



## **Australian Research in Power Systems Transition**

# **Topic 4 – Planning**

**2025/26 Resource adequacy, risk and resilience  
in low-carbon energy system planning: Methods,  
tools and metrics**

Commonwealth Scientific and Industrial Research  
Organisation

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# Acronyms

<b>AEMO</b>	Australian Energy Market Operator
<b>AEMC</b>	Australian Energy Market Commission
<b>AI</b>	Artificial intelligence
<b>AR-PST</b>	Australian Research in Power Systems Transition
<b>CER</b>	Consumer energy resources
<b>CSIRO</b>	Commonwealth Scientific and Industrial Research Organisation
<b>DER</b>	Distributed energy resources
<b>DNSP</b>	Distribution network service provider
<b>ECMC</b>	Energy and Climate Change Ministerial Council
<b>ELR</b>	Energy-limited resources
<b>ESS</b>	Energy storage systems
<b>ESOO</b>	Electricity Statement of Opportunities
<b>GPG</b>	Gas-powered generators
<b>ISP</b>	Integrated System Plan
<b>ISON</b>	International System Operator Network
<b>IASR</b>	Inputs, Assumptions and Scenarios Report
<b>NLR</b>	National Laboratory of the Rockies
<b>NEM</b>	National Electricity Market
<b>PISP</b>	Parser of the Integrated System Plan
<b>PRAS</b>	Probabilistic Resource Adequacy Suite
<b>REZ</b>	Renewable energy zone
<b>SME</b>	Subject matter expert
<b>TPSS</b>	Transition Plan for System Security
<b>VPP</b>	Virtual power plant
<b>VRE</b>	Variable renewable energy

# 1. Introduction

Australia's rapid transition towards decarbonised energy systems, driven by the integration of substantial variable renewable energy (VRE) and energy-limited resources (ELR) such as energy storage systems (ESS), is fundamentally changing its reliability risk profiles. As the generation mix becomes increasingly weather-dependent, traditional models, metrics, and methods for resource adequacy<sup>1</sup> assessments, built on assumptions of perfect behaviour, average values and deterministic parameters, are no longer sufficient to capture the probabilistic and energy-constrained nature of the resource mix. Moreover, increasing exposure of supply infrastructure to extreme weather events, such as heatwaves, thunderstorms and droughts, heightens the risk of common-mode failures and underscores the need for innovative approaches to assessing resource adequacy in a weather-driven electric power system.

Advancing resource adequacy assessments in this context requires new methodologies that can incorporate weather dependencies and address emerging operability challenges associated with time-coupled resources, such as batteries. A key priority is the accurate quantification of the contribution of ESS and distributed energy resources (DER) to the power and energy adequacy of the system, and the extent to which these resources, together with VRE, can replace conventional generation to safely achieve decarbonisation targets. This remains a highly complex task, as the market-driven operation of ESS and DER does not necessarily fully align with the operational behaviour desired to ensure system adequacy.

In line with the CSIRO–AR–PST research roadmap, this project addresses critical planning challenges to determine the impacts and merits of flexible, energy-constrained technologies in achieving a reliable resource mix. Core contributions of the project include developing an open-source toolkit for studying reliability in systems with deep penetration of VRE and ELR, advanced modelling of flexible technologies to realistically assess their contribution to adequacy and determining suitable metrics to quantify reliability risks that power systems could face in the coming years. The resulting modelling capabilities, tools and technical evidence will support industry stakeholders and researchers in planning and operating a reliable power system with an inherently probabilistic and energy-limited mix of resources.

This stage of research under the AR–PST roadmap aligns with the resource adequacy component within the broader domain of power system planning. The objectives of this research are guided by the original roadmap<sup>2</sup> projects outlined below.

- A. Develop an open-source modelling and implementation framework, including models and datasets, to efficiently perform resource adequacy and resilience studies of the NEM with system operability considerations (*Planning roadmap – Research project R2S1P1*).
- B. Investigate the methodological and modelling steps for developing a time-sequential framework for resource adequacy and resilience assessments with operability considerations, addressing in particular the complexities of temporal variation in renewable output and the management of energy storage (*Planning roadmap – Research project R3S4P1*).
- C. Propose a comprehensive model for integrating and assessing the role of CER and DER in resource adequacy and resilience assessment frameworks (*Planning roadmap – Research projects R3S4P2, R5S3P2*).
- D. Analyse the changing reliability risk profile of the NEM across various scenarios through relevant metrics, addressing an ultra-deep penetration of VRE, energy storage and DER/CER (*Planning roadmap – Research projects R3S1P1, R3S3P2*).
- E. Determine the methodological steps, relevant drivers and assumptions for developing suitable scenarios to plan for resilience under deep penetration of VRE, storage and DER (*Planning roadmap – Research projects R1S2P1, R3S2P1*).

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<sup>1</sup> Resource adequacy encompasses the long-term planning perspective of reliability: Resource adequacy studies the potential risks to supply infrastructure and whether there will be sufficient available resources to meet electricity demand. In Australia, this is also often referred to as reliability – in contrast to security, which is an operational requirement for supplying demand.

