CSIRO Australian Research Planning for Global Power Systems Transformation

Topic 8 “Distributed Energy Resources”

Document ID: UoM-CSIRO-GPST-DER-M3_Research_Plan_v01

Research Organisation: The University of Melbourne
Department of Electrical and Electronic Engineering
Power and Energy Systems Group

Date: 3rd September 2021

Authors: Luis(Nando) Ochoa
Arthur Gonçalves Givisiez
Dillon Jaglal
Michael Z. Liu
William Nacmanson

Contact: Prof Luis(Nando) Ochoa
luis.ochoa@unimelb.edu.au

Executive Summary

This document corresponds to the Australian Research Plan for Topic 8 "Distributed Energy Resources – Challenges and Opportunities from Very High Levels of Distributed Energy Resources" produced by The University of Melbourne as part of the "Australian Research Planning for Global Power Systems Transformation" project led by CSIRO.

The Research Plan considers a horizon of 10 years (2022 to 2032) and focuses on Australia. Distributed Energy Resources (DERs), in the context of this work, is defined by CSIRO as encompassing domestic/residential and small industrial generation and flexible resources such as solar PV, batteries, flexible loads, and electric vehicles.

A total of 10 Research Questions across six areas covering DER challenges have been refined and translated into Research Activities using the expertise of the team at The University of Melbourne, extensive reviews, and the feedback from Australian and international stakeholders.

Based on the refined research questions, the Australian capability assessment and the prioritisation of the research questions done in the previous sections, the proposed timeline of the Research Plan is presented in Table 1. To illustrate the timeline of the research activities and the potential implementation of the corresponding outputs/findings, the horizon of 10 years (as defined for this Research Plan, section 1) is assumed to start in 2022. In practice, due to funding processes, contracts, etc., the start date might occur in 2023 or later.

The main aspects of Table 1 and the following sections are described below:

- Priority. Although all research questions are considered relevant to Australia, to distinguish their relative urgency, three priority levels (*Very High*, *High* and *Medium*) are assigned to the research questions as discussed in section 6.9.
- Start Year. Although 6 research questions could start in parallel in 2022, 4 research questions have prerequisites due to strong dependencies with other tasks or Topics. In particular, RQ1.1, RQ1.2 and RQ2.1 would need to wait for the DER orchestration frameworks to be agreed/defined to some extent (potentially by Topic 7 "Architecture") for these research questions to be investigated (as discussed in section 6.1.3). In the case of RQ1.2 and RQ4.2, partial outputs/findings from other research questions would be needed to start the corresponding investigations.
- Research Activities. To answer each research question, several activities of different types and durations have been identified (further details in sections 7.2 to 7.11). Given the very technical and practical nature of many of the research questions, some activities can benefit from carrying out trials and some from relatively short pieces of work. These activities have been classified into the following three types (and used as 'tags' in sections 7.2 to 7.11).
    - [Short-Term Research]. 1 to 2 years of work that can be done by research organisations and/or consultancy companies.
    - [Trial]. 2 to 3 years of work devoted to actual field trials to test concepts, technologies, implementation aspects, etc. and that are led typically by key stakeholders such as AEMO and/or DNSPs.
    - [Long-Term Research]. 3 to 4 years of in-depth research work typical of a PhD project (or equivalent) and, thus, done by research organisations.

  The total duration of the combined activities per research question has been adjusted to reflect the feedback from the stakeholders (section 6.1.3).

- Buffer. Given that research questions can have activities that can take longer than others, a buffer was created to illustrate that shorter activities can start later if needed.
- Implementation. This corresponds to the time it might take for the outputs and findings from the research activities for each question to be implemented/adopt by industry and/or Government. In particular, RQ1.3 and RQ5.2 are those considered to take longer due to the nature of standards and rule changes. The duration for each research question has been tuned according to the feedback from the stakeholders (section 6.1.3).

It is important to highlight that the priorities and timelines provided in Table 19 do not necessarily mean that research funding would need to be allocated to research questions with *Very High* priority first. The timeline can also be used to prioritise research questions based on, for instance, how immediate the implementation/adoption of outputs would be.

Finally, for the 10 identified Research Questions to be successfully answered in the context of Australia, it is crucial that the corresponding research activities (presented in sections 7.2 to 7.11) are carried out considering:

- States and Territories Characteristics. Different States and Territories in Australia have (and might continue to have) different DER uptakes, different demand/population growth, different monitoring infrastructures at the distribution level (particularly in terms of smart meters), etc. The research activities need to be carried out considering those differences.
- DER is not only solar PV. As discussed in presented in section 3.1, rooftop solar PV will continue to be the most prominent DER technology in terms of installed capacity for the next 10 years. Within this period, batteries will increasingly provide more opportunities. However, given that the uptake of EVs is expected to be very high from 2030 onwards, EVs should be considered throughout the research activities to ensure that our electricity system is prepared accordingly.

Table 1. Timeline of the Research Plan

Long-term Research, Trial, Short-term Research, Prerequisite, Buffer, Implementation, Letters = Research Activity

<table>
<tr><th>Priority</th><th>Research Questions</th><th>2022</th><th>2023</th><th>2024</th><th>2025</th><th>2026</th><th>2027</th><th>2028</th><th>2029</th><th>2030</th><th>2031</th><th>2032</th></tr>
<tr><td rowspan="14">Very High</td><td rowspan="3">RQ0.1 What data flows (DER specs, measurements, forecasts, etc.) are needed to ensure AEMO has enough DER/net demand visibility to adequately operate a DER-rich system in different time scales (mins to hours)?</td><td colspan="4">B, E, F, G</td><td colspan="2" rowspan="3">Implementation</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="3">D</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">A, C, D, H, I</td><td colspan="2"></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="3">RQ1.3 What is the role of DER standards in concert with the future orchestration of DERs?</td><td colspan="4">A, B</td><td colspan="5" rowspan="3">Implementation</td><td></td><td></td></tr>
<tr><td colspan="3">C</td><td></td><td></td><td></td></tr>
<tr><td colspan="2">C</td><td colspan="2"></td><td></td><td></td></tr>
<tr><td rowspan="3">RQ4.1 What are the minimum requirements for a DER-rich distribution network equivalent model to be adequate for its use in system planning studies?</td><td colspan="4">B, C</td><td colspan="2" rowspan="3">Implementation</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="3">E</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">A, C, D, E</td><td colspan="2"></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">RQ5.1 What are the necessary organisational and regulatory changes to enable the provisioning of ancillary services from DERs?</td><td colspan="3">A, B</td><td colspan="2" rowspan="2">Implementation</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">A, B, C, D</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="3">RQ5.2 What are the necessary considerations of establishing a distribution-level market (for energy and services)?</td><td colspan="4">B, C, D, E</td><td colspan="5" rowspan="3">Implementation</td><td></td><td></td></tr>
<tr><td colspan="3">C, E</td><td></td><td></td><td></td></tr>
<tr><td colspan="2">A</td><td colspan="2"></td><td></td><td></td></tr>
<tr><td rowspan="11">High</td><td rowspan="3">RQ1.1 For each of the potential technical frameworks for orchestrating DERs in Australia (e.g., based on the OpEN Project), what is the most cost-effective DER control approach to deal with the expected technological diversity and ubiquity of DERs?</td><td colspan="2" rowspan="3">Agreement on Frameworks (Topic 7)</td><td colspan="4">A, B, D, F</td><td colspan="2" rowspan="3">Implementation</td><td></td><td></td><td></td></tr>
<tr><td colspan="3">C, F, G</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">E, G</td><td colspan="2"></td><td></td><td></td><td></td></tr>
<tr><td rowspan="3">RQ1.2 For each DER control approach, what is the most adequate decision-making algorithm (solution method)?</td><td colspan="2" rowspan="3">Agreement on Frameworks (Topic 7)</td><td colspan="4">A, B, C</td><td colspan="2" rowspan="3">Implementation</td><td></td><td></td><td></td></tr>
<tr><td colspan="3">B, C, D, E</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">D, E, F</td><td colspan="2"></td><td></td><td></td><td></td></tr>
<tr><td rowspan="3">RQ3.1 What are the most cost-effective ancillary services that can be delivered by DERs considering the expected technological diversity and ubiquity of DERs?</td><td colspan="4">E</td><td colspan="2" rowspan="3">Implementation</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="3">A, B, D, E, F, G</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">A, B, C, D, F</td><td colspan="2"></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">RQ4.2 What is the minimum availability of ancillary services from DERs at strategic points in the system throughout the year and across multiple years?</td><td colspan="3" rowspan="2">Partial outputs/findings from RQ3.1, RQ5.1</td><td colspan="4">B, D</td><td colspan="3" rowspan="2">Implementation</td><td></td></tr>
<tr><td colspan="2">A, C</td><td colspan="2"></td><td></td></tr>
<tr><td rowspan="3">Medium</td><td rowspan="3">RQ2.1 For each of the potential technical frameworks for orchestrating DERs and the corresponding decision-making algorithms, what is the most cost-effective communication and control infrastructure?</td><td colspan="3" rowspan="3">Agreement on Frameworks (Topic 7) and Partial outputs/findings from RQ1.2</td><td colspan="4">A, D</td><td colspan="3" rowspan="3">Implementation</td><td></td></tr>
<tr><td colspan="3">A, B, D</td><td></td><td></td></tr>
<tr><td colspan="2">B, C</td><td colspan="2"></td><td></td></tr>
</table>

Table of Contents

Acknowledgement

We would like to thank all the Australian and international stakeholders that kindly participated in our engagement sessions and the workshop. Their valuable expert comments and feedback have been used, to the extent possible, to improve different aspects of the Research Plan presented in this document.

The names and affiliations of the Australian and international stakeholders are listed as appendices at the end of this document.

- Appendix C – Australian Stakeholder Engagement
- Appendix D – International Stakeholder Engagement
- Appendix E – Australian Stakeholder Workshop

Abbreviations and Acronyms

AEMC	Australian Energy Market Commission
AEMO	Australian Energy Market Operator
ARC	Australian Research Council
AER	Australian Energy Regulator
ARENA	Australian Renewable Energy Agency
BESS	Battery Energy Storage Systems
CapEx	Capital Expenditure
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DER	Distributed Energy Resource
DNSP	Distribution Network Service Provider
DMO	Distribution Market Operator
DR	Demand Response
EV/s	Electric Vehicle/s
ENA	Energy Networks Australia
HV	High Voltage (e.g., 22kV or 11kV line-to-line)
LV	Low Voltage (below 1kV, e.g., 400V line-to-line)
NEM	National Electricity Market
OLTC	On-Load Tap Changer
OpEx	Operational Expenditure
RQ	Research Question
SCADA	Supervisory Control and Data Acquisition
V2G	Vehicle to Grid
VPP	Virtual Power Plant
WEM	Wholesale Electricity Market

1. Introduction to Topic 8 "Distributed Energy Resources"

Australia has currently one of the largest residential solar PV penetrations in the world, with almost 1 in 4 houses with this technology. Battery storage systems are also becoming attractive as they allow storing excess PV generation during the day to use it later at night. Electric vehicle adoption, although modest today in Australia, is expected to grow in the coming years. These distribution-connected technologies, commonly known as Distributed Energy Resources (DER), which are also becoming common in many countries around the world, not only bring multiple challenges to the operation and planning of the whole power system but also opportunities.

The net demand seen by AEMO, the Australian system operator, has changed dramatically in recent years due to DER, mainly because of residential solar PV. We now have a lower (or even negative) net demand [1] at multiple transmission/distribution interfaces during PV generation hours but still a significant peak net demand later in the day. There is also uncertainty not only due to the weather-related variability of solar PV but also due to the local settings (e.g., frequency response, Volt-Watt functions, etc.) and the future uptake of the technology. All of this makes the task of operating and planning the power system economically, securely, and reliably, much more complex. And this complexity is only going to be exacerbated with higher PV penetrations, new DER technologies and new interactions of DER (such as the provision of services) with the whole system.

