



Market Modelling Methodologies

August 2019

For Forecasting and Planning the National
Electricity Market and Eastern and South-Eastern
Gas Systems

Important notice

PURPOSE

AEMO has prepared the Market Modelling Methodology to provide information about how AEMO fulfils its [long term forecasting and planning] functions under the National Electricity Law and the National Electricity Rules and the National Gas Law and the National Gas Rules. This report updates the previous methodology information provided within the Market Modelling Methodology and Input Assumptions Report, July 2018, available at https://www.aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/ISP/2018/Market-Modelling-Methodology-Paper.pdf.

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VERSION CONTROL

Version	Release date	Changes
1	16/8/2019	Initial 2019 methodology release

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1. Introduction

AEMO provides planning and forecasting information for the National Electricity Market (NEM), and eastern and south-eastern gas systems, as part of its functions under the National Electricity Law and the National Electricity Rules and the National Gas Law and the National Gas Rules.

AEMO produce a comprehensive suite of planning and forecasting publications each year, including:

- **Electricity Statement of Opportunities (ESOO)** – a supply adequacy assessment of the NEM. Provides market and technical data to assess the reliability of the electricity market over a 10-year outlook period. The ESOO incorporates an independent forecast for electricity consumption, maximum demand, and minimum demand over a 20-year outlook period for the NEM, previously referred to as the National Electricity Forecasting Report (NEFR).
- **Gas Statement of Opportunities (GSOO)** – reports on the transmission, production, and reserves supply adequacy of Australia’s eastern and south-eastern gas markets over a 20-year outlook period. The GSOO incorporates an independent forecast for gas consumption, and maximum gas daily consumption, previously referred to as the National Gas Forecasting Report (NGFR).
- **Integrated System Plan (ISP)** – provides an integrated roadmap for the efficient development of the NEM over the next 20 years and beyond. Its primary objective is to maximise value to end consumers by designing the lowest cost, secure and reliable energy system, capable of meeting any emissions trajectory determined by policy makers at an acceptable level of risk..
- **Victorian Annual Planning Report (VAPR)** – considers the adequacy of the Victorian transmission network to meet its reliability requirements and identifies development opportunities to address emerging network limitations.

These reports comprise AEMO’s forecasts of the potential evolution of the NEM and the eastern and south-east Australian gas network across the long term. Each report typically presents several alternative futures given the uncertainty of point forecasts when market and economic drivers can change significantly over the forecast period.

An overview of the suite of planning and forecasting publications is shown in Figure 1 below.

AEMO generally uses four models to perform market modelling activities:

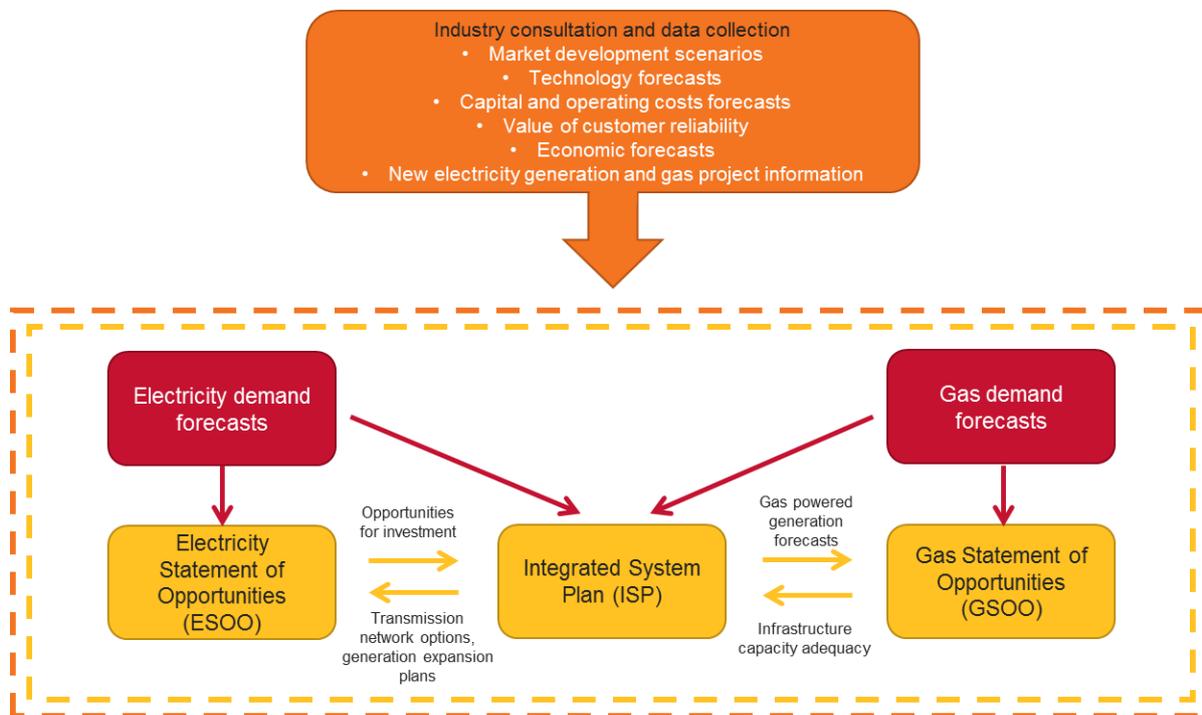
- The capacity outlook model, including two variants of differing granularity.
- The time-sequential model.
- The network development outlook model.
- The gas supply model.

These models and other supporting activities form an iterative loop ensuring market modelling activities’ quality, completeness, and robustness.

This document provides an overview of methodologies employed to support AEMO’s market modelling activities across a range of publications. Supplementary methodology and input assumption reports are also

provided with each publication^{1,2,3}. These highlight specific assumptions or approaches of relevance in that planning publication cycle. Independent methodologies also are provided to explain AEMO’s forecasting approach for electricity and gas consumption, maximum demand, minimum demand, as well as connection point forecasts.

Figure 1 AEMO’s primary national planning and forecasting publications – NEM, and eastern and south-eastern gas systems



1.1 Data sources and flow

Assumption data originates from many sources, both externally and as a result of AEMO’s activities in the national gas and electricity markets. Individual publications produce bespoke methodology or assumptions reports, those values should take precedence to that presented here. At a high level:

- Electricity and gas demand forecasts are available at AEMO’s forecasting portal (<http://forecasting.aemo.com.au/>).
- Generator technical and economic parameters are available as part of AEMO’s Planning and Forecasting inputs, assumptions and methodologies (available at <https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/Inputs-Assumptions-and-Methodologies>).
- Regional boundary definitions and marginal loss factors are published annually, as Loss Factors and Regional Boundaries (available at: <http://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Security-and-reliability/Loss-factor-and-regional-boundaries> .)

Appendix A1 presents default data sources and the items taken from each.

Data updates become available at different times of the year. Each planning report uses the latest data that is available when modelling commences.

¹ AEMO. Gas Statement of Opportunities methodology, at <https://www.aemo.com.au/Gas/National-planning-and-forecasting/Gas-Statement-of-Opportunities>.

² AEMO. Electricity Statement of Opportunities methodology, at <https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/NEM-Electricity-Statement-of-Opportunities>.

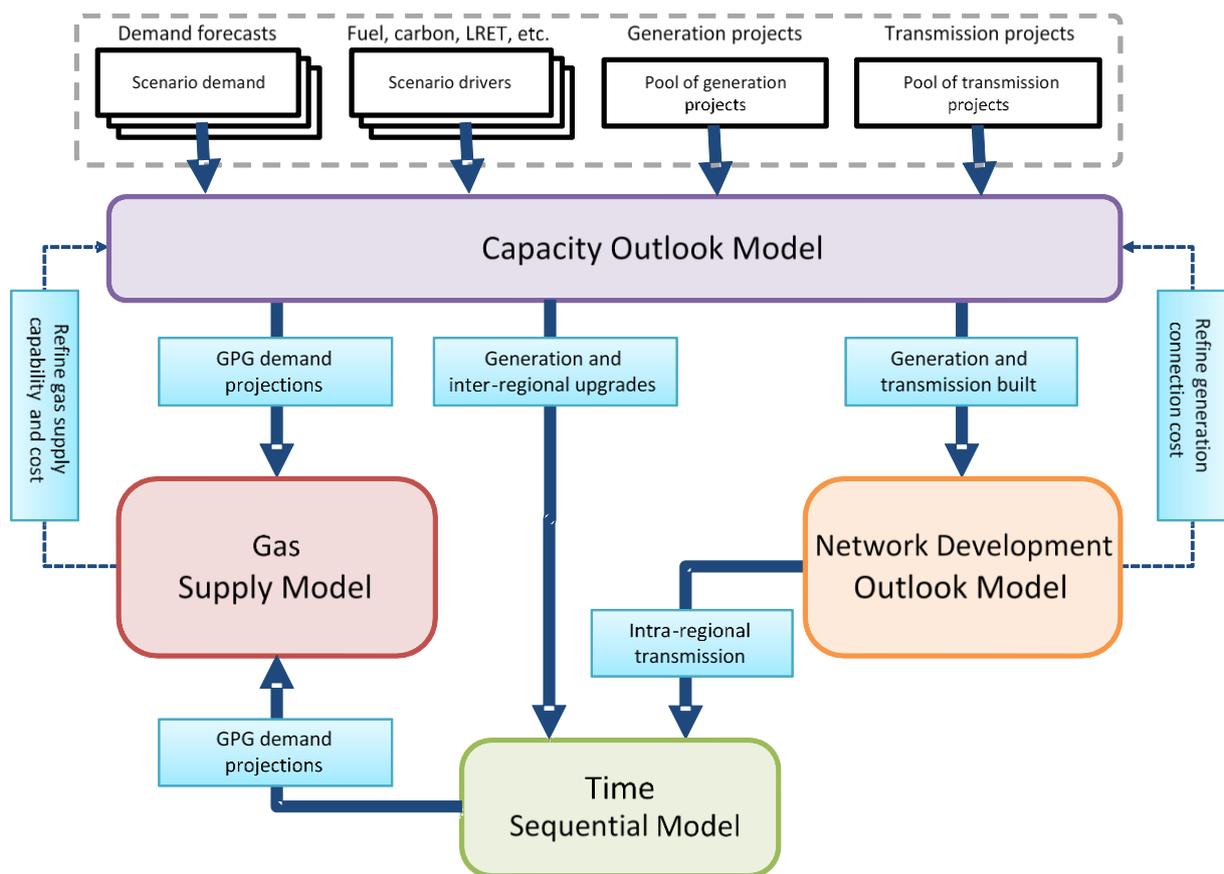
³ AEMO. ISP methodology, at <http://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/Integrated-System-Plan>.

2. Models

AEMO’s long-term planning begins with the development of a series of credible global economic and technological development scenarios⁴. These scenarios are designed to cover a wide range of potential and credible futures and describe the environment in which Australia’s energy networks may operate in the long term.

AEMO’s forecasting suite of tools consists of four mutually-interacting planning models, shown in Figure 2. These models incorporate the assumptions about future development described by the scenarios and simulate the operation of energy networks to determine a reasonable view as to how those networks may develop under different demand, technology, policy, and environmental conditions.

Figure 2 Market modelling process flow



Each model may be described at a high level as follows:

⁴ In the context of AEMO planning, a scenario is a set of assumptions covering economic and policy settings, estimates of generation technology costs, fuel and carbon cost trajectories, price-demand relationships, and other externalities that influence but are not materially affected by the generation and transmission outlook developed by capacity outlook modelling.

- **Capacity outlook model** – determines the most cost-efficient long-term trajectory of generator and transmission investments and retirements to maintain power system reliability, as well as gas supply and transmission. Two variants exist:
 - **Long Term Integrated model (IM)** – co-optimised model of the electricity and gas systems which considers the interdependencies between each system to determine optimal thermal generation investments, retirements, transmission, gas field and pipeline investment plans, over the longest time horizon (25 years or beyond).
 - **Detailed Long Term (DLT) model** – co-optimised model of the electricity system in isolation to the gas market, optimising new generation investments and transmission developments, as well as renewable energy zone (REZ) development opportunities, using inter-regional transmission and other long-lived thermal generation development decisions produced by the IM capacity outlook model. The DLT model is a more granular capacity outlook approach that provides chronological, detailed representations of the long term via a multi-step solve, with reduced foresight relative to the IM to compensate for the increased model complexity.
- **Time-sequential model**⁵ – carries out half-hourly and/or hourly simulation based on available data, of generation dispatch and regional demand while considering various power system limitations, generator forced outages, variable generation’s availability, and bidding models. This model validates insights on power system reliability, available generation reserves, emerging network limitations, and other operational concerns. Depending on the study this model is used for, the generation and transmission outlook from the capacity outlook model may be incorporated.
- **Network development outlook model** – examines and investigates possible engineering and operational solutions to emerging transmission network limitations identified by the capacity outlook model and time-sequential model.
- The **Gas supply model** is used primarily to assess gas reserves, production and transmission capacity adequacy for the GSOO. The model performs gas network production and pipeline optimisation at daily time intervals.

Table 1 summarises the respective models used for AEMO’s Forecasting publications.

Table 1 Major publication models

Publication	Capacity outlook model	Time-sequential model	Network development outlook model	Gas supply model
ESOO		✓	✓	
GSOO	✓	✓	✓	✓
ISP	✓	✓	✓	✓
VAPR	✓	✓	✓	

The capacity outlook models, time-sequential model and gas supply model all make use of the PLEXOS Integrated Energy Model platform developed by Energy Exemplar.

The network development outlook model utilises PSS/e software.

⁵ The time-sequential model is composed of three simulation phases: 1. PASA – schedules maintenance, 2. Medium-term schedule – optimises energy production schedule, 3. Short-term schedule – hourly or half-hourly simulation.

2.1 National Electricity Market topology

The NEM is comprised of the five Commonwealth States of Queensland, New South Wales (including the Australian Capital Territory), Victoria, South Australia, and Tasmania, referred to as regions and shown in Figure 3⁶. AEMO's electricity modelling replicates these regions, representing the network as a system of five regional reference nodes connected by inter-regional flow paths.

The regional topology allows the model to respond to regional changes in demand, and to optimise regional generation and inter-regional transmission expansion. This arrangement also mirrors the operation of the National Electricity Market Dispatch Engine (NEMDE), which is responsible for directing generation dispatch in the NEM.

Figure 3 Regional representation of the NEM, including existing interconnectors

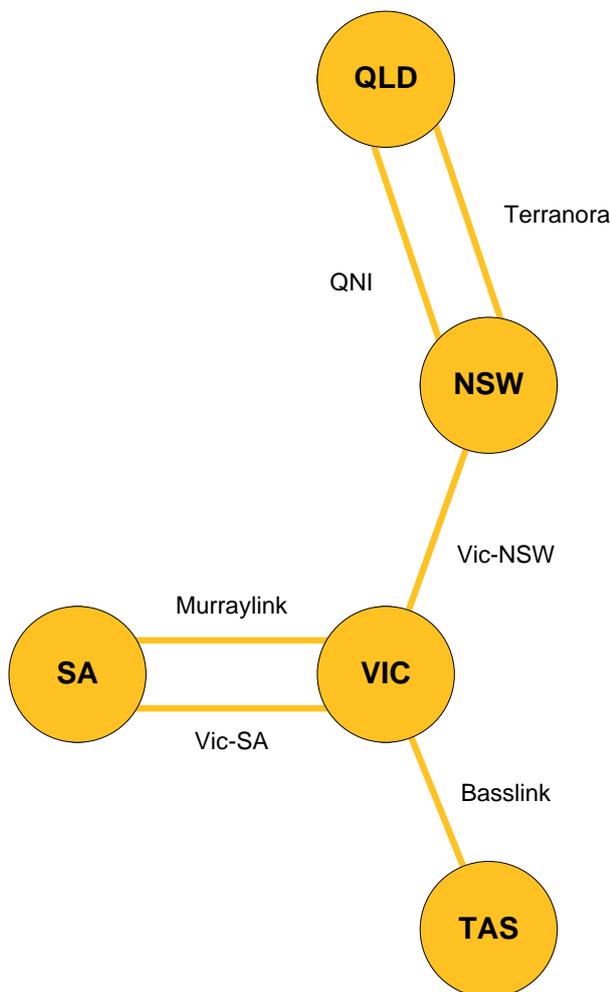


Figure 4 shows the electricity infrastructure and the latest regional boundaries definition for the NEM. AEMO also produces an interactive map that contains a clear visualisation of regional definitions as well as key outcomes from AEMO's planning and forecasting publications⁷.

⁶ The Australian Capital Territory is included within the New South Wales NEM region.

⁷ AEMO Interactive Map, at <http://www.aemo.com.au/aemo/apps/visualisations/map.html>.

2.1.1 Modelling geographical and electrical diversity

A regional representation cannot account for differences in energy resources and infrastructure limitations within a region. To incorporate these aspects, AEMO’s electricity modelling defines planning zones subject to the specific modelling exercise, shown in Table 2. Each zone is modelled considering the expected quality and availability of generation resources, including the correlation of renewable generation resources, to inform the capacity outlook model and time sequential modelling.

Energy resource availability and cost, along with generation build limits dictated by the intra-regional network dynamics, are defined according to these zones. Network constraint equations capture transmission limits between zones.

Zones with the greatest resources, or those with the lowest resource cost, will likely receive new generation first, provided network limits do not unduly constrain that generation.

In some cases, the low cost of generation in a particular zone may justify both investment in generation and transmission infrastructure to supply power elsewhere.

AEMO has identified Renewable Energy Zones (REZ) – an extension to previous planning zones. REZs are geographical areas in the NEM where clusters of large-scale renewable generation can be developed to promote economies of scale. Ideally, REZs will also allow for geographical and technological diversity for large scale renewable projects.

