Topic 4 – Planning

2024/25 Integrated energy system infrastructure planning: Unlocking the value and flexibility from distribution networks and electricity-hydrogen energy hubs

Commonwealth Scientific and Industrial Research Organisation

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Contents

Acronyms

AEMO	Australian Energy Market Operator
AEMC	Australian Energy Market Commission
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DER	Distributed energy resources
DNSP	Distribution network service provider
ECMC	Energy and Climate Change Ministerial Council
GPST	Global Power System Transformation
GSOO	Gas Statement of Opportunities
HILP	High Impact Low Probability
HtP	Hydrogen-to-power
ISP	Integrated System Plan
REZ	Renewable energy zone
UoM	The University of Melbourne
VPP	Virtual Power Plant

1. Introduction

The planning of energy systems is facing significant challenges due to a manifold of new interactions and the increasing diversity of new technologies connected to the system. On the one hand, this trend is highlighted by the fast uptake of renewable energy towards the decarbonisation of the energy sector and the increasing active participation of customers through different controllable assets in distribution networks (e.g., electric vehicles, community batteries). These assets are vital for linking the supply and demand side, and for unlocking operational flexibility provided by distributed energy resources (DER) through adequate investments. On the other hand, the emerging production of green hydrogen as an alternative to traditional carbon-based energy carriers opens new value streams and business opportunities, such as hybrid electricity-hydrogen energy hubs. These hubs can support the development of the hydrogen industry in Australia and leverage economies of scale to produce hydrogen for local consumption and export. Additionally, they could enhance the operational flexibility of the system through its capacity to transform and store energy vectors (e.g., hydrogen and electricity) at different duration timescales.

However, current planning approaches fall short in efficiently assessing the coordination between transmission and distribution systems, as well as the complex interactions between the electricity system and the infrastructure for green hydrogen production. Hence, system planners require new methodologies that allow performing real-world integrated energy system planning while capturing the synergies and trade-offs between infrastructure at different scales. Moreover, such methodologies must be capable of providing key insights and informing as to what extent investments in distribution systems or in infrastructure to produce green hydrogen could delay, displace, or compete with investments at the transmission level, while striking a balance between cost-effectiveness, system reliability, security, and resilience, as well as computational efforts.

Against this background, and in line with the recommendations outlined in the final report[1] for Stage 3-Topic 4 of the CSIRO-GPST roadmap, the 2021 research plan[2], and AEMO's 2024 ISP, this research project aims at developing scalable (i.e., computationally efficient) methodologies capable of informing planners about the required developments to successfully perform an integrated energy system infrastructure planning (transmission, distribution, hydrogen). Building upon these developments, we aim to study how it is possible to represent distribution networks to explicitly and efficiently include them in planning; how investments in distribution networks would unlock the clean energy and flexibility of DER, potentially displacing or deferring other investments (e.g., transmission-level lines or storage); how planners can represent hybrid energy hubs; what are the drivers for investing in such hubs; and to determine the value of different types of energy storage within integrated planning. In doing so, the University of Melbourne (UoM) will collaborate closely with AEMO, and potentially other stakeholders, to receive relevant inputs, feedback, and to jointly define specific sets of pertinent case studies.

In this vein, the main goal of this project is to propose methodological approaches geared towards representing the planning of active distribution systems and hybrid energy hubs with adequate detail to efficiently integrate them within planning frameworks, assessing drivers, limitations, potential benefits, and techno-economic implications of this integration at a whole-system level. As part of the project, proofs of concept and validations with different system models will be conducted to demonstrate the principles, applicability, and scalability of the proposed methodologies. The project tasks and their alignment with the planning roadmap are as follows:

A. Develop a methodological framework to efficiently represent the flexibility, network role, and investment needs of active distribution systems for planning purposes (Planning roadmap[2] - Research projects **R4S3P1**, **R5S2P1**).
B. Assess and quantify the potential techno-economic benefits and implications of integrating the option of investing in active distribution systems within power system planning (Planning roadmap[2] - Research project **R5S1P1**).
C. Propose a comprehensive and modular framework for integrating, designing, and assessing hybrid energy hubs in planning integrated hydrogen-electricity systems (Planning roadmap[2] - Research project **R5S3P1**).
D. Analyse the potential value and development drivers of integrating hybrid energy hubs within electricity-hydrogen infrastructure planning (Planning roadmap[2] - Research project **R3S3P3**).