The Research Plan for Topic 8 "Distributed Energy Resources – Challenges and Opportunities from Very High Levels of Distributed Energy Resources" as part of the "Australian Research Planning for Global Power Systems Transformation" project led by CSIRO, aims to outline several opportunities for Australian research engagement with the Global Power System Transformation Consortium and related research on the electricity system transformation.

The Research plan considers a horizon of 10 years (from 2022 to 2032) and focuses on Australia. Distributed Energy Resources (DER), in the context of this work, is defined by CSIRO as encompassing domestic/residential and small industrial generation and flexible resources such as solar PV, batteries, flexible loads, and electric vehicles.

CSIRO provided an **initial breakdown of the different DER challenges into five areas**, four technical ones and one institutional:

- (Area 1) Control Architecture of DERs;
- (Area 2) Communication Requirements for Monitoring and Control of DER;
- (Area 3) Ancillary Services Provided by DERs;
- (Area 4) Influence of DER on System-Level Planning; and,
- (Area 5) Overcoming Institutional Challenge.

The following sections provide the context and research aspects **(formulated by CSIRO)** to be considered within each of the areas.

1.1. (Area 1) Control Architecture of DERs

'Traditional' centralised control approaches do not scale well with the increasing complexity of managing exceptionally high numbers of DERs – so efficient distributed control architectures, making use of appropriate device characterisations and limited communications must be established.

Some approaches to consider are:

- The system operator directly controlling DERs via aggregated setpoints, perhaps utilising the Virtual Power Plant (VPP) concept, but this would not be taking full advantage of DER capabilities.
- Utilising a hierarchical control structure with Distributed Network Operators (DNOs) aggregating their own resources and letting the system operator to control the aggregate but DNO controlling individual resources.
- Implementing decentralised and distributed control. The necessary coordination would be achieved by autonomous control algorithms of DERs executing an overall control strategy decided by the system operator. The challenge here is how to achieve the required coordination with limited communication – so that the emergent behaviour through localised control achieves system wide objectives. There is a lot of interest in the concept of distributed/decentralised control for power system applications from the control community which could be utilised.

1.2. (Area 2) Communication Requirements for Monitoring and Control of DERs

Effective monitoring and control of a power system is impossible without communication. Hence it is essential that communication infrastructure is developed for monitoring purposes (one-way) and two-way infrastructure allowing effective control.

The key challenge is balancing the level of monitoring/communication and control with the value this yields – through a communications architecture that is closely linked to an appropriate control architecture (see above).

This interdependency between monitoring, communication and control means that they should be considered together, and the suitability of existing communications infrastructure – in terms of reliability, latency, bandwidth, (cyber)security – relative to investing in a bespoke system must be considered.

1.3. (Area 3) Ancillary Services Provided by DERs

DERs can provide ancillary services, but this must be either through local system sensing or extensive high-quality communications. In this context, we seek to quantify which system-level services can be performed efficiently by DER.

- Frequency response (mainly for batteries but also for wind/solar providing that they have some headroom). Primary frequency control is rather straightforward as it would be simply the frequency-based droop control, but more challenging would be secondary frequency control with limited communication.
- DER can also provide more flexibility for real-time balancing. The question is, what would be the most effective strategy for batteries while maintaining headroom for DG.
- Voltage control
- Congestion management
- Power system restoration[1]
- Resource adequacy

[1] As mentioned in section 2.1 Assumptions, Limitations and Exclusions, given that Topic 8 focuses on the interactions of DER technologies with the whole power system, isolated/off-grid microgrids are excluded.

1.4. (Area 4) Influence of DER on System-Level Planning

There are a number of both market and technical integration considerations that must be addressed in incorporating DER into the electricity system-level planning (example).

- Evaluation of how DER assets behave during power system disturbances, and development of models to predict and manage combined DER performance. This fits closely with a need for ensure standards are developed that DERs operate predictably – underpinning energy system security & interoperability.
- A need for information on DER specifications and locations to enable effective grid integration.
- Changes to market design to support a two-way energy system in which DER can participate – to provide wholesale energy and/or ancillary services to the electricity grid and market.

In the near term, the first of these will be needed to ensure generation adequacy to underpin the need for any transmission network expansion. In the longer term, changes to market arrangements will unlock additional system-level benefits.

1.5. (Area 5) Overcoming Institutional Challenge

While there are many technical challenges to overcome, probably the major single challenge is overcoming the institutional challenge. The system operator has historically been solely responsible for power system control, so finding not only technical pathways to a new distributed control paradigm, but also the organisational change to support a new operational model will be a challenge.

1.6. CSIRO Requirements

As required by CSIRO, this document includes:

- A review of the current status of technology and solutions in the topic area, with a focus on identifying specific areas in which Australia has unique, existing technology, and solutions relevant to the topic.
  - Details in Section 3 "Review of Status of Technology and Solutions".
- A review of related activities underway by AEMO, networks, government, research organisations, and others, and a discussion of how the plan aligns with these activities.
  - Details in Section 4 "Review of Past and Ongoing Australian Activities".
- Further refinement and exposition of listed research questions.
  - Details in Section 6 "Refined Research Questions and Prioritisation".
- Prioritisation of research questions into which are most applicable for Australian researchers to lead, where Australian researchers might collaborate, and where Australia should learn from others.
  - Details in Section 6 "Refined Research Questions and Prioritisation".
- Development of a research plan for the topic area, including identification of opportunities for Australian researchers to help answer specific research questions, with specific research activities and outputs specified.
  - Details in Section 7 "Research Plan".
- Identification of potential information, data, and resource needs to effectively prosecute the research plan. Identification of risks associated with the research plan development and

mitigation strategies. Identification of key stakeholders (in Australia and overseas) required to advance Australian research in the topic area.

- Details in Section 7.12, Section 7.13, and Section 7.14.

2. Methodology

The development of the Research Plan for Topic 8 "Distributed Energy Resources – Challenges and Opportunities from Very High Levels of Distributed Energy Resources" presented in this document as well as the refinement of the Research Questions were guided by the International Energy Agency (IEA)'s "Energy Technology Roadmaps" [2]. The different phases and activities identified by the IEA are illustrated in Figure 1.

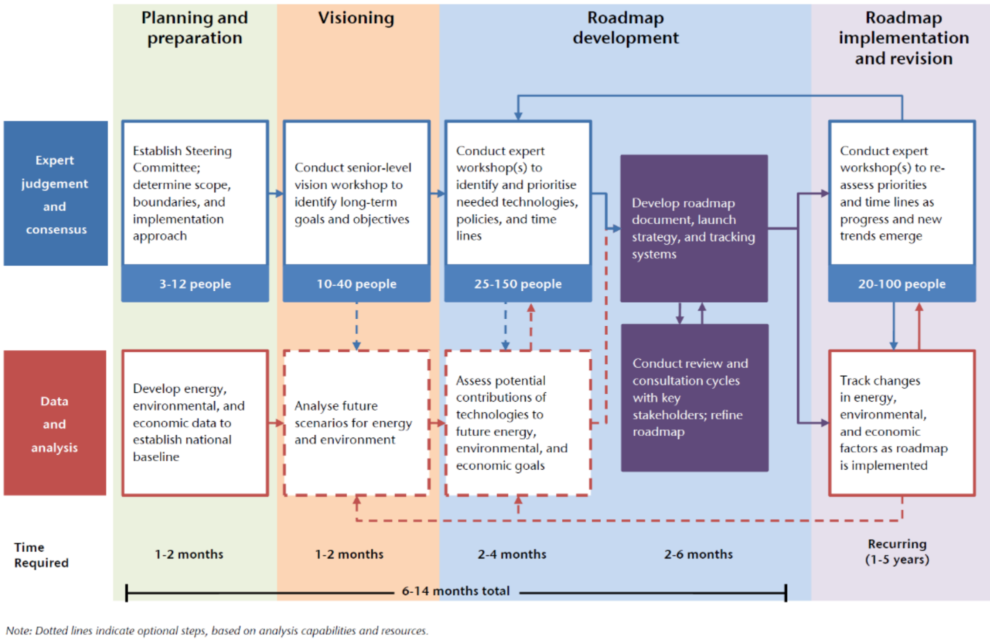

Figure 1. Roadmap Process Outline (source: IEA's "Energy Technology Roadmaps" [2])

Given that the scope of Topic 8 and the initial set of Research Questions were largely defined by CSIRO, only the following activities of the first three phases were considered:

- Phase 1 "Planning and Preparation". The main activity for this phase corresponds to the gathering and analysis of relevant data to establish a baseline.
- Phase 2 "Visioning". The main activity is to conduct senior-level workshops.
- Phase 3 "Roadmap Development". The main activity is to produce the roadmap based on the inputs from the previous phases.

Based on the activities above, as well as the requirements from CSIRO, a more detailed methodology was defined to complete each of them and, ultimately, produce the Research Plan. Every step in the methodology builds on the extensive, world-class research experience of the team at The University of Melbourne which includes a deep understanding of DER, of the interactions of DER with the power grid, and of the potential DER orchestration strategies required to facilitate the provision of system-level services whilst ensuring distribution network integrity[2]. The steps of the adopted methodology are briefly described below.

1. Review of Status of Technology and Solutions in Australia. A review of the current status of DER and DER solutions, with a focus on identifying specific areas in which Australia has unique, existing technology, and solutions relevant to DER.

[2] For more information visit https://sites.google.com/view/luisfochoa

2. Review of Ongoing Australian Activities. A review of DER-related activities underway by AEMO, networks, government, research organisations, and others.
3. First Refinement of the Research Questions. Based on the reviews and the expertise of the team at The University of Melbourne, the initial set of Research Questions is refined before they are shared with stakeholders.
4. Australian Stakeholder Engagement. Multiple sessions with different types of stakeholders with the aim of collecting their expert views on the relevance of the research questions (and aspects related to them) and the ability of Australia to answer them in the next few years.
5. Second Refinement of the Research Questions. Based on the feedback from the stakeholder engagement sessions, a further refinement of the research questions is carried out.
6. Prioritisation of Research Questions. Based on the reviews and the feedback from the stakeholder engagement sessions, the research questions are given qualitative priorities (e.g., low, medium, high) so they can be allocated in the timeline of the research plan.
7. Development of the (Draft) Research Plan. A (draft) research plan is produced with the refined research questions and their prioritisation within the adopted horizon.
8. International Stakeholder Engagement. Multiple sessions with international experts with aim of collecting the views on the relevance of the research questions (and aspects related to them), how those questions are being answered abroad and identification of key international stakeholders.
9. Australian Stakeholder Workshop. A workshop with different types of Australian stakeholders with the aim of collecting their expert views on the identified research outputs, the priority of the research questions, the timeline of research activities, and the potential risks associated with the research plan.
10. Refinement of the Research Plan. Based on the feedback from CSIRO, the international stakeholder engagement sessions, and the Australian stakeholder workshop, the final refinement of the critical components of the research plan is carried out.
11. Research Plan. A research plan is produced containing all the elements requested by CSIRO, including potential information/data required, risks and mitigation strategies and key stakeholders.

2.1. Assumptions, Limitations and Exclusions

As defined by the Global Power System Transformation Consortium and CSIRO, this Research Plan considers a horizon of 10 years (2022 to 2032) and focuses on Australia. Distributed Energy Resources (DERs), in the context of this work, is defined by CSIRO as encompassing domestic/residential and small industrial generation and flexible resources such as solar PV, batteries, flexible loads, and electric vehicles. Consequently, medium to large-scale DER technologies with individual capacities exceeding 100kW (e.g., solar PV farms, wind farms, utility-scale batteries) are excluded from this work.

Furthermore, given that Topic 8 focuses on the interactions of DER technologies with the whole power system, isolated/off-grid microgrids are excluded from this work.