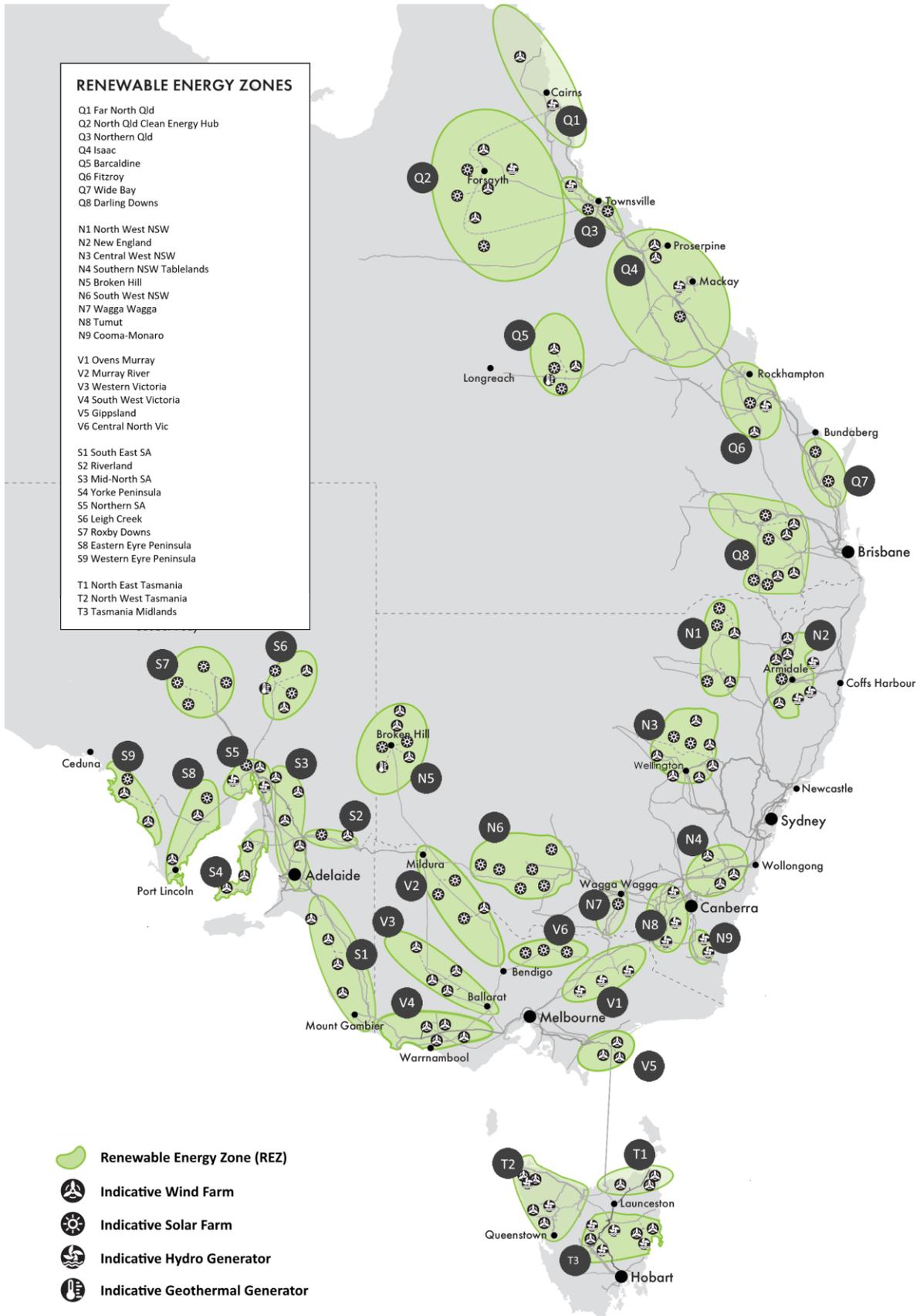
The purpose of identifying the location and timing of REZs is to enable the efficient connection of new geographically diverse generation sources while maintaining reliable supply to consumers. To efficiently and reliably connect this generation will require complementary network development at both intra and inter-regional level. The REZs identified by AEMO are shown in Table 2 and Figure 5.

Table 2 Renewable Energy Zones

REZ number	REZ name	NEM region
Q1	Far North QLD	QLD
Q2	North Qld Clean Energy Hub	QLD
Q3	Northern Qld	QLD
Q4	Isaac	QLD
Q5	Barcaldine	QLD
Q6	Fitzroy	QLD
Q7	Wide Bay	QLD
Q8	Darling Downs	QLD
N1	North West NSW	NSW
N2	New England	NSW
N3	Central West NSW	NSW
N4	Southern NSW Tablelands	NSW
N5	Broken Hill	NSW
N6	South West NSW	NSW
N7	Wagga Wagga	NSW

REZ number	REZ name	NEM region
N8	Tumut	NSW
N9	Cooma-Monaro	NSW
V1	Ovens Murray	VIC
V2	Murray River	VIC
V3	Western Victoria	VIC
V4	South West Victoria	VIC
V5	Gippsland	VIC
V6	Central North Vic	VIC
S1	South East SA	SA
S2	Riverland	SA
S3	Mid-North SA	SA
S4	Yorke Peninsula	SA
S5	Northern SA	SA
S6	Leigh Creek	SA
S7	Roxby Downs	SA
S8	Eastern Eyre Peninsula	SA
S9	Western Eyre Peninsula	SA
T1	North East Tasmania	TAS
T2	North West Tasmania	TAS
T3	Tasmania Midlands	TAS

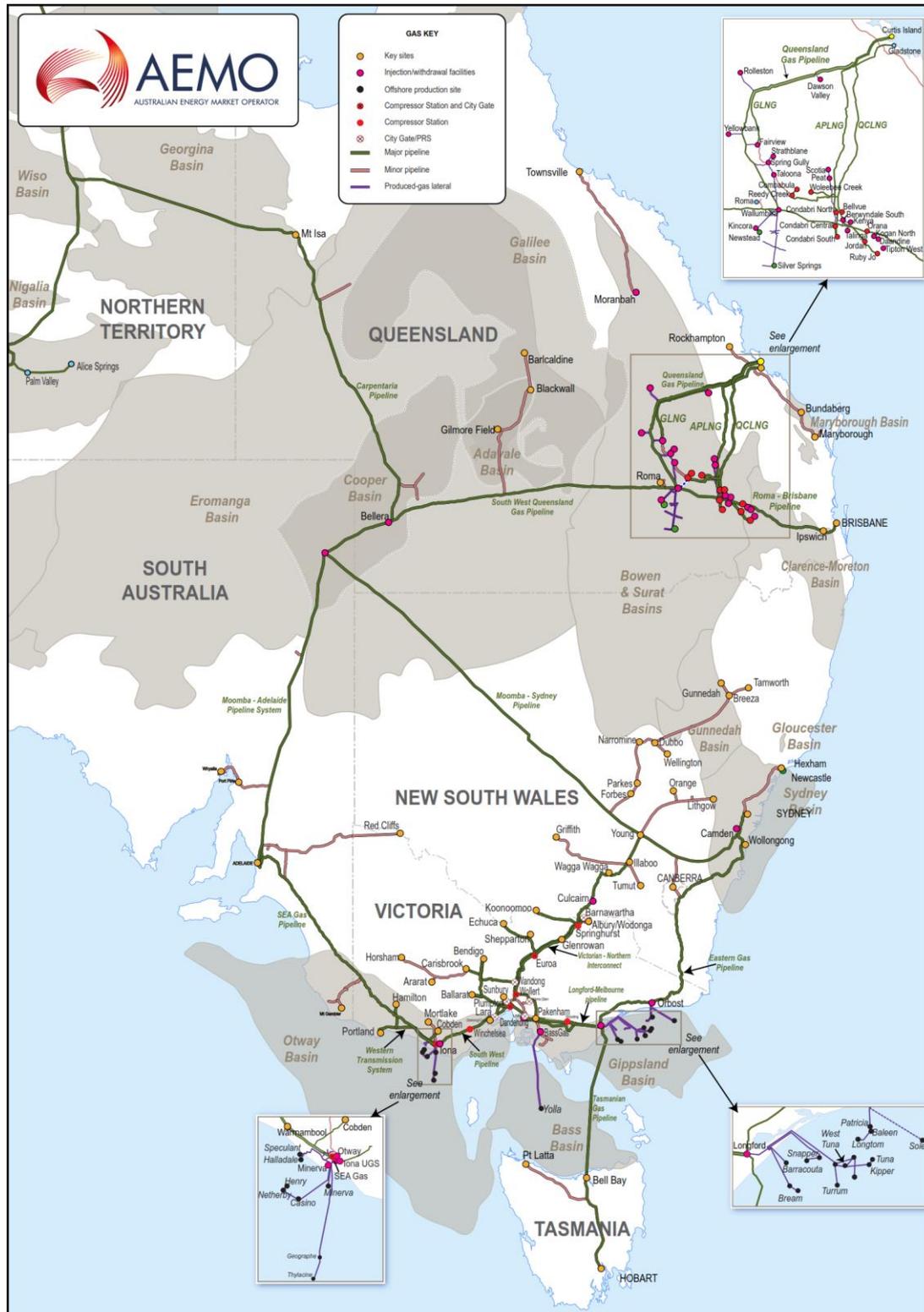
Figure 5 Renewable Energy Zones map



2.2 Gas network topology

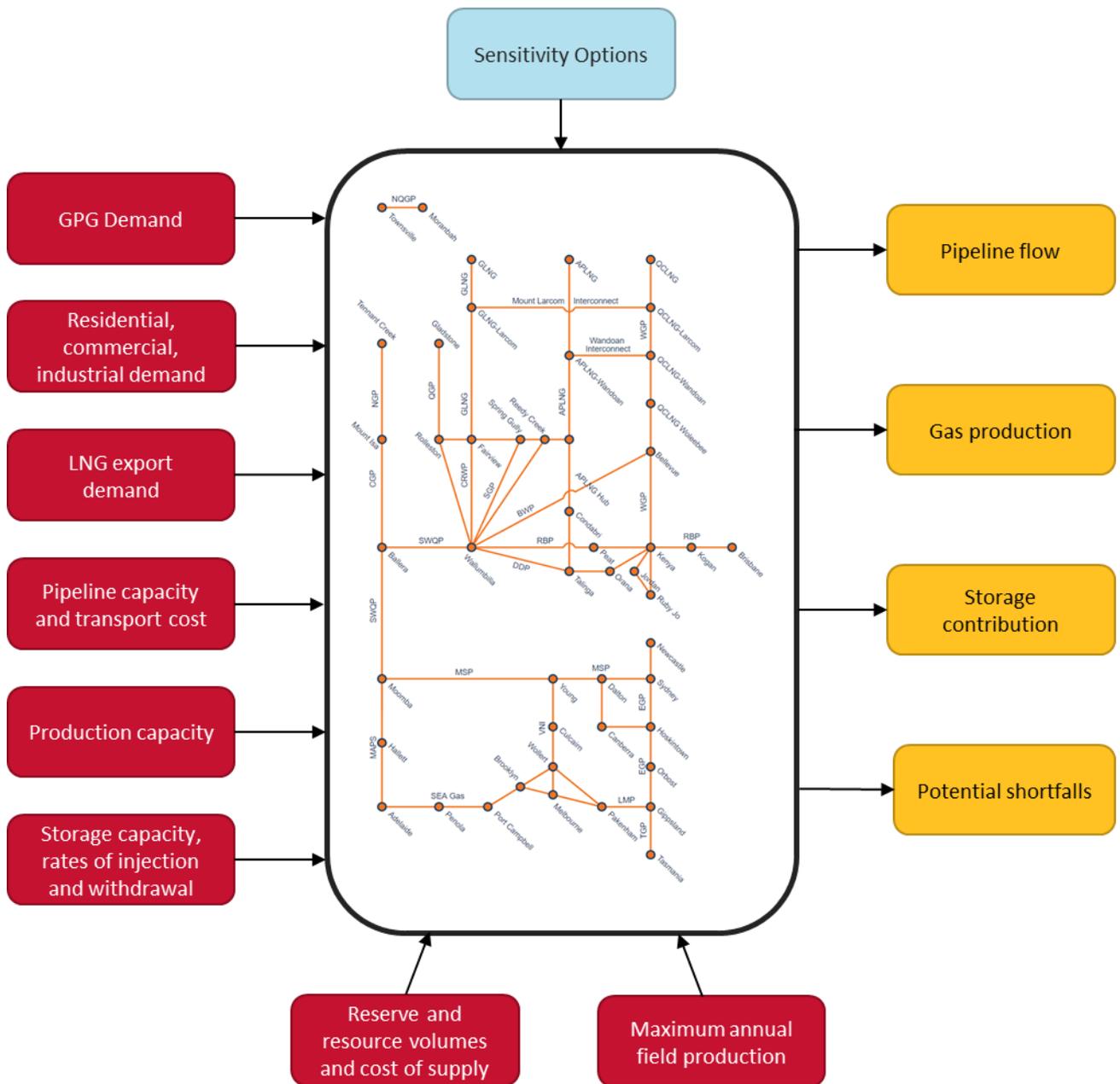
Major gas transmission and production infrastructure in eastern and south-eastern Australia is shown in Figure 6. This map (and AEMO's gas supply model) includes the recent completion of the Northern Gas Pipeline (NGP) linking Tennant Creek with Mt Isa.

Figure 6 Eastern and south-eastern Australian gas production and transmission infrastructure



The gas supply model incorporates major gas transmission pipelines, demand centres and production facilities, as shown in Figure 7.

Figure 7 Gas model topology, inputs, and outputs



2.3 Capacity outlook model

The capacity outlook model consists of two separate models - the IM and DLT models - which complement each other in identifying the optimal generation and transmission pathway in the long-term across different scenarios.

The IM co-optimises electricity generation and transmission investment and withdrawals, along with gas production and pipeline infrastructure, to efficiently meet future operational demand and government policy objectives (such as renewable generation development) at lowest cost for the entire system. Gas and

electricity sector-coupling is included in the IM capacity outlook model, given the critical dependencies between these two sectors.

The objective of the capacity outlook models, in combination, is to minimise the capital expenditure and generation production costs over the long term planning outlook (at least 20 years), subject to:

- Ensuring there is sufficient supply to reliably meet demand at the current NEM reliability standard⁸, allowing for inter-regional reserve sharing.
- Meeting legislated and likely policy objectives (in accordance with the scenario definitions).
- Observing physical limitations of the generation plant and transmission system.
- Accounting for any energy constraints on resources.

The modelling approach applies a mathematical formulation of a linear program to solve for the most cost-efficient generation and transmission development schedule (considering size, type, location, and commissioning and retirement date of generation and transmission assets).

The capacity outlook model is rich in options for the location and technology of new generation, candidates for retirement, and transmission augmentation options. These options are outlined in the Planning and Forecasting inputs, assumptions and methodology documentation, published each year.⁹

Due to the size of the problem and the length of the planning horizon, it is necessary to make some simplifying assumptions, trading off some model accuracy for computational manageability. These simplifications may include:

- Aggregating hourly demand across the 20+ year planning horizon into a representative number of load blocks.
- Breaking the optimisation into smaller steps.
- Simplifying the network representation, using static notional interconnector limits.
- Reducing the number of integer decision variables by linearising generation and transmission build, operational and retirement decisions (effectively allowing partial units or lines to be built if desired). Many of these key linear decisions are subsequently validated via sensitivity analysis, applying 'with' and 'without' modelling as required.
- Using minimum capacity reserve levels to approximate the amount of firm capacity required in each region to meet the reliability standard.
- Using minimum capacity factors and minimum load levels to represent minimum technical and economic duty cycles for thermal generators across the NEM.

The DLT model is a chronological optimisation which has greater resolution relative to the IM, although some load aggregation is still required. Computational feasibility of this model is maintained by breaking the optimisation into smaller steps. This technique allows increased granularity to preserve the original chronology of demand (and renewable resource) time series, thus ensuring a greater reflection of renewable intermittency, storage balancing capabilities and other inter-temporal constraints which require a chronological relationship between simulation intervals.

Another technique used to ensure tractability involves a preliminary screening of the set of generation candidates. This involves optimising the DLT model for a representative selection of snapshot years across the horizon to determine whether a technology is part of the most economically efficient solution at any time across the planning horizon. Applying a snapshot year approach essentially isolates the selected years,

⁸The reliability standard specifies that the level of expected USE should not exceed 0.002% of operational consumption per region, in any financial year. Australian Energy Market Commission (AEMC) Reliability Panel. Available at <https://www.aemc.gov.au/our-work/developing-electricity-guidelines-and-standards>.

⁹AEMO. Planning and Forecasting inputs, assumptions and methodologies, at <https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/Inputs-Assumptions-and-Methodologies>.

reducing the problem size significantly allowing greater technology development options to be included. Candidates that are planted in at least one of the snapshot years are retained and fully optimised in subsequent DLT simulations spanning the entire study period. Build options that are not developed in any of the snapshot years are withdrawn from further assessment. The screening is carried out for each scenario and sensitivity. Reinstating candidates is considered based on the results of the full DLT simulation that follows as well as the insights provided by the time-sequential simulations. This is captured through the iterative simulations between the DLT and ST models.

As the capacity outlook models rely on some problem simplifications to manage simulation timeframes, detailed analysis is subsequently carried out using the time-sequential model. Where necessary, a feedback loop is included allowing the time-sequential model to inform the capacity outlook model. This feedback might include setting minimum operational constraints or maximum build limits on generators based on observations in the gas models, the time-sequential model, and power system models, or refining the minimum capacity reserves to meet the reliability objective based on time-sequential model analysis.

This feedback is critical from a whole-of-system perspective to make sure that gas consumption in the capacity outlook models (which is inevitably less granular) is representative and could be adequately supplied given reserve estimates and pipeline constraints in the gas system. Further, it enables inclusion of system security considerations that would otherwise not be captured directly within the model, and then need to be represented by adding additional constraints into the formulation. Not considering these would risk invalidating the projections.

Consequently, generation and transmission expansion development is finalised through an iterative modelling process where the capacity outlook model and the time-sequential model are used to deliver a range of expansion plans for all scenarios. Where possible, decisions made by the modelling during the early stages of the development are 'locked down' if common to many of the simulations. These development options could be interconnector builds, generation developments or retirements that are driven by consistent settings across the scenarios. This helps improve the robustness of the expansion/retirement plan by reducing the number of decisions to be made in subsequent iterations and improves stability between scenarios.