<sup>2</sup> L. Zhang, S. Püschel-Løvengreen, G. Liu, R. Laird, and P. Mancarella. Australia's Global Power System Transformation Research Roadmap. Topic 4: "Planning". [https://www.csiro.au/-/media/EF/Files/GPST-Roadmap/Topic-4-Planning-Final-report\\_with-AltText-2.pdf](https://www.csiro.au/-/media/EF/Files/GPST-Roadmap/Topic-4-Planning-Final-report_with-AltText-2.pdf)

## 2. Research completed

To describe the project’s progress to date, the tasks outlined in the preceding section are disaggregated and displayed in the Gantt chart presented in Figure 1.

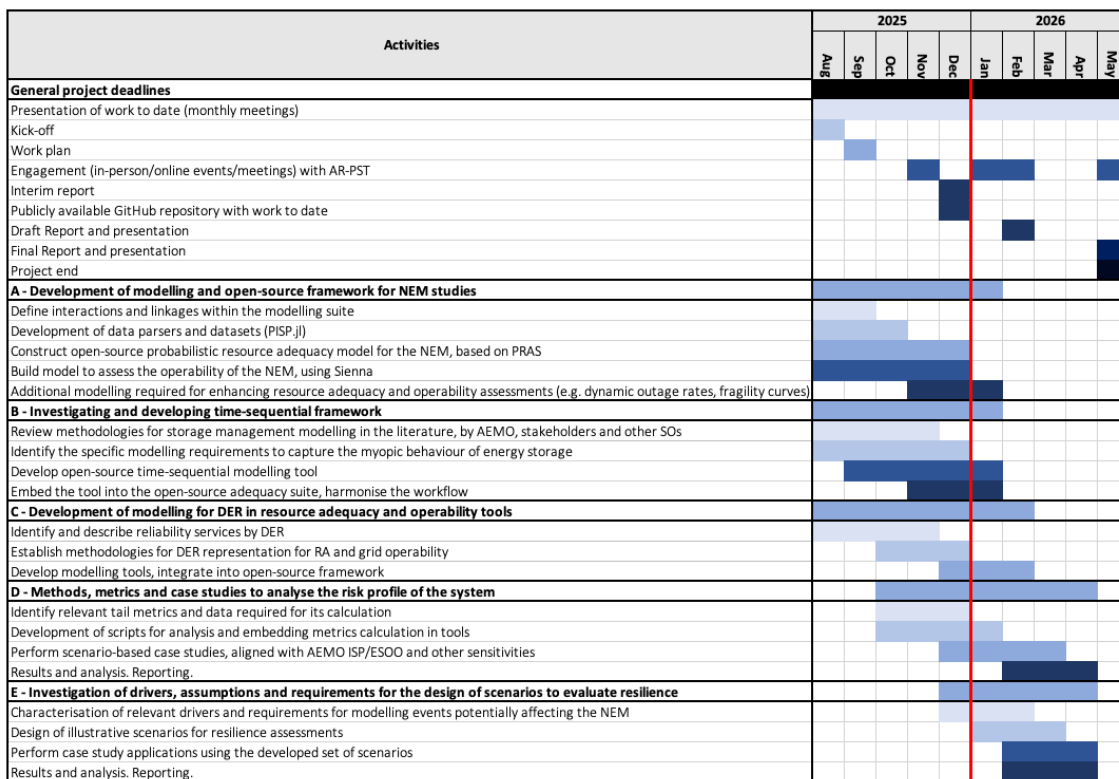


Figure 1: Stage 5 project Gantt chart

As a major milestone to date and in line with the objectives of Task A and project deliverables, an initial version of the GitHub repository containing the modelling suite for adequacy and operability studies using real data from the East Coast Australian power system has been delivered alongside this report.

This suite, available at <https://github.com/ARPST-UniMelb>, comprises three independent and interoperable packages: **PISP.jl**, **PRASNEM.jl**, and **SiennaNEM.jl**. These enable the generation of datasets and models of the East Coast Australian power system for conducting adequacy and operability studies. A brief overview of each package is provided below.

- **PISP.jl** stands for Parser of the Integrated System Plan (ISP). It is a data-parsing toolkit written in the Julia programming language that generates datasets for planning studies of the Australian East Coast Electricity System, based on AEMO’s workbooks for the 2024 ISP and IASR. PISP allows the generation of datasets containing technical parameters for conventional and renewable generation, transmission, storage, and distributed energy resources, as well as hourly-granularity generation traces of utility-scale and distributed solar, wind, and hydro inflows and electricity demand.

The datasets generated by PISP are structured using a common data format with specific identifiers for each element in the system, enabling high modelling interoperability with **PRASNEM.jl** and **SiennaNEM.jl**. Importantly, the datasets generated by PISP directly condense and format the public information made available by AEMO, while providing users with the flexibility to customise parameters, enabling extensive sensitivity analyses and parameterisations to create specific scenarios. The datasets also enable users to perform studies with other power systems modelling platforms.