Given the existing overlaps of Topic 8 "Distributed Energy Resources" with other topics, the refinement of the research questions was done not only considering DERs as a critical aspect of the question but also with an adequate depth to avoid covering aspects likely to be covered by other topics. More specifically, the following considerations were made:

- Topic 1 "Inverter Design". More detailed research questions related to DER capabilities and standards that focus on voltage stability, frequency stability, damping, and faults, are likely to be covered by this topic.
- Topic 3 "Control Room of the Future". Research questions associated with the visualisation of DER information in the control room might be covered by this topic.
- Topic 4 "Planning". More detailed research questions about how DER and DER services affect and/or help whole-system planning are likely to be covered by this topic.
- Topic 6 "Services". Research questions associated with the opportunities, limitations and reliability of DER services might be covered by this topic.
- Topic 7 "Architecture". The potential DER orchestration frameworks (e.g., as those define by the Open Energy Networks Project [3]) and the research questions associated with them are likely to covered by this topic.
- Topic 9 "DER and Stability". More detailed research questions related to DER inverter modelling in the context of stability might be covered by this topic.

2.2. Australian Stakeholder Engagement

Twelve (12) online sessions were held on Thursday 10th June and Tuesday 15th June with more than 30 Australian stakeholders from different sectors, including DNSPs, energy retailers, aggregators, manufacturers, solution providers, consultancy, research/academia, and government. The list of stakeholders who provided their expert views during the sessions is included in the Appendix C – Australian Stakeholder Engagement.

Each 45-minute session had from 1 to 5 stakeholders. Given the number of the research questions (10 research questions after the first refinement, details in the Appendix A – First Refinement of Research Questions), stakeholders were asked to select areas of interest. After each research question and corresponding key aspects were presented, the stakeholders were asked:

a) To confirm the relevance of the research question to Australia;
b) To assess whether key aspects were missing; and,
c) To assess whether Australia can answer/deliver the research question in a timely manner.

The feedback and comments from all stakeholders were noted, processed, and used in the second refinement of the research questions, their prioritisation, and, ultimately, in the development of the (Draft) Research Plan.

2.3. International Stakeholder Engagement

Seven (7) online sessions were held from Monday 26th July to Friday 30th July with 11 international experts from USA, UK, Italy, Ireland, and China representing different sectors, including DNSPs, solution providers, and research/academia. The list of stakeholders who provided their expert views during the sessions is included in the Appendix D – International Stakeholder Engagement.

Each 45-minute session had from 1 to 3 stakeholders. Given the number of the research questions, stakeholders were asked to select areas of interest. After each research question and corresponding key aspects were presented, the stakeholders were asked:

a) If the research question has been answered or is being answered in their country/region;
b) If their country/region has collaborated to answer the research question; and,
c) To assess whether key aspects were missing.

The feedback and comments from the experts were noted, processed, and used in the final refinement of the research questions, the list of potential international organisations with which Australia could collaborate, and, ultimately, in the development of the Research Plan.

2.4. Australian Stakeholder Workshop

An online workshop was held on Tuesday 17th August with 13 Australian stakeholders, from different sectors, including AEMO, DNSPs, energy retailers, aggregators, manufacturers, solution providers, consultancy, research/academia, and government. The list of stakeholders who provided their expert views during the sessions is included in the Appendix E – Australian Stakeholder Workshop.

The duration of the workshop was 90 minutes. To effectively capture the inputs from multiple stakeholders on several aspects, stakeholders were asked to provide their inputs via a virtual board. In particular, stakeholders were asked:

a) To provide their relative agreement/disagreement with the identified research outputs for each research question;
b) To determine the priority of the research questions relative to other questions;
c) To provide adjustments (if needed) to the identified time required by the activities of each research question to be completed;
d) To provide adjustments (if needed) to the identified time required for the outputs of each research question to be adopted/implemented by industry/Government;
e) To provide further comments/feedback associated with each research question; and,
f) To provide potential risks associated with the six areas and corresponding research questions.

The feedback and comments from all stakeholders were noted, processed, and used in the final refinement of the research questions, their prioritisation, potential timelines, risks, and, ultimately, in the development of the Research Plan.

2.5. Coordination with other Topics

The work done for Topic 8 was coordinated, to the extent that was possible, with the organisations producing research plans for other topics with synergies and/or overlaps with Topic 8. More specifically, discussions were held with:

- Topic 4 "Planning". Prof Pierluigi Mancarella, The University of Melbourne.
- Topic 7 "Architecture". Mark Paterson, Strategen.

3. Review of Status of Technology and Solutions in Australia

This section provides a review of the current status of DERs and solutions in Australia with the aim of identifying specific areas in which Australia has unique, existing technology, and solutions relevant to DERs.

First, a review of the latest available forecasts on the uptake of various DER technologies is presented. The predicted installed capacities of different DER technologies are then used to determine which DER technologies should be considered a priority for the Research Plan. The more widespread a DER technology is, the more likely it will bring challenges and opportunities to the whole system and, hence, should be captured in the research plan.

Then, the current standards and connection requirements for residential DERs in Australia are summarised, identifying the gaps and opportunities. Ultimately, these gaps and opportunities are used to inform the refinement of research questions and, consequently, the Research Plan.

Finally, a summary of commercially available solutions or solutions at final stage of development/trials for DER orchestration is presented to provide an overview of what is already being covered by Australian companies.

3.1. Australian DER Uptake in the Years Ahead

AEMO delivers many planning and forecasting publications to inform decision making, including the Electricity Statement of Opportunities (ESOO) [4] and the Integrated System Plan (ISP) [5]. To inform these publications, AEMO publishes publicly available data and information on these forecasts (e.g., forecasted GSP, demand, etc.), which importantly include forecasts on several types of DERs [6]. The AEMO forecast for DERs is based on a combination of CSIRO's *"Projections for small-scale embedded technologies"* [7] and Green Energy Markets' *"Projections for distributed energy resources – solar PV and stationary energy battery systems"* [8].

The forecast analysis covers both the short-term, for which the proposed research plan will be undertaken (5-10 years), but also for the longer term, so as not to ignore the long-term DER trends that Australia will need to be ready for (15-30 years). Furthermore, historically, these forecasts (e.g., rooftop PV over the last 10 years) have underpredicted DER uptake. Therefore, long-term forecasts may help also prepare for potential faster-than-expected DER uptakes and trends.

Divided into five scenarios, the forecasts consider various potential economic, social and political possibilities (which are developed in consultation with industry and consumer groups for use by AEMO) [6-8]. These range from lowest DER uptake to the highest DER uptake scenario: Slow Change, Central, High DER, Fast Change, and Step Change.

The forecasts under these scenarios are summarised by installed capacity for 2025, 2030, 2035 and 2049 in Table 2 to Table 5. Below each table (using the average of these scenarios) DER technologies are ranked in prioritisation of which will see the most installed capacity for that year, with an arrow indicating any shift in ranking from the previous list. Finally, Figure 2 shows graphically the average forecasted installed capacity of DERs up to 2049.

2025 DER Forecast Summary

Table 2. 2025 AEMO DER Installed Capacity Forecast across NSW, QLD, SA, TAS and VIC [6]

Scenario	2025 DER Installed Capacity Forecast (MW)					
	Rooftop PV	PV Non-Scheduled Generation (<100kW)	Electric Vehicles w/ 7kW Charger	Battery Energy Storage (<100kW)	VPP Aggregated Battery Energy Storage	Summer Demand Side Participation (Reliability Response)
Slow Change	13,657	1,178	108	835	52	698
Central	16,018	1,522	427	1,237	155	900
Fast Change	17,776	1,700	3,542	1584	337	900
High DER	18,233	2,416	4,860	4,247	1,092	900
Step Change	19,684	3,058	5,025	4,562	1,276	1,139
Average	17,074	1,975	2,792	2,493	582	908

Considering the average of the scenarios, the prioritisation of DER by 2025 is:

1. Rooftop PV
2. Electric Vehicles w/ 7kW charger (Level 2)
3. Battery Energy Storage
4. PV Non-Scheduled Generation <100kW
5. Summer Demand Side Participation - Reliability Response
6. VPP Aggregated Battery Energy Storage

2030 DER Forecast Summary

Table 3. 2030 AEMO DER Installed Capacity Forecast across NSW, QLD, SA, TAS and VIC [6]

Scenario	2030 DER Installed Capacity Forecast (MW)					
	Rooftop PV	PV Non-Scheduled Generation (<100kW)	Electric Vehicles w/ 7kW Charger	Battery Energy Storage (<100kW)	VPP Aggregated Battery Energy Storage	Summer Demand Side Participation (Reliability Response)
Slow Change	16,219	1,443	969	1,230	119	714
Central	19,433	3,089	6,250	5,221	557	1,126
Fast Change	22,033	2,526	19,195	4,231	1,451	1,126
High DER	25,745	4,093	26,298	9,725	3,835	1,126
Step Change	28,974	4,749	30,679	11,045	4,719	1,616
Average	22,481	3,002	16,678	5,807	2,136	1,142

Considering the average of the scenarios, the prioritisation of DER by 2030 is:

1. Rooftop PV
2. Electric Vehicles w/ 7kW charger (Level 2)

3. **Battery Energy Storage**
4. **PV Non-Scheduled Generation <100kW**
5. **VPP Aggregated Battery Energy Storage**
6. **Summer Demand Side Participation (Reliability Response)**

2035 DER Forecast Summary

Table 4. 2035 AEMO DER Installed Capacity Forecast across NSW, QLD, SA, TAS and VIC [6]

Scenario	2035 DER Installed Capacity Forecast (MW)					
	Rooftop PV	PV Non-Scheduled Generation (<100kW)	Electric Vehicles w/ 7kW Charger	Battery Energy Storage (<100kW)	VPP Aggregated Battery Energy Storage	Summer Demand Side Participation (Reliability Response)
Slow Change	17,900	1,842	11,175	1,919	214	750
Central	22,563	3,957	22,134	5,221	1,214	1,402
Fast Change	25,774	3,443	40,044	7,746	3,152	1,402
High DER	32,562	6,118	52,037	15,887	7,029	1,402
Step Change	37,144	6,815	70,810	18,331	8,730	2,175
Average	27,186	4,262	39,240	9,820	4,068	1,426

Considering the average of the scenarios, the prioritisation of DER by 2035 is:

1. **Electric Vehicles w/ 7kW charger (Level 2)**
2. **Rooftop PV**
3. **Battery Energy Storage**
4. **PV Non-Scheduled Generation <100kW**
5. **VPP Aggregated Battery Energy Storage**
6. **Summer Demand Side Participation (Reliability Response)**

2049 DER Forecast Summary

Table 5. 2049 AEMO DER Installed Capacity Forecast across NSW, QLD, SA, TAS and VIC [6]

Scenario	2049 DER Installed Capacity Forecast (MW)					
	Rooftop PV	PV Non-Scheduled Generation (<100kW)	Electric Vehicles w/ 7kW Charger	Battery Energy Storage (<100kW)	VPP Aggregated Battery Energy Storage	Summer Demand Side Participation (Reliability Response)
Slow Change	23,930	2843	39,730	2,411	369	847
Central	31,329	5,458	56,015	9,557	3,051	2,271
Fast Change	38,270	5,983	65,601	12,801	7,189	2,271
High DER	47,267	11,548	84,319	22,651	13,296	2,271
Step Change	53,662	12,712	162,841	25,973	16,226	3,960
Average	38,892	7,709	81,701	14,679	8,026	2,324

Considering the average of the scenarios, the prioritisation of DER by 2049 is:

1. Electric Vehicles w/ 7kW charger (Level 2)
2. Rooftop PV
3. Battery Energy Storage
4. VPP Aggregated Battery Energy Storage
5. PV Non-Scheduled Generation <100kW
6. Summer Demand Side Participation (Reliability Response)