2.3.1 Planning for weather variability and climate change

The availability of renewable energy, including hydro generation is important given the degree of penetration of intermittent and weather driven generation projected over the medium term. The weather driven generation will be affected by short-, medium- and long-term climatic trends such as: seasonal weather variability, El Nino/La Nina and climate change. To capture short- and medium-term weather diversity AEMO optimises expansion decisions across multiple historical weather years known as 'reference years'. Where practical, these weather years also capture the variance around a long-term climate trend.

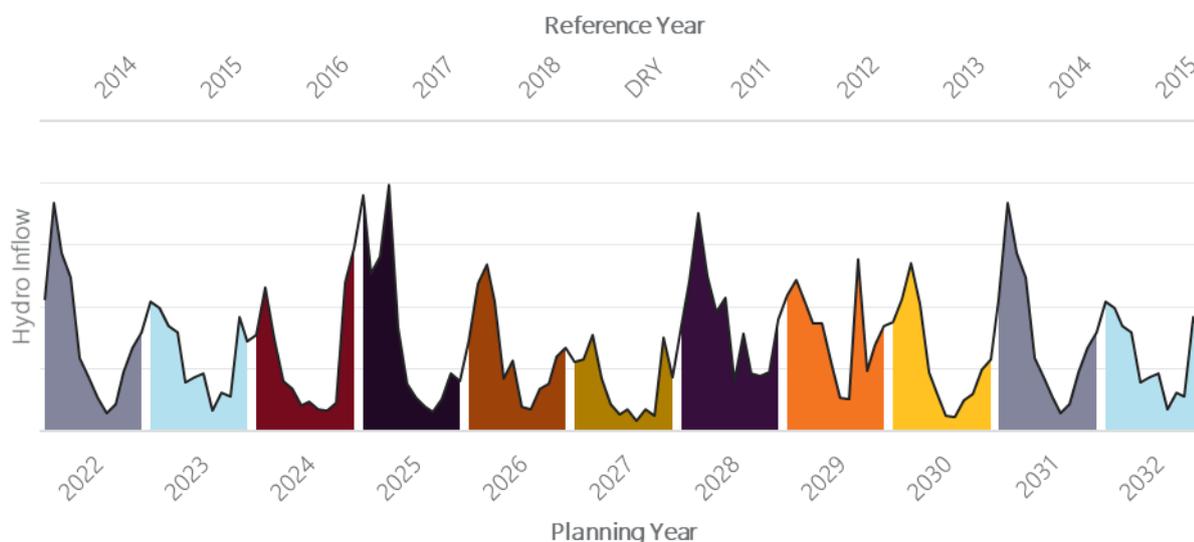
Short- and medium-term weather diversity

The use of multiple reference years allows the modelling to capture a broad range of weather patterns affecting the coinciding customer demand, wind, solar and hydro generation outputs. This approach increases robustness of AEMO's expansion plans by inherently considering the risks of renewable energy "droughts", representing extended periods of very low output from any particular renewable generation source, which are observed across the NEM.

To achieve this, AEMO uses a "rolling reference years" approach which involves combining a number of demand and renewable historical profiles including hydro inflows to produce a time series that would capture a variety of weather patterns throughout the planning horizon. To appreciate the effect of persistent drought and its potential impact on long-term hydro yield, AEMO also models water years representative of a severe water drought, and scales historical water inflows throughout the planning horizon in line with scenario definitions and forecast rainfall and inflow outlooks.

Within the capacity outlook models, reference years are matched to the planning years by rolling through and repeating each of the input reference years. This approach results in a repeating sequence of reference years across the study period as illustrated in Figure 8.

Figure 8 Rolling reference years in capacity outlook modelling



Climate change

Climate change is predicted to drive substantial variation in weather patterns, and therefore coincident customer demand and renewable generation profiles. However, in many cases the range of uncertainty is large. AEMO seeks to consider both:

- The uncertainty attributable to future atmospheric greenhouse concentrations
- The uncertainty attributable to climate modelling

Representative Concentration Pathways (RCPs) have been developed by climate scientists to describe possible pathways for atmospheric greenhouse gas concentrations, and the associated climate change impacts. Development of “Shared Socio-economic Pathways” (SSP) has broadened the future climate scenarios, providing narratives around global emissions drivers, mitigative capacity and adaptive capacities that may result in particular RCPs. The RCP / SSP framework is designed to be complementary, and AEMO has considered it appropriate to apply this framework, focusing on RCPs, to long term planning and forecasting scenarios. Each scenario modelled is allocated an RCP that is consistent with the scenario narrative. Where possible, the physical impacts of this RCP are incorporated where relevant to the electricity sector.

For a given future atmospheric greenhouse concentration specified by the RCP, AEMO will sample appropriate global climate models (GCMs) to determine (at minimum) a median-case outcome, as well as a best- and worst-case outcome for sensitivity testing. Each GCM is internally consistent across all relevant variables (wind, solar, temperature, precipitation), so the selection of GCMs for each case must consider the impact across all relevant variables. The proposed GCM for the Australian electricity sector are shown in Table 3.

Table 3 Selected global climate models (GCMs)

Case	GCM*	Impacts
Best Case	NorESM1-M	Hot and Wet
Median Case	ACCESS1-0	Middle of the pack
Worst Case	GFDL-ESM2M	Hot, Dry and Windy

* Further details on each GCM are available at <https://www.climatechangeinaustralia.gov.au/en/support-and-guidance/faqs/eight-climate-models-data/>.

This climate adjustment is captured in the modelling by applying a linearised indexation of reference years across the capacity outlook and time-sequential models. This approach is most relevant in the ISP, given that the physical symptoms of climate change are more observable within the longer planning horizon.

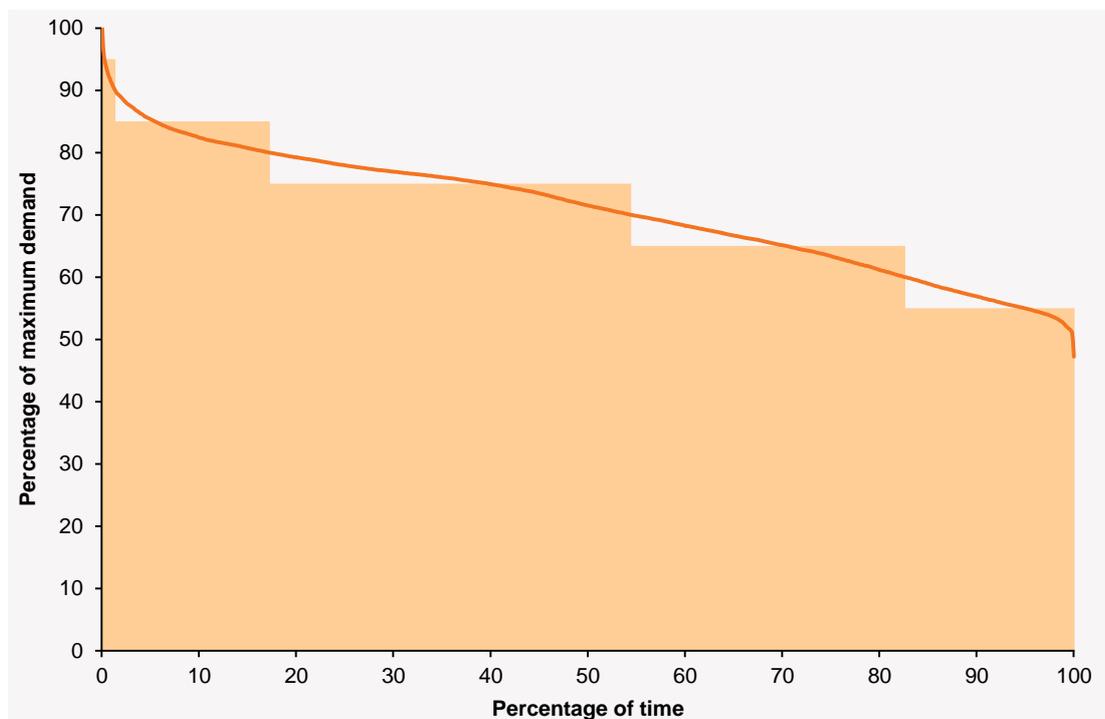
This climate adjustment is captured in the modelling by applying a linearised indexation of reference years across the capacity outlook and time-sequential models. This approach is most relevant in the ISP, given that the physical symptoms of climate change are more observable within the longer planning horizon.

2.3.2 Load blocks

The IM model uses the Load Duration Curve (LDC) approach to approximate hourly demand.

Load blocks are created for each month modelled, using a 'best-fit' approach to approximate the monthly load duration curves, as demonstrated in Figure 9. The monthly partitioning captures seasonal variation and maximum and minimum demands are preserved, but within each month the demand chronology is lost. The exact number of load blocks used in the capacity outlook models is highest at the start of the forecast period and may reduce through the horizon to reduce the problem complexity. The exact number of blocks at any stage may change depending on the modelling purpose and need for finer granularity.

Figure 9 Example representation of a load duration curve partitioned into five load blocks



To ensure supply capacity adequacy, 10% probability of exceedance (POE) demand curves are used, while operational consumption is modelled on a 'sent out' basis (rather than 'as generated') to allow the modelling to reflect the potential change in generation auxiliary loads resulting from a changing generation technology mix.

When modelling operational consumption, the hourly rooftop PV and large non-scheduled generation trace is first netted off the underlying consumption trace before aggregating into load blocks. This ensures the load blocks represent periods of similar operational demand, which is more relevant for determining scheduled dispatch.

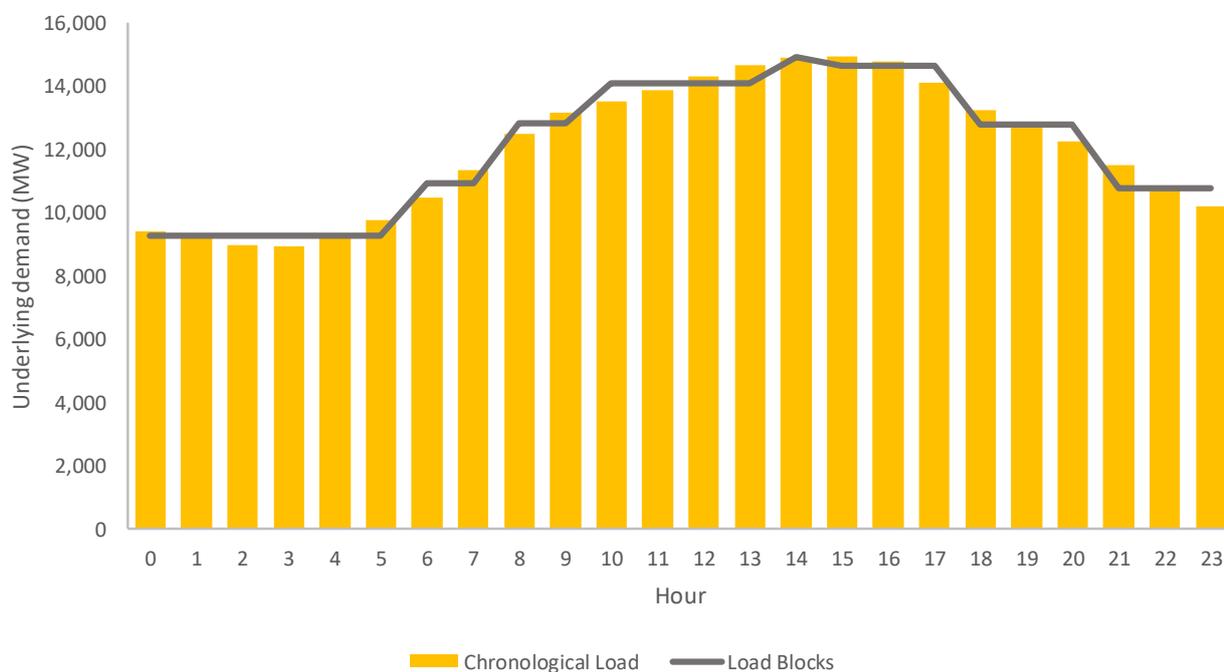
Each load block typically represents a number of time periods within the month with similar operational demand levels. However, other time-varying data, such as wind and solar generators' availability, could vary considerably within that same load block. The LDC approach effectively averages these to a single

representative availability value, smoothing the hourly intermittency and chronology of wind and utility-scale solar generation. To enhance representation of renewables, particularly solar, time periods with high solar activity are aggregated into the same blocks, whereas night and early morning periods with zero or very low solar activity are kept separate, regardless of the operational demand profile. This materially improves solar representation avoiding a representation of solar generation at night.

AEMO has developed the DLT to compensate for these known yet necessary simplifications. The DLT simulates with aggregations at a daily level in a chronological fashion, thus increasing dramatically the model’s granularity. The regional demand time series fed into the DLT is fitted with a step function so that the total number of simulation periods per day is reduced from twenty-four hours to a small, but still representative, number of load blocks. These load blocks are created using a weighted least-square fit method which performs an optimisation that minimises the sum of squared errors (i.e. the square of the difference between the hourly demand fed into the model and the step function approximation). The weighted least square approach has the advantage of fitting the step function more tightly to the original demand time series – allocating more blocks to higher load periods and less to periods of low demand. The duration of each block can therefore vary depending on how the underlying intervals are grouped together.

Figure 10 provides an example of eight load blocks approximating the forecast hourly underlying demand of New South Wales for a sample day in 2018-19. The methodology produces a load block ‘trace’ that varies to reasonably fit the hourly demand profile. More load blocks are reserved to shoulder and peak periods as a result of the weighted least-squares approach, whereas off-peak hours are generally represented by fewer and thus longer blocks. Given the diurnal nature of solar generation, the increased granularity of the model during peak demand periods, particularly during daylight hours, increases the ability of the model to value renewable energy despite resource intermittency.

Figure 10 Example representation of load blocks vs daily chronological demand



Due to computational limitations, the finer chronological resolution of the DLT is not able to model efficiently the length of planning horizon of the IM. Instead, the planning horizon is broken into multiple smaller steps of five to seven years. As such, in any step generation expansion decisions are made with limited foresight of the planning horizon. Given assumed continued cost reductions of renewable energy technologies and storage technologies, allowing the model to invest in these technologies based on limited future foresight is not likely to result in significant regret cost (unlike build decisions for larger thermal plant, which may be exposed to volume risk as emission constraints become more constraining over time). The shorter planning

step is therefore considered an acceptable trade-off for this second optimisation, to better assess the mix of generation technologies and locations that minimises total system costs, including the cost of transmission access and the need for balancing services such as storage. As required, iterations with time sequential modelling may then lead to refinements of the generation mix produced by the capacity outlook models.

2.3.3 Reserve modelling

The reliability standard, set by the National Electricity Rules, specifies that a region's maximum expected unserved energy (USE) should not exceed 0.002% of energy consumption per year.

Due to the lack of granularity in the IM model, it is not possible to get an accurate, probabilistic assessment of the USE level in any given year. Instead, minimum capacity reserve levels for each region are used as a proxy; more detailed assessments of supply adequacy can then be simulated in future modelling stages with more granular models. These minimum capacity reserve levels are generally set equal to the size of the largest generating unit (although may be adjusted over time as the generation mix evolves and if the time-sequential modelling indicates that more (or less) firm capacity needs to be built in a region to avoid reliability standard breaches). The capacity outlook models (both IM and DLT) ensure that sufficient firm capacity is installed/maintained within each region, or imported from neighbouring regions, to meet these minimum capacity reserve levels.

Key reserve modelling inputs included:

- Minimum capacity reserve levels (in the first instance, set to the size of the largest generating unit in the region).
- Maximum inter-regional reserve sharing (based on notional interconnector transfer capabilities).
- Firm capacities (discounted for wind farms and solar farms to reflect the intermittent nature of these technologies).

Firm contribution factors

AEMO develops wind and solar contribution factors that specify the amount of wind and solar generation that can be relied on during times of maximum demand. Wind generation during peak demand depends on both wind speed and the operational limitations of wind turbines across the region. Wind is intermittent by nature, with periods of low wind (and in some cases very high wind) resulting in low generation output. Solar generation depends on levels of cloud cover and the time of the peak demand (being before or after sunset).

AEMO computes the wind and solar contribution to peak demand to be the 85th percentile level of expected wind and solar generation across summer or winter peak periods (top 10% of thirty-minute trading intervals) for each region in the NEM, averaged across all reference years. AEMO calculates these factors for both existing generators and new entrant wind and solar farms, using historical generation (existing) and forecast renewable generation resources across each region's REZs. Currently, for Queensland and Tasmania there is insufficient existing generators to provide sufficient rigour in determining an existing technology contribution to peak factor. As such, AEMO applies the new entrant contribution to peak factor for both existing and new entrant generator in these regions. For solar generation, a contribution to peak of zero may result if rooftop PV generation has shifted the timing of the top 10% of demand intervals sufficiently such that the 85th percentile generation is observed after sunset.

These contribution factors are only used by the capacity outlook model to estimate the renewable generation contribution to meeting the minimum reserve margins.

2.3.4 New entrant candidates

AEMO generally considers a wide range of available generation technologies as new entrant candidates as specified in the respective assumptions book for each modelling exercise

To represent variation due to geographical location, AEMO includes distinct options for renewable generators for each of the REZ described in Section 2.1.1. In this way, resource variability and cost differences are

captured, and the model reasonably reflects potential geographical diversification within regions. For thermal generation developments, and storage, the candidates are considered on a regional basis, with the specific connection location considered within the time-sequential modelling.

The financial economic viability of each generation technology (determined by its economic and technical parameters in Chapter 4) is one influence on the likelihood of the generator being developed in the model, but equally important is the value provided by generation at the time that it is available. For wind and solar resources, the timing of expected generation (driven by resource generation profiles), the correlation to demand, and the network capacity all influence the economically efficient build decisions.

