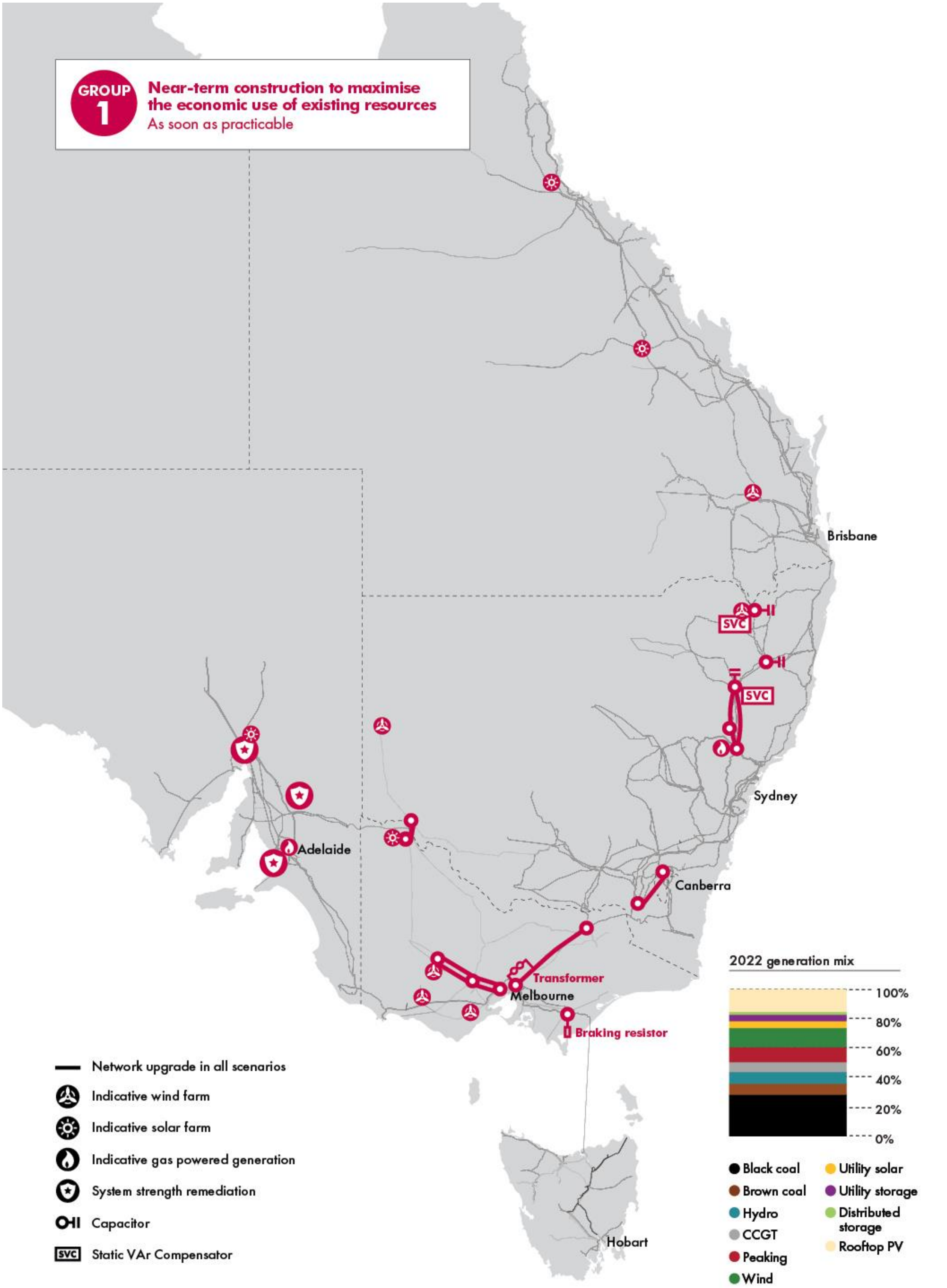

Table 9 Group 1 transmission development details

Network upgrade	Details	Benefits†	Indicative timing
Minor NSW to QLD upgrade	Increase in transfer capacity from Queensland to New South Wales by 190 MW. Increase in transfer capacity from New South Wales to Queensland by 460 MW.	Reliability/capital deferral	2020
Minor VIC to NSW upgrade	Increase in transfer capacity from Victoria to New South Wales by 170 MW.	Reliability/capital deferral	2020
SA system strength remediation	System strength remediation to support system security when GPG is displaced by renewable energy	Fuel costs & capital deferral	2020
Transmission augmentation to access renewable energy in Western Victoria	Capacity increase for renewable generation in western Victoria	Fuel costs & capital deferral	2023
Transmission augmentation to access renewable energy in North-Western Victoria (Murray River REZ)	Capacity increase for renewable generation in north-western Victoria	Fuel costs & capital deferral	2024

† Reliability and capital deferral benefits are reported together here because a reliability need can be met through capital investment in flexible generation.

Minor upgrades between Queensland, Victoria and New South Wales

In the short term, AEMO recommends incremental upgrades to the existing Queensland to New South Wales and Victoria to New South Wales interconnectors:

- These upgrades could reduce the scale of new GPG capacity in New South Wales, and support the projected supply reduction in the region when Liddell Power Station retires in 2022.
- Additional flexible generation in New South Wales may still be required to complement interconnector upgrades and support reliability after Liddell retires. AEMO will consider this in the 2018 ESOO, to be published in August 2018.
- These upgrades would also increase transfer capacity from New South Wales to Queensland, increasing system flexibility and allowing more efficient sharing of generation resources between these regions.
- Refer to Section 6.3.7 for information on the net market benefits projected to be realised from this upgrade in conjunction with the wider ISP network development plan.
- Refer to Appendix D for more details on the proposed upgrades. AEMO recommends that jurisdictional planners consider a range of options and staging when conducting RIT-Ts to incrementally upgrade these interconnectors.

Transmission developments to access renewable energy in Victoria

AEMO is currently undertaking a RIT-T[103] for transmission development in western Victoria for committed and anticipated new renewable generation development in these areas. Subject to approval of the RIT-T[104], major stages of transmission development would be needed in western and north-western Victoria for the significant amount of new renewable generation development projected in these areas.

This would involve a major upgrades of transmission capacity in stages:

- Between Horsham to Ballarat to Sydenham by 2024 to support large-scale renewable generation development (mainly wind).
- Between Red Cliffs and Buronga linked with the proposed new RiverLink interconnector (indicatively 2022 to 2024) to support large-scale renewable generation development (mainly solar), providing increased transfer capacity from Victoria to New South Wales via the RiverLink interconnector.
- Developments within Victoria aligned with the future development of SnowyLink South (indicatively 2035 – part of Group 3), that support large-scale renewable developments of wind and solar across Victoria's western and north-western regions.

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[103] AEMO. Western Victoria Renewable Integration RIT-T. Available at: https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/Victorian-transmission-network-service-provider-role/Regulatory-investment-tests-for-transmission.

[104] AEMO. Western Victoria Renewable Integration RIT-T. Available at: https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/Victorian-transmission-network-service-provider-role/Regulatory-investment-tests-for-transmission.

Improving system strength in South Australia

In December 2016, AEMO published its 2016 NTNDP[105]. This report included an assessment of whether further NSCAS are required in the next five years. In this assessment, AEMO identified an NSCAS gap to provide system strength in South Australia. ElectraNet has agreed to meet this gap[106] under the new fault level shortfall framework[107]. This fault level shortfall:

- Requires the provision of system strength services, including fault current, for areas of South Australia with high non-synchronous penetration levels.
- Is required for maintaining power system security.
- Exists today, and is required for the remainder of the current five-year NSCAS planning horizon (until 1 July 2021) and beyond.

AEMO is collaborating with ElectraNet to validate the technical capability of any proposed solutions to ensure power system security. ElectraNet plans to deliver a solution to improve system strength in South Australia within the next 18-24 months. This solution will help to support high levels of renewable generation in South Australia.