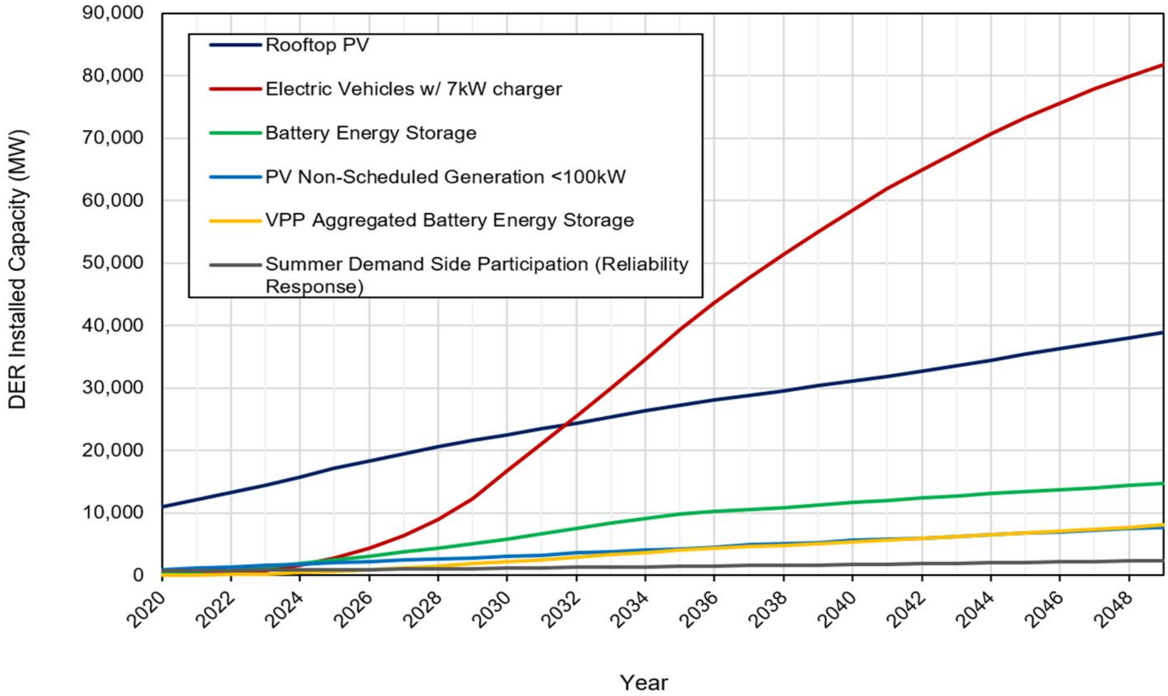

Figure 2. Average of AEMO Scenarios for DER Installed Capacity Forecast

It can be seen in Table 2 and Table 3 that for most scenarios in the next 10 years, the most dominant DER in terms of installed capacity is rooftop PV, followed by Electric Vehicles (EVs), Battery energy storage, PV Non-scheduled generation <100kW, VPP Battery energy storage and, finally, demand response. **From these forecasts, it is possible to conclude that rooftop PV will be the biggest DER challenge in terms of installed capacity for the next 10 years**.

However, just following these next 10 years, EVs with a 7kW charger (also known as Level 2 charger) are forecasted to potentially overtake rooftop PV by 2030 (in terms of installed capacity) as shown in Table 4 and Figure 2. **Therefore, it is crucial for the research plan to consider the trends of DER uptake beyond the 10-year horizon to adequately prepare Australia for an extremely high uptake of EVs**. By 2040, EVs (with a 7kW charger) could be reaching nearly double (188%) the installed capacity of rooftop PV (potentially higher since this is an average of scenarios). This is concerning given the technical challenges rooftop PV at current penetrations (around 20% of all residences) is already bringing in Australia, both in distribution networks and at the system level.

Furthermore, during the mid-2030s battery storage operating as a VPP will come very close to equalling the installed capacity of PV Non-Scheduled Generation <100kW, while exceeding it by 2044 (according to the average of the five scenarios).

It is clear from these forecasts that, Electric Vehicles w/ 7kW charger (Level 2), Rooftop PV, Battery Energy Storage and VPP Aggregated Battery Energy Storage will be the dominant DER technologies in the next 10-30 years in Australia.

3.2. Australian DER Standards and Connection Requirements

Information related to existing Australian DER standards is summarised in Table 6. Although this is not an exhaustive list, it helps identifying where Australia is currently at for DER standards as well as the main gaps and opportunities.

Table 6. Australian DER Technology Standards and General Requirements

DER Technology	Standards	General Requirements	Gaps and Opportunities
Residential PV	• AS/NZS 4777.1:2016 • AS/NZS 4777.2:2005 • AS/NZS 4777.2:2015 • AS/NZS 4777.2:2020 • AS/NZS 4777.3:2002 • IEC62109.1 • IEC62109.2 • AS/NZS 5033:2005 • AS/NZS 5033:2012 • AS/NZS 5033:2014 • AS/NZS 5033:2014/Amdt 1:2018	• Passive Volt-Watt functions. • Passive Volt-var functions. • Passive frequency-Watt over-frequency emergency droop response. • Short duration under voltage disturbance ride-through. • Connection and Installation requirements. • Inverter trip settings. • Anti-islanding, power quality/harmonics etc.	• No underfrequency availability mandated. • No orchestration-related mandatory standard. • Do not fully prevent distribution network issues from PV.
Residential Battery Energy Storage System	• AS/NZS 4777.1 2016 • AS/NZS 4777.2 2015 • AS/NZS 4777.2 2020 • AS/NZS 5139	• Passive underfrequency droop response by ceasing charging (if using PV generation). • Short duration under voltage disturbance ride-through. • Connection and Installation requirements. • Inverter trip settings. • Anti-islanding, power quality/harmonics, etc.	• No mandated injection of power for underfrequency events beyond ceasing charging. • No mandated charging for over frequency events. • No standard to prevent distribution network problems (e.g., getting 100% state-of-charge from PV generation by midday). • No orchestration-related mandatory standard. Different for each VPP provider/aggregator to implement. • Most modern batteries have VPP capability included but not because of a standard.

Electric Vehicle (light duty)	• EV Chargers
	  ○ Type 1 – J1772 (AC)
	  ○ Type 2 - Mennekes (AC/DC)
	  ○ CHAdeMO (DC)
	  ○ CSS Type 1 (AC/DC)
	  ○ CSS Type 2 (AC/DC)
	  ○ Tesla (AC/DC)
	• EV Charging Power Levels
	  ○ Level 1 (3.6kW)
	  ○ Level 2 (7kW)
	  ○ Level 3 (25kW+)
	• AS/NZS 4777.2 2020
	• IEC 61851-1
	• IEC 61851-1 : 2.0
	• IEC 61851-21-1 : 1.0
	• IEC 61851-21-1 : 1ED 2017
	• IEC 61851-21-2 : 1ED 2018
	• IEC 61851-22
	• IEC 61851-23 : 1.0
	• IEC 61851-23 : 1.0 : COR 1
	• AS IEC 61851.23:2014
	• IEC 61851-23:2014 COR 1:2016
	• IEC 61851-25:2020
	• ISO 15118-8:2020
	• And many more…
		• Charger plug type standardisation and functionality.
		• Charger level standardisation.
		• Connection and installation requirements.
		• Some Electric Vehicles can operate in V2G mode exporting power to the grid under AS/NZS 4777.2 2020 and use ISO 15118-8:2020.
		• Short duration under voltage disturbance ride-through.
		• Inverter trip settings.
		• Anti-islanding, power quality/harmonics, etc.
			• No Volt-Watt response for distribution voltage issues when charging normally.
			• No mandatory frequency related standard when charging normally. Only when operating in V2G mode under ASNZ4777 rules. Larger EV charging stations may employ demand response, however.
			• No mandatory DER orchestration standard.
			• While there is a V2G communication standard, it is not a mandatory standard for EV chargers.
			• Charger plug types have their own developments to enable V2G, etc. E.g., CHAdeMO can support V2G, CSS may not support V2G until 2025.

Demand Side Participation	• AS 4755-2007 • AS/NZS 4755.1:2017	• Demand response capability and modes for appliances and smart devices. Controllable loads are connected and able to respond to remote signals and reduce energy demand. • Response separated by price bands.	• Lack of standard for the integration with other DER orchestration schemes. • Australia is a world leader in standards for demand side participation. Already working on updating the standards for DER types such as changing the charging of EVs in response to price signals and emergency signals.

Wind Farms/PV Farms	• National Electricity Amendment Rule 2020 No. 5 • Power System Data Communication Standard • ICCP IEC60870-6 TASE.2	• A requirement that Scheduled Generators and Semi-Scheduled Generators set their generating systems to operate in frequency response mode within one or more performance parameters (which may be specific to different types of plant), which: (1) must include maximum allowable deadbands which must not be narrower than the primary frequency control band outside of which Scheduled Generators and Semi Scheduled Generators must provide primary frequency response; and (2) may include (but are not limited to): droop and response time. • AEMO must publish on its website and maintain, a register of Scheduled Generators and Semi-Scheduled Generators who have been granted a variation or exemption from any primary frequency response parameters in the Primary Frequency Response Requirements. • A common power system data communication standard and communication protocol that applies to all ancillary services providers in the NEM.	• Lack of standard for integration with other DER orchestration schemes. • The Primary Frequency Response Requirements must not require a Scheduled Generator or Semi-Scheduled Generator to: (1) maintain stored energy in its generating system for the purposes of satisfying clause 4.4.2(c1); or (2) install or modify monitoring equipment to monitor and record the primary frequency response of its generating system to changes in the frequency of the power system for the purpose of verifying the Scheduled Generator's or Semi-Scheduled Generator's compliance with clause 4.4.2(c1).
Large-Scale BESS	• Power System Data Communication Standard • ICCP IEC60870-6 TASE.2	• Grid-scale batteries must have connection access granted. Furthermore, they must register and gain approval to provide any ancillary services (to ensure they are of adequate quality, etc). • A common power system data communication standard and communication protocol that applies to all ancillary services providers in the NEM.	• Lack of standard for integration with other DER orchestration schemes. • It is not mandatory for all grid scale batteries to provide frequency response services, unlike Scheduled Generators and Semi-Scheduled Generators.

The main gap and opportunity for all types of DER is a lack of standards related to DER orchestration, including a standard type of communication that could be used to orchestrate DER assets in a coordinated manner (under direction from various possible stakeholders). While this exists to some degree for demand response (being able to respond to remote signals and price points), it is not in a manner that can be easily integrated with other DER assets potentially providing other types of services (e.g., involving the injection of power).

Despite rooftop PV and batteries having some level of primary frequency response standard, it does not fully utilise the potential of these DER assets. For example, battery energy storage systems could in theory inject power (beyond ceasing charging and using PV) following a drop in frequency, or PV systems inject power beyond an export limit if there is spare generation. Although it could be argued that DER orchestration and aggregation (e.g., VPPs) could fill this gap, due to a lack of DER orchestration standards, this can be challenging in practice.

While current standards for rooftop PV address voltage issues on distribution networks, there is no alternative to deal with asset congestion. Meanwhile, **there are currently no standards for battery energy storage systems to help manage distribution network issues** (currently, all batteries will be fully charged by PV at similar times, leading to concurrent high exports of excess generation).

While EVs are progressing well in being able to technically provide V2G services under current standards, not all EVs are required to be able to do this. Furthermore, the ability of EVs to provide V2G services is limited by the type of charging technology (e.g., CHAdeMO vs CSS). Finally, **there are currently no standards for EVs to respect distribution network constraints**, such as the Volt-Watt and Volt-var standards in AS/NZS 4777.2:2020, or a coordinated charging standard whereby power could be limited within a local area by a DNSP but still deliver a full charge by morning. To address some of these concerns a *"Vehicle-Grid Integration Standards"* workforce has been recently formed by AEMO to identify where the absence of a standard may lead to negative impact on consumers and, importantly, catalogue international standards that may be candidates for adoption/modification to cater for the identified gap [9].

Table 7 presents the connection requirements for residential solar PV as set by some of the DNSPs in Australia[3]. It should be noted that for most of these DNSPs batteries do not count towards the inverter size limit, but export limits are still fixed. Furthermore, EVs operating in V2G also must respect the export limits, whilst no "import power" limits exist. Residential consumers are limited to the size of EV charger (no more than level 2, 7kW) and, ultimately, the fuse for the service cable to the house.