2.3.5 Linear build decisions

The capacity outlook model can build new generation or transmission developments of specific size or continuous size.

The first method better reflects the discrete and 'blocky' nature of new build and estimates costs with higher confidence (for example, the cost of a 300 MW OCGT is well-known), but results in a 'mixed integer program' which rapidly becomes computationally impractical.

The second method reduces computational overhead by allowing build of incremental capacities but results in non-standard capacities for new thermal generation or transmission augmentations, with costs more difficult to confirm (for example, the input costs assumed for a 300 MW OCGT are less likely to apply for a 94.2 MW OCGT).

To keep computation time manageable, the capacity outlook models employs the second method for all new generation build and retirements as well as transmission augmentations. Where partial outcomes are obtained, the following heuristics and iterations between IM and DLT models are used to resolve these linear decisions into realisable project sizes:

- **Interconnector augmentations** – in the IM model, transmission augmentation options that have many alternative options between the same regions are simplified to a MW capacity in each flow direction. The IM then identifies the optimal timing and size of the transmission need, which is then validated by the DLT model, using 'installed' and 'not installed' variations to identify the decision of least overall cost. Sensitivities on augmentation timing are also undertaken to identify the optimal timing with respect to system costs. Where only single augmentation options exist, a 50% minimum build threshold of the transmission capacity is used to then trigger DLT validation, as above. Transmission augmentation options that are similar in capacity but differ in geographical routes or other considerations may be considered in further detail in the time-sequential modelling and power system modelling considering the influence they may have on transmission constraints, with the insights providing a potential feedback loop between IM-DLT-ST-PSS/e models.
- **Thermal generation investments** – high utilisation thermal generation developments such as coal plant and CCGTs are optimised by the IM and validated by the DLT model. This validation may involve optimising both with and without the investments (or divestments for retirement decisions) to determine which choice, when converted to a whole development (or retirement), is least cost. New generators are considered committed only if at least 50% of the notional generator size is built in the IM. For example, if 1.3 CCGTs were built in the IM model, only one CCGT would be modelled in the DLT and subsequently in the time-sequential model. If peaking plant are running hard in the time-sequential model, the decision to round down rather than up in this example may be revisited in subsequent iterations of the DLT.
- **Renewable generation builds** – planting of new renewable generation is allowed to remain continuous, as the size of a wind/solar farm is less rigid than thermal generators. Renewable generators can typically be scaled to any size by adding more turbines / panels. Storage candidates are also treated in this way, unless they relate to specific storage projects in which case the thermal generation investment criteria are applied.

2.3.6 Build limits and lead times

In the capacity outlook model, the maximum amount of new generation of any technology type that can be established in any zone is limited in the model ("build limits"). Build limits associated with generation investments reflect minimum development timeframes for each generation technology, and maximum development levels for generation technologies on at least a regional basis, considering resource and transmission access. Construction lead times for each technology type are reflected in the model by specifying the earliest build date.

For renewable generators in REZs, different layers of constraints are designed to capture both resource potential as well as transmission limitations that could constrain the deliverability of energy produced in certain REZs. The limits represent existing transmission access, and these limits can change either due to:

- Interconnector developments which can improve transmission access to REZs, or
- Explicit transmission developments that increase, at an appropriate cost, transmission access between the NEM transmission network and the REZ.

The capacity outlook models choose to develop transmission only if it is economical to do so, considering the cost and benefit of transmission. In the context of REZs, estimated investment cost of mitigating intra-regional transmission congestions are converted into annualised charges and applied to the model as penalty prices on 'soft' REZ build limit constraints.

2.3.7 Retirement candidates

The capacity outlook model allows for existing generators to retire if the retirement minimises total system costs or if a predefined technical age limit is met (typically up to 50-60 years), or if a generator has advised AEMO of its intention to decommission generating capacity. As generators are now required to inform AEMO of their expected closure year, this is the primary retirement influence.

Retirement of under-utilised existing generation assets may avoid the overhead cost of keeping the unit in service but may advance rehabilitation costs for cleaning up the site. The capacity outlook model co-optimises these costs among other components when developing the generation and transmission development schedule.

To manage the size of the mathematical problem, retirement decisions may be optimised linearly in the IM model, thus leading to partial retirements. Where partial retirements were obtained a rounding method was applied to determine whether and when a generator is retired. As per interconnector augmentations, any retirement of at least 50% of a unit by the end of the horizon was validated (as a whole unit retirement) by the DLT model.

2.3.8 Operational Limits

In long-term planning studies, AEMO applies reasonable assumptions to project future investment needs. It is recognised that the actual limits and constraints that would apply in real time operations will depend on a range of factors, as the real-world conditions will often vary to some extent from those assumed in planning projections, no matter how reasonable the assumptions applied. The objective of the capacity outlook models in combination is to minimise the capital expenditure and generation production costs over the long-term planning outlook, subject to:

- Ensuring there is sufficient supply to reliably meet demand at the current NEM reliability standard, allowing for inter-regional reserve sharing.
- Meeting current and likely policy objectives.
- Observing physical limitations of the generation plant and transmission system.
- Accounting for any energy constraints on resources.

In the capacity outlook models, the relative coarseness of the models requires that these limitations are applied using simpler representations such as minimum capacity factors to represent technical constraints or

likely gas consumption. This helps ensure that relatively inflexible coal-fired generators are not dispatched intermittently, and that likely gas consumption is not under-estimated at this initial stage.

Operational limits included in the capacity outlook models include:

- **Minimum capacity factors** are informed through analysis of historical behaviours, and through endogenous application of the iterative nature of the layered market models. That is, the capacity outlook models are informed initially by applying minimum capacity factors that represent historical behaviours or other physical constraints and are refined as informed by more detailed time-sequential analysis.
- **Maximum capacity factors** are also applied to baseload power stations to reflect physical constraints, such as fuel constraints, that impact the operations of a power station. As not all limits are public information, analysis of historical operating behaviours may assist in identifying these levels.
- **Minimum stable levels** are defined by the minimum of observed historical performance of generators over the past several years, and the generator performance standards. AEMO maintains a register of generator performance standards¹⁰.
- **Seasonal ratings** are applied to match the planned seasonal availability from generators, informed by the generator's submissions to AEMO's Generator Information survey. The submissions are a key input to AEMO's ESOO modelling and represents a 10-year projection of seasonal availability. For the capacity outlook model, the horizon beyond the initial 10-years repeats the seasonal trend observed in the submitted data.
- **Generator maintenance** and unplanned outages are captured through the derating of each generator, applied to all periods. This approach conservatively applies across all periods, resulting in less capacity available on average and avoiding major supply disruption due to large-generator outages. The time-sequential model assists in validating the forecast reliability of the power system in the capacity outlook model. Transmission maintenance is not captured.

2.3.9 New transmission projects

The capacity outlook model includes network representations of committed, advanced, and proposed transmission augmentations. Projects differ in terms of lead time, investment costs and transfer capabilities, and are selected based on their ability to reduce total system costs. Some augmentations are dependent on the development (or non-development) of other projects – the models take these interactions into consideration. The projects, and their related capabilities and assumptions, were developed in consultation with the relevant TNSPs.

Further to inter-regional augmentations the capacity outlook models feature soft constraints to represent intra-regional network limitations affecting REZs development. That is, it allows the increased access to generators connected to REZs so long as a financial penalty is paid, equivalent to the reasonable cost of augmentations specific to that REZ, as described in section 2.3.6 above.

2.3.10 Generic constraints

Inter-temporal constraints

Inter-temporal energy constraints limit the generation production, reflecting energy limits that mean that operational decisions at one point in time affect the availability of the generator to operate in the future. For example, hydroelectric generators with storage facilities are influenced by seasonal or annual water inflows, and the decisions to use stored water throughout the year. In some instances, energy constraints may be modelled simply, through the use of capacity factor constraints, while in others a generic constraint may be applied. In this case, the capacity outlook model and/or medium-term schedule (see Section 3.4.1) decides on

¹⁰ Generator performance standards – further information available at <https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Security-and-reliability/Generator-performance-standards>.

a production schedule throughout the year with 'recycle' constraints to ensure that water storages at the end of a simulation period is the same as the initial level.

Generally, the model uses the same technique of scheduling production throughout the year for all inter-temporal constraints such as energy limitations and emission budget constraints.

Network limitations

The capacity outlook models are configured with a regional representation of the NEM, and are not explicitly capable of considering intra-regional power flows, either as a model result or for the purposes of modelling the physical limitations of the power system.

In the capacity outlook models, key transmission limitations are isolated to interconnectors with a single notional defined import and export limit. As the expansion model is regional these limits can influence the ability for adjacent regions to share export capabilities to meet high demand periods. This reserve sharing is defined independently of the notional import and export limit to adequately reflect the prevailing conditions at peak demand periods between regions.

In the real-time NEM Dispatch Engine (NEMDE), a series of network constraint equations control dispatch solutions to ensure that intra-regional network limitations are accounted for. The time-sequential model contains a subset of the NEMDE network constraint equations to achieve the same purpose.

2.3.11 Network losses

Transmission lines are not perfect conductors, and power transfer between locations results in a loss of energy. To account for this, the underlying demand in the models includes an allowance for intra-regional transmission losses explicitly. The capacity outlook model also applies the marginal loss factors (MLFs) of generators as calculated annually by AEMO.¹¹ For new generator options, a 'shadow' generator is chosen based on the connection point of the generation option.

For inter-regional transmission flows, the models calculate losses as a quadratic function based on the demand in both connected regions and the flow on the interconnector itself.

Further discussion on the treatment of network losses is provided in Chapter 2.4.6.

2.4 Time-sequential model

The generation and transmission outlook developed by the capacity outlook model is validated using a time-sequential model that mimics the dispatch process used by NEMDE.

The time-sequential model considers the modelled time horizon at a much higher resolution compared to the capacity outlook model. The time-sequential model optimises electricity dispatch for every hour in the modelled horizon, and includes Monte Carlo simulation¹² of generation outages, allowing the development of metrics of performance of generation (by location, technology, fuel type, or other aggregation) and transmission (flow, binding constraint equations).

The time-sequential model is used to provide insights on:

- Possible breaches of the reliability standard.
- Feasibility of the generation and transmission outlook when operating conditions and network limitations are modelled.
- Number of synchronous generators online.

¹¹ AEMO. Loss Factors and Regional Boundaries, at <http://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Security-and-reliability/Loss-factor-and-regional-boundaries>.

¹² The Monte Carlo approach simulates the model iteratively, taking into account random events to ensure that the result is statistically robust. See Section 5.1.

- Generation mix and fuel offtake.
- Network augmentation benefits.
- Impact of inter-regional demand diversity.
- Diversity between intermittent supply and demand.
- Unplanned generation outages.

Modification of the capacity outlook model, or further investigation using power flow studies, may be triggered by these insights.

2.4.1 Simulation phases

The time-sequential model is composed of three interdependent phases run in sequence. Designed to better model medium-term to short-term market and power system operation, these phases are:

- PASA – allocates generator units’ maintenance schedule while maximising spare capacity across an outlook period. The resulting maintenance outage schedule is passed on to both the medium-term schedule and short-term schedule
- Medium-term schedule – schedules generation for energy limited plants over a year, i.e. hydroelectric power stations or emission-constrained plants. A resulting daily energy target or an implicit cost of generation is then passed on to the short-term schedule to guide the hourly dispatch.
- Short-term schedule – solves for the hourly generation dispatch to meet consumption while observing power system constraints and chronology of demand and variable generation. This phase uses a Monte Carlo mathematical approach to capture the impact of generator forced outages on market outcomes.

2.4.2 Supply bidding models

While the investment and production costs are the primary drivers of the capacity outlook model, generator bidding behaviour drives the time-sequential model hourly dispatch results.

Bidding behaviours are typically difficult to determine as they depend on each company’s risk profile, contract position, and future ownership of new entrants.

AEMO may use any of the following generator bidding models, or a combination throughout the outlook period, depending on the purpose of the modelling:

- Short Run Marginal Cost (SRMC) model – the simplest bidding model, which represents perfect competition. This model assumes that all available generation capacities are bid in at each unit’s SRMC. Consequently, this model is fast to solve and renders insights excluding competition benefits.
- Bidding behaviour model – this model uses historical analysis of actual bidding data and benchmarked to historical generation levels to define generator bids, rather than costs, that determine the generator dispatch outcomes. The historical bid analysis captures current market dynamics such as contract and retail positions of portfolios by ensuring that modelled generator bids broadly replicate dispatch preferences of generators and portfolios submitted in each generator’s actual historical bids. Portfolio outage management (by adjusting bids at times of generator outages to maintain portfolio positions) is considered for some large generation portfolios. In the short term these dynamics are assumed to stay relatively unchanged, however the degree of change in the energy mix in the medium to long term may reduce the accuracy of this approach beyond the next few years.
- Nash-Cournot model – used to study the modelled generators’ production by dynamically changing generators bids such that their profit is maximised, given assumptions regarding costs and contract positions. The modelled generator may sacrifice cleared generation volumes in exchange for price increases and higher revenue if in so doing it increases the resulting price received and therefore maximises profit. This method provides the model with a dynamic choice to alter generator behaviours depending on prevailing conditions in the time-sequential simulation, differing to the bidding behaviour model which captures static generator bids.

2.4.3 Unit commitment

Unit commitment optimisation determines which generating units to switch on, and for how long. Apart from the dispatch cost, this optimisation also includes the generator units' assumed start-up cost, minimum uptime and minimum stable level. For example, the optimisation considers whether it is economically optimal to keep generators on at low generation levels, even when making a loss, to avoid the cost of restarting later.

This methodology solves the whole outlook period (24 hours) simultaneously and includes an additional day of look ahead at less granular resolution to inform unit commitment decisions towards the end of the 24 hours. Otherwise, units may choose to shut down towards midnight without considering the cost of restarting the next day.

A combination of Nash-Cournot bidding model and unit commitment is used by AEMO to forecast the level of inertia and gas-powered generation (GPG) fuel offtake.

It should be noted that unit commitment optimisation and minimum stable levels are not relevant for peaking plant when using an hourly model resolution and are therefore not included in the market model. These units are capable of starting up to operate for minutes rather than hours, and it would not be appropriate to impose a constraint in the market model that forces them to remain operating at their technical minimum stable level for an entire hour if dispatched. While these units do have minimum stable levels, on average across the hour they may be generating at a lower level due to changes in unit commitment.

These peaking units also do not materially impact the annual gas consumption that would need to be reflected in the gas-electricity integrated market model.

Therefore, to maximise the efficiency of the market model and not create computational burden that does not materially impact the results, minimum capacity factors (in the capacity expansion plan) and unit commitment decisions (in the time sequential modelling) are only imposed on generators that:

- Are required to be on-line for system security purposes.
- Are involved in unit commitment constraints (such as "that at least two units must be on-line at all times)
- Are likely to materially impact the level of annual gas consumption
- Have limited flexibility to start up and shut down (such as coal-fired generation).

2.4.4 Large-scale storage operation optimisation method

Large-scale storage operation (battery, hydro, pumped hydro, or any other storage medium) is expected to generate opportunistically based on price and the efficiency loss associated with charging and discharging the storage. For example, in a future energy mix with high renewable penetration, variable renewable energy may be smoothed by effectively charging storages when high renewable energy volumes are available, for later discharge when renewable energy is low.

The second phase of the time-sequential model (medium-term schedule) completes an energy management study across a year to schedule energy consumption and generation from storages when most needed. This is further refined by the third phase of the time-sequential simulation, where network limitations are included on a more granular time scale. The latest assumptions can be found in AEMO's planning and forecasting inputs, assumptions and methodologies data set.¹³

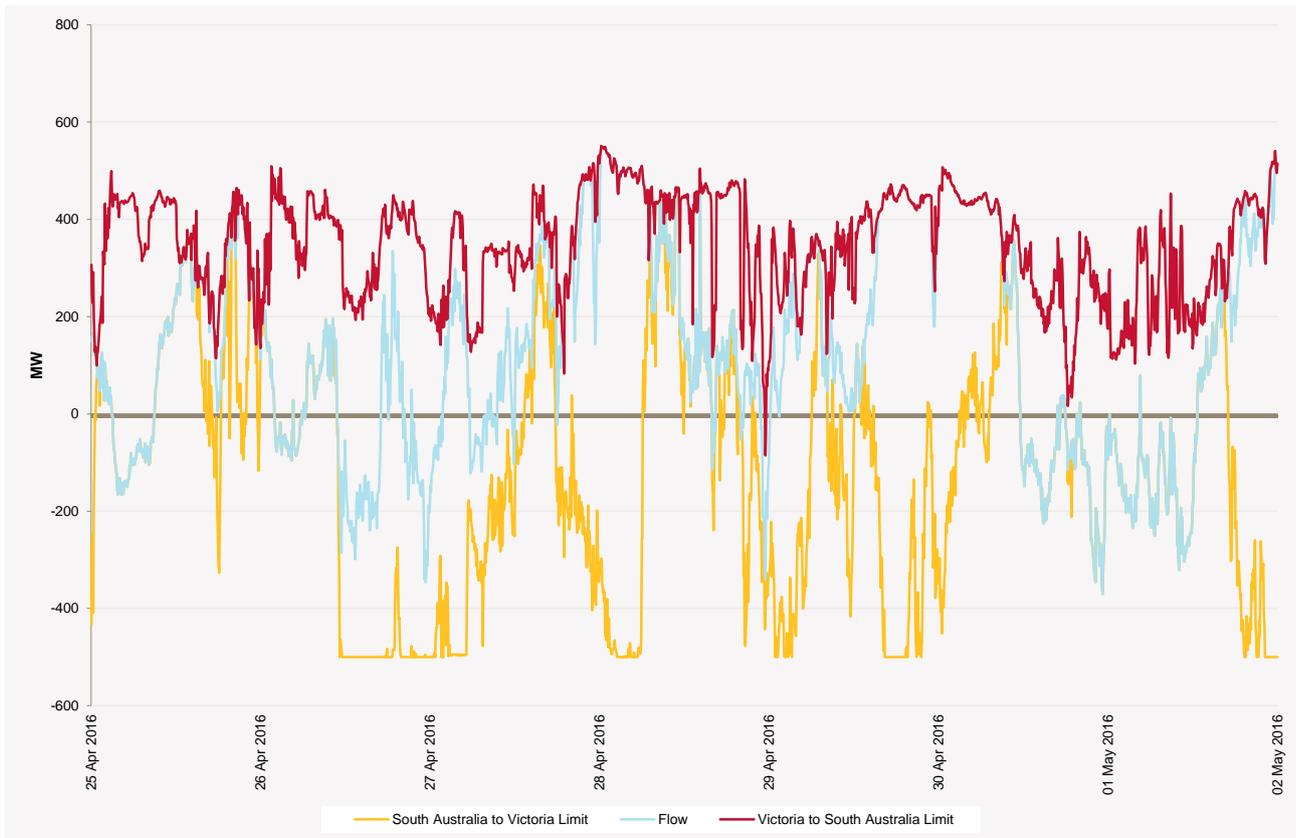
2.4.5 Transmission limits

Inter-regional constraint equations

Interconnector flow limits change in response to network conditions. Figure 11 shows 5-minute limits and flow on the Victoria–South Australia (Heywood) interconnector for one week in April 2016.