6.3.2 Group 2 – developments in the medium term to enhance trade between regions, provide access to storage, and support extensive development of REZs

Group 2 developments look towards the mid-2020s, preparing for the withdrawal of Liddell in 2022, supporting renewable energy targets, and lowering costs. Retirement of the coal-fired generation fleet requires major investment to replace. Based on the analysis undertaken, the lowest-cost solution is a mix of renewable generation, storage, and some flexible GPG.

The proposed initiatives in this group are of a larger scale and cost than those in Group 1, and require longer lead times to design and develop. Work needs to commence immediately on refining the requirements, finalising the design, and establishing implementation processes and plans for developments in this group, to support the lowest-cost outcomes for consumers. AEMO notes that the ESB is undertaking a review on how to best integrate the ISP with the regulatory approval processes, and suggests that these type of significant and necessary projects are suitable for consideration in this process.

A new generation mix based on renewables is shown to be lower-cost than new coal-fired generation, however, while existing generators still operate, they can generate at lower costs. The developments in this group also support the efficient operation of existing coal- and gas-fired generation in the NEM as the proportion of renewable generation, both at consumers' premises and grid-connected, continues to grow.

Australia has high quality renewable resources in a broad range of locations. As a result, the REZ developments identified in the ISP do not conform to the stereotype of long network extensions to remote locations. Over the coming decade, renewable generators are encouraged to connect in areas with existing transmission capacity.

The ISP shows that an interconnected energy highway would provide better use of renewable resources across the NEM, through both access to lower-cost resources and realising the benefits of diversity from different resources in different locations with different generation profiles. It also facilitates better use of the less flexible thermal (coal- and gas-fired) generation, which, through enhanced interconnectivity, can more efficiently meet the operational demand net of renewable generation.

To maintain reliability, there is a need to ensure the dispatchability of this future energy mix. AEMO expects a strong role for energy storage devices that can shift renewable energy production at scale and provide capacity firming support during peak load conditions.

Once existing spare transmission capacity has been fully utilised, REZs can be accommodated through coordinated development of shared network infrastructure. To this end, the ISP interconnector development plan has been optimised, with a plan to augment REZs across the NEM.

Route selection is critical – cost savings available if interconnectors pass through identified REZs can further alleviate the need for intra-regional network extensions to remote locations. A view to future climate risk resilience will also influence route selection, with projected increases in extreme weather events and bushfires increasing the value of route diversity.

To support the flexibility and system security required of this future energy mix, the ISP shows a strong role for energy storage that can shift renewable energy production at scale and provide firming support as well as system security. The ISP examines how federal and state government-supported large-scale hydro and battery storage investments will support this emerging long-term need. Specifically, while AEMO acknowledges that alternative solutions may be

[105] AEMO. 2016 National Transmission Network Development Plan. Available at: http://www.aemo.com.au/Electricity/NationalElectricity-Market-NEM/Planning-and-forecasting/National-Transmission-Network-Development-Plan.

[106] ElectraNet, Strengthening South Australia's Power System, available at https://www.electranet.com.au/what-we-do/projects/power-system-strength/.

[107] AEMC, Managing Power System Fault Levels, available at https://www.aemc.gov.au/rule-changes/managing-power-system-fault-levels.

available in the future, the plan identifies that increases in interstate energy interchange to take advantage of location diversity, coupled with large-scale storage and flexible gas generation, are essential components of a system that relies on significant levels of variable, zero-fuel cost (and hence low marginal cost) renewable energy.

To accomplish this, the model demonstrates the economic value of network investment to efficiently support development of the Snowy 2.0 and Battery of the Nation proposals.

AEMO understands that a final decision to go ahead with the Snowy 2.0 project is likely before the end of 2018. When a final decision is made on the commitment of Snowy 2.0, a new link from Tumut to Bannaby ("SnowyLink North") and associated works between Bannaby and Sydney West would provide benefits from the mid-2020s. AEMO also understands that there is a desire to progress the Battery of the Nation initiative, which would provide additional pumped hydro storage in Tasmania for use across the NEM. Further information on the performance and costs of this proposed project will become available soon.

AEMO will work with project proponents to refine the timing of the commissioning of these projects and requisite transmission investment for energy delivery. The relevant transmission developments are:

- SnowyLink – provides route diversity to harden the grid against extreme climate conditions, and unlocks high quality renewable energy resources, reducing connection costs for new renewable generation needed once the majority of the coal fleet retires. Without this interconnection, AEMO's modelling indicates that more balancing services (such as GPG or energy storage) would be required to address the lack of diversity that arises from concentrating renewable generation in clusters.
- MarinusLink – facilitates development of Tasmania as either one or multiple REZs. This would be beneficial if further renewable generation development in Tasmania delivers the potential value highlighted by Battery of the Nation studies[108]. While MarinusLink does not form part of the ISP under all scenarios, this assessment is based on preliminary information available to AEMO, and warrants further review as new information is obtained.

A major interconnection upgrade between South Australia and New South Wales (RiverLink) is also included in this stage. AEMO's modelling shows this is expected to be economically beneficial when developed, under almost all plausible futures, and the long lead time means action would be needed very soon.

Group 2 – action should be taken now, to initiate work on projects for implementation by the mid-2020s which would:

- *Establish new transfer capacity between New South Wales and South Australia of 750 MW.*
- *Increase transfer capacity between Victoria and South Australia by 100 MW.*
- *Increase transfer capacity from Queensland to New South Wales by a further 378 MW.*
- *Provide network access to the proposed Snowy 2.0 pumped storage project (subject to final project commitment).*
- *Provide access to renewable energy sources in all regions through maximising the use of the existing network and route selection of the above developments.*
- *Coordinate DER in South Australia.*
- *Subject to final project commitment, continue to work with project proponents on a design for transmission networks to support strategic storage initiatives in New South Wales and Tasmania, to deliver the overall lowest-cost solution for customers.*

[108] See https://www.hydro.com.au/clean-energy/battery-of-the-nation.