[1] P. Apablaza, C. Alcarruz, R. Chen, B. Moya, S. Mhanna, P. Mancarella. Energy infrastructure planning under deep uncertainty: Assessing impacts and benefits of energy system integration. G-PST Research Roadmap Stage 3. June 2024. https://www.csiro.au/-/media/EF/Files/GPST-Roadmap/Stage3-Final/Topic-4_Planning.pdf
[2] 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

2. Research completed

To describe the project's progress, the tasks presented in the previous section are disaggregated and presented in the Gantt chart depicted in Figure 2.1.

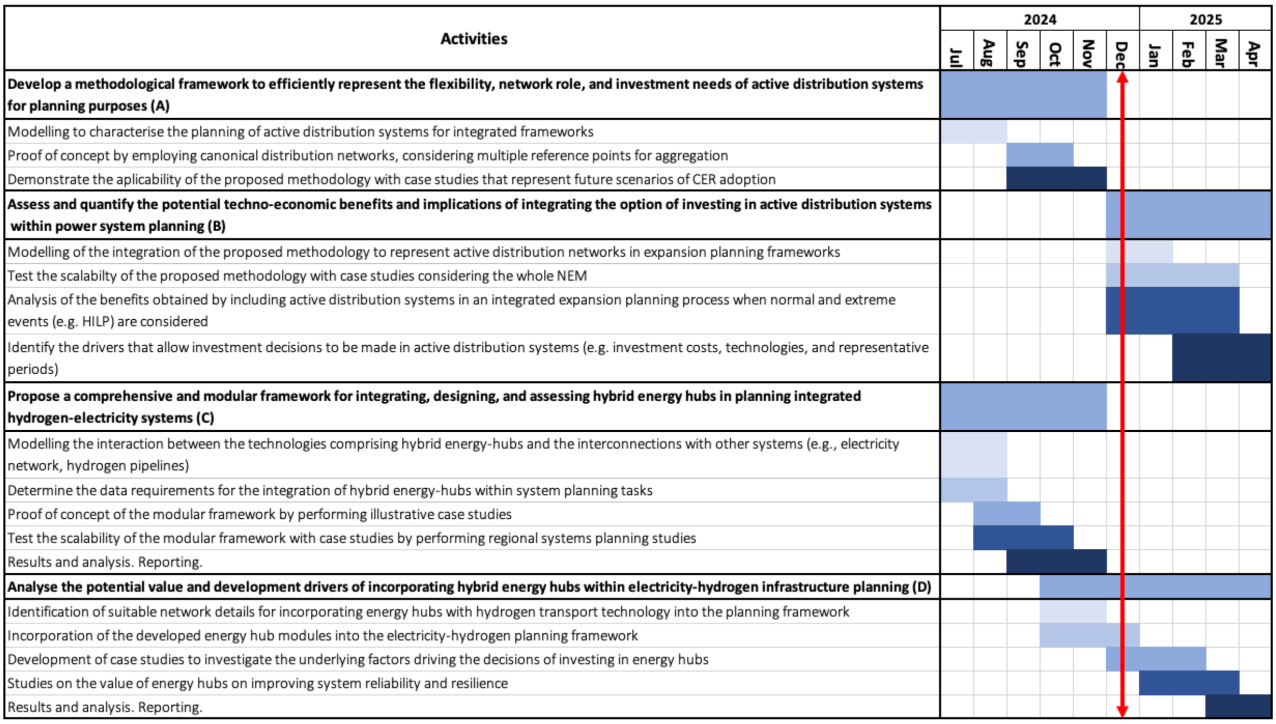

Figure 2.1: Project's Gantt chart

So far, a methodology to represent the planning of active distribution systems for coordinated whole-system planning frameworks has been proposed and completed (*Task A*). This methodology encompasses investment costs to support increasing penetration levels of DER and represents the operational flexibility that such investments unlock through equivalent aggregated modelling. Additionally, a modular framework for the design of hybrid energy hubs has been developed (*Task C*). This framework addresses the principles and potential benefits of them, such as economies of scale, reductions in connection costs, and increased efficiency. Both tasks were developed as expected and will serve as baseline for the activities in the upcoming months.