¹³ AEMO. Inputs, assumptions and methodologies, at <https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/Inputs-Assumptions-and-Methodologies>.

Figure 11 Interconnector limits in actual operation, Heywood Interconnector



AEMO implements these variations in interconnector flow limits in the time-sequential model by modelling dynamic power system constraints where inter-regional network limits change as a function of the state of the system, that is, individual generation level, transfer level, online inertia, and demand.

Intra-regional constraint equations

The time-sequential model contains a subset of the NEMDE network constraint equations to capture intra-regional flow limitations. The subset of network constraint equations includes approximately 2,500 to 3,000 pre-dispatch¹⁴, system normal pre-contingent N-1 transmission constraint equations reflecting operating conditions where all elements of the power system are assumed in-service. They model important aspects of network operation and include contingency for maintaining secure operation in the event of outage of a single network element.

In general, the following constraint equations are included:

- Thermal – for managing the power flow on a transmission element so it does not exceed a rating (either continuous or short-term) under normal conditions or following a credible contingency.
- Voltage stability – for managing transmission voltages so that they remain at acceptable levels after a credible contingency.
- Transient stability – for managing continued synchronism of all generators on the power system following a credible contingency.

¹⁴ NEMDE contains equation sets for dispatch, pre-dispatch, ST PASA, and MT PASA. Within these sets, other sets cover specific network conditions such as outages, rate of change, frequency control ancillary services, and network service agreements. Pre-dispatch equations are used because dispatch equations contain terms that rely on real-time SCADA measurements not available to simulation models.

- Oscillatory stability – for managing damping of power system oscillations following a credible contingency.
- Rate of change of frequency (RoCoF) constraints – for managing the rate of change of frequency following a credible contingency.

The effect of committed projects on the network is implemented as modifications to the network constraint equations that control flow. The methodology for formulating these constraints is in AEMO's Constraint Formulation Guidelines¹⁵.

A set of network constraints is produced and applied for every scenario modelled. This set may reflect

- Extracted constraints from the AEMO Market Management Systems (MMS).
- Network augmentations appropriate for the scenario.
- Adjustments to reflect the impact of new generation capacities.
- Other adjustments to reflect assumptions of system operating conditions.

The latest set of constraint equations used in market modelling activities is contained within the ESOO data sets¹⁶.

Excluded constraint equations

Operationally, AEMO also uses other types of constraint equations that are invoked as required depending on system conditions. These may include:

- Outage constraint equations.
- Frequency control ancillary service (FCAS) constraint equations.
- Condition-specific constraint equations such as RoCoF and network support agreements.

These constraint equation types are commonly excluded from the market simulations as they may be operational in nature or caused by transmission outage or non-credible events.

Shadow generators

Since the exact location and connection point of all possible new entrant generators cannot be determined in advance, AEMO assumes they would be connected to nodes where there are already existing commissioned generators. This allows the new entrant power plant to 'shadow' the impact of the existing capacity to the network (thermal constraints and marginal loss factor).

The criteria for selecting a node to connect the possible new entrant depends on:

- Available network capacity.
- Proximity to the specified zone the new entrant is modelled to be connected.
- Access to fuel source (such as pipelines).

Existing thermal constraints are modified to reflect impact of these new entrant generators on the network.

Stability constraints and RoCoF constraints are sometimes not adjusted as this is not as straightforward as the thermal constraints adjustment.

¹⁵ AEMO. Constraint Formulation Guidelines, at http://www.aemo.com.au/-/media/Files/Electricity/NEM/Security_and_Reliability/Congestion-Information/2016/Constraint_Formulation_Guidelines_v10_1.pdf.

¹⁶ AEMO. ESOO model and constraint ratings, at <https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/NEM-Electricity-Statement-of-Opportunities>.

2.4.6 Inter-regional loss model

In the time-sequential model, losses on notional interconnectors are modelled using the marginal loss factor equations defined in the *List of Regional Boundaries and Marginal Loss Factors* report¹⁷. For most interconnectors, these are defined as a function of regional load and flow.

AEMO uses proportioning factors to assign losses on interconnectors to regions. Operationally, this is used to determine settlement surplus. In long term modelling, proportioning factors are used to allocate losses to demand in each region. Proportioning factors are derived from marginal loss factors, as described in *Proportioning of Inter-Regional Losses to Regions*. Proportioning factors are given in the annual *List of Regional Boundaries and Marginal Loss Factors* report.

Future augmentation options between regions not currently interconnected will have an estimated proportioning factor assigned to each region.

2.5 Gas supply model

The gas supply model assesses reserves, production and transmission capacity adequacy for the GSOO. The model performs gas network production and pipeline optimisation at daily time intervals that minimises the total cost of production and transmission, subject to capacity constraints.

Assessment of reserves requires the gas supply model to consider the difference between production and pipeline solutions to supply any shortfall. An augmentation of production near supply shortfall may draw on a different reserve to a pipeline augmentation solution, leading to different reserve depletion projections.

For example, a supply shortfall in Melbourne may be addressed by increasing production from the Gippsland Basin, increasing production from the Otway Basin, or increasing pipeline capacity between the Moomba–Sydney Pipeline and Melbourne, which will ultimately source gas from north-eastern South Australia or Queensland.

The gas supply model does not contain cost-related information in sufficient detail to form a reliable view on pipeline and production augmentation based on cost-efficiency alone. It therefore does not co-optimize pipeline expansion from a number of options like the capacity outlook model does. Instead, when a supply shortfall is reported that may be alleviated with a transmission project, the model can be used to perform sensitivity analysis to test the ability of an augmentation or new supply source to restore supply.

More information on the detailed gas supply and demand methodologies are available within AEMO's GSOO publication materials¹⁸.

2.6 Network development outlook model

The network development outlook model contains a highly detailed representation of the physical transmission network underlying the NEM, including individual generating units, transmission lines, transformers, switching elements, reactive power management elements, and loads represented at transmission connection points. All major transmission elements and limitations in the NEM are represented.

In most cases, major transmission elements are those that operate at 66 kilovolts (kV) and above, however there are some radial elements operating that are not represented, and there are some elements operating at lower voltages that are represented because they perform transmission functions.

¹⁷ AEMO. Loss Factors and Regional Boundaries, at <http://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Security-and-reliability/Loss-factor-and-regional-boundaries>.

¹⁸ AEMO, Gas Statement of Opportunities methodology – supply adequacy, at <https://www.aemo.com.au/Gas/National-planning-and-forecasting/Gas-Statement-of-Opportunities>

The model is used to assess intra-regional transmission system adequacy under a range of conditions.¹⁹ Different types of planning studies require a different level of detail in the network representation as well as the adequacy assessment. For example, long-term planning studies such as the ISP are more exploratory in nature and require a higher level network representation than a study into the local needs of a specific area.

The assessment is performed by undertaking load flow analysis, which calculates the instantaneous flow of power between locations where energy is generated and where it is used. This modelling validates the generation and transmission outlook from the capacity outlook model and the dispatch outcomes of the time-sequential model by confirming that the power system continues to operate in a secure and reliable manner as demand changes and the generation mix changes.

Reliability is assessed by monitoring the loading on the transmission network when the power system is operating with all equipment in-service (system normal) and also under a potential unplanned outage of a transmission network element or generating unit. The assessment considers the capability of the transmission system for transfer of energy and identifies network limitations²⁰ that may be constraining power flow.

2.6.1 Ratings

Ratings on modelled transmission elements change according to the instant of time considered in each model solution. In summer, transmission element capability ratings are generally lower because higher ambient temperatures make it more difficult for those elements to dissipate heat.

AEMO uses continuous ratings for system normal pre-contingency load flow analysis.

Transmission elements may be operated above their continuous ratings for short periods of time. These short-term ratings are used for contingency load flow analysis, as contingencies are expected to be cleared relatively quickly by power system operators.

2.6.2 Response to network limitation

The primary result of the load flow analysis is a list of the transmission system elements that may be overloaded during times of high demand under the projected conditions of demand and generation and transmission expansion. To inform this assessment, hourly generation and interconnector flows for snapshots in time are obtained from the time-sequential model.

When the power system model identifies thermal overload on monitored power system elements, AEMO modelling addresses the overload using a series of techniques that attempt to minimise costs:

- Re-dispatch generation – more expensive generation closer to the load is dispatched in preference to the generation that was dispatched by the time-sequential model.
- If simple re-dispatch cannot address the overload, relocate new generation to an alternative connection point in the same planning zone.
- If relocation of generation in the same zone cannot address the overload, relocate new generation to an adjacent zone.
- If relocation and re-dispatch of generation cannot address the overload, choose an appropriate intra-regional transmission system augmentation to address the overload directly. This may be an option presented by jurisdictional planning bodies in their annual planning reports or an option developed by AEMO.
- If intra-regional transmission augmentation is required and the cost of identified augmentations is considered material to the generation and transmission outlook, the augmentation cost is added to the

¹⁹ The capacity outlook model contains options to augment inter-regional transfer capabilities, but its regional representation prevents consideration of intra-regional limitations.

²⁰ Thermal limitations arise due to the resistance of transmission lines to the flow of electrical current. When energy flows, transmission lines heat up and begin to sag. Transmission lines may be damaged if allowed to become too hot for too long and if allowed to sag, they could breach minimum safety clearances. Thermal limitations constrain the flow of current to prevent unsafe operation or potentially damaging heating of the conductors.

costs of new generation considered by the capacity outlook model, in the zone where the augmentation is required. The capacity outlook model is re-solved, which may result in the relocation of generation, different transmission system augmentations being chosen, a combination of both, or no change to the expansion plan. Alternatively, additional peaking generation capacity may be added to the region to support load if the network overload results in USE. The expansion plan is considered stable when no further locations of transmission overload are identified.

3. Demand assumptions

3.1 Demand forecasts

Change in demand for electricity and gas is one of the drivers of the evolution of energy production and transmission systems. Demand can be measured in two ways:

- The amount of energy that is consumed over the course of time.
- The amount of power that is consumed instantaneously.

For electricity, these are referred to as *consumption* and *maximum demand* (MD) respectively, and are measured in megawatt hours (MWh, energy) or megawatts (MW, power).

For gas, where instantaneous demand has a lesser impact on supply, the concept of instantaneous power is less relevant and gas demand is often expressed in terms of a specific timeframe: maximum hourly quantity (MHQ), maximum daily quantity (MDQ) or annual quantity. All are measured in gigajoules (GJ), terajoules (TJ) or petajoules (PJ) depending on the length of time under consideration.

AEMO incorporates regional electricity and gas demand projections within the scenarios defined for Planning and Forecasting activities, including the ISP, ESOO and GSOO. The electricity forecasts present 10%, 50% and 90% POE MD and consumption projections for each NEM region up to 20 years into the future. These projections are extended to a longer range for use in all long-term market modelling activities. The 50% POE projections reflect an expectation of typical MD conditions. The 10% POE projections reflect an expectation of more extreme MD conditions driven by variations in weather conditions. Projected consumption is the same in each case. The 90% POE MD forecast is not considered in assessing gas and electricity infrastructure requirements for the ISP.

The electricity forecasts may be represented as operational or underlying, 'sent out' or 'as generated'; typically they are represented as operational demand 'sent out':

- Operational demand refers to the electricity used by residential, commercial, and large industrial consumers, as supplied by scheduled and significant non-scheduled generating units. It does not include demand met by rooftop PV (that is, operational demand decreases as rooftop PV generation increases).
- 'Sent out' refers to operational consumption or demand that excludes generator auxiliary load.

AEMO's demand forecasting methodology and current assumptions are detailed in the Demand Forecasting Methodology Information Paper and supplementary materials²¹.

3.2 Demand traces

The operational annual consumption, maximum demand and minimum demand forecasts are converted into half-hourly demand traces for each region for use in the capacity outlook models and the time-sequential model. Demand trace development relies on historical reference years to provide guidance on the typical daily and weekly demand shapes, variations from hour to hour, and correlations with other regions. The use

²¹ AEMO, 2018, Electricity Demand Forecasting Methodology Information Paper, at https://www.aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/NEM_ESOO/2018/Electricity-Demand-Forecasting-Methodology-Information-Paper.pdf.

of historical reference years is internally consistent with capturing weather variability for renewable generation, hydro inflows, and network ratings.

The process used to develop the demand traces is detailed in the Demand Forecasting Methodology Information Paper.

3.2.1 Electric vehicles and small -scale battery storage

Electric vehicles (EVs) are expected to become a new source of electricity demand within the typical timeframes of AEMO's long-term planning, and may provide the capability to also discharge to offset consumption at times of peak demand with implementation of vehicle-to-home discharging. Charging of EVs will add load to the power system, and the timing of this will depend on the available infrastructure to drivers, driving behaviours and distances and the availability of tariffs that may incentivise charging structures that minimise grid disruption and costs.

Small-scale batteries charge and discharge typically to manage household loads, however the development and deployment of battery aggregators will enable the development of virtual power plants (VPP). AEMO models aggregated distributed storage systems as operating to meet system peaks (rather than household demand). These VPPs are assumed to operate with day-ahead foresight and optimise charge and discharge behaviours to minimise total system costs. These batteries could also be operated to offset the risk of unserved energy. Currently, no limitation is placed on the frequency of aggregators to interact with these VPP-enabled ESS devices.

Non-aggregated battery systems installed by homeowners are assumed to operate to minimise costs for supply paid for that household. This is much more passive behaviour, and may not discharge optimally with market requirements, instead following default battery algorithms to discharge when stored energy is available to meet demand that exceeds on-site generation through rooftop PV systems.

3.2.2 Demand side participation

Demand-side participation (DSP) typically appears as short-term curtailment of non-scheduled load or the provision of unscheduled generation in respect to the demand for, or price of, electricity. It may also occur in accordance with a contractual arrangement between a Participant and a customer. It is often provided by industrial customers that have large, yet interruptible, loads. The DSP projections represent the most likely amount of response, at defined wholesale price bands, and are assumed 100% reliable when applied to market modelling.

Submissions to AEMO's DSP data portal²² assist in developing these DSP projections.

3.3 Gas demand forecasts

Gas demand forecasts are produced for four customer categories:

- Mass market (residential and commercial) customers.
- Large industrial facilities.
- GPG.
- LNG export facilities.

Detailed forecasts are developed by AEMO each year and published in the GSOO. Detailed descriptions of daily gas demand development are presented in the GSOO methodology document²³.

²² AEMO. Demand Side Participation Information Guidelines, at <https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/Demand-Side-Participation-Information-Guidelines>.

²³ AEMO. Gas Statement of Opportunities, at http://aemo.com.au/-/media/Files/Gas/National_Planning_and_Forecasting/GSOO/2019/Gas-Demand-Forecasting-Methodology.pdf.

4. Supply assumptions

4.1 Energy production facilities

4.1.1 Electricity generation parameters

All market simulation results are influenced by the generator's technical parameters used in the models. Table 4 provides a summary of the key parameters and describes how they are incorporated within the market models. Generator properties such as capacities, efficiency, marginal loss factors, minimum generation levels, and forced outage rates simultaneously drive the modelling results, details of these parameters are presented in the ISP assumptions book²⁴.

Table 4 Summary of generator technical parameters

Parameters	Description	Relevance	Modelling methodology
Rated capacities	Seasonal capacities reflect thermal generators weather dependence	Summer regional capacities tend to be lower than winter	Seasonal ratings of capacities
Minimum generation level	Technical minimum stable loading	Forces units to generate at a certain level	Constant minimum generation level
Firm capacities	Reliable capacity able to generate during peak demand	Contributes to the available capacity to serve maximum demand and minimum capacity reserve level	Seasonal ratings for scheduled generator Contribution to peak demand for variable generators
Ramp rate	Rate at which generation can increase output	May constrain generation output	Constant rate from minimum generation level to maximum capacity
Minimum uptime	Technical limitation on the length of time thermal generators must remain online	Impact the unit commitment schedule	Number of hours
Auxiliary load	Station load that supports operation of the power station	Lessens the generation supplied to the operational consumption	As percentage of 'as gen' production
Heat rate	Efficiency of converting the chemical or potential energy to electrical energy	Cost of electricity production	Constant conversion rate
Emission rate	CO ₂ -e production for each MWh of electric energy produce.	Achieving targeted carbon budgets	Constant emission production rate

²⁴ AEMO. ISP Assumptions, at <https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/Integrated-System-Plan>.

Parameters	Description	Relevance	Modelling methodology
Inflow rates	Historical reservoir inflow represented as monthly inflow rates	Hydroelectric generators availability depends on dam levels	Annual sequence based on historical data
Outage rates	Historical maintenance and unplanned failure rates describe the probability of capacity derating of each technology	Further lowers the regional available capacity to serve operational consumption	Maintenance rates and probability of failure and derated capacities
Marginal loss factor	Impact of network losses on spot prices is represented as loss factors.	Incentivise generators that lowers network losses and penalize those the increase it	Factor for each node in the NEM

The generation economic parameters outlined in Table 5 influence the results of both the capacity outlook model and the time-sequential model.