For single-phase consumers, most DNSPs have a fixed inverter limit of 10kW, with some requiring 5kW (but are looking to increase this limit). Furthermore, most DNSPs have an export limit of 5kW for single-phase consumers, with some exceptions permitting 10kW. For three-phase consumers,

[3] The connection requirements listed in Table 7 are for residential rooftop solar customers (and hence fall under the rooftop PV forecast in section 3.1). While the PV panel can be of any size (e.g., connected with a battery on the DC side), some DNSPs would limit the inverter size and require an export limit. For PV Non-Scheduled Generation (<100kW), also shown in the forecast, the connection requirements in Table 6 are not relevant. Those installations correspond to small-scale PV farms and commercial customers with large roof spaces (in use or disused factories, etc.) for which export limits would be determined by the DNSP or would be based on the customer's connection agreement.

most connection requirements limit the inverter to 30kW and the majority of DNSPs permit exports between 15-30kW.

These connection requirements presented in Table 7 demonstrate the reality of distribution networks and the problems they face, with DNSPs forced to introduce fixed export limits to manage voltage rise and asset congestion issues from PV. Importantly, **however, these connection requirements can also create a barrier for DER-based services for AEMO**. For example, at certain times of the day, DER may be able to export more power (either as energy sold or ancillary services provided) without creating voltage or asset congestion issues, but are restricted by the fixed export limits imposed by the connection requirements.

Table 7. Australian DNSP Connection Requirements for Residential Rooftop Solar PV

State	DNSP	PV Connection Requirement (kW)			
		Single Phase		Three Phase	
		Inverter limit	Export limit	Inverter limit	Export limit
ACT	Evo Energy	10	5	30	15
NSW	Essential Energy	5	5	15	15
	AusGrid	10	10	30	30
	Endeavour energy	10	5	30	30
NT	Power and Water	5	5	7	7
QLD	Energex	5	5	15	15
	Ergon Energy	10	5	30	15
SA	SA Power Networks	10	5	30	15
TAS	TasNetworks	10	10	30	30
VIC	Citipower/Powercor	5	5	10	10
	Jemena	10	5	30	15
	AusNet Services	10	5	30	15
	United Energy	10	10	30	30
WA	Western Power	10	5	30	30
	Horizon Power	10	5	30	15

Thus, there is an opportunity to explore the use of dynamic export/import limits for DER in distribution networks. This is already an idea being trialled today, for example the ARENA-funded Project EDGE [10-12] involving the DNSP AusNet Services and AEMO, and the ARENA-funded project Flexibile Exports for Solar PV involving the DNSPs SA Power Networks and AusNet Services [13]. ARENA has also created a dedicated workstream to explore the value of dynamic limits (also known as dynamic operating envelopes) [14]. **It is becoming evident that fixed export limits can truncate the potential of DER to provide services to the wider power system**.

The subsequent problems, therefore, are “what can be achieved through implementing dynamic export limits” and “what is required to achieve this on a wide scale”. Ultimately, dynamic export/import limits are likley to provide benefits to both the wider power system, as well as individual consumers. As evidenced by these projects, intelligent coordination is required for a dynamic limit, including the ability to communicate with many separate DER devices (something that is not currently standardised for DERs).

3.3. Available Solutions for DER Orchestration

This section presents a summary of the commercially available solutions or solutions at final stage of development/trials for DER orchestration that are offered by more than 20 companies in Australia. Although this is not an exhaustive list of solutions, it provides a good overview of what is already being covered in Australia.

Each solution/product is classified by tier, scope, consumer group, and the DER technology that the solution applies to. These classifications are explained below.

- Solution/Product **Tier**
  - Tier 1: integrated solution for DER orchestration; these are the companies that carry out the orchestration task of DERs (e.g., system integrator or a VPP).
  - Tier 2: products that are enablers of DER orchestration (e.g., equipment manufacturer or software providers).
- Solution/Product **Scope**
  - System-level services / Ancillary services / Transmission network services.
  - Distribution network services.
  - Consumer energy management.
- Solution/Product by **Consumer Group**
  - Residential.
  - Commercial and industrial.

The available solutions for residential DER orchestration are shown in Table 8, while those for commercial and industrial DER orchestration are shown in Table 9.

Tier 1 solutions, those that provide some level of DER orchestration, corresponds to less than 30% of all available solutions. They are almost equally divided into residential, and commercial and industrial consumer groups. Two are the main services provided by Tier 1 solutions: system-level services and consumer energy management. System-level services are usually related to wholesale energy market and frequency control ancillary services (FCAS), while consumer energy management are usually related to management of DERs inside the consumer building (e.g., residential, commercial). There is at least one Tier 1 solution being tested to provide distribution services.

Table 8. Available Solutions for Residential DER Orchestration

Tier	Scope of Solution			DER Technology					Company
	System-Level Services	Distribution Network Services	Consumer Energy Management	PV	BESS	EV	DR	Others	
1	X		X	X	X				AGL
2	X	X	X	X	X		X	X	Mondo
2	X	X	X			X	X		Jet Charge
2			X			X	X		EO Charging
2			X	X		X	X		EVSE
2	X	X	X			X	X		Greenflux
2	X	X	X	X	X	X	X	X	GreenSync
2			X	X			X		Solar Analytics
2			X	X	X		X		Enphase

2	X	X	X	X	X		X		Evergen
1, 2	X	X	X	X	X				Tesla
2	X	X	X	X	X		X		SwitchDin
2	X	X	X	X	X	X	X		SolarEdge
1	X			X	X				Origin
1	X		X	X	X				Simply Energy
1, 2	X		X	X	X				Sonnen

Tier 2 solutions, which are enablers of DER orchestration (but there is no actual DER orchestration), correspond to almost 70% of the available solutions. They are almost equally divided into residential, and commercial and industrial consumer groups. Since Tier 2 solutions are enablers, they can enable any of the three types of services (system-level services, distribution network services, and consumer energy management) as, ultimately, it will depend on how the infrastructure is managed. Currently, these Tier 2 solutions are mainly being used for consumer energy management, mostly based on the reduction of consumers’ bill and response to tariffs.

Table 9. Available Solutions for Commercial and Industrial DER Orchestration

Tier	Scope of Solution			DER Technology					Company
	System-Level Services	Distribution Network Services	Consumer Energy Management	PV	BESS	EV	DR	Others	
2	X	X	X	X	X		X	X	Mondo
2	X	X	X		X	X	X		Reposit Power
2	X	X	X			X	X		Jet Charge
2			X			X	X		EO Charging
2			X	X		X	X		EVSE
2	X	X	X			X	X		Greenflux
2	X	X	X	X	X	X	X	X	GreenSync
2		X					X		Luceo Energy
1	X		X	X	X		X	X	Enel X
2			X	X	X				Epho
2	X	X	X	X	X		X		Evergen
2			X			X			Evie
2	X	X	X	X	X		X		SwitchDin
2	X	X	X	X	X	X	X		SolarEdge
1	X		X	X	X				Simply Energy
1, 2	X		X	X	X				Sonnen

Even though DER orchestration is still not fully studied/understood and complete technical solutions (e.g., standards, connection requirements, control strategy/architecture) are not available, the solutions listed in Table 8 and Table 9 show that Australia has many companies that are already innovating and, therefore, making their own technical decisions to make their products/services available. Since companies do not fully disclose the technicalities of their products/services, it can be assumed that they are based on existing standards (international or national), novel in-house designs, or a mix of both. In addition, it is likely that most of the commercially available solutions cater for specific technical challenges and DER technologies that are of interest to the company. Therefore, there is still a need for thorough research on DER orchestration. And collaboration with industry can certainly improve the results and speed up the process.

3.4. Key Remarks

Australia is one of the world leaders in the adoption of rooftop solar PV with almost 1 in 4 houses having this technology. In the last decade, the corresponding challenges brought by such an uptake has also sparked the need for more adequate standards, connection requirements, and commercial innovation. Today, there are multiple companies providing highly innovative solutions for the orchestration of DERs. However, most of the commercially available solutions tend to cater for specific technical challenges and DER technologies; they do not cover multiple DER technologies or different aspects that might be needed in the future. Therefore, further developments and innovations are still needed.

Below are some of the main findings from this review.

- Rooftop solar PV will continue to be the most prominent DER technology in terms of installed capacity for the next 10 years. Within this period, batteries will increasingly provide more opportunities. However, given that the uptake of EVs is expected to be very high from 2030 onwards, EVs should also be considered in the research plan.
- In terms of standards, the main gap and opportunity for all types of DERs is the lack of standards related to DER orchestration.
- Despite solar PV and batteries having some level of primary frequency response standard, it does not fully utilise the potential of these technologies.
- There are no standards for batteries to help manage distribution network issues.
- There are no standards for EVs to respect distribution network constraints.
- The fixed export limits adopted by DNSPs to manage voltage rise and asset congestion issues from residential PV can also create a barrier for DER-based services for AEMO. Thus, there is a clear opportunity to explore the use of dynamic export/import limits for DERs in distribution networks.
- Solutions for DER orchestration represent the minority (less than 30%) of all identified available solutions. The rest are enablers (no actual DER orchestration) and focus on consumer energy management. Thus, there is a clear opportunity to further develop and improve solutions for DER orchestration.
- Almost all the solutions for DER orchestration focus on providing market-based services to AEMO (at the transmission level). Distribution network services are largely unexplored. While regulation and rules might still be a barrier for those services, there is still an opportunity to explore the practical aspects and effectiveness of potential solutions.

4. Review of Past and Ongoing Australian Activities

This section presents an analysis of more than 90 projects and activities (both completed and ongoing) involving the integration of DER and that have been carried out in Australia over the past decade. The main sources of information include the ARENA projects database [15], the AEMO's National Electricity Market Distributed Energy Resources Program [16], and the ENA projects database [17]. For completeness, other sources were also considered such as, ARENA Distributed Energy Integration Program (DEIP) [18], AEMO standards [19, 20], the Centre for New Energy Technologies (C4NET) projects [21], CSIRO energy projects [22], the Australian Energy Regulator (AER) [23], the Australian Energy Market Commission (AEMC) [24], and the Energy Security Board (ESB) Post 2025 Electricity Market Design [25]. These projects and activities involve a wide range of organisations (e.g., AEMO, DNSPs, aggregators, energy retailers, manufacturers, solution providers, research organisations, consumer groups, state/local governments) and, therefore, capture the existing capabilities and know-how in Australia.

The analysis of these 92 projects is broken down per DER technology and presented for each of the five areas identified by CSIRO for Topic 8. Based on the publicly available information, projects and activities involving large-scale DER were excluded. The complete raw data can be found in the Appendix F – Past and Ongoing Australian Activities.

4.1. (Area 1) Control Architecture of DERs

33 projects and activities were identified as relevant to "(Area 1) Control Architecture of DERs". The aggregated cost (of these projects and activities) is **$214.2 million**.

The breakdown of these projects and activities per DER technology is shown in Table 10. Some projects involve more than one DER technology. The category 'Others' refers to projects that do not specifically focus on a DER technology or are not related to the other DER technologies.

From Table 10, it is evident that both **PV and BESS have attracted the most interest**. On the other hand, EVs have attracted the least attention.

Table 10. Past and Ongoing Australian Activities for Area 1

	PV	BESS	DR	EVs	Others
Total Number of Projects	10	15	8	6	9
Aggregated Cost of Projects#	$ 149.5M	$ 150.9M	$ 32.7M	$ 21.9M	$ 18.8M
Average Cost of Projects#	$ 15.0M	$ 10.1M	$ 4.1M	$ 3.7M	$ 2.1M

Projects without publicly available information are omitted.

4.2. (Area 2) Communication Requirements for Monitoring and Control of DERs

43 projects and activities were identified as relevant to "(Area 2) Communication Requirements for Monitoring and Control of DERs". The aggregated cost (of these projects and activities) is **$298.6 million**.

The breakdown of these projects and activities per DER technology is shown in Table 11. Some projects involve more than one DER technology. The category 'Others' refers to projects that do not specifically focus on a DER technology or are not related to the other DER technologies.