<u>Task A</u> of the project involved a thorough understanding of academic approaches for the coordinated planning of transmission and distribution systems. In addition, a comprehensive survey was conducted to examine current planning and regulatory frameworks worldwide. This analysis focused on understanding how transmission and distribution systems are planned and the degree of coordination between these processes. From this review, clear insights and guidelines were identified for developing a methodology that is suitable for real world applications of coordinated transmission and distribution system planning. The main insights obtained at this stage are:

- It was identified that methodologies that support parallel computing and decouple decision-making are needed for integrated planning to be applicable within real-world contexts, as they allow for efficient communication through a reduced set of variables. In this sense, such approaches leverage the know-how capabilities of system operators and are suitable under current and most common regulatory frameworks that clearly define independent roles of transmission and distribution system operators, as additional information can be produced and shared among stakeholders through their own tools, allowing for a more informed decision-making process.
- Following up on this, the proposed methodology focusses on computing parametric investment cost functions to support multiple levels of DER adoption. This information can be employed for whole-system planning purposes, accounting for the additional investments needed to unlock those levels of DER. Thus, any distribution network service provider (DNSP) can produce this information with their tools, pass it on to, and inform the system planner (e.g., AEMO).

- For this parametric approximation, an equivalent model that represents the flexibility limits of active distribution systems based on the concept of dynamic operating envelopes was defined. By employing this approach, the distribution side can be modelled through a reduced set of operational variables and constraints, avoiding the need for considering full distribution network models in whole-system planning frameworks.
- This methodology is modular and scalable as it can be applied in any voltage level of distribution systems. However, it has been noted that an important aspect worth analysing is the level of detail needed (i.e., sub transmission, MV feeder, LV feeder, etc.) to produce this information from a whole-system perspective. This aspect will be further evaluated in the upcoming tasks of the project.
- DER orchestration provides benefits for distribution system planning (i.e., investment cost reductions), reducing the need for distribution network reinforcements while relying more on active network management solutions such as distributed storage and reactive compensation, enhancing the flexibility within distribution systems. In this context, the benefits of DER orchestration quantified in the 2024 ISP could be potentially increased if the distribution side is properly accounted for. This aspect will also be further explored as the project continues.

Task C of the project involved the development of a modular and scalable framework for the design and assessment of hybrid energy hubs in the context of whole-system planning. Aggregating technologies within a hub can leverage the co-location of technologies in the same area before connecting to the main power grid. Subsequently, case studies were conducted to examine the implications of incorporating hybrid energy hubs into integrated electricity and hydrogen system planning, compared to individual investment for each technology. The case studies demonstrate how hybrid energy hubs influence resources allocation, investment portfolios, and system costs. The following conclusions can be drawn:

- The developed modular framework co-locates electricity generation, hydrogen production, and storage technologies within the same area in order to reduce the costs associated with grid connection infrastructure and improving the utilisation of assets. Instead of optimising each technology individually with their associated connection and building costs, a collective approach to hub infrastructure allows direct coupling of electricity generation with hydrogen production, minimising redundancy and lowering connection costs with shared infrastructures, such as transformers and grid connection points. Additionally, the shared infrastructure in hubs reduces per-unit costs for renewable energy installations and electrolysers, making it economically viable to deploy higher capacities within the hub framework.
- The inclusion of hybrid energy into integrated electricity and hydrogen system planning unlocks system-wide benefits by optimising the sizing, placement, and operation of technologies across the system. Investing in renewable energy generation in Renewable Energy Zones (REZ) to supply electricity for both the grid and hydrogen production incurs significant costs due to the need for extensive grid connection and transmission infrastructure, particularly as hydrogen export demand is projected to grow in Australia. The case studies demonstrate that incorporating hybrid energy hubs into the integrated system planning facilitates local electricity generation within the hub to directly support hydrogen production, reducing reliance on grid injection and minimising the need for additional transmission capacity, thereby lowering overall system costs.