Table 5 Generator economic parameters summary

Parameters	Description	Relevance	Modelling methodology
FO&M cost	Annual fixed cost for keeping plants in service	Increases the cost of keeping the plants in service	Fixed cost per MW of installed capacity
VO&M cost	Additional cost for running the units	Impacts the generators' running costs	Fixed rate per MWh of electricity production
Gas fuel cost	Gas price path for each existing GPG and gas zones	Impacts the gas generators' running costs	Fixed rate per GJ of fuel consumed
Coal fuel cost	Coal price path for each existing coal plants	Impacts the coal generators' running costs	Fixed rate per GJ of fuel consumed
Build cost	Overnight investment cost for each available generation technology	Shift from one technology to another over the outlook period	Overnight cost per MW of capacity
Connection cost	Cost of accessing network	Represents additional cost for network access	Overnight cost per MW of capacity
WACC	Cost of capital	Amortisation of build cost	Percentage
Economic life	Project life	Capital payment period	Number of years
Minimum capacity factors	Represents the minimum technical and economic duty cycles	Applied on the Capacity Outlook Model to represent the minimum economic running regime	Percentage of total available energy for production
Reservoir initial dam level	Latest dam levels	Available water for generation at the start of every year	Dam volume levels are updated every year in GL

This information for each of these data sets comes from a variety of sources. AEMO's current assumptions are collated and reported within the 2019 Inputs and Assumptions Workbook, available as part of AEMO's planning and forecasting inputs, assumptions and methodologies data set²⁵.

²⁵ AEMO. Inputs, assumptions and methodologies. Available at <https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/Inputs-Assumptions-and-Methodologies>

Marginal loss factors

MLFs represent the incremental loss incurred for an incremental unit of power supplied at connection points and determines the marginal impact of losses on spot prices. It incentivises generator development and operation to locations that lowers network losses and penalises those the increase losses.

MLFs are pre-computed figures that are influenced by forecast demand, network configuration, and generation dispatch. This is modelled explicitly as a static factor that does not change over the outlook period.

AEMO performs an annual study to estimate the MLF for each connection point using historical network performance and forecast consumption. Generators are assigned with the MLF for the connection point they are connected to.

For further information, please refer to the latest Loss Factors and Regional Boundaries page²⁶.

4.1.2 Gas production facilities

The gas supply model contains a representation of approximately 40 gas production facilities that inject gas into the eastern and south-eastern Australian gas transmission network. The representation is limited to the connection point and maximum supply capacity of each facility, and the annual field production limits. The gas supply model also contains LNG import facilities as a build option to address any potential gas shortfalls.

The gas supply-demand outlook model does not contain information about forced outages, production ramp rates or maintenance schedules.

The gas supply model uses a representation of the cost of gas production at each facility to optimise pipeline flows.

For further information, please refer to the latest Gas Supply Adequacy Methodology Information Paper²⁷.

4.2 Energy project commitment criteria

New generation or gas production projects may be included in the capacity outlook model, time-sequential model, or gas supply model simulations.

In the capacity outlook model, new generators are partitioned by fuel type, technology, and location within the electricity planning zones. Each technology will take on specific values for parameters of importance such as thermal efficiency, emission characteristics, minimum stable generation levels, standard capacities, build costs, and appropriate earliest dates for which the technology is considered current.²⁸ Each location imposes different fuel costs that reflect the fuel availability and transport requirements applicable to each zone. Committed projects are included in the capacity outlook and time-sequential models.

The time-sequential model uses the generation and transmission outlooks developed by the capacity outlook model.

The gas supply model includes committed production and transmission projects and a selection of proposals that are assessed for their efficacy in eliminating supply shortfall.

²⁶ AEMO. Loss Factors and Regional Boundaries, at <http://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Security-and-reliability/Loss-factor-and-regional-boundaries>.

²⁷ AEMO, 2019 Gas Supply Adequacy Methodology Information Paper, at https://www.aemo.com.au/-/media/Files/Gas/National_Planning_and_Forecasting/GSOO/2019/Gas-Supply-Adequacy-Methodology.pdf.

²⁸ Technologies that are not yet in commercial development are assigned an earliest build date.

Electricity projects

New generation and transmission projects are assessed against five different commitment categories, described in Table 6, that must be assessed to determine the level of commitment. Depending on the number of these categories that have been satisfied, the commitment level is determined as shown in 0.

Table 6 Commitment Category descriptions

Category	Criteria
Site	The project proponent has purchased/settled/acquired (or commenced legal proceedings to purchase/settle/acquire) land for the construction of the project.
Major components	Contracts for the supply and construction of major plant or equipment components (such as generating units, turbines, boilers, transmission towers, conductors, and terminal station equipment) have been finalised and executed, including any provisions for cancellation payments.
Planning consents, construction and connection approvals, EIS	The proponent has obtained all required planning consents, construction approvals, connection contracts (including Generator Performance Standard agreement from AEMO in the form of the 534A letter), and licences, including completion and acceptance of any necessary environmental impact statements.
Finance	The financing arrangements for the proposal, including any debt plans, must have been concluded and contracts executed.
Final construction and commercial use dates set	Construction of the proposal must either have commenced or a firm commencement date must have been set. Commercial use date for full operation must have been set.

Table 7 Minimum commitment criteria

Category	Committed	Committed *		Advanced		Maturing	Emerging	Publicly Announced
Site	●	●	●	●	●	●	●	●
Components	●	●	●	●	●	●	●	●
Planning	●	●	●	●	●	●	●	●
Finance	●	●	●	●	●	●	●	●
Date	●	●	●	●	●	●	●	●

A commitment category is deemed to be satisfied if all associated questions have been answered in the positive, with the category represented as green. An amber status reflects that some, but not all, of the questions have been answered in the positive. A status of red means that no questions within that category were answered positive.

Table 8 provides a description for each of these commitment categories.

Committed new generation projects are sourced from AEMO's Generation Information Page, using the latest information available when modelling begins. Committed generation projects are included, with fixed timing and without build costs, in all electricity modelling.

Conceptual utility-scale generation and storage projects are developed using a combination of technology cost and performance data from different sources which can be found at AEMO’s website²⁹.

The capacity outlook model develops a generation and transmission outlook for each studied scenario. The plant configurations selected as candidates for entry are included in the capacity outlook model.

Table 8 Commitment category descriptions

Commitment status	Description
Committed	Projects that will proceed, with known timing, satisfying all five of the commitment criteria. That is, all categories are green.
Committed*	Projects that qualify as “Advanced” and where construction or installation has also commenced. Typically, Committed* projects are included in sensitivity analysis for MLF calculations and in the base case for reliability assessments.
Advanced	Projects that are highly likely to proceed, satisfying Site, Finance and Date criteria plus either Planning or Components criteria. Progress towards meeting the final criteria is also evidenced.
Maturing	Projects that have progressed with site, planning applications, and finance arrangements, but not to the point that they can be classified as advanced. Maturing projects may be explicitly included in scenario analysis to assess future reliability or market impacts and are tested for economic efficiency in capacity outlook modelling.
Emerging	Projects with financing arrangements, but site/planning approvals/construction is uncertain, and development is strongly subject to changes in policy or commercial environment. These projects may be explicitly included in scenario analysis to assess future market impacts and are tested for economic efficiency in capacity outlook modelling. However, a higher weighted average cost of capital will be assumed to reflect greater development uncertainty compared to proposed projects.
Publicly announced	These projects have been announced publicly, but do not yet have any finance arrangements in place. Costs and capabilities of these projects are developed using recently-completed projects and projections of cost components such as raw material supply and labour.

Gas projects

AEMO is working with industry to clarify project definitions for gas projects to create a set of commitment criteria similar to electricity projects. In the interim, AEMO applies the following definitions for production and transmission projects:

- **Committed** projects are actively under development planning and have passed final investment decision (FID).
- **Anticipated** projects are actively under development planning utilising existing production infrastructure, so there is a reasonable likelihood of them proceeding. These anticipated projects may include quantities of undeveloped reserves and contingent resources.
- **Uncertain** projects are those projects that are considered much more uncertain to be developed and are not as far along the development planning path. In the long term, uncertain projects include uncertain 2C contingent³⁰ and prospective resources that are accessible by existing pipeline and processing infrastructure.

New gas projects are sourced from AEMO’s annual GSOO survey, using the latest information available when modelling begins. Committed projects are included with fixed timing and without build costs, in all gas

²⁹ AEMO. ISP Available at <http://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/Integrated-System-Plan>.

³⁰ 2C contingent reserves refer to the best estimate of contingent resources – equivalent to 2P (proved and probable reserves), except for one or more contingencies or uncertainties currently impacting the likelihood of development.

modelling. Anticipated, uncertain and generic projects are included as candidates in the capacity outlook model or included as fixed sensitivities in the GSOO modelling.

4.3 Renewable resources

4.3.1 Variable generation

Generally, the following variable generation types are modelled, for planning purposes:

- All scheduled and semi-scheduled generation.
- Some significant non-scheduled generation with capacities greater than or equal to 30 MW.
- Those that are believed to impact simulated network capability.

As variable generation's output depends on their fuel source availability, wind farm generation is limited by the wind speed, and solar farms are limited by solar irradiance.

AEMO considered a range of requirements for the selection of preferred REZs. This section presents the methodology applied to determine resource quality, potential wind and solar generation capacity, transmission investment to develop REZs, projected network losses and diversity of renewable generation within the region and across REZs.

4.3.2 Renewable Resource quality

The resource quality for potential REZs is 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. This information has been provided by DNV-GL.

AEMO represents the wind resource available in each REZ in two tranches, to represent the resource quality differences that are observed in the mesoscale data. The first tranche represents the highest quality wind resource, and maximum build limits are applied given the land area identified through the mesoscale data at a 5km resolution (the granularity of the mesoscale data).

The second tranche represents the remaining good quality resource – above the average of the REZ, as wind development would be targeted at only the better wind sites. Build limits also apply for this second tranche.

Wind generation profiles

The DNV-GL mesoscale data provides wind measurements at a granularity of 5km. AEMO's representation of the renewable resource must sample from this dataset (or historical measurements for existing wind farms) to produce reasonable representations of wind resources.

AEMO represents the wind resource available in each REZ in two tranches, to represent the resource quality differences that are observed in the mesoscale data. The first tranche represents the highest quality wind resource (top 5%), and maximum build limits are applied given the land area identified through the mesoscale data at a 5km resolution (the granularity of the mesoscale data).

The second tranche represents the remaining good quality resource – above the average of the REZ, as wind development would be targeted at only the better wind sites (sites which are in the top 20% of locations, not including the first tranche resources). Build limits also apply for this second tranche.

Where possible, generation traces for existing wind farms are based on historical output for the period that they have been in full service. For earlier reference years (prior to commissioning) AEMO applies a power curve derived from metered output to mesoscale data at the wind farm's location (the nearest 5km grid location) to construct the generation profile. For new wind farms AEMO applies a reference wind-turbine power curve to the selected REZ tranche 5km location.

Solar generation profiles

For solar generation, AEMO considers a collection of connection points within each REZ as potential network connection locations. Using the nearest available BOM weather station's satellite irradiance data³¹ and using the System Advisor Model (SAM)³² AEMO develops a solar resource trace for each location. Air temperature measurements and wind speed data is captured within the SAM model to capture the effects of ambient temperatures on the generation profile, with higher ambient temperatures (adjusted by the cooling effect of wind) de-rating the generation capability of the panels. AEMO uses the mesoscale wind data and BOM weather station temperature measurements for this.

Existing and committed solar projects are modelled as either single-axis tracking or fixed flat panels, depending on the technology actually installed. New REZ solar traces are either single-axis tracking (as the dominant solar PV technology) or concentrated solar thermal.

Generation traces for the energy available from existing, committed and potential wind and solar farms are created over the same reference years as the demand traces and hydro inflows. The base traces model what each generator would have produced if it was operating during the reference period and not constrained by the limitations of the network. These base traces are projected into the future as per the demand traces, such that the weather relationships between demand, solar and wind conditions are preserved.

4.3.3 Network capacity and transmission investment

High level network studies are undertaken to identify additional generation which can be accommodated within the existing network. In addition, interconnector expansion options are assessed to identify additional generation that may be enabled by interconnectors developed near or through REZs. The following steps are undertaken:

- Amount of additional generation which can be added within the existing transmission network capability.
- Amount of additional generation which can be added with inter-regional network upgrade options.
- Network expansion to connect REZs to the major transmission network and amount of generation which can be accommodated.
- Cost estimate of transmission network expansion to connect REZs

The cost estimates to connect each REZ is applied within the capacity outlook models as a linear cost to increase the development potential of each REZ beyond existing transmission connection capabilities. Expansion of the REZ capacity may then be selected by the capacity outlook models at the determined linear expansion cost. Inter-regional network upgrades also may be selected to increase REZ expansion capacity.

4.3.4 Hydroelectric generation schemes

The NEM contains scheduled hydroelectric generators in Tasmania, Victoria, New South Wales, and Queensland. These schemes are typically modelled with their associated reservoirs and water inflows. For each reservoir, the capacity, initial levels, and the expected inflows considering rainfall variability and climate change all determine the availability of energy for hydroelectric generation.

Hydro schemes are generally grouped into three modelling methods:

- Generator constrained – for the Victorian hydroelectric generation scheme (excluding Murray).
- Storage managed – for the Tasmanian hydroelectric generation scheme.
- River chain – for all other hydroelectric generation scheme.

³¹ At <http://www.bom.gov.au/climate/how/newproducts/IDCJAD0111.shtml>.

³² System Advisor Model (SAM) developed by the National Renewable Energy Laboratory (NREL) is a techno-economic model designed to facilitate decision making for the renewable energy industry. More information is available at <https://sam.nrel.gov/>.

In the market simulations, AEMO applies a 'return to average conditions' approach. Reservoir levels are restored to initial levels by the end of each simulated year. Reservoir levels are initialised with levels as at 1 July of the current year, while inflow data reflects long-term average conditions from the start of the simulation period.

For the capacity outlook models, some aggregations and simplifications of some hydro schemes may be used if it is deemed not material to the overall objective of the modelling, and if it simplifies the problem size sufficiently to warrant the simplification.

Generation constrained

Victorian hydroelectric generators' production is modelled by placing a maximum annual capacity factor constraint on each individual generator. The model schedules the electricity production from these generators across the year such that the system cost is minimised within this energy constraint.

Storage management

Tasmanian hydroelectric generation is modelled by means of individual hydroelectric generating systems linked to one of three common storages:

- Long-term storage.
- Medium-term storage.
- Run of river.

Table 9 identifies how schemes or power stations are allocated across these storages and provides an indication of the energy in storage available.

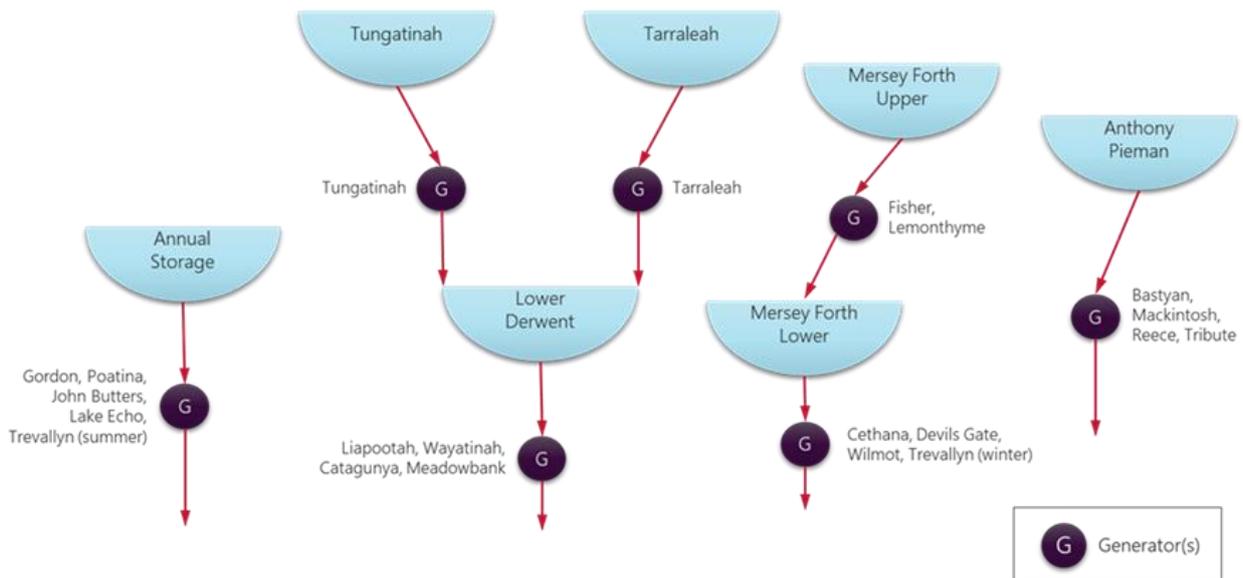
Energy inflow data for each Tasmanian hydro water storage is determined from historical monthly yield information provided by Hydro Tasmania.

Table 9 Storage energy (in GWh) of the three types of generation in Tasmania

Storage Type	Energy in storage	Schemes and Stations
Long-term	12,000	Gordon, Poatina John Butters, Lake Echo, Trevallyn (summer)
Medium-term	400	Derwent
Run of River	200	Antony Pieman, Mersey Forth, Trevallyn (winter)

AEMO's approach to modelling the existing Tasmanian hydro schemes relies on a 7-pond topology designed to better capture different levels of flexibility associated with the different types of storage outlined above (Figure 12).

Figure 12 Hydro Tasmania scheme topology



River chain

Other hydroelectric generation, including the Snowy Scheme is represented by a physical hydrological model, describing parameters such as:

- Maximum volume.
- Initial storage volume.
- Monthly reservoir inflow rates reflecting historical inflows.