- **PRASNEM.jl** is a modelling framework implemented in the Julia programming language for conducting a large number of high-speed time-sequential operational simulations of the NEM, with the ability to assess the impact of outages across generation, transmission and storage. This framework builds upon the Probabilistic Resource Adequacy Suite (PRAS)<sup>3</sup>, which performs sequential Monte Carlo sampling of random infrastructure outages. PRASNEM provides tools for performing resource adequacy studies of the Australian east-coast electricity system, based on data generated by PISP.jl. It also offers a wide range of optional parameters to enable custom studies and is designed to support detailed analysis of results. Users of PRASNEM can produce outputs that support comprehensive analysis of unserved energy events, regional adequacy assessments, and system-wide quantification of the adequacy benefits of selected generation, transmission, storage, and DER-based projects.
- **SiennaNEM.jl** is a Julia-based modelling framework for detailed system operation studies. It is grounded in the Sienna<sup>4</sup> modelling suite and supplied with datasets via PISP.jl. It is designed to perform detailed scheduling analysis of the Australian east-coast electricity system by enabling the construction and solution of economic dispatch (ED) and unit commitment (UC) models. The framework accommodates a large number of technical constraints, including ramping and minimum online and offline times of generators, time-coupled operation of energy-limited resources and options for managing renewable generation outputs. It also provides post-processing, data analysis, and visualisation capabilities to deliver high-quality insights from model outputs. SiennaNEM.jl benefits from Sienna's broader modelling ecosystem, allowing users to extend the provided base for the east-coast Australian electricity system to perform studies using other Sienna features.

Progress has also been made on Task B, which focuses on evaluating and developing models of energy storage systems for adequacy studies. So far, the literature review has been completed, and significant advances have been made in developing models to assess the contribution of energy storage to resource adequacy. The key findings and developments to date can be summarised as follows:

- Across the technical literature, it is widely accepted that storage can potentially contribute to adequacy by temporally shifting energy, mainly from periods of surplus to periods of generation scarcity or high demand. However, for given storage parameters, the exact value of storage contribution to adequacy of supply is highly dependent on the modelling assumptions regarding its operation. A common modelling approach in both academic literature and industry practice is to assume an idealised behaviour of energy storage. Namely, storage operates with perfect time-ahead knowledge of all events happening in the system, such as infrastructure outages or sudden weather variations. However, this assumption risks overestimating storage's contribution to adequacy, as real storage operations inherently lack full knowledge of system events and may be primarily driven by market signals.
- As storage operations are naturally performed under imperfect foresight of the system's conditions, the contribution of storage to adequacy may be reduced when compared to idealised assessments. Several factors can hinder the effective contribution of storage to adequacy. Among these drivers are uncertainty in system events (e.g., outages), forecasting limitations in prices and other system conditions (e.g., limited foresight horizon), market-driven dispatch and charging signals (e.g., prices not low enough preceding a critical period), and imperfect coordination between operators (i.e., the system operator and the storage operator). Modelling approaches for each of these drivers have also been identified and characterised.
- Complementary modelling to PRASNEM has been undertaken to capture key drivers of imperfect storage operation and more accurately quantify their contribution to resource adequacy which PRASNEM would not be suitable to do. The developed modelling includes the option to represent

<sup>3</sup> G. Stephen, "Probabilistic Resource Adequacy Suite (PRAS) v0.6 Model Documentation," NREL/TP--5C00-79698, May 2021. doi: [10.2172/1785462](https://doi.org/10.2172/1785462).

<sup>4</sup> C. Barrows, S. Dalvi, S. Dhulipala, K. Doubleday, R. Henriquez Auba, G. Konar-Steenberg et al., "Sienna Modeling Framework," NREL/TP--6A40-90227, 2024. doi: [10.2172/2376836](https://doi.org/10.2172/2376836)

storage dispatch more realistically, based on market expectations and accounting for imperfect foresight of potential events, while still allowing it to respond to unexpected system-wide conditions (e.g., outages). The modelling aims to provide transparency and flexibility in storage modelling details, enabling users to compare and adapt their own storage behaviour assumptions.

Regarding Task C, which aims to develop a comprehensive model for evaluating the roles of CER and DER in resource adequacy, the literature review has been completed, and progress has been made toward developing models to assess their contributions to adequacy. For example, also through continuous collaboration with the National Laboratory of the Rockies (NLR, former NREL), a demand response module has been incorporated into PRASNEM.jl, employing the technical parameters presented in AEMO's ISP. The main insights from the work conducted to date are as follows:

- Across the literature and in industry practice, CER and DER have been found to contribute to adequacy through different domains: providing power and energy (distributed generation), shifting demand away from critical times (generally through some form of distributed storage), and supporting the system in critical periods by reducing demand (via demand response).
- Payback constraints in demand response (i.e., the need to serve demand shortly after it has been reduced to handle peak periods) and limited asset coordination might limit the contribution of CER and DER to supply adequacy. Furthermore, uncertain asset availability and limited visibility into their status (e.g., whether flexible loads are online or offline, or the state of charge of distributed batteries) highlight technological challenges that must be resolved to ensure DER can fully contribute to adequacy from a planning perspective.
- Because DER includes a broad range of technologies, various modelling choices have been identified for representing DER in the context of adequacy of supply. The most common approaches include aggregation of DER as supply-side units and pre-optimised demand modelling. Nevertheless, no single modelling approach consistently outperforms the others across all criteria for model design, as greater detail, particularly regarding the asset coordination, increases computational complexity, potentially leading to intractability.
- Modelling of CER and DER has been conducted in PRASNEM.jl at a technology level to differentiate their contributions. Distributed generation, such as rooftop PV, is aggregated as supply sources. Coordinated distributed storage is modelled as virtual power plants (VPPs) in a parameterised manner in terms of power and energy to quantify the adequacy contribution of different levels of coordination. Demand response is available to reduce demand during critical high-demand or low renewable generation periods. Further work to evaluate CER and DER in resource adequacy will focus on analysing and comparing alternative modelling assumptions for demand response, quantifying the potential benefits of various levels of CER and DER coordination for adequacy, and assessing the impact of imperfect visibility on these resources from the operator's perspective.

Task D builds on the developments made in Tasks A–C to evaluate the reliability risk profile of the NEM. So far, work on this task has identified pertinent metrics for assessing the adequacy of supply in power systems, their data requirements, applications, and meanings. The findings have been synthesised into a comprehensive survey that delineates the current space for metrics, describing their practical implementation, the jurisdictions that utilise them, and the specific objectives they aim to fulfil. The principal outcomes of this analysis are summarised below.

- Risks to the adequacy of supply in electric power systems are typically assessed through probabilistic studies that quantify the average, or expected, supply shortfall. Measurements to quantify these risks usually include the event magnitude (energy not supplied) or duration. The event-level information is then aggregated into statistical measures, commonly referred to as *adequacy metrics*.
- In Australia, the adequacy of the east-coast power system is measured by an event-magnitude-focused metric, the normalised expected annual unserved energy (often referred to as EUE). Across jurisdictions, other metrics are used, including event-frequency measures in North America (e.g., Loss of Load Expectation, LOLE) and the UK (Loss of Load Probability, LOLP) and event-duration-based metrics in Europe (e.g., Loss of Load Hours, LOLH).

- A combination of multiple metrics, encompassing those covering the average values and tail of the distribution of shortfall events, appears to be the best-suited approach to appropriately represent an evolving reliability risk profile<sup>5</sup>. Assessments using average-only metrics (e.g. EUE, LOLE) may be prone “dilute” the impacts of the most challenging operating conditions during the risk quantification process, possibly hiding fragilities of the system.
- The increased risk due to the potential occurrence of shortfall events that are more infrequent (i.e., with less relative weight in probability distributions) but (much) larger in magnitude and duration (i.e., with potentially greater impacts if they materialise), the so-called “*tail risk*”, can be better characterised through *tail* metrics such as the Value-at-Risk (VaR) and the Conditional Value-at-Risk (CVaR).
- Resource adequacy metrics are also able to provide evidence of how different proportions of new resources (e.g. firm capacity, storage and variable generation) could contribute to achieving an optimal mix. However, the quantification of these contributions is strictly linked to the metrics used. Evidence in the literature shows that a given mix of resources may keep expected unserved energy (an average-based metric) within desired limits yet still yield significant variation over the duration of load-shedding events. This contrast highlights the potential to adopt multi-metric approaches to capture the different dimensions of reliability risk.

### 3. Outstanding activities

In line with the originally proposed Gantt chart, which has insofar been respected quite closely, the following tasks are planned for the remainder of the project:

- **Continuous maintenance and updates of the open-source repository until the end of the project:** Over the course of this research stage, the project team will continue to provide ongoing updates, improvements, and support for the packages comprising the *AR-PST UniMelb* open-source repository.
- **Tasks A – C:** As detailed previously, an initial version of storage and CER and DER modelling have been developed and implemented within the open-source frameworks. These models will be refined over the coming months in line with discussions with project partners and SMEs. In parallel, parameterisations of key reliability factors (e.g., outage rates, fragility curves, weather profiles) will be refined to support the case studies presented in the final report.
- **Task D:** The overarching objective of Task D is to analyse and quantify risks to the adequacy of supply of the Australian East Coast Electricity System under very high penetrations of VRE, energy storage systems and DER. The completion of this task will build on the completed developments from Tasks A, B, and C, providing an understanding of potential operating conditions (e.g. low state of charge of energy storage systems, infrastructure outages, renewable energy availability, market-driven operation of ELR, etc.) that could compromise the system's ability to meet demand. To achieve this, the remaining activities within this task are the following:
  - Develop the required implementations within the open-source modelling suite to calculate a set of reliability metrics (including expected unserved energy, the loss of load expectation, the Value-at-Risk and the Conditional Value-at-Risk) to assess the system-level adequacy.
  - Perform an assessment of the reliability risk profile of the NEM across a wide range of relevant operational and long-term scenarios, quantified through appropriate metrics.
- **Task E:** The objective of this task is to define the key methodological steps, drivers and assumptions needed to develop scenarios that support resilience planning under high penetrations