3. Outstanding activities

Following the information presented in the Gantt chart, the following tasks are planned for the remainder of the project:

- Task B *(Integration of active distribution systems planning as investment option)*:
    - Determine the best modelling practice for integrating active distribution systems as decision-making variable for whole-system expansion (i.e., coordination scheme), and analyse the scalability of such integrated planning framework.
    - Assess the benefits that come from the integration of active distribution systems under normal and extreme events consideration, aiming at identifying the main drivers (e.g., investment costs, technologies) that might shift the development of the Australian power system towards active distribution systems.
- Task D *(Integration of hybrid energy hubs within electricity-hydrogen planning):*
    - Incorporate hybrid energy hubs with electricity-hydrogen transmission infrastructures (electricity lines and H_2 pipelines) into integrated system planning framework, identifying the key drivers influencing investment decisions in hybrid energy hubs.
    - Quantify the benefits of operational flexibility provided by hydrogen technologies through an analysis of different operational conditions across various scenarios and understand the impacts of these technologies on system resilience.

4. Progress against the Roadmap

This section describes the general progress of the "Planning" topic against the most updated research plan[1], based on the activities being carried out in the current project stage. Table 1 presents a general prospect of the different activities that were initially designed for the "Planning" topic, specifying the different Research Programmes (R), Streams (S), and projects (P).

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 up to date. Notwithstanding the above, and taking into account the critical discussions regarding the importance of thorough considerations of gas infrastructure in the planning of the NEM[3,4], as well as the forecast natural gas supply gaps outlined in the most recent AEMO Gas Statement of Opportunities (GSOO)[5], we recommend the following date extensions for research projects **R3S3P3** and **R5S1P1:**

- **R3S3P3** *"Modelling the impacts and benefits of other infrastructure and sector coupling (e.g., gas, hydrogen) on power system reliability and resilience"*: Extend the end date from May-25 to **May-26**
- **R5S1P1** *"Modelling the impact and flexibility embedded in the interactions between power systems and other energy systems for planning studies"*: Extend the end date from May-25 to **May-26**

This recommendation for date extension is driven by the need of a deeper understanding of the impacts gas infrastructure can have in the planning of the electricity system while maintaining a long-term reliable, secure and resilient operation. To date, within topic 4, these two research projects have progressed with a focus on modelling and understanding the role of green hydrogen in integrated system planning given the great opportunities envisaged for Australia. Nevertheless, as outlined by different stakeholders (AEMO, AEMC, ECMC) during this year, the interactions between natural gas and the electricity system will become more critical for the operation of the NEM, making it necessary to develop methodologies and models to assess the planning, and related uncertainties, of an integrated electricity-gas-hydrogen system more extensively.

As for the specific progress of topic "Planning" during stage 4, the ongoing project is designed to continue the work developed and build upon the insights found during stage 3[1]. In particular, the current project focuses on developing methodologies to integrate distribution networks and hybrid hubs in planning frameworks. As illustrated in Table 2, the core of the past and ongoing tasks is centred around a portfolio of activities from Research Programme 5 (R5, Distributed Energy Systems), with interactions with programmes R3 and R4. The table also depicts the completion estimates for each relevant research activity by the end of the ongoing research stage.

[3] AEMO. Integrated System Plan (ISP) Methodology. Issues Paper – Standard Consultation for the National Electricity Market. https://aemo.com.au/consultations/current-and-closed-consultations/2026-isp-methodology
[4] ECMC. Review of the Integrated System Plan. August 2023. https://www.energy.gov.au/energy-and-climate-change-ministerial-council/energy-ministers-publications/review-integrated-system-plan
[5] AEMO. 2024 Gas Statement of Opportunities. March 2024. https://wa.aemo.com.au/energy-systems/gas/gas-forecasting-and-planning/gas-statement-of-opportunities-gsoo

Table 1: Summary of research programmes, streams, and projects for Topic 4 Planning