Figure 40 Group 2 integrated development plan map

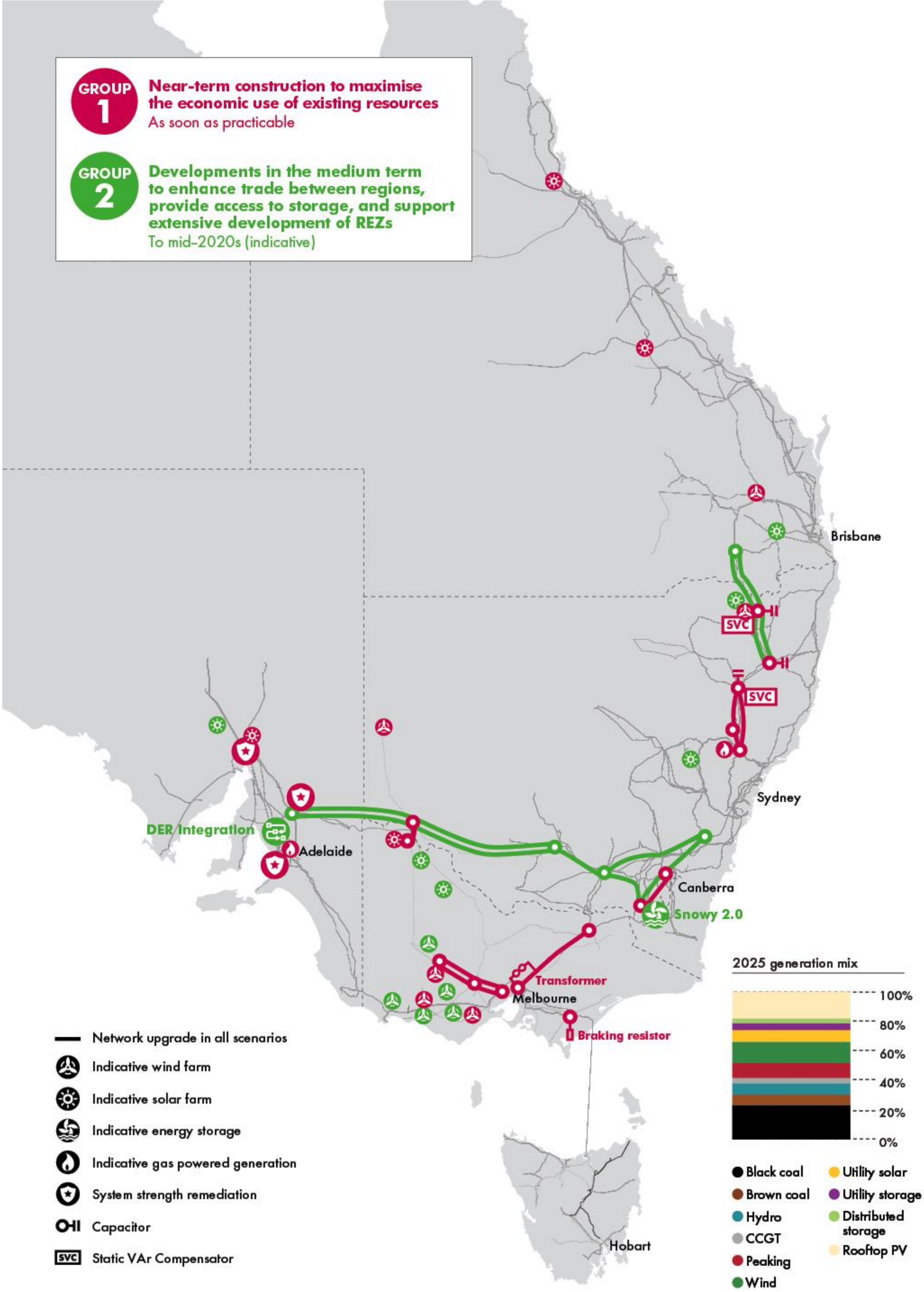


Table 10 Group 2 transmission development details

Network upgrade	Details	Driver†	Indicative timing
RiverLink (SA to NSW upgrade)	New transfer capacity between New South Wales and South Australia of 750 MW Increase in transfer capacity between Victoria and South Australia by 100 MW	Fuel cost benefits	2022 to 2025*
Medium NSW to QLD upgrade	Increase in transfer capacity from Queensland to New South Wales by a further 378 MW	Reliability/capital deferral	2023
SnowyLink North	Network access for Snowy 2.0 to support New South Wales demand	Reliability/capital deferral/fuel cost benefits	2025**
SnowyLink South	Increase in transfer capacity between Victoria and New South Wales by approximately1800 ***	Reliability/capital deferral/fuel cost benefits	2034**
MarinusLink	Increase in transfer capacity between Victoria and Tasmania by approximately 700 MW	Reliability/capital deferral/fuel cost benefits	2033**

† Reliability and capital deferral benefits are reported together here because a reliability need can be met through capital investment in flexible generation.
* Dependent on approvals and development time
** Dependent on project commitments for, and timing of, proposed Snowy 2.0 and Battery of the Nation projects
*** The capacity increase for SnowyLink South assumes that SnowyLink North is also completed.

A new interconnector from South Australia to New South Wales – RiverLink

The analysis highlights a projected benefit in prioritising a new interconnection path between South Australia and New South Wales (RiverLink). This development is the most progressed interconnector upgrade at this time, with ElectraNet undertaking a RIT-T and having recommended this option in their June 2018 report[109]:

- This upgrade would allow renewable and baseload generation in other NEM regions to be transported to South Australia, providing cost reductions in South Australia through fuel savings from reduced GPG requirements.
- Improving network capacity for this transmission route allows for potential new REZs that could then be accessed along the RiverLink corridor, opening up the Riverland and Murray River REZ (which was also identified by the New South Wales Government as a priority, the “South West” energy zone).
- The upgrade is projected to help use resources more efficiently across the NEM, with greater supply sharing between New South Wales, Victoria, and South Australia.
- As noted in Section 5.3, the Open Networks report included a case study for the system security challenges in South Australia, which found that from 2024-25 it will no longer be possible to reduce interconnector flows to zero if required during certain periods, making the delivery of another interconnection vital for system security.
- Refer to Section 6.3.7 for information on the net market benefits projected to be realised from this upgrade in conjunction with the wider ISP development plan, and to Appendix D for more details on the proposed upgrades.

A medium to large interconnector upgrade between New South Wales and Queensland

ISP modelling indicates a need to incrementally upgrade the existing interconnector between New South Wales and Queensland. AEMO recommends exploring options to develop REZs in northern New South Wales when jurisdictional planners conduct feasibility studies. All options to efficiently augment the New South Wales to Queensland interconnector, including the option of a larger upgrade, the use of HVDC and HVAC options, and the potential for augmentation staging should be considered when seeking regulatory approvals via a RIT-T.

See Appendix D for more information.

An interconnector upgrade from Victoria to New South Wales – SnowyLink

A large capacity Victoria to New South Wales interconnector upgrade (“SnowyLink”) is flagged ahead of, and in preparation for, retirement of existing coal-fired generation in the mid-2030s:

- SnowyLink can be delivered in two stages – a north component (“SnowyLink North”) connecting Snowy 2.0 to Sydney, followed by a south component (“SnowyLink South”) that enhances interconnection between Victoria and New South Wales.

[109] ElectraNet. South Australia Energy Transformation RIT-T. Available at: https://www.electranet.com.au/projects/south-australian-energy-transformation/.

- The timing and capacity of later interconnector upgrade options will ultimately be influenced by factors including actual timing of coal-fired generation retirements, REZ developments and capacities, demand changes, and the development of the Snowy 2.0 scheme.
- The analysis shows that the use of DER and demand-side management could potentially defer or reduce local transmission upgrades. However, it is unlikely to alter the need for or timing of major interconnector upgrades. It could also play an important role in providing the flexibility required to be able to maintain reliability of supply in the periods where generation has retired, but transmission capacity has not been able to be built within sufficient time. The impact of DER on transmission development is discussed further in Section 6.3.7.
- See Appendix D for more details on the proposed upgrades.

New interconnection from Tasmania to Victoria – MarinusLink

The economic justification behind an additional Bass Strait interconnector is expected to be driven primarily by the long-term need for energy storage across the NEM, and the projected replacement of energy produced by brown coal-fired generation in Victoria. Additional benefits would include accessing high-quality wind resources in Tasmania and improving hydro efficiencies by repurposing and refurbishing existing assets.

AEMO's least-cost modelling did not automatically select additional interconnection to the Tasmanian region (MarinusLink) in the Base development plan, with the analysis suggesting alternative energy storage developments (based on the input assumptions, including renewables and storage, and the least-cost modelling approach taken). The merits of Battery of the Nation and associated new interconnection to Tasmania will largely depend on the actual costs of energy storage in Tasmania relative to those on the mainland.

The full range of benefits suggested in the recent study by HydroTas[110] into development of the Battery of the Nation project have not been explored in detail in this ISP. AEMO supports the Battery of the Nation feasibility studies[111] being undertaken by Hydro Tasmania to evaluate energy storage opportunities in Tasmania, and considers it prudent to continue to investigate the project to ensure it can be made available to the market, when needed, with the shortest possible lead times for construction.

AEMO will also undertake further work in the year ahead to better understand how this project may be best be incorporated in next year's ISP.

In particular, AEMO will increase its current engagement with key stakeholders to better understand:

- The opportunity to leverage the current hydropower system (and future augmentation opportunities) highlighted by Stage 1 Battery of the Nation studies.
- Storage cost differences between regions, and the impact these differences may have on timing and location of future energy storage.

Refer to Appendix D for more information on interconnection between Tasmania and Victoria.

6.3.3 Group 3 – longer-term developments to support REZs and system reliability and security

Group 3 developments broadly look beyond the mid-2020s to the mid/late-2030s, driven primarily by expected retirement of a significant amount of the NEM's coal-fired generation and forecast costs of renewable generation and storage at that time.

As noted, given the scale of the investment and building time required, it will be important to retain existing coal-fired generators until the end of their technical life to maintain reliability.