<sup>5</sup> The need to understand the full risk profile has also been highlighted by AEMO in “Submission to the AEMC on the draft report of ‘Review of Form of the Reliability Standard and the Administered Price Cap (APC),’” May 2024. Available: <https://www.aemc.gov.au/market-reviews-advice/review-form-reliability-standard-and-apc> .

of VRE, storage and DER. In doing so, the task specifically seeks to address a major gap in practical approaches to systematically develop and apply resilience-oriented scenarios in reliability studies. The outstanding activities for this task are as follows:

- Provide a characterisation of relevant triggers or events (e.g., specific climate conditions that would lead to the materialisation of stressors for the system) to be accounted for in the design of scenarios for resilience evaluations.
- Determine the data requirements, potential data sources, and methodological steps for modelling specific system hazards in scenarios for resilience evaluations.
- Design an illustrative set of scenarios, complementing AEMO’s Energy Adequacy Assessment Projection (EAAP) to evaluate system resilience for the Australian East Coast Electricity System, applying the characterisations and data requirements previously investigated.
- Perform case studies assessing the resilience and reliability of the Australian East Coast Electricity System employing the modelling suite developed under Task A across relevant resilience-oriented scenarios.

## 4. Progress against the Roadmap

This section outlines the progress achieved in this stage of the project in relation to the latest research roadmap for the “Planning” topic. Regarding the general progress against the research roadmap, the activities conducted so far (including stages 1, 2, 3, and 4) are aligned with the expected progress to date. The activities in the previous stages have focused on integrated planning in contexts such as distribution systems and hydrogen systems, and in the light of uncertainty and risk. Table 3 in the Appendix summarises the full research progress to be achieved at the end of stage 5, describing all activities that have progressed during stages 2-5.

As for the specific progress during stage 5 against the research roadmap, the current project focuses on developing open-source tools, advanced modelling, and methods for evaluating adequacy and operability in a power system dominated by storage and DER. As illustrated in Table 1, the core of the completed and ongoing tasks is centred around a portfolio of activities from Research Programme 3 (R3, Reliability and Resilience), with interactions with programmes R1 (Long-term Uncertainty), R2 (Power System Operation) and R5 (Distributed Energy Systems). The table shows the progress estimates for each relevant research project (indicated in the *Code* column) of the original research roadmap for the Planning topic by the end of the current research stage.

Table 1: Expected progress for the research activities by the end of the ongoing project, Stage 5

TASK	PROGRAMME	STREAM	PROJECT	CODE	Envisaged progress
Task A	Power System Operation	Steady-state operation modelling	Modelling the steady-state operation of the system considering the trade-off between computational efficiency and model precision	R2S1P1	20%
Task B	Reliability and Resilience	DER/IBR response to different events	Modelling and analysing the impact on planning from IBR (including and in particular batteries) response to credible contingencies and high impact low probability (HILP) events	R3S4P1	10%
Task C	Reliability and Resilience	DER/IBR response to different events	Modelling and analysing the impact on planning from DERs and distribution network assets response to credible contingencies and high impact low probability (HILP) events	R3S4P2	20%
	Distributed Energy Systems	Distributed energy resources impact	Modelling and analysing the contribution of DERs to system reliability (security and adequacy) and resilience	R5S3P2	10%
Task D	Reliability and Resilience	Reliability and resilience metrics	Developing new metrics to quantify the benefits to reliability and resilience associated with the investment in new system assets	R3S1P1	30%
		Credible and non-credible contingencies	Profiling power system risks under various contingencies and indistinct events for future low-carbon grid with high penetration of IBR/DERs	R3S3P2	20%
Task E	Long-term Uncertainty	Climate change impact on individual power system components performance	Modelling of climate change for power system planning purposes (different types of events, spatio-temporal representation, probabilities, correlation, etc.)	R1S2P1	20%
	Credible and non-credible contingencies	Impact of climate change	Assessing the reliability and resilience of power system considering the impact of climate change and extreme weather conditions on its infrastructure/components	R3S2P1	10%

## 5. Research relevance to Australia

This research project supports Australia's energy transition by laying the foundation for a new generation of models, tools, and capabilities to assess the resource adequacy and operability of future Australian power systems. The project examines the changing reliability risk profile of the East Coast Australian Electricity System and highlights market factors, operational strategies, and weather events that could lead to critical operating conditions relevant to AEMO, the AEMC and other stakeholders involved in reliability planning.

More broadly, the project develops and delivers advanced open-source tools, planning models that account for the energy-constrained nature of ESS, CER, and DER, and methods to support the development of resilience-oriented scenarios. Ultimately, this project contributes with technical evidence and practical recommendations to enable the effective design of a reliable system dominated by VRE, ESS, CER, and DER. The outcomes of the project will directly help address key technical constraints of different technologies that might otherwise hinder the integration of renewables, CER, and DER or drive up the costs of the Australian energy transition, supporting a more reliable and cost-effective path to decarbonisation.