Table 11. Past and Ongoing Australian Activities for Area 2

	PV	BESS	DR	EVs	Others
Total Number of Projects	11	14	12	6	15
Aggregated Total Cost of Projects#	$ 145.5M	$ 142.0M	$ 73.5M	$ 21.9M	$ 62.7M
Average Total Cost of Projects#	$ 13.2M	$ 10.1M	$ 6.1M	$ 3.7M	$ 4.2M
# Projects without publicly available information are omitted.					

From Table 11, it is evident that both **PV and BESS have attracted the most interest**. On the other hand, EVs have attracted the least attention.

4.3. (Area 3) Ancillary Services Provided by DERs

41 projects and activities were identified as relevant to "(Area 3) Ancillary Services Provided by DERs". The aggregated cost (of these projects and activities) is **$322.2 million**.

The breakdown of these projects and activities per DER technology is shown in Table 12. Some projects involve more than one DER technology. The category 'Others' refers to projects that do not specifically focus on a DER technology.

From Table 12, it is evident that **both PV and BESS have attracted the most interest**. On the other hand, EVs have attracted the least attention.

Table 12. Past and Ongoing Australian Activities for Area 3

	PV	BESS	DR	EVs	Others
Total Number of Projects	14	17	16	4	13
Aggregated Total Cost of Projects#	$ 141M	$ 160.2M	$ 104.3M	$ 14.6M	$ 49.3M
Average Total Cost of Projects#	$ 10.1M	$ 9.4M	$ 6.5M	$ 3.7M	$ 3.8M
# Projects without publicly available information are omitted.					

4.4. (Area 4) Influence of DERs on System-Level Planning

24 projects and activities were identified as relevant to "(Area 4) Influence of DER on System-Level Planning". The aggregated cost (of these projects and activities) is **$48.1 million**.

The breakdown of these projects and activities per DER technology is shown in Table 13. Some projects involve more than one DER technology. The category 'Others' refers to projects that do not specifically focus on a DER technology.

From Table 13, it is evident that **both EVs and BESS have attracted the most interest**. On the other hand, DR has attracted the least attention.

Table 13. Past and Ongoing Australian Activities for Area 4

	PV	BESS	DR	EV	Others
Total Number of Projects	8	7	2	4	11
Aggregated Total Cost of Projects#	$ 8.0M	$ 11.2M	$ 7.6M	$ 19.7M	$ 6.8M
Average Total Cost of Projects#	$ 1.0M	$ 1.6M	$ 3.8M	$ 4.9M	$ 0.6M
# Projects without publicly available information are omitted.					

4.5. (Area 5) Overcoming Institutional Challenge

38 projects and activities were identified as relevant to "(Area 5) Overcoming Institutional Challenges". The aggregated cost (of these projects and activities) is **$226.7 million**.

The breakdown of these projects and activities per DER technology is shown in Table 14. Some projects involve more than one DER technology. The category 'Others' refers to projects that do not specifically focus on a DER technology.

From Table 14, it is evident that **both PV and BESS have attracted the most interest**. On the other hand, DR has attracted the least attention.

Table 14. Past and Ongoing Australian Activities for Area 5

	PV	BESS	DR	EV	Others
Total Number of Projects	14	15	6	8	14
Aggregated Cost of Projects#	$ 144.1M	$ 140.5M	$ 12.2M	$ 25.5M	$ 49.5M
Average Cost of Projects#	$ 10.3M	$ 9.4M	$ 2.0M	$ 3.2M	$ 3.5M

Projects without publicly available information are omitted.

4.6. Analysis Across Areas

A breakdown per area across all the 92 projects and activities is shown in Table 15. Some projects involve more than one area.

Table 15. Past and Ongoing Australian Activities Across Areas

	Area 1	Area 2	Area 3	Area 4	Area 5
Total Number of Projects	33	43	41	24	38
Aggregated Cost of Projects#	$ 214.2M	$ 298.6M	$ 322.2M	$ 48.1M	$ 226.7M
Average Cost of Projects#	$ 6.5M	$ 6.9M	$ 7.9M	$ 2.0M	$ 6.0M

Projects without publicly available information are omitted.

From Table 15, it is evident that **"(Area 2) Communication Requirements for Monitoring and Control of DERs" and "(Area 3) Ancillary Services Provided by DERs" have attracted the most interest in recent years**. On the other hand, "(Area 4) Influence of DER on System-Level Planning" is significantly less investigated by recent projects and activities.

4.7. Key Remarks

In the past decade, Australia has invested hundreds of millions of dollars on innovation projects and activities involving different small-scale DER technologies, as well as addressing different technical and non-technical challenges (covering the five areas identified by CSIRO).

Unsurprisingly, due to the high uptake of solar PV in Australia and the urgent need to address the challenges being faced by AEMO and the distribution companies, a significant proportion of the projects and activities involve solar PV. This is closely followed by batteries as their uptake is also creating opportunities.

The areas that attracted the most interest and funding are "(Area 2) Communication Requirements for Monitoring and Control of DERs" and "(Area 3) Ancillary Services Provided by DERs". Given the technical nature of the challenges within these two areas, they have inspired large demonstrations/trials which, in turn, require significant funding. Nonetheless, many of these large projects also investigate aspects of other areas such as “(Area 1) Control Architecture of DERs” and “(Area 5) Overcoming Institutional Challenges”, making them also areas of high interest.

While this review demonstrates that there are already significant capabilities and expertise within Australian industry and research organisations to tackle the different challenges brought by DERs, they have been largely focused on solar PV and batteries. More needs to be done in terms of the orchestration of different types of DERs, particularly in preparation of the expected high uptake of EVs. Furthermore, although most of the five areas are being well covered by innovation projects and activities, “(Area 4) Influence of DERs on System-Level Planning” has not attracted as much interest. Although this might be because of the nature of the area (relevant mostly to AEMO and not necessarily requires demonstrations/trials), the level of funding might suggest that more work is needed.

5. Review of Key International Activities

By capturing, to some extent, the existing capabilities and know-how around the world, it is possible to benchmark the capabilities of Australia. To achieve this, this section presents a brief analysis of key, large-scale international projects or activities (both completed and ongoing) involving the integration of DER and that have been carried out over the past decade.

The main starting points to find these projects were the websites of:

- international agencies (such as the International Renewable Agency, IRENA);
- recognised international conferences (such as the CIRED and IEEE PES PowerTech);
- recognised international publications (such as the IEEE Power & Energy Magazine); and,
- transmission system operators (TSO) and DNSPs around the world.

All the information captured for each of the identified projects was based on the publicly available project website(s) and/or content at the time of search.

In total, **25 international projects** were selected as relevant. Most of these projects (16) are in Europe, involving mainly the UK, Belgium, Italy, Spain, and Germany. The rest (9) are in the USA. This highlights, as expected, the close link between the uptake of DER in those countries and the need for those activities. The breakdown of these projects per DER technology and for each of the five areas identified by CSIRO for Topic 8 is shown in Table 16. The complete data (including the corresponding country) can be found in the Appendix G – Key International Activities.

The category 'PV' refers to rooftop PV systems, while the category 'BESS' refers to small-scale BESS, and the category 'Others' refers to projects that do not specifically focus on a DER technology, or the project considers other types of DER that were not explicitly named in the table. Note that some projects involve more than one DER technology and/or more than one area, therefore the total number of projects per DER technology or per project area is not a direct sum of individual cells in the same column or row.

From Table 16, it is evident that **PV, DR, and Others have attracted more interest in recent years**, while EV has attracted the least interest. It is also evident that **"(Area 2) Communication Requirements for Monitoring and Control of DERs" and "(Area 3) Ancillary Services Provided by DERs" have attracted more interest in recent years**, while "(Area 4) Influence of DER on System-Level Planning" is the least investigated area by recent projects.

Table 16. Past and Ongoing Key International Activities by DER Technology and Across Areas

		Number of Projects					Total # Projects per DER Technology
		Area 1	Area 2	Area 3	Area 4	Area 5	
DER Technology	PV	8	7	8	1	2	**10**
	BESS	5	6	5	0	4	**9**
	DR	4	6	10	2	4	**12**
	EV	2	1	3	1	2	**3**
	Others	6	6	6	3	3	**11**
Total # Projects per Area		**11**	**14**	**15**	**4**	**9**	-

5.1. Key Remarks

In the past decade, different countries around the world have invested hundreds of millions of dollars on innovation projects and activities involving different small-scale DER technologies as well as addressing different technical and non-technical challenges (covering the five areas identified by CSIRO).

Some loads (such as air-conditioning systems or water heaters) are well-known to be capable of being controlled so as to help in the system operation, so it is not surprising that many of the identified international projects focused on DR. Nonetheless, given the high uptake of DER also happening around the world, especially solar PV, and the urgent need to address the challenges being faced by systems operators and the distribution companies, a significant proportion of the international projects and activities also involved solar PV and DER in general (category ‘Others’).

The areas that attracted the most interest and funding are “(Area 2) Communication Requirements for Monitoring and Control of DERs” and “(Area 3) Ancillary Services Provided by DERs”. Similar to what was found in Australia, the technical nature of the challenges within these two areas led to large demonstrations/trials which, in turn, require significant funding. Nonetheless, many of these large projects also investigate aspects of another area such as “(Area 1) Control Architecture of DERs”, making this one also an area of high interest.

Consequently, this review shows that there is a **strong alignment between Australian activities with those around the world**. This means that Australia indeed has significant capabilities and expertise within **Australian industry and research organisations** and, therefore, is in a **strong position to lead new activities to tackle the challenges brought by DER**.

6. Refined Research Questions and Prioritisation

The original research questions (RQs) identified by CSIRO went through a "First Refinement" using the expertise of the team at The University of Melbourne and the findings from the reviews carried out as part of this work. These new research questions were the ones discussed during the stakeholder engagement sessions and can be found, along with the corresponding feedback, in Appendix A – First Refinement of Research Questions.

The latest version of the research questions for each of the areas considered as DER challenges are presented in this section. The research questions are the result of the "Second Refinement" which considers the analysis and incorporation of the feedback gathered during the Australian stakeholder engagement sessions. Overall, the number (10 in total) and nature of the research questions discussed with the stakeholders did not change significantly. The evolution of all the research questions can be found in the Appendix B – Research Question Change Log.

The key aspects associated with each research question (encapsulating the context and challenges) have been subjected to further refinements that include the feedback from the international stakeholder engagement sessions and the Australia stakeholder workshop.

6.1. Summary of Stakeholder Feedback

This section presents a summary of the feedback received in each of three engagement activities:

- Australian Stakeholder Engagement (12 online sessions with 30+ participants);
- International Stakeholder Engagement (7 online sessions with 10+ participants); and,
- Australian Workshop (1 online session with 10+ participants).

6.1.1. Australian Stakeholder Engagement

The summary below follows the structure used to gather feedback (as presented in section 2.2). More details can be found in Appendix A – First Refinement of Research Questions.

a) Relevance of the research questions to Australia. The overwhelming majority of stakeholders not only found all the research questions relevant to Australia but also highlighted the need for them to be answered urgently. The question related to standards (RQ1.3), as initially presented to the stakeholders, was considered to have an inadequate angle. As a result, this question was reformulated based on the feedback[4].
b) Missing key aspects. Aspects related to end consumers (or customers) and cost-effectiveness were consistently brought up in most research questions. This includes consumer-centric analysis, consumer engagement/acceptance of technology, and cost implications.
c) Ability of Australia to answer/deliver the research questions in a timely manner. The overwhelming majority of stakeholders had a very strong view that Australia is well-positioned to answer most research questions and that Australia is considered a leader in many areas related to DERs. Nonetheless, many stakeholders had strong views that the outcomes from the research questions involving rule changes (RQ5.1 and RQ5.2) and/or

[4] RQ1.3 evolved from "To what extent can DER standards alone (no DER orchestration and no markets) extract valuable services for AEMO (e.g., response to frequency changes) while ensuring distribution network integrity?" to "What is the role of DER standards in concert with the future orchestration of DER?".

standards (RQ1.3) would take several years as the processes for new regulations and new standards can be extremely time consuming and can depend on multiple factors.