RESEARCH PROGRAMME	STREAM	CODE	PROJECT	FTE	EXPECTED START	EXPECTED END
1. Long-term Uncertainty	Scenario development for planning studies	R1S1P1	Methodologies to forecast evolving generation, DER portfolio and demand	2	Jun-25	May-26
		R1S1P2	Quantifying impact and uncertainty of sector coupling for scenario development (e.g., electrification, hydrogen policies, etc.)	2	Jun-25	May-26
		R1S1P3	Modelling long-term uncertainty in power system planning with the consideration of HILP events (adequacy and security) and critical operation conditions	3	Jan-23	May-26
	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	Jun-27	May-29
		R1S2P2	Modelling the impact of extreme (high/low) temperatures on conventional generation, RES output, network components, demand, etc.	2	Jun-27	May-28
		R1S2P3	Modelling of asset failure under extreme weather conditions, fragility curve of individual component, common mode failure and cascading failure characteristics, etc.	2	Jun-27	May-28
	Uncertainty in policy and market developments	R1S3P1	Impact and interactions between market developments and system planning (e.g., capacity markets)	4	Jun-25	May-27
		R1S3P2	Impact of carbon pricing and other externalities on planning	3	Jun-25	May-27
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	Dec-23	May-26
		R2S1P2	Quantifying reactive power requirement and modelling its provision in power system planning (minimum demand)	2	Jun-26	May-27
		R2S1P3	Quantifying the impact of imperfect competition in the operational and planning decisions of future power systems	2	Jun-25	May-26
	System dynamics modelling for planning purposes	R2S2P1	Dynamic modelling of new technologies (e.g., storage, electrolyser) and its representation in power system planning	3	Jun-26	Apr-28
		R2S2P2	Developing models, stability analysis methodologies and test conditions for future power systems under different portfolios of grid-forming and grid-following IBRs	4	Jun-26	May-28
	Security constraints formulation	R2S3P1	Representing steady-state and dynamic security constraints into the steady-state operation model used in power system planning	2	Jun-26	May-27
		R2S3P2	Identifying black start requirements of future power systems and the black start capabilities of new technologies. Modelling black start services in power system planning	2	Jun-26	May-27
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	Jun-27	May-28
		R3S1P2	Quantifying the value of differentiated reliability and resilience for different customer groups	2	Jun-27	May-28

	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	Jun-27	May-29
	Credible and non-credible contingencies	R3S3P1	Identifying credible and non-credible contingencies, including indistinct events, for different system states aiming to reduce the size of planning studies	1	Jun-27	May-28
		R3S3P2	Profiling power system risks under various contingencies and indistinct events for future low-carbon grid with high penetration of IBR/DERs	2	Jun-26	May-27
		R3S3P3	Modelling the impacts and benefits of other infrastructure and sector coupling (e.g., gas, hydrogen) on power system reliability and resilience	2	Oct-23	May-25
	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	Jun-26	May-28
		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	Jun-25	May-26
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	Jan-23	May-26
		R4S1P2	Developing a consistent decision-making framework to coordinate market-driven (e.g., generation) and regulated (e.g., transmission) investments while considering reliability	2	Jun-25	May-27
		R4S1P3	Designing the optimal schemes (e.g., mandatory, market-incentivized, hybrid) for services provision to maintain system reliability and resilience	2	Jun-25	May-27
	Methodologies for decision-making under uncertainty	R4S2P1	Methodologies and tools to integrate reliability and resilience assessments into the decision-making process with tractability considerations and a process-oriented structure	4	Jun-27	May-28
		R4S2P2	Modelling investment flexibility in power system planning decision making by enhancing the decision structure and the representation of scenario trees	2	Jan-23	May-26
		R4S2P3	Methodologies and tools to incorporate the assessment of non-network solutions value streams in the network expansion problem	1	Jun-23	May-25
	Interdependence	R4S3P1	Modelling investment decisions (including demand response) at distribution network level and determining the methodologies to integrate them in power system planning	1	Jun-24	May-26
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	Jan-23	May-25
	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	Jun-23	May-26
		R5S2P2	Modelling distributed energy systems (e.g., DERs, VPPs) operation and determining data requirement to represent their operation for planning studies	1	Jan-23	May-25
		R5S2P3	Developing equivalent model to represent the aggregated dynamic behaviour of distributed IBRs for planning studies	3	Jun-26	May-28
	Distributed energy resources impact	R5S3P1	Modelling the impact of high DERs penetration on power system planning	2	Jun-24	May-27
		R5S3P2	Modelling and analysing the contribution of DERs to system reliability (security and adequacy) and resilience	3	Nov-23	May-25

Table 2: Expected progress for the research activities by the end of the ongoing project stage