The highlighted aspects of the project closely relate to the current Australian context, particularly concerning the key priorities for reliability planning outlined in the latest versions of the ISP<sup>6</sup> and ESOO<sup>7</sup>, the discussions initiated by the AEMC regarding updates to the reliability standard for 2028-2032<sup>8</sup>, the operability challenges caused by imperfect foresight on storage operations recently detailed in the 2026 draft ISP<sup>9</sup>, and the updated research agenda of AEMO and the ISON<sup>10</sup> within the planning domain for 2026. Furthermore, this research aims to influence and enrich the understanding of relevant stakeholders, including AEMO, AEMC, ECOM, and DNSPs, regarding possible shortcomings in the current power system reliability framework in Australia. It also intends to contribute with technical evidence for future methodological improvements to facilitate timely investment in and operation of an appropriate mix of resources across generation, transmission, and distribution systems to guarantee system reliability.

## 6. Recommended research priorities

The recent publication of the Draft 2026 ISP for the National Electricity Market (NEM) and the 2025 Transition Plan for System Security<sup>11</sup> (TPSS), coupled with ongoing discussions initiated by the Australian Energy Market Commission (AEMC) regarding the review of the reliability standard for the NEM, highlight the significance of system planning as a fundamental component of Australia's energy transition.

In particular, the aforementioned reports indicate that gas-powered electricity generators (GPGs) will likely play an important role as backup resources to ensure reliability, especially during extended periods of low variable renewable generation (VRE *lulls*), both by providing firm capacity and by pre-charging batteries. It is also recognised that infrastructure development must occur in a timely manner, not only within the electricity system as existing GPGs retire, but also upstream in the gas system (including storage, transport,

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<sup>6</sup> AEMO, "Draft 2026 Integrated System Plan", Dec. 2025. Available: <https://www.aemo.com.au/consultations/current-and-closed-consultations/draft-2026-isp-consultation>.

<sup>7</sup> AEMO, "2025 WEM Electricity Statement of Opportunities". Jul. 2025. Available: <https://www.aemo.com.au/energy-systems/electricity/wholesale-electricity-market-wem/wem-forecasting-and-planning/wem-electricity-statement-of-opportunities-wem-esoo>

<sup>8</sup> AEMC, "2026 Reliability Standard and Settings Review," Nov. 2025. Available: <https://www.aemc.gov.au/market-reviews-advice/2026-reliability-standard-and-settings-review>

<sup>9</sup> AEMO, "Draft 2026 ISP Appendix A4. System operability". Dec. 2025. Available: <https://www.aemo.com.au/-/media/files/major-publications/isp/draft-2026/a4-system-operability.pdf>

<sup>10</sup> ISON, "System Operator Priorities", Dec. 2025. Available: <https://www.aemo.com.au/-/media/files/initiatives/international-system-operator-collaboration/system-operator-priorities-report-2026.pdf>

<sup>11</sup> AEMO, "2025 Transition Plan for System Security," Dec. 2025. Available: <https://www.aemo.com.au/-/media/files/major-publications/tpss/2025-transition-plan-for-system-security.pdf>

production, and regasification facilities) to ensure GPGs have sufficient fuel supply to operate. However, the ISP focuses on optimising grid-scale electricity infrastructure, revealing potential economic and operational risks if gas infrastructure is not properly incentivised, planned, or deployed. At the same time, there are emerging policy discussions about increasing large load connections<sup>12</sup>. Specifically, data centres for AI processes<sup>13</sup> and hydrogen electrolyzers<sup>14</sup> for fuel production highlight challenges related to the costs, timing and siting of infrastructure required to support their growth. This uptake also points to potential opportunities for these loads to contribute to system reliability when operated as flexible demands.

The complexity of unanswered questions in the outlined topics underscores the need for research targeted to the Australian energy system planning domain. Based on the analysis conducted so far, the interim results obtained in the current project, discussions with project partners and stakeholders, and considering the urgent challenges that Australia faces, we recommend concentrating on the following research activities (which we call “Tasks”) from the original research plan:

- ***Task 1: Infrastructure planning of integrated electricity and gas systems to ensure reliability of supply and system operability***

- The 2025 TPSS for the NEM and 2025 ESOO for the WEM highlight the correlation of the reliability of electricity systems and the adequacy of gas infrastructure. This is mainly because GPG can act as a backup to address extended “Dunkelflaute” periods, by providing firm capacity and pre-charging storage, as well as a measure to handle increasing failure rates of coal-fired generators and the uncertainties surrounding their closure timing.

However, as outlined by the AEMC<sup>8</sup>, capital costs of GPG are increasing, and their operation is becoming more energy-constrained<sup>12</sup> as existing natural gas supply capabilities are forecast not to be sufficient, especially in southern Australia, posing potential reliability and economic risks (as more expensive fuels may be employed instead). Hence, from a planning perspective, it is critical to systematically analyse the influence of these economic factors and binding physical constraints to provide consistent evidence supporting an investment pathway with timely investments across electricity and gas systems, thereby ensuring reliable, secure, and resilient operation.