Latest information on the monthly storage inflows used in market modelling studies can be found in the 2019 Inputs and Assumptions Workbook.³³

Since the 2018 ISP, AEMO has improved the modelling detail associated with the Snowy Hydro scheme and proposed Snowy 2.0 project, including updated rainfall inputs as well as a revised generation and pond storage topology. Figure 13 presents a representation of the topology currently modelled.

³³ AEMO. 2019 Inputs and Assumptions Workbook, available as part of AEMO's Planning and Forecasting inputs, assumptions and methodologies, at <https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/Inputs-Assumptions-and-Methodologies>.

Figure 13 Snowy Hydro scheme topology

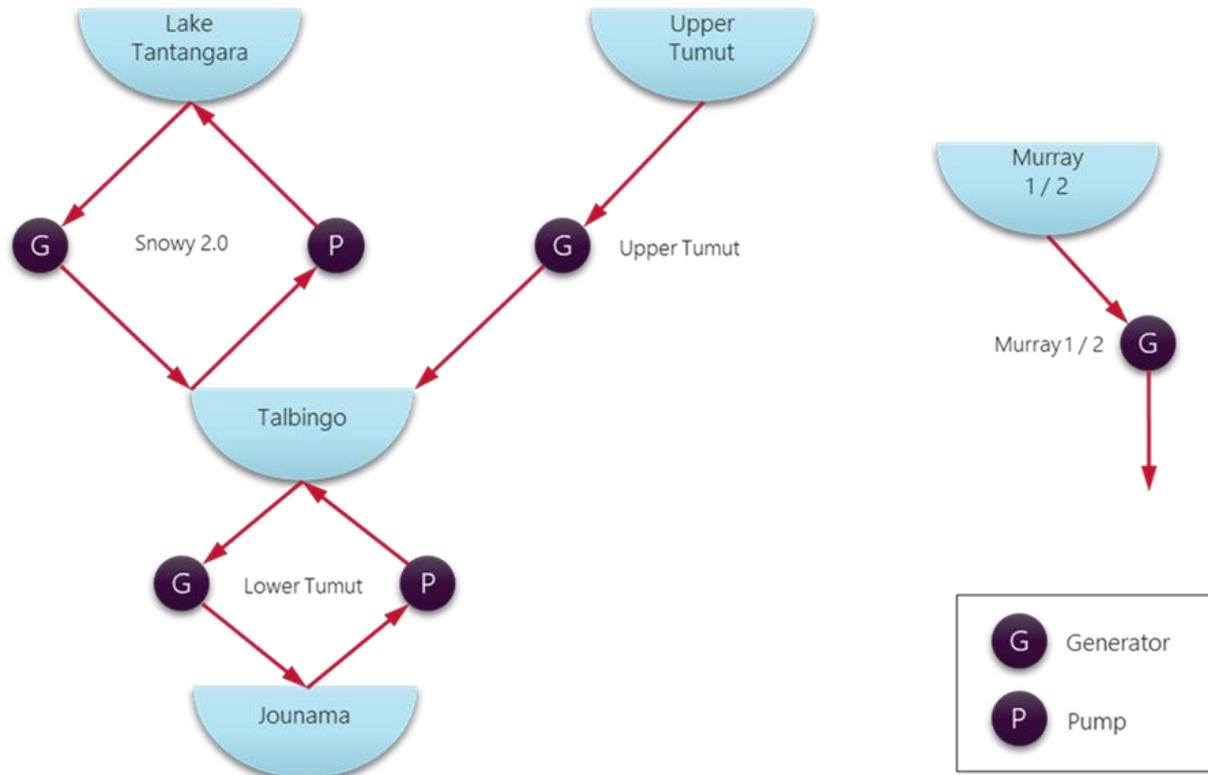
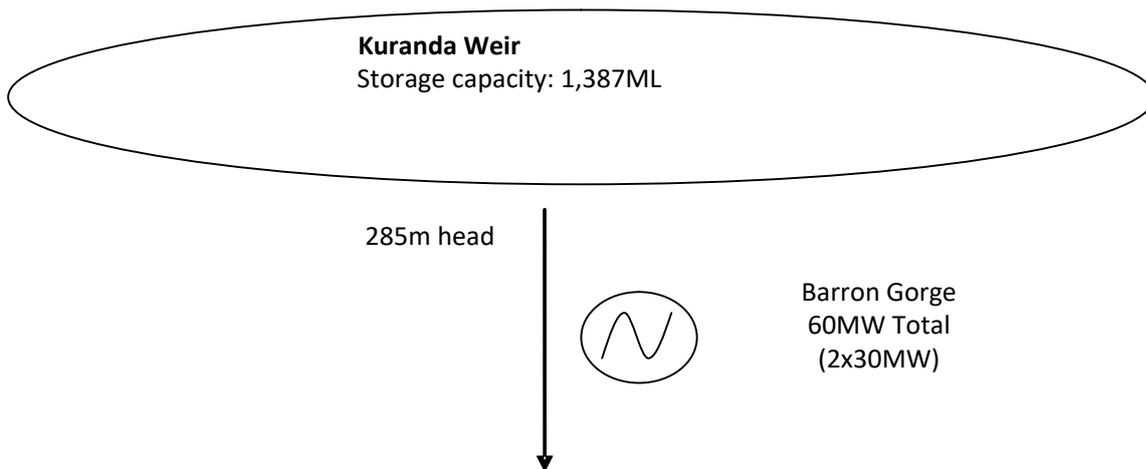


Figure 14 to Figure 22 provide graphic representations of the other hydrological models used in the market simulations, as well as the registered capacity of the adjoining generating units.³⁴

Figure 14 Barron Gorge power station hydro model



³⁴ Storage capacities are defined in megalitres (ML).

Figure 15 Blowering power station hydro model

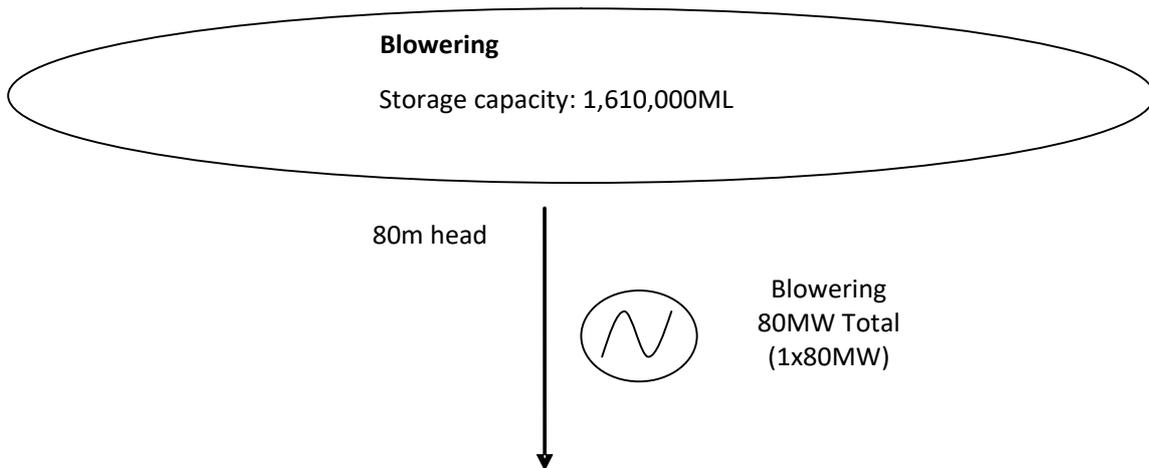


Figure 16 Hume power station hydro model

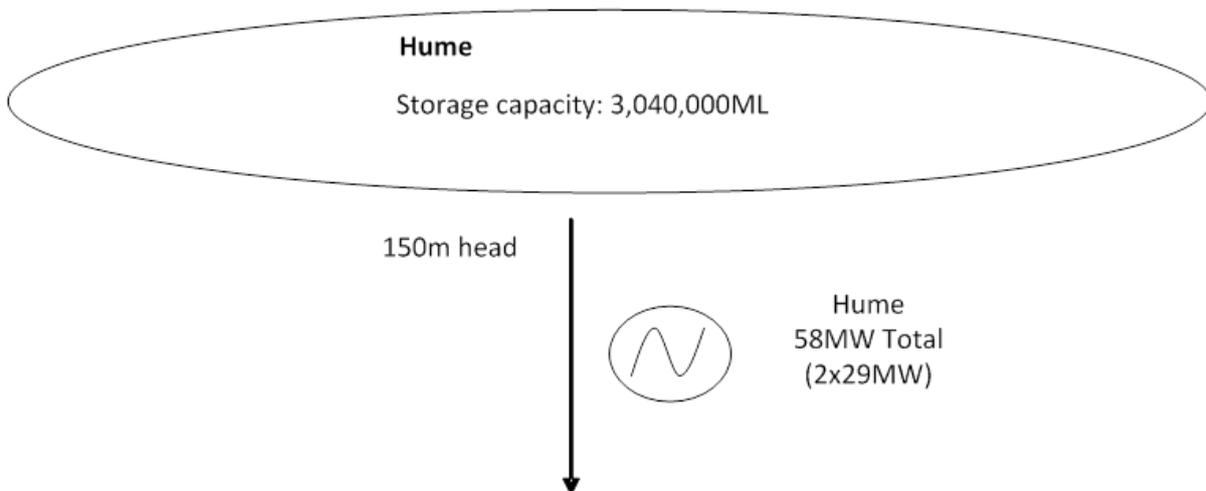


Figure 17 Kareeya power station hydro model

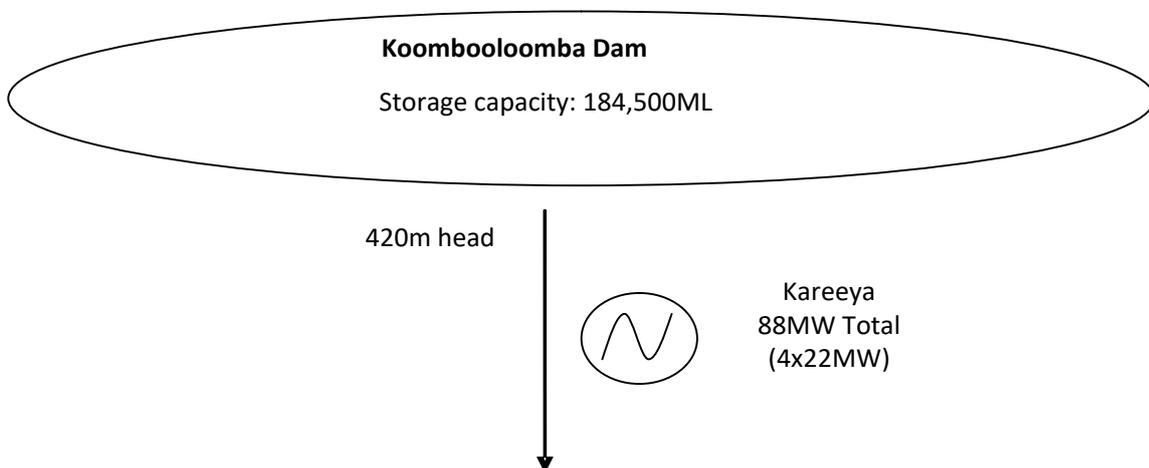


Figure 18 Guthega power station hydro model

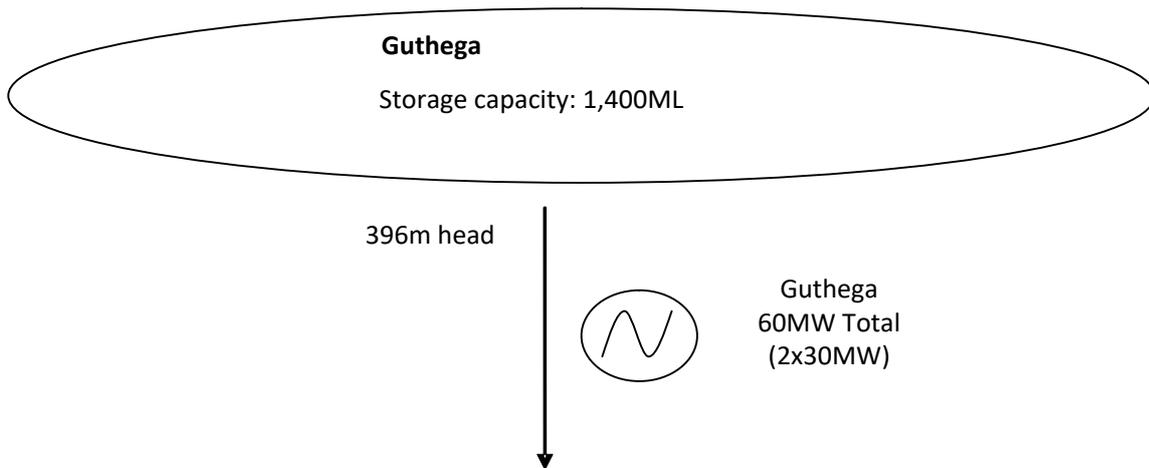
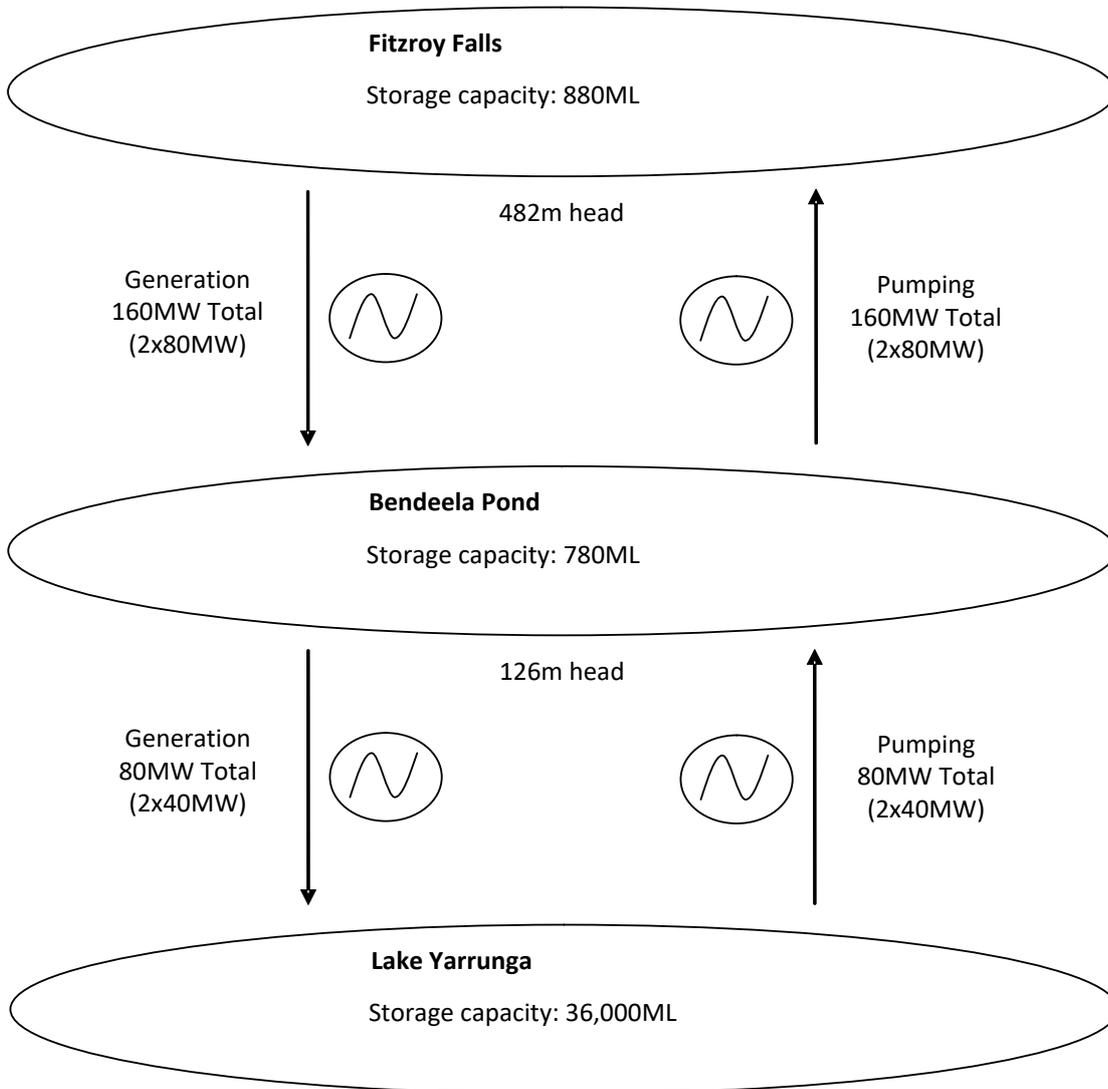


Figure 19 Shoalhaven power station hydro model



Note. Origin Energy has proposed an expansion of the Shoalhaven pumped hydro scheme, increasing the storage capacity of the project. As this project is not yet committed, the representation provided reflects the existing capacity only.