As larger amounts of coal-fired generation plant capacity retire in Queensland, New South Wales, and Victoria, it is expected that it will be replaced with new renewable capacity. Further development of the grid at this stage is projected to provide the lowest cost to continue to meet demand and ensure reliable supply across the NEM.

The ISP provides a coherent pathway to a more strongly interconnected grid by the mid-2030s. At this point, a more strongly interconnected grid will:

- Provide access to a large capacity of conventional generation, renewable generation, and storage to meet consumer demand.
- Provide the capacity to best locate and use those resources.
- Take advantage of geographic, time, and resource diversity in renewable resources, and allow more efficient operation of coal-fired generation and GPG.

[110] HydroTas, Battery of the Nation - Analysis of the future National Electricity Market, April 2018, available at https://www.hydro.com.au/clean-energy/battery-of-the-nation/future-state.

[111] See https://www.hydro.com.au/clean-energy/battery-of-the-nation.

- Improve reliability and resilience of the system by allowing resources within and across regions to meet consumer demand and promote greater resilience.

This replacement generation needs to be complemented with storage – both battery storage and pumped hydro storage (or equivalents) – and transmission. It is important to deliver the optimum mix within the portfolio of solutions to minimise the total cost of supply. While actual investment in generation and storage projects will be driven by market incentives and technology costs at the time, the transmission grid to support this requires planned, regulated investment.

The strategic design and selection of a transmission route is critical. Cost savings are available if interconnectors pass through identified REZs and alleviate the need for intra-regional network extensions to remote locations. A view to future climate risk resilience will also influence route selection, with projected increases in extreme weather events and bushfires increasing the value of route diversity.

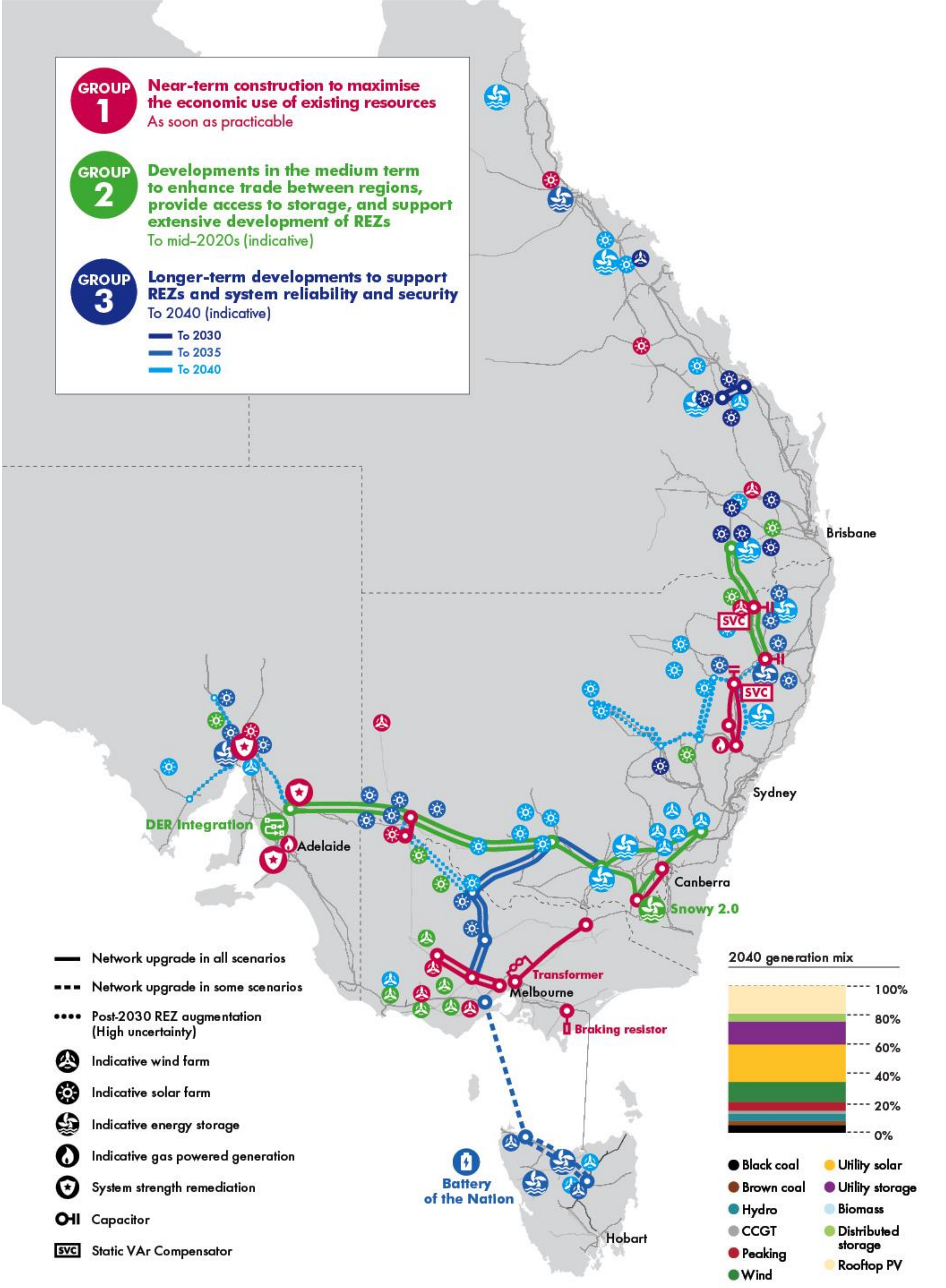
A number of additional REZs will need to be assessed to provide access to the low-cost resources required to replace the energy previously supplied by retiring coal-fired generators. This includes a number of new REZs in New South Wales and Queensland.

There is time to consult on, refine, and finalise initiatives in Group 3, including the selection of preferred REZs and their timing. The refinement of the projects in this group will also include consideration of the timing of transmission development. Given potential increases in risk as generation units age, the planned investments should occur in sufficient time to provide a level of flexibility in the event of unexpected and unrepairable catastrophic plant failure.

Group 3 – in the longer term, to the mid-2030s and beyond, the capability of the grid should be enhanced to:

- *Increase inter-regional and intra-regional transfer capacity across the NEM.*

Figure 41 Group 3 integrated development plan map



6.3.4 The value of interconnection with high DER

As noted earlier, the ISP identifies developments that are robust in a range of plausible futures, and significant interconnector augmentation features in Groups 2 and 3.

ISP modelling shows a more interconnected grid being projected to drive lower costs, even if load growth is lower or if there is much greater use of DER.

The high DER scenario shows the potential for greater use of DER to lower the total costs to supply. The case reduces the projected need for intra-regional transmission to provide access to the incremental REZs, but still shows the need for greater increased national transmission capacity to take advantage of diversity and better utilise dispatchable generation. This analysis also shows the need for DER to be optimised to the needs of the system if it is to deliver the potential it offers. This will require communications and coordination of DER accompanied by improved pricing signals. The analysis in the ISP only addresses wholesale level costs, and further work is required to quantify the overall value of DER to consumers.