This task would build on the reliability-oriented developments of the current stage, as well as on detailed modelling of gas flow dynamics (e.g., detailed linepack representation) already developed in previous stages of the AR-PST research. From the Research Plan, the activities to be performed under this Task should be associated with:

- **R1S1P2:** Quantifying impact and uncertainty of sector coupling for scenario development (e.g., electrification, hydrogen policies, etc.)
- **R3S3P2:** Profiling power system risks under various contingencies and indistinct events for future low-carbon grid with high penetration of IBR/DERs
- **R3S3P3:** Modelling the impacts and benefits of other infrastructure and sector coupling (e.g., gas, hydrogen) on power system reliability and resilience
- **R5S1P1:** Modelling the impact and flexibility embedded in the interactions between power systems and other energy systems for planning studies

- ***Task 2: Development and assessment of planning strategies for the secure integration of large flexible loads into the Australian energy system***

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<sup>12</sup> AEMO, “2026 General Power System Risk Review”. Dec 2025. Available: [https://www.aemo.com.au/-/media/files/stakeholder\\_consultation/consultations/nem-consultations/2025/2026-gpsrr/2026-gpsrr-approach-paper-overview.pdf](https://www.aemo.com.au/-/media/files/stakeholder_consultation/consultations/nem-consultations/2025/2026-gpsrr/2026-gpsrr-approach-paper-overview.pdf)

<sup>13</sup> Oxford Economics “Data Centre Energy Demand Final Report,” Jul. 2025. Available: [https://www.aemo.com.au/-/media/files/stakeholder\\_consultation/consultations/nem-consultations/2024/2025-iasr-scenarios/final-docs/oxford-economics-australia-data-centre-energy-consumption-report.pdf](https://www.aemo.com.au/-/media/files/stakeholder_consultation/consultations/nem-consultations/2024/2025-iasr-scenarios/final-docs/oxford-economics-australia-data-centre-energy-consumption-report.pdf)

<sup>14</sup> AEMO, “Draft 2026 ISP Appendix A3. Renewable Energy Zones”. Dec. 2025. Available: <https://www.aemo.com.au/-/media/files/major-publications/isp/draft-2026/a3-renewable-energy-zones.pdf>

- According to AEMO's 2026 Draft ISP<sup>6</sup>, electricity consumption from data centres is expected to triple over the next five years, potentially reaching up to 15.6 TWh by 2030, with most new demand concentrated in urban centres such as Melbourne and Sydney. The Draft ISP also anticipates the potential deployment of large hydrogen production loads (electrolysers) across the NEM from the early 2030s, driven in part by opportunities to absorb excess VRE. An important decision, highlighted in the ISP, is whether such loads, particularly electrolysers, should be co-located within REZs<sup>13</sup> alongside VRE developments to capitalise on periods of surplus generation<sup>15</sup>. More broadly, strategically coordinating the siting and operation of multiple flexible large loads may uncover additional techno-economic synergies that have not yet been examined in the Australian context.
- In addition, the system reliability implications of this rapid uptake of large loads are not yet well understood, particularly given their potentially flexible nature, which may allow them to support resource adequacy. However, their highly dynamic and still uncertain operating profiles require advanced modelling to systematically quantify their adequacy value. There is also significant uncertainty about the required grid-scale investments and operational strategies for managing these loads within the broader energy system, requiring the development of technical evidence to support investment planning and regulatory and operational decisions in the coming years. From the Research Plan, the activities to be performed in this Task would be associated with:
  - **R2S1P1**: Modelling the steady-state operation of the system, considering the trade-off between computational efficiency and model precision
  - **R3S1P2**: Quantifying the value of differentiated reliability and resilience for different customer groups
  - **R4S1P3**: Designing the optimal schemes (e.g., mandatory, market-incentivised, hybrid) for service provision to maintain system reliability and resilience
  - **R5S2P1**: Identifying the sources and availability of demand side flexibility, quantifying its aggregated profile, and determining its representation in power system planning

The two research Tasks are not in any priority order for the next stage of the project, but we believe they are essential for quantifying and evaluating potential risks to the Australian energy system. Both aspects, optimal and timely infrastructure planning across electricity and gas systems, and the assessment of the impacts and needs to support the secure integration of large loads, are of importance to ensure the energy transition keeps progressing. We estimate that both tasks proposed above would require similar resources as in the current, ongoing research project. In this context, Table 2 summarises how the activities in the proposed Tasks could advance the project activities envisaged in the original research plan.

Table 2: Progress expected at the end of the proposed Tasks for the research activities envisaged in the research plan.