Figure 20 Wivenhoe power station hydro model

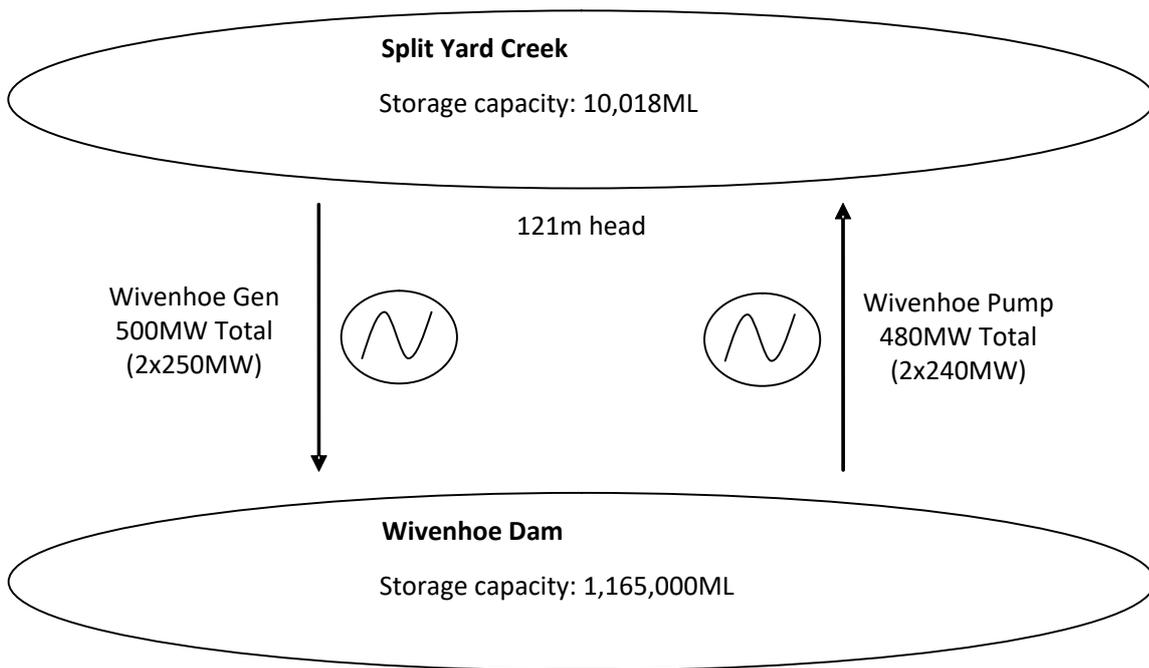


Figure 21 Eildon power station hydro model

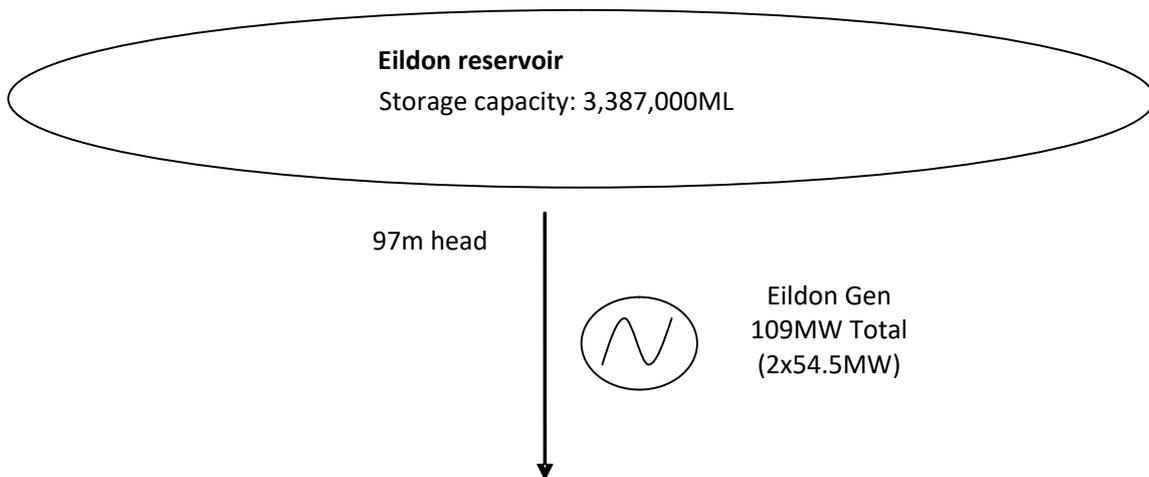
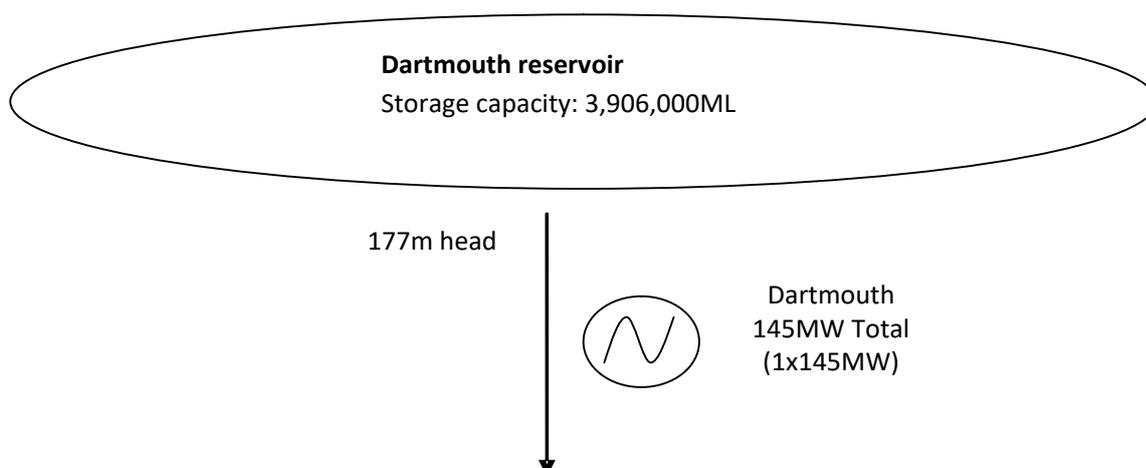


Figure 22 Dartmouth power station hydro model



4.3.5 New pumped hydro schemes

Pumped hydro energy storage (PHES) candidates are modelled as closed systems where the amount of water available to cycle between upper and lower reservoirs is assumed to be constant throughout the technical life of the asset.

AEMO models multiple PHES storage depth options equivalent to 6, 12, 24, and 48 hours.

Entura³⁵ outlined the cumulative amount of storage available per NEM region for each storage size (6-hour storage, 12-hour storage, 24-hour storage, and 48-hour storage). For example, Entura identified 1,200 MW of available 6-hour and 12-hour storage locations in Victoria, 700 MW of 24-hour and 400 MW of 48-hour storage. However, these storage limits were not mutually exclusive; for every MW of 48-hour storage developed, there may be one MW less storage of smaller depth available.

AEMO applies a pre-allocated approach in initially determining the limits applied to all pumped storage depth options in each NEM region, based on storage depth preferences observed in AEMO's ISP PHES Insights modelling³⁶. Acknowledging the pre-determined nature of these limits, AEMO will apply further refinements and adjustments to the limits based on modelling outcomes, if these limits prove to be overly constraining.

This approach will allow the capacity outlook model to identify a suite of storage candidates across the forecast horizon, addressing evolving challenges that are mitigated by alternative storage duration options. AEMO will refine the storage limits where reached by "shifting" capacity from higher duration candidates to smaller duration if identified as a lower cost option by the model.

For example, based on the identified limits in Victoria, if the model identifies the need for 1,200MW of six hour storage and only 600MW for 12 hour storage, AEMO would then explore increasing the six hour limit by reallocating capacity from the 12 hour candidates. This approach allows for large duration candidates to be repurposed if under certain scenarios shorter duration storage provides for a lower cost outcome.

³⁵ Entura, 2018, Pumped hydro cost modelling, at https://www.aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/Inputs-Assumptions-Methodologies/2019/Report-Pumped-Hydro-Cost-Modelling.pdf.

³⁶ ISP Insights – Building power system resilience with pumped hydro energy storage, at https://www.aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/ISP/2019/ISP-Insights---Building-power-system-resilience-with-pumped-hydro-energy-storage.pdf.

5. Analysis

5.1 Reliability assessments

AEMO's long-term market modelling activities take into account uncertainties in energy consumption, maximum demand, generator outages and variable generations' intermittence and coincidence with consumption by employing a Monte Carlo simulation approach. A Monte Carlo simulation is an iterative method of running models that:

- Uses different sets of input parameter sensitivities to generate a large population of results that supports statistically robust conclusions.
- In AEMO's market modelling, captures the impact of key uncertainties such as generator outage patterns, weather sensitive demand, intermittent generation availability, and coincidence of demand across regions.

For each iteration of the Monte Carlo simulation, AEMO uses a combination of generator random forced outages, a reference year, and a demand profile that adheres to specific consumption, minimum demand and maximum demand targets. For reliability assessment studies such as the NEM ESOO, hundreds of Monte Carlo iterations are normally completed per simulation year to create statistically robust results and capture the impact of uncertainties around these parameters.

The ESOO methodology report³⁷ is the primary reference for the current methods employed when conducting reliability assessments.

5.2 Market benefits

Some modelling exercises (such as the ISP, a Regulatory Investment Test for Transmission (RIT-T) or the VAPR) are designed to determine the benefit to the market delivered by specific network or non-network augmentation projects.

To value any proposed augmentation, detailed costings of the augmentation, and the counterfactual scenario without the augmentation developed, are modelled. The difference in cost between these two cases represents the market benefit of the augmentation. Where an augmentation is expected to affect the development of generation, a generation expansion plan will also be developed for each case.

AEMO demonstrates the economic value of the augmentation options by providing a high level overview of the potential benefits that are allowable by the Australian Energy Regulator (AER) in a RIT-T.³⁸ The allowable market benefits may include:

- Capital costs benefits – indicates savings from deferring investments.
- Operating cost benefits – indicates operating costs reduction which may include fuel, operating, maintenance, and transmission loss costs savings.
- DSP benefits – the savings from avoiding price-sensitive responses.

³⁷ AEMO, ESOO Methodology Document, at https://www.aemo.com.au/-/media/Files/Stakeholder_Consultation/Consultations/NEM-Consultations/2019/Reliability-Forecasting-Methodology/ESOO-Methodology-Document-v2---draft-2019.pdf.

³⁸ Australian Energy Regulator, at <https://www.aer.gov.au/networks-pipelines/guidelines-schemes-models-reviews/rit-t-and-rit-d-application-guidelines-2018>.

- Reliability benefits – indicates customer reliability improvements measured by the reduction in USE. Reduction in USE due to long-term non-credible contingencies may also be evaluated.
- Environmental scheme benefits – savings from reduced payments for renewable targets.
- Competition benefits – optional under the RIT-T.
- Option value – refers to a benefit that results from retaining flexibility in a situation where there is uncertainty regarding future outcomes, the information that is available in the future is likely to change, and the credible options available are sufficiently flexible to respond to that change.
- Ancillary services benefit – the reduction in net costs required to provide sufficient ancillary services to meet the projected system needs.

The sum of these benefits represents the total market benefits of an augmentation. Comparing these potential market benefits with the cost of the augmentation provides an insight into whether this project is likely to be justified under the RIT-T.

Market benefit analysis requires comparison of a discounted cash flow of total system costs using the most up-to-date range of discount rates.

5.2.1 Generation capital costs

An augmentation may defer generation capital expenditure, saving the cost to finance investment during the deferral period. In extreme cases, generation may not need to be built at all. An augmentation may allow a less capital-intensive form of generation to be established in an alternate location.

Generation capital deferral benefits are determined by capacity outlook modelling outcomes.

5.2.2 Transmission capital costs

An augmentation may defer the need to build other transmission projects. Transmission capital deferral benefits are determined by capacity outlook model outcomes.

5.2.3 Operating cost benefit

An augmentation may relieve limitations on existing or new generation with lower fuel, emissions, fixed or variable operating costs, allowing lower-cost generation to operate more frequently.

System operating cost benefit includes:

- Production costs savings – due to lowered operational costs and includes transmission loss cost.
- Fixed operating and maintenance costs savings – due to decreased total fixed costs incurred for keeping generators in service.

5.2.4 Transmission system losses

An augmentation may allow generation to be dispatched closer to the locations where energy is consumed, reducing the cost to transport energy on the network.

An augmentation may change the flow patterns on interconnectors in ways that reduce losses when transferring power between regions.

Transmission system loss benefits are determined by capacity outlook model outcomes (when new generation is established closer to load centres) and time-sequential modelling outcomes (when changes in network limitations change interconnector flow patterns).

5.2.5 Reliability benefits

A Value of Customer Reliability (VCR, usually expressed in dollars per kilowatt-hour) indicates the value different types of customers place on having reliable electricity supplies under different conditions. It is used to monetise USE so investment options can be compared on an economic basis.

An augmentation may reduce the amount of reported USE, reducing the penalties associated with failing to supply consumers. Reliability benefits are determined by time-sequential modelling outcomes.

5.2.6 Option value and competition benefits

AEMO's modelling activities may quantify option value or competition benefits if these benefits are considered to be material to the outcomes of the study.

6. Financial parameters

Cost-benefit comparisons between augmented and unaugmented cases use a discounted cash flow (present value) calculation to determine the present day value to the market of spending that occurs in the future.

6.1 Inflation

Monetary values in the models refer to real value, as opposed to nominal value.

6.2 Goods and Services Tax

Prices are exclusive of Goods and Service Tax.

6.3 Weighted average cost of capital

The capital cost of an investment is increased beyond its purchase price by the cost of finance. The weighted average cost of capital (WACC) is the rate that a company is willing to pay to finance its assets.³⁹ The WACC is the weighted sum of the cost of debt and the cost of equity, where the cost of debt is determined by interest rates, and the cost of equity is determined by reference against the returns received by other projects with similar risk.

AEMO uses real, pre-tax WACC values in its capacity outlook modelling.

6.4 Discount rate

Present value calculations estimate all future cash flows which are discounted to account for the amount of cash that would need to be invested in the present day to yield the same future cash flow. Lower discount rates emphasise market benefits that accrue later in the modelled horizon, while higher discount rates emphasise market benefits that accrue earlier in the modelled horizon.

AEMO uses a single discount rate to calculate the Net Present Value (NPV) of future cash flows. In AEMO's 2019-20 modelling AEMO applies the same discount rate as the WACC. Sensitivities testing variations in the discount rate may be considered for some analysis where appropriate.

6.5 Project lifetime

Capital investments are annualised over the life of the asset in order for costs to be compared against annual market benefits over the planning horizon.

³⁹ The return the company would expect to receive from an alternative investment with similar risk.

A1. Summary of information sources

AEMO's inputs and assumptions are documented in the 2019 Input and Assumptions Workbook, available at:

- https://www.aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/Inputs-Assumptions-Methodologies/2019/2019-Input-and-Assumptions-workbook.xlsx.

Other inputs are available on AEMO's Input, Assumptions and Methodologies web page, available at:

- <https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/Inputs-Assumptions-and-Methodologies>.

The table below summarises other sources of information.

Table 10 Summary of information sources

Information	Source
Committed and proposed transmission augmentations	Sourced from the Transmission Annual Planning Reports from each Transmission Network Service Provider.
Demand side participation	AEMO internal study, based on industry engagement, available in the ISP Assumptions Workbook and AEMO Demand Side Participation estimates. Available at https://www.aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/Inputs-Assumptions-Methodologies/2019/ .
Emissions intensity factors	Based on external consultation study performed by ACIL Allen – Emission Factors Assumptions Update (at https://www.aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/NTNDP/2016/Data_Sources/ACIL-ALLEN---AEMO-Emissions-Factors-20160511.pdf), published in the 2019 Input and Assumptions Workbook.
Existing and new gas production, storage and transmission infrastructure	GSOO Inputs. Available at https://www.aemo.com.au/Gas/National-planning-and-forecasting/Gas-Statement-of-Opportunities .
Gas and coal prices	Prices are derived by AEMO based on wholesale gas and coal price forecasts produced by Core Energy and Wood Mackenzie. These wholesale prices reflect the underlying market conditions assumed in each of the forecast scenarios. AEMO has adjusted these external forecasts in the near term to reflect recent observations of wholesale prices. The price forecasts (reports and databooks) are available at https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/Inputs-Assumptions-and-Methodologies .
Gas production and transmission costs	GSOO supply input data files. Available at https://www.aemo.com.au/Gas/National-planning-and-forecasting/Gas-Statement-of-Opportunities .

Information	Source
Gas reserves	GSOO supply input data files. Available at https://www.aemo.com.au/Gas/National-planning-and-forecasting/Gas-Statement-of-Opportunities .
Generation inventory	Generation Information Page. Available at http://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/Generation-information .
Generator performance parameters	Based on external consultation study performed by GHD (at http://www.aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/Inputs-Assumptions-Methodologies/2019/GHD-AEMO-revised---2018-19-Costs_and_Technical_Parameter.xlsb), published in the 2019 Input and Assumptions Workbook. Available at https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/Inputs-Assumptions-and-Methodologies .
Marginal loss factors and proportioning factors	Loss Factors and Regional Boundaries. Available at http://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Security-and-reliability/Loss-factor-and-regional-boundaries .
Minimum capacity reserve levels	AEMO internal study, published in the 2019 Input and Assumptions Workbook. Available at https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/Inputs-Assumptions-and-Methodologies .
New generation technology costs	CSIRO – Gen Cost 2018, available at: https://publications.csiro.au/rpr/download?pid=csiro:EP189502&dsid=DS1 .
Projections of demand for LNG export	GSOO Inputs based on engagement directly with LNG producers and external consultation with Lewis Grey Advisory (at https://www.aemo.com.au/-/media/Files/Gas/National_Planning_and_Forecasting/GSOO/2018/Projections-of-Gas-and-Electricity-Used-in-LNG-2017-Final-Report-19--12-17.pdf). Available at https://www.aemo.com.au/Gas/National-planning-and-forecasting/Gas-Statement-of-Opportunities .
Regional electricity energy and maximum demand forecasts and gas demand forecasts	National Electricity Forecasts, published in ESOO, and National Gas Forecasts, published in GSOO. Available at http://forecasting.aemo.com.au/ .
Reliability Standard	Reliability Standards (AEMC). Available at https://www.aemc.gov.au/our-work/developing-electricity-guidelines-and-standards .
Renewable energy targets	Clean Energy Regulator Available at http://www.cleanenergyregulator.gov.au/RET/ . Implementation of GreenPower, ACT 100% renewables, QRET and VRET targets as described in the 2019 Input and Assumptions Workbook.
Significant constraint equations	AEMO internal development. Available at https://www.aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/Inputs-Assumptions-Methodologies/2019/ .
Wind contribution to peak demand	Available in the 2019 Input and Assumptions Workbook, available at Available at https://www.aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/Inputs-Assumptions-Methodologies/2019/2019-Input-and-Assumptions-workbook.xlsx .