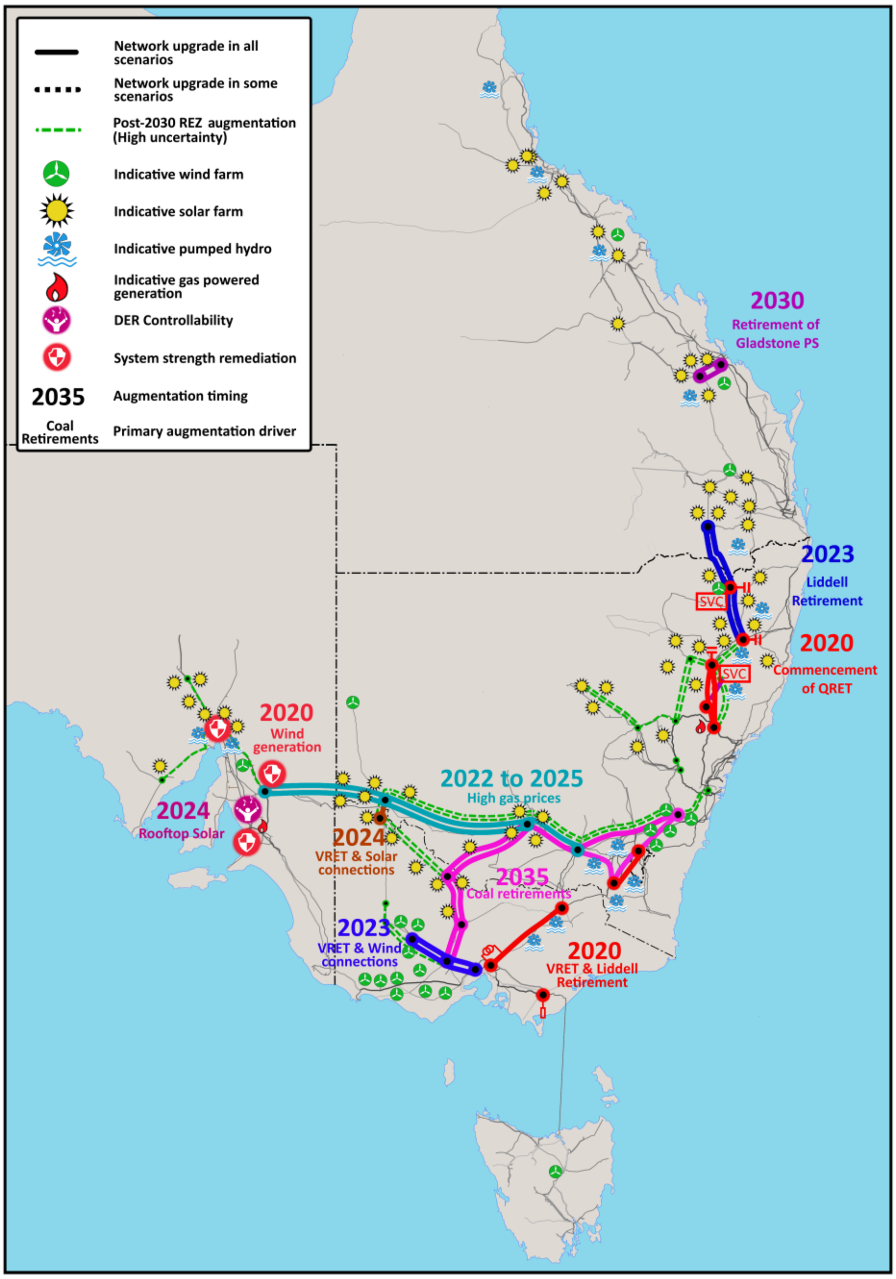
6.3.5 The Base development plan

The stages of the Base development plan are outlined in Figure 42. Individual elements are outlined in the following sections:

- A staged upgrade between Queensland and New South Wales (shown in red and blue) – first to support reliability in New South Wales following the retirement of Liddell Power Station, and then to efficiently export solar generation from Queensland driven by the QRET.
- Staged upgrades between Victoria and New South Wales (shown in red and pink) – to support reliability in New South Wales following the retirement of Liddell Power Station, and to efficiently transfer power between New South Wales and Victoria.
- Increased interconnection to South Australia (shown in teal) – to share diverse resources between South Australia and the eastern states, and reduce fuel costs relating to GPG in South Australia.
- Upgrades in Western Victoria (shown in dark blue and brown) – to support the efficient delivery of the VRET and connect new REZs.

Emerging system strength and DER opportunities are outlined in Chapter 5.

Figure 42 The Base development plan



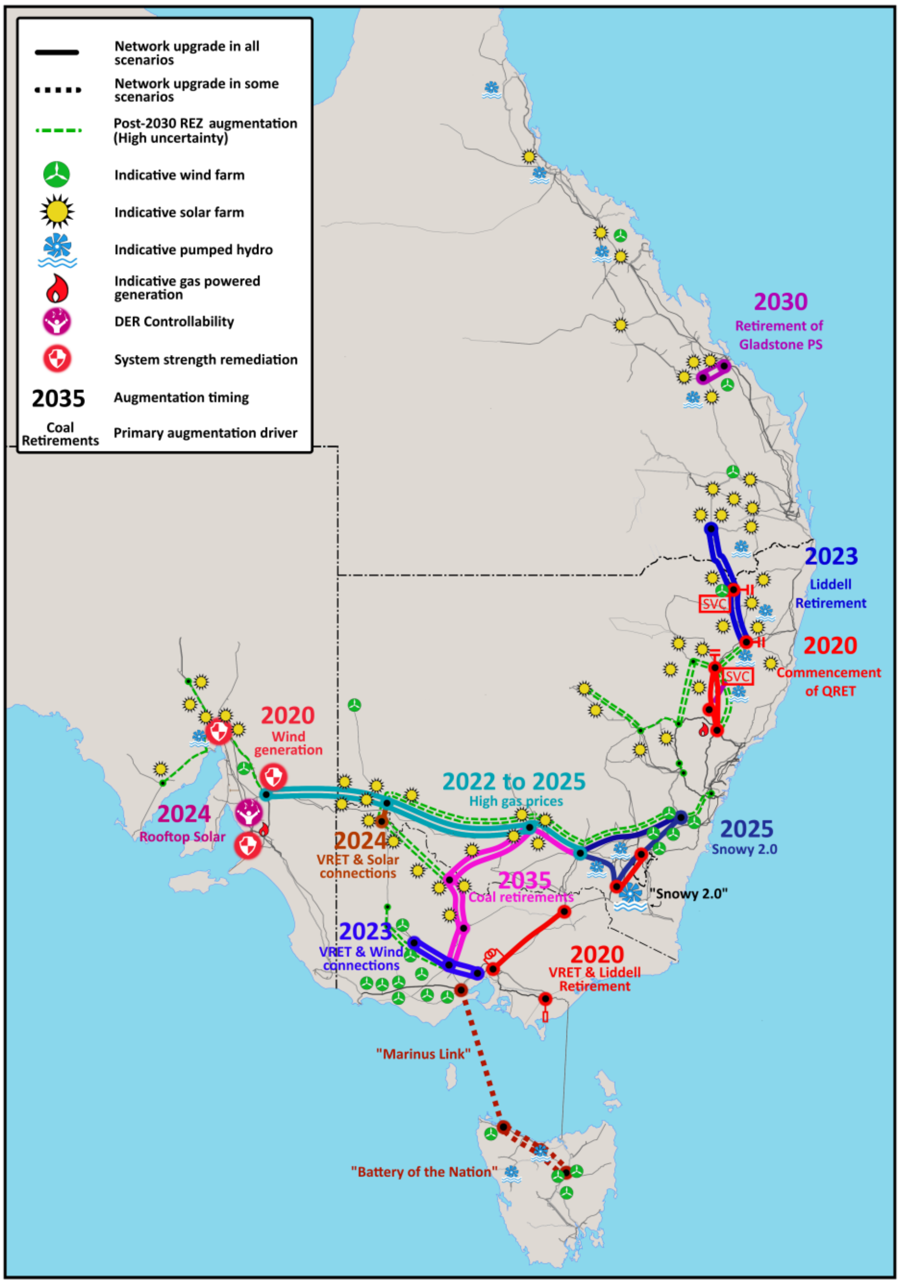
6.3.6 The Base development plan with storage initiatives

The Base development plan can be modified to accommodate storage initiatives. This plan incorporates the proposed Snowy 2.0 pumped hydro project in 2025, and the proposed Battery of the Nation project in 2033. The case was developed on the basis of the projected need for storage as coal-fired plant retires, and strong support from project proponents to bring the Snowy 2.0 project to commitment status soon after the ISP is published.

Figure 43 outlines the indicative projected optimal timing of network developments for the Base plan with storage initiatives. The primary differences from the Base development plan are:

- The northern component of the SnowyLink upgrade is developed a decade earlier, in 2025, allowing the Snowy 2.0 project to improve reliability to New South Wales.
- The MarinusLink (in this analysis, assumed as a second Bass Strait interconnector) is developed in 2033, supporting efficient development of additional wind and storage in Tasmania.