TASK	PROGRAMME	STREAM	PROJECT	CODE	Envisaged progress
Task A	Decision Making	Interdependence	Modelling investment decisions (including demand response) at distribution network level and determining the methodologies to integrate them in power system planning	R4S3P1	30%
	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	40%
Task B	Distributed Energy Systems	Distributed energy resources impact	Modelling the impact of high DERs penetration on power system planning	R5S3P1	20%
Task C	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	40%
Task D	Reliability and Resilience	Credible and non-credible contingencies	Modelling the impacts and benefits of other infrastructure and sector coupling (e.g., gas, hydrogen) on power system reliability and resilience	R3S3P3	60%

5. Research relevance to Australia

Australia's power system is expecting a substantial development of DER and potential for green hydrogen production (for domestic use and exports) due to the significant availability of renewable resources and the decarbonisation goals of the country. However, current planning approaches do not account for the possibility of developing these resources and usually consider them as an inherent feature of analysed scenarios, leaning heavily on new transmission for unlocking REZs around the country to transport the energy produced to load centres. This may result in decisions that could lead to stranded, underutilised, or redundant assets and potentially higher costs, as synergies and trade-offs between large- and small-scale assets, global and local production, or electricity-gas-hydrogen infrastructures are not considered.

Therefore, improved planning methodologies are needed to address these challenges and achieve robust decisions regarding new infrastructure investments across energy systems and vectors. In this sense, research is undergoing to understand the most efficient methodologies to integrate these aspects in planning frameworks. In turn, this will enable lower costs, enhanced flexibility, increased efficiency, and reduced renewable energy curtailment. These developments will also provide new perspectives on how decision-making can be spread across energy vectors and networks, building a system capable of achieving net zero emissions at minimum cost.

In this context, this research project studies and quantifies the modelling requirements for, and the outcomes of, integrated planning approaches (e.g., transmission-distribution and electricity-hydrogen) and the benefits unlocked by including flexible and adaptive investment options (e.g., storage, demand response and network reinforcements within active distribution systems and hydrogen storage, fuel cells, battery storage among others embedded in hybrid energy-hubs) and their ability to defer, displace or compete with investments in large scale infrastructure.

The aforementioned aspects strongly align with the current Australian context, and in particular, with the critical priorities for future iterations of the Integrated System Plan. This alignment is also justified by the ambitious objectives of both the ECMC ISP review and NER rule changes[6,7] being undertaken by the AEMC, in order to achieve an enhanced ISP that provides greater considerations about the role of distribution systems and the interactions between the electricity system and other energy carriers like gas and hydrogen. In this context, this research supports and informs relevant stakeholders, including AEMO, AEMC, ECMC, DNSPs, and more generally in the context of the G-PST consortium, on methodological approaches to efficiently integrate, assess and value the integrated planning of transmission, distribution, gas and hydrogen systems.

[6] AEMC, Better integration and community sentiment into the ISP. June 2024. https://www.aemc.gov.au/rule-changes/better-integration-gas-and-community-sentiment-isp-0
[7] AEMC, Improving consideration of demand-side factors in the ISP. June 2024. https://www.aemc.gov.au/rule-changes/improving-consideration-demand-side-factors-isp

6. Recommendations for research priorities

Based on the analysis conducted so far, the interim results obtained in the current project, the discussions with project partners and stakeholders, and considering the urgent challenges and requirements the Australian energy system faces for further developments and enhancements of planning methodologies to successfully achieve an integrated system, we recommend focusing on the following research activities (which we call "Tasks") from the original research plan:

- *Task 1: Integrated transmission-distribution system planning under uncertainty*
    - This task would build upon the methodological developments expected at the end of the current stage, where we analyse and assess the coupling of distribution systems planning within the transmission expansion planning process. In addition, AEMO currently proposed an approach to assess distribution networks augmentation options in the ISP[3], which is aligned with the principles proposed so far during this project. In this vein, it will be key to explore the robustness, applicability, and determine which additional developments could be needed for an integrated transmission-distribution planning framework to cope with ***real-world*** challenges.