6.1.2. International Stakeholder Engagement

The summary below follows the structure used to gather feedback (as presented in section 2.3).

a) Relevance of the research questions to their country/region. All the research questions were considered relevant to the countries being represented by the participants. However, it was highlighted that, even within a country, the importance/urgency of certain research questions depends on the uptake and type of DER seen by each region within a country (or State, as in the US). Furthermore, although it was mentioned that there are multiple recent and ongoing research activities already trying to answer some of the research questions (see section 5 Review of Key International Activities), more work is needed.
b) Collaborations to answer the research questions. Different types of collaborations exist around the world. One of the most critical aspect to consider, however, is to ensure that there are collaborations between industry and research organisations/academia within the same country. It was also highlighted that collaborations in Europe exist not only thanks to the European-wide funding sources but also because of the commonality of the DER uptake/challenges and regulation among many countries. On the other hand, in the US, some States have very different DER uptake/challenges as well as regulation, making collaborations more difficult. In general, collaborations with overseas organisations (i.e., outside Europe or outside the US) was not common but do exist.
c) Missing key aspects. Some stakeholders had strong views on the need for adequate regulation and standards (mainly related to RQ5.1, RQ5.2, and RQ1.3). Regulation can allow DNSPs to manage some DER services (already happening in the UK). Regulation can also (and should) promote closer collaboration between transmission and distribution. In terms of the creation of new standards, while it is considered a long process, it is one that needs to capture -to the extent that is possible- future DER services and corresponding communications.

6.1.3. Australian Workshop

The summary below follows the structure used to gather feedback (as presented in section 2.4). More details (including further comments provided by stakeholders) can be found in Table 33 and Table 34 (Appendix E – Australian Stakeholder Workshop).

a) Agreement/disagreement with the identified research outputs for each research question. Overall, the stakeholders agreed with the key outputs identified for all the RQs.
b) Priority of the research questions relative to other questions. The priority presented to the stakeholders was based on the total time needed by the research activities of each RQ to be completed plus the time for the outputs to be adopted (by industry and/or Government). However, the feedback from the stakeholders made it clear that a more intuitive prioritisation is one based on the urgency to answer each RQ. As a result, three RQs increased their priority and four RQs decreased their priority.
c) Adjustments (if needed) to the identified time required by the activities of each research question. Overall, stakeholders had a view that a total of 5 years for research activities was too long. As a result, all RQs had the total time of their research activities slightly shortened (up to 4 years in cases where long-term/PhD-level research might be required).

d) Adjustments (if needed) to the identified time required for the outputs of each research question to be adopted/implemented by industry/Government. In general, most stakeholders were optimistic in that the adoption of outputs/findings could be relatively fast. As a result, most RQs had the time for the adoption of outputs slightly shortened.
e) Further comments/feedback associated with each research question.
    - It was highlighted that agreement on the potential DER orchestration frameworks (used in RQ1.1, RQ1.2, and RQ2.1) is needed before further research is carried out. As a result, the timelines of those RQs have been modified to cater for that.
    - The regulation related questions (RQ5.1 and RQ5.2) were considered as fundamental as they can potentially shape many of the technical questions.
    - In general, it was clear that some RQs need adequate clarifications in the Research Plan to avoid confusion. For instance, RQ1.2 was perceived as a question that should be addressed by the market (e.g., aggregators, solution providers) and not by public research. However, the intent of RQ1.2 was to provide transparency around potential decision-making algorithms.
    - Stakeholders also highlighted that some RQs need to cover cybersecurity aspects.
f) Potential risks associated with the six areas and corresponding research questions. With respect to the research plan, one of the main risks mentioned by the stakeholders was that the research outputs might take too long and become irrelevant. By that time, some decisions could have already been made by industry and/or Government. Another risk highlighted by stakeholders is that the research outputs might not be readily implementable by industry and/or Government, and this can hinder/delay their adoption.

6.2. (Area 0) DER Visibility for Whole-System Operations

Based on the reviews carried out, our expertise, and discussions with Prof Mancarella (lead of Topic 4 "Planning"), this new area and its corresponding research question were introduced to capture the more immediate research needed to address DER visibility at the system level. This new area and its research question were part of the "First Refinement" and, therefore, were also discussed during the stakeholder engagement sessions.

It is worth mentioning that aspects associated with the visualisation of DER information in the control room of AEMO might be covered by Topic 3 "Control Room of the Future".

Research Question 0.1

RQ0.1 *What data flows (DER specs, measurements, forecasts, etc.) are needed to ensure AEMO has enough DER/net demand visibility to adequately operate a DER-rich system in different time scales (mins to hours)?*

Key aspects to be considered:

- Effects of existing DER standards on the quantification of net demand. The mix of old and new standards (e.g., different settings for PV's Volt-Watt, different settings for inverter tripping) makes it very challenging for AEMO and DNSPs to quantify the potential response/behaviour that a DER-rich net demand could have in different time scales throughout the day. Furthermore, not all DER installations (e.g., solar PV) follow the required standards. DNSPs are aware that, for different reasons, DER installers decide to use other standards/settings. These cases, although a fraction, can affect the expected response from DERs due to voltage and/or frequency changes and might need to be taken into account.

- Cost-effectiveness for the consumer and society. Whether is AEMO, the DNSPs or third parties collecting the data, it needs to be done in the most cost-effective way for the end consumers. This means that the value of DER/net demand visibility (and the corresponding data) needs to be understood and quantified. Furthermore, given the potential societal benefits from data access, there might be opportunities in making it freely available to different stakeholders (e.g., communities, DER manufacturers, DER solution providers, research organisations, etc.).
- Existing metering infrastructure. It is important to assess the extent to which existing infrastructure used by DNSPs, from smart meters (applicable to some states in Australia) to SCADA measurements, can already deliver the necessary data flows.
- Responsibilities and Coordination. Defining the roles and responsibilities of the different entities (e.g., DNSPs, aggregators, DER operators) that need to provide data useful to the quantification of net demand is crucial in this process. The creation of a single provider (or data concentrator) might even bring efficiencies. However, all this needs to be done considering the unique characteristics (DNSPs, available infrastructure, DER status, etc.) of each state in Australia.
- Effects of distribution networks on the quantification of net demand. If quantifications are done by aggregating the potential exports/imports of DERs solely based on the installed capacity, then it neglects the effects that the distribution network will have on the aggregated power flows seen at higher voltage levels. For instance, due to curtailment (resulting from inverter functions or export limits), power losses, reactive power, etc.
- Approaches to extend DER Visibility. The extent to which advanced approaches (statistical, machine learning, etc.) can be considered to make decisions where there is a low visibility of distribution networks and the corresponding DERs needs to be understood and quantified.
- Effects of DERs managed by aggregators. While direct measurements can provide visibility of DERs and net demand, the more DERs are managed by aggregators (for instance, to participate in markets), the more challenging it is for AEMO to differentiate non-flexible and flexible demand.
- Targeted forecast (e.g., per zone sub) of DERs/net demand. Much more geographically granular forecasts of DERs/net demand (next hour, next day) can reduce uncertainty. The trade-off between less or more granular forecasts needs to be understood.
- Data privacy and ownership. If data from every users/customers is to be used, then it is important to consider aspects related to privacy as well as ownership of the data.
- Cybersecurity. Having data flows involving multiple parties (and even end users/customers) will require adequate cybersecurity measures.

6.3. (Area 1) Control Architecture of DERs

This area assumes that, in the future, Australia (or each state) will adopt a technical framework for orchestrating DERs. Such a framework defines the interactions and roles among AEMO, DNSPs, and aggregators to facilitate the provision of services (to AEMO and DNSPs) from DERs managed by aggregators. Potential frameworks have been defined by the Open Energy Networks Project [3].

It is important to highlight that:

- the research questions associated with the specific technical aspects of DER orchestration frameworks are likely to be covered by Topic 7 "Architecture"; and,
- more detailed research questions related to DER capabilities and standards that focus on voltage stability, frequency stability, damping, and faults, are likely to be covered by Topic 1 "Inverter Design".

The DER control approaches considered in this area refer to the technical approach by which DERs are actually controlled/managed by the corresponding entity within a given framework. For instance, in the framework defined by the Open Energy Networks Project as "Hybrid" (where the DNSP has the role of Distribution System Operator), then DER would be (indirectly) controlled by the DNSP. Because of this, **it is crucial that there is an agreed position on these DER orchestration frameworks (which is linked to Topic 7 "Architecture") before the research questions below (in particular, RQ1.2 and RQ1.2) can be addressed.**

Finally, it is important to highlight that RQ1.1 and RQ1.2, which are related to the most adequate DER control approach and decision-making algorithm, respectively, are questions that eventually will be answered by testing what is made available in the market by solution providers. However, the intent of these research questions is to provide transparency to society, regulators, and other stakeholders around the spectrum of potential DER control approaches and decision-making algorithms as well as the corresponding benefits.

Research Question 1.1

RQ1.1 *For each of the potential technical frameworks for orchestrating DERs in Australia (e.g., based on the OpEN Project), what is the most cost-effective DER control approach to deal with the expected technological diversity and ubiquity of DERs?*

Key aspects to be considered:

- Cost-effectiveness. Identifying the most cost-effective approach to control DERs is key. This might require making compromises in terms of accuracy, speed, and scale, thus affecting the potential services that can be provided by DERs.
- Consumer impacts. Identifying the potential impacts/effects on end consumers and their DERs from each approach is important. Without consumer acceptance/engagement, there will not be DER orchestration.
- Scalability of centralised approaches. Although centralised approaches are commonly adopted by system operators and distribution companies around the world, the number of DER installations and sheer size and unbalanced nature of distribution networks can bring scalability challenges.
- Feasibility of distributed approaches. Distributed approaches might enable the management of DERs across large areas whilst still capturing the physics of distribution networks. For instance, DERs could be controlled within local communities and this control could be supervised remotely.
- Adequacy to the type of service/time scales. Depending on the type of service and the corresponding time scales, it is conceivable that there will be no single control approach able to deliver them all cost-effectively. Different approaches might need to co-exist.

- Desktop-based analysis and real-world trials. There is a significant number of projects in Australia that are testing different DER control approaches. While desktop-based analyses can provide scale and explore different scenarios, any future research needs to consider the findings from completed trials and, when possible, also implement real-world trials to test potential solutions, understand the practical challenges, and assess the potential cost.
- Effectiveness due to a lack of LV circuit models. Most DNSPs in Australia do not have validated/complete electrical LV circuit models. This means that some approaches will need to make conservative considerations as a proxy of the LV circuits. Understanding the effectiveness of approaches when using such considerations is important.
- Future-proof approaches. Any potential DER control approach should be able to adapt to the changes in DER uptake, not only in terms of the numbers of installations but also potential new technologies. It should also be flexible enough to facilitate future requirements.
- Data transfer and communication infrastructure requirements of each control approach. The data and communication requirements of each approach will be important when assessing their cost-effectiveness.
- Metrics that capture the interests and concerns of all stakeholders. Ultimately, the comparisons among potential DER control approaches should be done considering metrics that capture the (sometimes conflicting) interests and concerns of all stakeholders involved.
- Cybersecurity. Cybersecurity aspects associated with each potential DER control approach must also be considered.

Research Question 1.2

***RQ1.2** For each DER control approach, what is the most adequate decision-making algorithm (solution method)?*

Key aspects to be considered:

- Adequacy to the type of service/time scales. Depending on the type of services and corresponding time scales, different decision-making algorithms might perform better.
- Efficiency due to accuracy/changes of electrical network models. The performance of decision-making algorithms that are dependent on network models might be affected by the accuracy of those models and potential topological changes. This, in turn, might require the adoption of conservative considerations to cater for those limitations/challenges. This needs to be considered when assessing the efficiency and practicality of each of them.
- Future-proof algorithms. Given the evolving nature of network models and visibility/monitoring, the use of algorithms that can somehow be adapted as more data and capabilities are available, might speed up their implementation.
- Optimisation-based algorithms. Optimisation-based algorithms have a role to play, however, the corresponding limitations (e.g., scalability) or required adaptations to overcome them need to be understood.
- Rule-based algorithms. Rule-based algorithms, although practical, might not produce the most efficient results or might be difficult to adapt when complexity increases. These potential challenges need to be investigated.