Figure 43 The Base development plan with storage initiatives



6.3.7 Economic assessments

Annual market benefits associated with the Base development plan are categorised as follows:

- **Capital deferral** – a benefit derived from being able to reduce (or defer) generation investment (for example, reducing the total amount of generation required to be built by increasing transmission capacity between regions).
- **Fuel savings** – a benefit realised by reducing the total cost of fuel (for example, allowing generation with lower fuel costs to displace higher cost generation, or enabling existing generation to operate more efficiently).
- **Access to renewables** – a capital deferral benefit achieved by reducing the amount of transmission investment needed to connect REZs (for example, by building an interconnector through a REZ, there is less need to augment other REZs).
- **Operating and maintenance (O&M)** – a benefit derived from reducing fixed and variable generation operating and maintenance costs.

In any given year, these annual market benefits may be positive or negative, depending on the portfolio of resources and transmission selected. For example, when comparing benefits of development plans with and without new interconnection, one plan may have more capital-intensive renewable generation investment with low fuel costs, while the other may have more investment in new GPG which has lower capital costs but higher fuel costs. The gross annual benefits of the development plan represent the total annual capital and production cost savings associated with inter-regional transmission development, being the sum of the individual benefits identified, whether positive or negative.

These gross annual benefits are compared against the inter-regional transmission investment costs of the Base development plan to derive annual net market benefits. Because the different investments being compared have unequal asset lives, the estimated capital investment costs for both generation and transmission are first converted into equivalent annuities, using an assumed weighted average cost of capital of 6%. This allows lumpy capital investment to be expressed as a sequence of constant annual cash flows over the life of the asset.

The present value of a future annual net market benefit represents its worth right now. The net present value (NPV) is the sum of the present values of all future cash flows (both positive and negative).

The analysis shows that the Base development plan would deliver positive net market benefits under the Neutral ISP cases and a range of potential future scenarios. The following table shows the NPV of net market benefits of interconnector augmentation projected for each case.

Table 11 Net market benefits for interconnector upgrade plan ($ million NPV)

Scenario	Net benefits from interconnector upgrades ($ million)
Base cases	
Neutral	$1,192
Neutral with storage initiatives	$1,249
Scenarios	
Slow change	$1,777
Fast change	$1,499
High DER	$1,985
Sensitivity	
Increased role for gas	$544

The present value of annual benefits delivered by the Base development plan under each scenario, and the key sources of these benefits, are discussed in the next section with the aid of figures. To assist in interpreting these figures, the timings of proposed interconnector upgrades are highlighted with flags, the classes of benefits and costs are coloured areas, and the annual net market benefit is represented as a yellow circle.

Annual market benefits and costs for the Base development plan

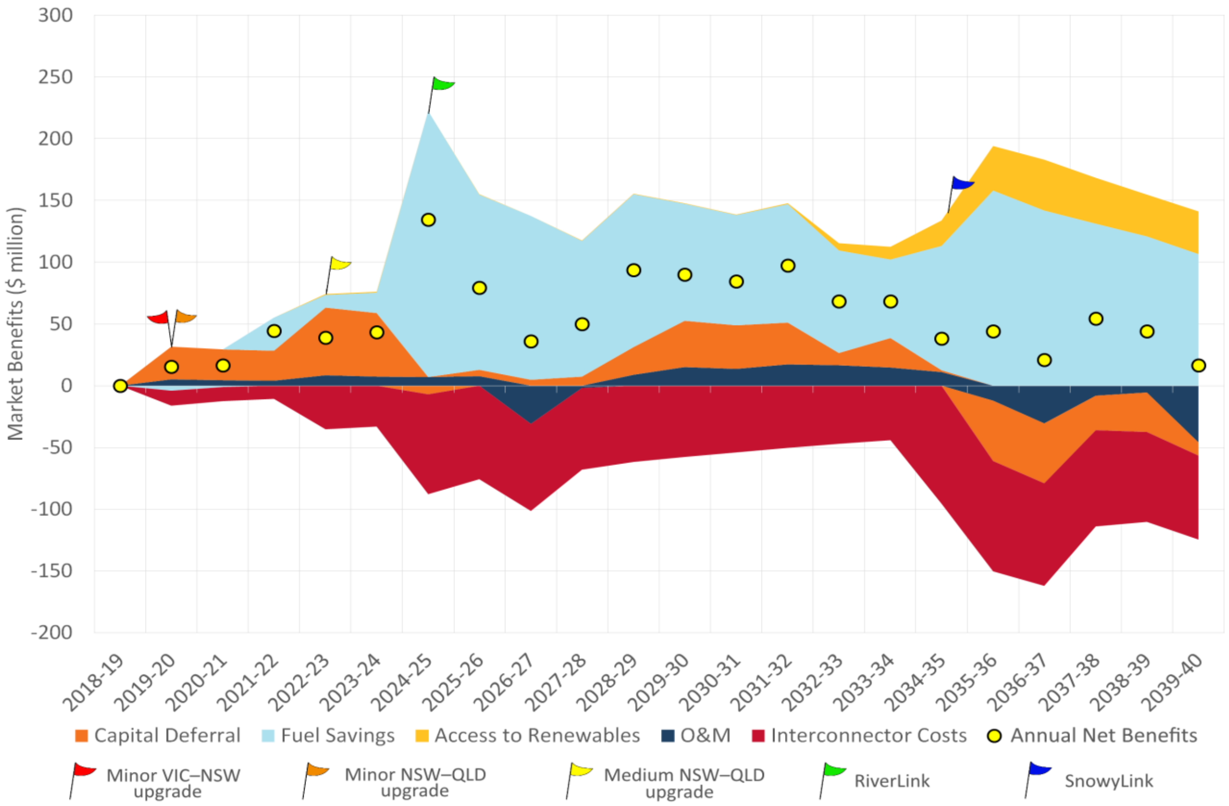
The projected annual market benefits associated with the Base development plan under the Neutral case are summarised by benefit class in Figure 44. It highlights:

- In 2020, or as soon as they can be built, minor upgrades from Queensland and Victoria to New South Wales are projected to provide capital deferral benefits by reducing the urgent need to invest in new flexible plant following the closure of Liddell Power Station in 2022. Over time, these minor upgrades are projected to alleviate network congestion and provide additional benefits through fuel savings by allowing surplus generation to be shared between New South Wales, Queensland, and Victoria, reducing the need to utilise high-cost fuels such as gas.
- In 2023, a medium upgrade to the New South Wales to Queensland interconnector is projected to provide fuel cost savings and capital deferral by allowing greater use of coal-fired generation in Queensland and renewable energy developed to achieve the QRET.
- In 2025, the RiverLink interconnector (South Australia to New South Wales) is projected to provide significant fuel cost savings by increasing competition across the NEM and reducing reliance on regional GPG to provide system security. In combination with the installation of synchronous condensers in South Australia (see Section 5.4.3), modelling indicates this would allow GPG in South Australia to be displaced by a combination of coal-fired generation (outside of South Australia) and renewable energy. Modelling projects that this interconnection would

deliver benefits as soon as it can be completed, and would remain economic unless gas prices were $6.50/GJ or lower. These fuel cost savings are the greatest contributor to the NPV of market benefits associated with this Base development plan.

- At times, O&M costs are greater under the Base development plan than with no new interconnector development, resulting in negative O&M annual benefits. This is influenced by slight differences in the mix of solar, wind and energy storage installed in any year, as the fixed and variable O&M for each technology differs.
- In the longer term, as more coal-fired generation retires, the SnowyLink project (major Victoria to New South Wales upgrade) delivers capital deferral benefits by unlocking access to REZ without the need to build additional intraregional transmission. It facilitates greater investment in, and sharing of, diverse renewable generation resources and storage across New South Wales and Victoria, and reduces the need for GPG and energy storage to provide firming services and manage the concentration of renewable generation. Consequently, generation capital deferral benefits are negative (more renewable generation investment required), but annual fuel cost savings increase (less need to burn gas).
- Annual net market benefits are positive in every year of the plan horizon. The gross annual market benefits associated primarily with fuel cost savings and capital deferral benefits, exceed the annualised cost of the minor upgrades and new interconnectors.