TASK	PROGRAMME	STREAM	"PLANNING" TOPIC RESEARCH ROADMAP PROJECT	ROADMAP CODE	Envisaged progress
Task 1	Long-term Uncertainty	Scenario development for planning studies	Quantifying impact and uncertainty of sector coupling for scenario development (e.g., electrification, hydrogen policies, etc.)	R1S1P2	20%
	Reliability and Resilience	Credible and non-credible contingencies	Profiling power system risks under various contingencies and indistinct events for future low-carbon grid with high penetration of IBRD/DERs	R3S3P2	35%
			Modelling the impacts and benefits of other infrastructure and sector coupling (e.g., gas, hydrogen) on power system reliability and resilience	R3S3P3	75%
Distributed Energy Systems	Multi-energy systems	Modelling the impact and flexibility embedded in the interactions between power systems and other energy systems for planning studies	R5S1P1	55%	
Task 2	Power System Operation	Steady-state operation modelling	Modelling the steady-state operation of the system considering the trade-off between computational efficiency and model precision	R2S1P1	65%
	Reliability and Resilience	Reliability and resilience metrics	Quantifying the value of differentiated reliability and resilience for different customer groups	R3S1P2	20%
	Decision Making	Metrics, objectives and risk modelling of different stakeholders	Designing the optimal schemes (e.g., mandatory, market-incentivized, hybrid) for services provision to maintain system reliability and resilience	R4S1P3	15%
	Distributed Energy Systems	Distributed energy markets and demand-side flexibility	Identifying the sources and availability of demand side flexibility, quantifying its aggregated profile, and determining its representation in power system planning	R5S2P1	55%

<sup>15</sup> AEMO, "Draft 2026 ISP Appendix A2. Development Opportunities". Dec. 2025. Available: <https://www.aemo.com.au/-/media/files/major-publications/isp/draft-2026/a2-generation-and-storage-development-opportunities.pdf>



# Appendix: Progress against the “Planning” research roadmap

Table 3: Summary of progress achieved with activities conducted during Stage 1-5 against the research roadmap, Topic 4 planning.

RESEARCH PROGRAMME (R)	STREAM (S)	CODE	PROJECT (P)	Total FTE	Completed FTE	PROGRESS	STAGES INVOLVED
1. Long-term Uncertainty	Scenario development for planning studies	R1S1P3	Modelling long-term uncertainty in power system planning with the consideration of HILP events (adequacy and security) and critical operation conditions	3	0.45	15%	2
	Climate change impact on individual power system components performance	R1S2P1	Modelling of climate change for power system planning purposes (different types of events, spatio-temporal representation, probabilities, correlation, etc.)	1	0.2	20%	5
2. Power System Operation	Steady-state operation modelling	R2S1P1	Modelling the steady-state operation of the system considering the trade-off between computational efficiency and model precision	2	0.8	40%	3&5
3. Reliability and Resilience	Reliability and resilience metrics	R3S1P1	Developing new metrics to quantify the benefits to reliability and resilience associated with the investment in new system assets	1	0.3	30%	5
	Impact of climate change	R3S2P1	Assessing the reliability and resilience of power system considering the impact of climate change and extreme weather conditions on its infrastructure/components	4	0.4	10%	5
	Credible and non-credible contingencies	R3S3P2	Profiling power system risks under various contingencies and indistinct events for future low-carbon grid with high penetration of IBR/DERs	2	0.4	20%	5
		R3S3P3	Modelling the impacts and benefits of other infrastructure and sector coupling (e.g., gas, hydrogen) on power system reliability and resilience	2	1.2	60%	3&4
	DER/IBR response to different events	R3S4P1	Modelling and analysing the impact on planning from IBR (including and in particular batteries) response to credible contingencies and high impact low probability (HILP) events	4	0.4	10%	5
		R3S4P2	Modelling and analysing the impact on planning from DERs and distribution network assets response to credible contingencies and high impact low probability (HILP) events	2	0.4	20%	5

4. Decision Making	Metrics, objectives and risk modelling of different stakeholders	R4S1P1	Modelling competing objectives, sources of risk, and risk appetite of different stakeholders in power system planning. Determination of metrics to value cost and risk	4	1	25%	<b>2</b>
		R4S2P2	Modelling investment flexibility in power system planning decision making by enhancing the decision structure and the representation of scenario trees	2	1	50%	<b>2</b>
	Methodologies for decision-making under uncertainty	R4S2P3	Methodologies and tools to incorporate the assessment of non-network solutions value streams in the network expansion problem	1	0.2	20%	<b>3</b>
	Interdependence	R4S3P1	Modelling investment decisions (including demand response) at distribution network level and determining the methodologies to integrate them in power system planning	1	0.3	30%	<b>4</b>
5. Distributed Energy Systems	Multi-energy systems	R5S1P1	Modelling the impact and flexibility embedded in the interactions between power systems and other energy systems for planning studies	3	1.2	40%	<b>2,3 &amp; 4</b>
	Distributed energy markets and demand-side flexibility	R5S2P1	Identifying the sources and availability of demand side flexibility, quantifying its aggregated profile, and determining its representation in power system planning	2	0.8	40%	<b>3 &amp; 4</b>
		R5S2P2	Modelling distributed energy systems (e.g., DERs, VPPs) operation and determining data requirement to represent their operation for planning studies	1	0.25	25%	<b>3</b>
	Distributed energy resources impact	R5S3P1	Modelling the impact of high DERs penetration on power system planning	2	0.4	20%	<b>4</b>
		R5S3P2	Modelling and analysing the contribution of DERs to system reliability (security and adequacy) and resilience.	3	0.9	30%	<b>3 &amp; 5</b>