      These challenges include a proper integration of DER flexibility, the differences in scale and scope of transmission and distribution planning (e.g., different time horizons, network representation, etc.), trade-offs between small- and large-scale investments (e.g., requirements and drivers to defer or anticipate investments) as well as the endogenous incorporation of planning uncertainties and risks faced by system planners (e.g. social licence, varying capital costs) in the decision-making process.
    - From the Research Plan, the activities to be performed in this Task would be associated with:
        - **Project R4S2P2:** Modelling investment flexibility in power system planning decision making by enhancing the decision structure and the representation of scenario trees
        - **Project R4S2P3:** Methodologies and tools to incorporate the assessment of non-network solutions value streams in the network expansion problem
        - **Project R4S3P1:** Modelling investment decisions (including demand response) at distribution network level and determining the methodologies to integrate them in power system planning
        - **Project R5S2P1:** Identifying the sources and availability of demand-side flexibility, quantifying its aggregated profile, and determining its representation in power system planning
        - **Project R5S3P1:** Modelling the impact of high DER penetration on power system planning.
- *Task 2: Methodological developments to assess the integrated expansion planning of electricity-gas-hydrogen infrastructure under uncertainty*
    - This task would build on the framework developed in Task D of the current stage to address the integrated planning of electricity-gas systems with uncertainty considerations. As highlighted in the most recent ISP methodology consultation[3] and required by the AEMC rule change under assessment[6,7], incorporating gas network considerations into the planning of the electricity system has become increasingly important for the NEM.

      From a planning perspective, it is critical to address these interactions due to the key role gas-powered electricity generation (GPG) will play in the future NEM, ensuring a reliable, secure, and resilient system operation. Nevertheless, there is significant uncertainty regarding both total gas demand and specific fuel availability for GPG. These uncertainties directly affect the operation of the electricity system, particularly since GPG provides essential flexibility and peaking capabilities during winter, peak demand, and low-renewable generation periods.

In this vein, methodological developments must therefore adequately address gas-related uncertainties to identify robust infrastructure development paths across both systems (pipelines, long-duration storage, generation, electricity transmission, and others) while ensuring an optimal short- and long-term operation in the two networks.

In addition, hydrogen could also play an important role in complementing GPG. As being assessed in other jurisdictions[8], hydrogen-to-power (HtP), the conversion of low-carbon hydrogen to produce electricity, offers a complementary alternative to natural gas as well as seasonal storage capabilities. Comprehensive modelling and assessments are required to determine this technology's potential in Australia and its role in an integrated electricity-gas-hydrogen system context.

- From the Research Plan, the activities to be performed in this Task would be associated with:
  - **Project R1S1P2:** Quantifying impact and uncertainty of sector coupling for scenario development (e.g., electrification, hydrogen policies, etc.)
  - **Project R3S3P3:** Modelling the impacts and benefits of other infrastructure and sector coupling (e.g., gas, hydrogen) on power system reliability and resilience
  - **Project R5S1P1:** Modelling the impact and flexibility embedded in the interactions between power systems and other energy systems for planning studies.

The two research Tasks are in no order of priority for the next stage of the project, but we believe are essential for shaping the future Australian energy system through an enhanced ISP. We estimate that *each* Task proposed above would roughly require similar resources as in the current, ongoing research project. In this context, Table 3 summarises how the activities in the proposed Tasks could advance the project activities envisaged in the original research plan.

Table 3: Progress expected at the end of the proposed Tasks for the research activities envisaged in the research plan.

TASK	PROGRAMME	STREAM	PROJECT	CODE	Envisaged progress
Task 1	Decision Making	Methodologies for decision-making under uncertainty	Methodologies and tools to incorporate the assessment of non-network solutions value streams in the network expansion problem	R4S2P3	70%
		Interdependence	Modelling investment decisions (including demand response) at distribution network level and determining the methodologies to integrate them in power system planning	R4S3P1	50%
	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	60%
		Distributed energy resources impact	Modelling the impact of high DERs penetration on power system planning	R5S3P1	40%
Task 2	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	15%
	Reliability and Resilience	Operational flexibility	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	50%

[8] Department for Energy Security & Net Zero. Hydrogen to Power: Government response to consultation on the need, and design, for a Hydrogen to Power market intervention. https://assets.publishing.service.gov.uk/media/6752e17620bcf083762a6caf/hydrogen-to-power-consultation-response.pdf