Figure 44 Present value of market benefits for Base development plan (Neutral)



In the Neutral case with storage initiatives, the annual market benefits are similar to those for the Neutral case. The primary differences driven by the Snowy 2.0 and Battery of the Nation storage initiatives are:

- A new transmission line between Tumut and Bannaby, and an additional line from Tumut to Wagga to Bannaby with associated works on the line between Bannaby and Sydney West are developed in 2025. Taken together, these upgrades (referred to as "SnowyLink North") allow the Snowy 2.0 project access to the national market, defer the need for other investment in generation, and assist in providing reliable supply to New South Wales.
- The MarinusLink (second Bass Strait interconnector) is developed in 2033, supporting efficient development of additional wind and storage in Tasmania to replace retiring thermal generation on the mainland.

The balance of the SnowyLink upgrade is not forecast to be required until after the next major power station closure in Victoria and further black coal power stations retire in New South Wales. ISP modelling has assumed that the

Yallourn Power Station retires in 2032[112]. Energy Australia has committed to providing a five-year notice period (under the recently agreed Victorian mining rehabilitation guarantee) prior to the closure of Yallourn Power Station, over and above the three years' additional notice if the rule change currently before the AEMC is accepted.

Scenario analysis

Results from the scenario modelling, outlined in Table 11 above, demonstrate that the projected net market benefits of the Base development plan are robust to a range of uncertainties, such as:

- Demand settings.
- Emissions reduction objectives.
- Supply-side settings.
- Gas market settings.

The following sections highlight the findings from the scenario-based analysis of the Base development plan.

Slow change and Fast change scenarios

The net market benefits projected for the Base network development plan are:

- $1.8 billion under the Slow change scenario.
- $1.5 billion under the Fast change scenario

In the Slow change scenario, more of the benefits are associated with making better use of existing assets. Lower forecast grid demand and potential industrial closures in this scenario would result in excess supply in some regions, and greater interconnection would then provide the system with greater flexibility to make use of the lowest-cost resources across the NEM.

In the Fast change scenario, more of the projected benefits are associated with accessing diverse renewable generation sources and minimising the balancing services required from GPG or storage.

High DER

One of the key questions the ISP sought to examine was whether high uptake and coordination of DER (to meet broader power system requirements when needed) could reduce or eliminate the need to develop large-scale generation and transmission infrastructure.

However, the analysis has demonstrated that the identified transmission developments of both Base development plans would deliver the greatest projected market benefits of all ($2.0 billion) under scenarios with very high DER.

The scale of projected retirements of existing generation means that even high uptake and coordination of DER is not projected to be sufficient alone to deliver a reliable power system. The retirements produce a large energy gap, that is best filled through diverse small- and large-scale renewable generation technologies, given the assumptions modelled.

For example, with more DER (predominantly rooftop and commercial PV), the value of utility-scale solar diminishes, because the two are highly correlated, and more energy storage is required to shift generation to times it is most needed. In this scenario, the geographic and technical diversity offered by utility-scale wind generation increases, and increasing transfer capacity between regions increases the system's ability to maximise this diversity. Accordingly, the Base development plan leads to more projected investment in wind and less utility-scale solar and storage under the high DER scenario, delivering capital deferral benefits.

In contrast, in the Neutral outlook, interconnection is projected to result in more investment in utility-scale solar and storage, and less investment in wind. This highlights the complementarity of wind, solar, and storage, and indicates that a balanced mix of these technologies will be needed to deliver reliable, secure, and affordable power in future. The transmission investment identified in the Base development plan helps achieve this balance across the NEM.

This is an important insight, as it demonstrates the importance of complementary transmission and utility-scale generation and storage investment, even in a highly distributed power system. There is no 'silver bullet' that can deliver the future power requirements on its own. A portfolio of diverse resources and transmission is required.

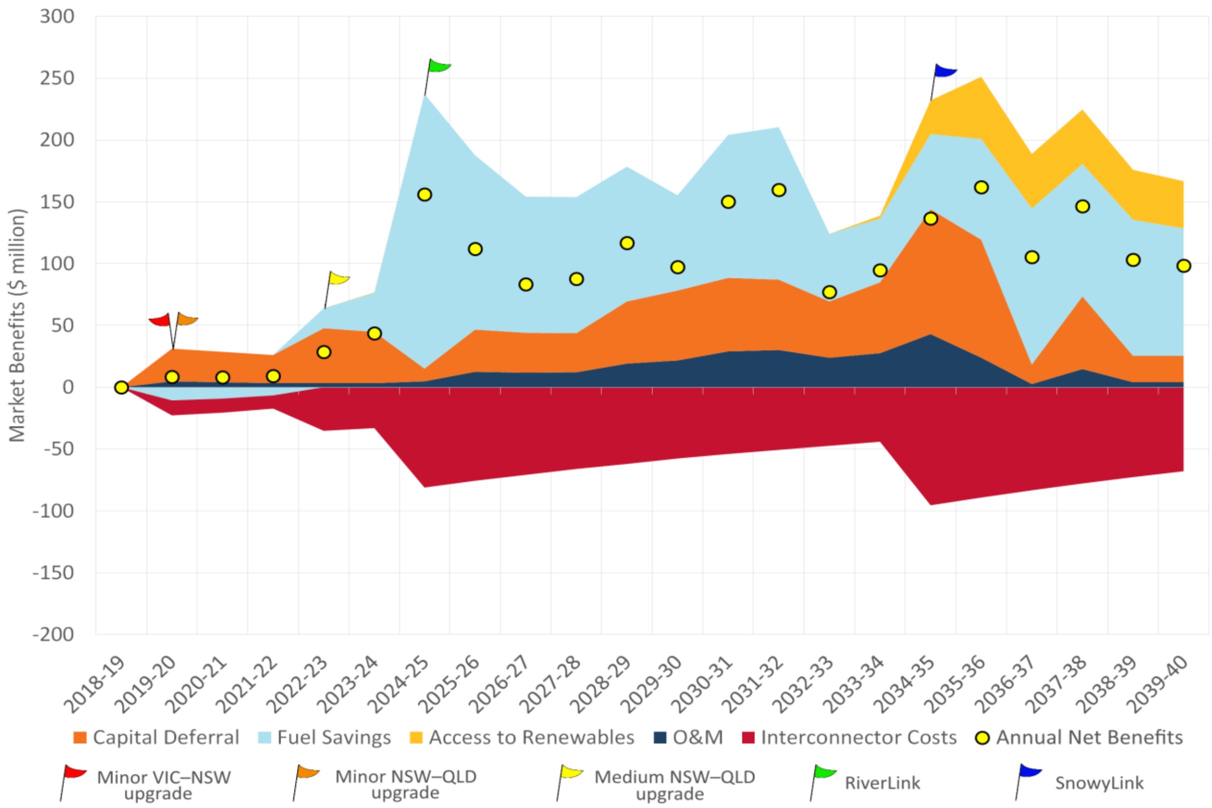
What greater uptake of coordinated DER can do is reduce the requirement for development of utility-scale renewable generation, resulting in less need for upgrades of intra-regional (local) network to connect those utility-scale developments.

[112] See http://earthresources.vic.gov.au/earth-resources-regulation/information-for-community-and-landholders/mining-and-extractives/latrobe-valley-coal-mines/yallourn-and-loy-yang-rehabilitation.

Enabling aggregated distributed storage systems to actively participate in the wholesale energy market is projected to be important for least-cost reliability for consumers, and is one of numerous measures that can help manage the challenges of the growth of passive DER (predominantly rooftop PV – see Section 5.3 for more information). Further work is required quantify this value, incorporating localised issues and opportunities within both transmission and distribution grids.

Figure 45 illustrates the projected annual market benefits for the Base development plan under the High DER scenario. Compared to the Neutral outlook, this figure highlights that increased interconnection under a High DER scenario is projected to yield greater operating and maintenance cost savings associated with the change in new generation investment.

Figure 45 Market benefits for Base development plan (High DER)



Sensitivities and key risks

In addition to the three scenarios, AEMO undertook sensitivities and investigations to assess:

- Increased role for gas – to test the impact of a very low gas price.
- The risk of early coal exits – to consider the benefits of bringing forward interconnector upgrades.

Increased role for gas

The majority of scenarios in the ISP show a limited role for gas, compared with some past plans where GPG was seen as an important transition technology. The Increased role for gas sensitivity explored the potential for a much lower gas price to change outcomes. A lower price of gas is shown to be able to significantly lower the overall resource cost and to change the preferred transmission investment program. With assumed very low gas prices, modelling showed lower projected benefits of the RiverLink interconnector. Further analysis indicated that a gas price below $6.50/GJ would be needed to entirely offset the net benefits of RiverLink.

Further, results show that the Base development plan would still be projected to deliver a positive net market benefit in this sensitivity.

Unexpected early power station exit

Replacing the energy, capacity, and other services provided by coal-fired generation as this plant reaches end of technical life is a major factor in the future development plans for the NEM. The timing of retirements of power stations is therefore a key driver in the plans. In this analysis, AEMO modelled coal-fired generation to end of life based on either public announcements of planned retirements, or based on an assumed technical operating life of 50 years. Actual timing of any retirements is a complex matter that will depend on a broad range of factors.

To test the resilience of the resource and network augmentation requirements outlined in the Base development plans to unexpected early exits, AEMO undertook modelling to separately test two potential risks:

- Unexpected early exit of all generation units from a key power station in New South Wales due to catastrophic failure – tested the impact of losing 1,300 MW of coal-fired generation in New South Wales in 2024.
- Unexpected early exit of all generation units from a key power station in Victoria due to catastrophic failure – tested the impact of losing 1,500 MW of coal-fired generation in Victoria in 2024.

In both cases, the power station closure was assumed to be unplanned and without notice.

Results highlight that an unexpected exit or prolonged failure of 1,300-1,500 MW of coal-fired generation in either New South Wales or Victorian regions would likely result in a serious breach of the reliability standard.

Table 12 indicates the scale of projected unserved energy if either of the two modelled risks were to eventuate. This initial analysis was expanded, and suggested that the Snowy 2.0 initiative, and/or earlier construction of SnowyLink, could help to mitigate the reliability risks associated with unexpected early closure of power stations. Further interconnection with Tasmania could also help provide power system resilience in the event that brown coal generation exits unexpectedly.

Table 12 Impacts of unexpected power station closures

Risk	ISP development plan alternatives	Projected unserved energy				
		NSW	QLD	SA	TAS	VIC
New South Wales coal power station closure	Base Plan	Medium	Very Low	Very Low	Very Low	Very Low
	Base Plan with SnowyLink built early	Low	Very Low	Very Low	Very Low	Very Low
	Base Plan with Snowy 2.0 and SnowyLink built early	Very Low	Very Low	Very Low	Very Low	Very Low
Victorian coal power station closure	Base Plan	Very Low	Very Low	High	Very Low	High
	Base Plan with SnowyLink built early	Very Low	Very Low	Medium	Very Low	Medium
	Base Plan with Snowy 2.0 and SnowyLink built early	Very Low	Very Low	Very Low	Very Low	Very Low

The major challenge is that all interconnector and large-scale storage options require planning and preparation, with some taking seven years or longer. In evaluating the economics of the ISP network development plan, the reported net market benefits are limited to resource costs. Bringing forward the longer-term interconnector plans would increase resource costs, but would provide resilience against unexpected early power station closure. Further work is required to assess the risk mitigation value created by advancing the timing of identified new transmission investment, rather than building "just in time".

At the request of ESB Chair Dr Kerry Schott AO, based on a Finkel Review recommendation, the AEMC has initiated a Rule Change request to require large electricity generators to provide at least three years' notice before closing[113].

[113] See https://www.aemc.gov.au/rule-changes/generator-three-year-notice-closure.

7. Next steps

System planning is continually refined as new information comes to light, and investment decisions are made and acted on. Following publication of the ISP, AEMO will engage with stakeholders to share the learnings arising from the ISP process.

The preparation of the ISP necessarily involves the exercise of judgement, in terms of both the methodology applied and the underlying assumptions. AEMO is committed to transparency. All relevant information and data used in preparing the ISP is provided on AEMO's website. AEMO will hold a technical workshop to help interested stakeholders better understand the plan, and to give them the opportunity to interrogate the analysis and assumptions. Feedback received during the workshop will help AEMO improve future processes.

AEMO will continue to work with TNSPs via the joint planning process to progress the decision-making process for Group 1 network investments proposed in the ISP. This will include working with ElectraNet on the South Australian Energy Transformation RIT-T and the South Australian system strength gap, and progressing AEMO's Western Victoria RIT-T. AEMO, TransGrid, and Powerlink will also initiate new RIT-Ts to examine upgrades to the Victoria to New South Wales and Queensland to New South Wales interconnectors.

Energy storage projects with the potential to critically influence the future of the NEM are under active consideration, including Snowy 2.0 and Battery of the Nation. AEMO will work with project proponents and other relevant parties to refine and update its assumptions and models related to energy storage as new information becomes available.

AEMO will also continue to collaborate with ESB members and other stakeholders to enhance regulatory and market frameworks, including via:

- The AEMC's review of the Coordination of Generation and Transmission Investment.
- The Australian Energy Regulator's (AER's) review of the RIT-T Application Guidelines.

These reviews will include consideration of the role of the ISP in bringing about timely strategic planning for the power system as a whole. These projects are being coordinated by the ESB within the broader context of the ESB's review of transmission planning and interconnection.

Power system operations and markets are rapidly becoming more complex and dynamic. AEMO is investing in its modelling capabilities and computing infrastructure to build its ability to deliver long-term forecasts and plans based on detailed power system and market information. Specifically, AEMO is:

- Developing enhanced modelling tools that allow it to undertake more detailed investigations into potential future power system risks.
- Working with TNSPs and industry manufacturers to build more detailed models of new technologies so it can better integrate them into the power system.
- Working with the BOM and CSIRO to improve AEMO's ability to make prudent provision for risks associated with climate change.
- Using existing market modelling capability to investigate the revenue sufficiency of incumbent and new generators under existing market arrangements, and inform exploration of alternative options that value essential system services like inertia and voltage management appropriately, and may support the commercial viability of some power system assets.
- Building on the sensitivity in the ISP of the potential early exit of coal-fired generators, consider options to mitigate the risks to customers through early investment in interconnectors or storage.
- Continuing to engage with stakeholders to improve understanding of how best to represent the benefits of further Tasmanian interconnection, including repurposing and refurbishing of existing hydro assets, in its ISP Model.
- Exploring ISP model enhancements to more tightly integrate REZ and DER solutions within the market modelling.

The security and resilience of the future power system will be further assessed in the next ISP, with a view to valuing resilience. The technical standards applying to all plant seeking to connect to the grid need to be forward-looking, technology-neutral, and designed to meet the current and emerging engineering needs of the system. AEMO will work with the COAG Energy Council to review the setting of the regular review and updating of these standards.

The ISP projects substantial wholesale benefits from DER, and that these benefits are best realised when those resources are coordinated and used. AEMO is continuing to investigate the requirement for increased coordination of DER, the infrastructure to support and integrate those resources, and their impact on the operation and cost of the distribution system. AEMO and ENA will continue collaborating on *Open Energy Networks*, a partnership that is the first of many collaborations AEMO will undertake as part of a new DER program. The DER program will use collaborations and pilot projects to learn more about possible DER market frameworks, new operational processes, technical standards, and data required to deliver the best outcomes for consumers[114].

Stakeholders who would like to receive information regarding the ISP technical workshop should email ISP@aemo.com.au.

[114] For more information about the DER program, see https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/DER-program.