- Role of data-driven algorithms. There is an opportunity in exploiting smart meter data to capture the physics of LV circuits. This, in turn, could be used as a proxy of electrical models and, hence, avoid the challenges of producing them accurately.
- Uncertainties. To the extent that is possible, algorithms should cater for the potential uncertainties brought by DER and demand behaviours.
- Trade-off between fairness and efficiency. The decision-making algorithms need to be able to adapt to different objective functions and capture, as needed, fairness and/or efficiency when controlling DERs.
- Metrics that capture the interests and concerns of all stakeholders. Ultimately, the comparisons among potential decision-making algorithms should be done considering metrics that capture the (sometimes conflicting) interests and concerns of all stakeholders involved. Public consultations might be needed in this process.

Research Question 1.3

***RQ1.3** What is the role of DER standards in concert with the future orchestration of DERs?*

Key aspects to be considered:

- Limitations and opportunities. Defining standards is a time-consuming process that, in some cases, ends up adopting the lowest common denominator among stakeholders. The need to ensure that DER standards in Australia are aligned with the international community, can also create delays. Nonetheless, it is important to understand the role and timelines that standards have in allowing/enabling innovations around DER orchestration (e.g., communications, interoperability, adaptability of settings, etc.). DER orchestration requirements could potentially be embedded into standards. Furthermore, given the relative short lifespan of DER installations (with respect to traditional network assets), there is also an opportunity for new standards to be widely adopted once DER installations are replaced.
- Trade-offs between the extraction and procurement of services. In terms of the extraction of services from DER, DER standards have focused on aspects such as under/over frequency responses to help with whole-system security. While there might be opportunities to further exploit such responses or even new types of responses, this should be done without compromising what DER orchestration could eventually do and, thus, make available via competitive markets from which services can be procured. Understanding those trade-offs is important for standards not to hinder DER orchestration.
- Effects on end users/consumers. The effects of new/advanced DER standards on consumers and their ability to use DER should be assessed.
- Readiness of DER technologies for such standards. The complexity of new/advanced DER standards might be limited by the ability or appetite of manufacturers to implement them.

6.4. (Area 2) Communication Requirements for Monitoring and Control of DERs

Like Area 1, this area assumes that, in the future, Australia (or each state) will adopt a technical framework for orchestrating DERs. Such a framework defines the interactions and roles among AEMO, DNSPs, and aggregators to facilitate the provision of services (to AEMO and DNSPs) from DERs managed by aggregators. The DER control approaches considered in this area refer to the technical approach by which DERs is actually controlled/managed by the corresponding entity within a given framework.

Consequently, **it is crucial that there is an agreed position on these DER orchestration frameworks (which is linked to Topic 7 "Architecture") before the research questions below (in particular, RQ1.2 and RQ1.2) can be addressed.**

Research Question 2.1

RQ2.1 *For each of the potential technical frameworks for orchestrating DERs and the corresponding decision-making algorithms, what is the most cost-effective communication and control infrastructure?*

Key aspects to be considered:

- Adequacy to the type of service/time scales. Depending on the type of services and corresponding time scales, different types of communication infrastructure will perform better or worse, or simply not be as cost-effective.
- DER communication and control standards/requirements. Defining the most cost-effective DER communication and control standards/requirements will be an important component in defining the most cost-effective infrastructure. This should consider legacy aspects, i.e., the integration of older equipment (and associated standards). Furthermore, given the existence of multiple communication standards today (which evolve independently of the power sector), focus could be given to the implementation of existing standards in the Australian context.
- Effects on end users/consumers. The effects of different communication and control infrastructures on consumers, their ability to use DERs, and the potential additional costs, should be assessed.
- Role of advanced techniques in filling the gaps. Techniques, such as state estimation or data analytics, should be explored to reduce the need for communications and sensors.
- Role of distribution network elements in the control of DERs. If distribution network elements (e.g., OLTCs, cap banks) are part of the control strategy, then coordination between the corresponding communication and control infrastructures should be considered.
- Cybersecurity. Cyber and cyber-physical security aspects associated with each potential DER control approach must also be considered.

6.5. (Area 3) Ancillary Services Provided by DERs

The services considered in this area correspond to (but not limited to) those listed as ancillary services by AEMO for the NEM and WEM.

It is important to highlight that:

- the research questions associated with the opportunities, limitations and reliability of DER services might be covered, to some extent, by Topic 6 "Services"; and,
- more detailed research questions related to DER inverter modelling in the context of stability might be covered by Topic 9 "DER and Stability".

Research Question 3.1

***RQ3.1** What are the most cost-effective ancillary services that can be delivered by DERs considering the expected technological diversity and ubiquity of DERs?*

Key aspects to be considered:

- Capability of DER technologies for each of the ancillary services. Different ancillary services have different requirements. There must be an adequate match between the capabilities of certain DER technologies and the characteristics of a given service.
- Value and expansion of services. The adoption of DERs per se does not guarantee that those technologies will be available to provide services. Ancillary services need to be valued adequately to make economic sense for DERs to provide different types of services. Furthermore, other markets might be needed (e.g., distribution-level services) to increase that value and, hence, encourage adequate availability of services from DERs.
- Agnostic ancillary services. To incentivise innovation, services required by AEMO need to be agnostic of the DER technology.
- Effects of end-user behaviour and availability on the services. Depending on the DER technology and its local use, the availability of certain services might be limited at times. It is important to understand the extent to which end users/consumers are willing to engage in the provision multiple services through third-party aggregators.
- Effects of distribution networks on the services. The provision of services is typically quantified at the connection point of DERs and only considers their installed capacity. This neglects the effects that the distribution network will have on the aggregated power flows seen at higher voltage levels. For instance, due to curtailment (resulting from inverter functions or export limits), power losses, reactive power, etc.
- Effects of distribution-level services on ancillary services. While new services bring more value to DERs, coordination and/or prioritisation should exist between the entities requesting the services to avoid issues/conflicts.
- Medium-to-large scale DERs vs small-scale DERs. Depending on the requirements of certain services (e.g., fast frequency response), it might be more cost-effective to have a few larger DERs than many small DERs, reducing the need for fast communication infrastructure, overheads, etc.

6.6. (Area 4) Influence of DERs on System-Level Planning

It is worth mentioning that more detailed research questions about how DER and DER services affect and/or help whole-system planning are likely to be covered by Topic 4 “Planning”.

Research Question 4.1

***RQ4.1** What are the minimum requirements for a DER-rich distribution network equivalent model to be adequate for its use in system planning studies?*

Key aspects to be considered:

- Different planning studies. Depending on the type of planning study (e.g., economic, security, reliability), different equivalent models will be needed (e.g., steady state analyses, fault analysis, for dynamic analyses, etc.).

- Minimum amount of data and accuracy needed (for each type of study). The minimum amount of data and accuracy needs to be defined for each type of equivalent model. Ultimately, there will be a trade-off between accurate models and the cost to achieve them.
- Location, type of measurements, and regularity needed to produce the equivalent models. Dynamic equivalent models, for instance, are developed from measurements at specific locations. Furthermore, given the variability of DER technologies, critical times during the day/week/season might also be needed.
- Limits on the scale of equivalent models. Despite the need for accuracy, the simulation tools used to do the planning studies might have limitations. This should be taken into account.
- Effects of uncertainty on the equivalent models. Not just the variability of DER technologies affects the accuracy of equivalent models. The existence of old and new DER standards, combined with consumer behaviour increase the uncertainty of the models. This can be further exacerbated by the provision of services from DERs.
- Effects of distribution networks on the equivalent models. Distribution networks have controllable elements (such as OLTCs, capacitor banks, and switches) that are operated regularly and can affect the overall behaviour of equivalent models.
- Effects of distribution network expansion and future operational strategies. Distribution networks will expand and their operational strategies will evolve. It is, therefore, important to capture, to the extent that is possible, these effects, particularly when certain equivalent models are used for long-term system-level planning purposes.
- Modelling consistency across DNSPs. AEMO might require an agreed consistent way of modelling distribution networks as different types of outcomes from multiple DNSPs might create challenges.

Research Question 4.2

RQ4.2 *What is the minimum availability of ancillary services from DERs at strategic points in the system throughout the year and across multiple years?*

Key aspects to be considered:

- Ancillary service. The quantification will depend on the type of ancillary service, corresponding time scales, and other requirements.
- DER uptake forecast. The predicted uptake of the different DER technologies will play a key role in the corresponding quantification of potential ancillary services from DERs.
- Effects of end-user behaviour and availability on the services. Depending on the DER technology and its local use, the availability of certain services might be limited at times. It is important to understand the extent to which end users/customers are willing to engage in the provision multiple services through third-party aggregators.
- Effects of distribution networks on the services. The provision of services is typically quantified at the connection point of DERs and only considers their installed capacity. This neglects the effects that the distribution network will have on the aggregated power flows seen at higher voltage levels. For instance, due to curtailment (resulting from inverter functions or export limits), power losses, reactive power, etc.
- Effects of distribution network expansion and future operational strategies. Distribution networks will expand and their operational strategies will evolve. It is, therefore, important

to capture, to the extent that is possible, these effects, particularly when certain equivalent models are used for long-term system-level planning purposes.

- More complexity in the horizon. The quantification becomes more complex the further in the horizon it is done. Not only the DER uptake becomes more uncertain but also the potential new DER technologies, their capabilities and, ultimately, the existence of DER orchestration and even distribution-level markets.

6.7. (Area 5) Overcoming Institutional Challenges

Although other topics do not explicitly address institutional challenges, the research questions below, RQ5.1 and RQ5.2, might have synergies with aspects associated with Topic 7 "Architecture". Furthermore, existing work in this area needs to be leveraged. For instance, the research program iGrid[5], which involved CSIRO, identified back in 2011 institutional barriers that are still relevant.

Research Question 5.1

***RQ5.1** What are the necessary organisational and regulatory changes to enable the provisioning of ancillary services from DER?*

Key aspects to be considered:

- Potential frameworks for orchestrating DER. Such a framework defines the interactions and roles among AEMO, DNSPs, and aggregators to facilitate the provision of services (to AEMO and DNSPs) from DER managed by aggregators. Potential frameworks have been defined by the Open Energy Networks Project [3]. However, there is still a need for a transparent production of business models across all parties involved.
- Incentives for AEMO to incorporate DER at the core of its business. Although DER has is bringing significant challenges to AEMO, there are no incentives to embrace DER in a holistic manner, at the core of AEMO's business.
- OpEx and/or CapEx made by DNSPs to facilitate ancillary services from DER. Not only an adequate framework is needed but also recognising that DNSPs will incur in additional capital and operational expenditures due to DER and their provision of ancillary services. Without capturing these expenditures in the regulation, DNSPs will be disincentivised to actively facilitate DER.
- Knowledge sharing across the industry. ARENA, DNSPs, AEMO and many other organisations have collectively spent millions of dollars on multiple projects that involve the provision of ancillary services from DER. There is know-how, expertise, tools available, however, there is no adequate mechanism for key stakeholders such as AEMO and DNSPs to absorb them and use them in their businesses.
- Ability of aggregators to manage added complexity. Innovations around DER orchestration, such as the use of operating envelopes, can also create added complexity to aggregators. It is important to understand the effects and viability of any added complexity.
- Liabilities in a more complex, inter-dependent environment. The more DER provide services, the more important is to adequately define liabilities.

[5] Intelligent Grid Research Program, http://igrid.net.au/

- Customer engagement. Provision of services or DER orchestration is dependent on users/consumers engagement, so customer-centric approaches/processes to ensure engagement are of fundamental importance.

Research Question 5.2

***RQ5.2** What are the necessary considerations of establishing a distribution-level market (for energy and services)?*

Key aspects to be considered:

- Extent of the potential benefits across Australia. The expected benefits from distribution-level markets need to be assessed considering the different characteristics and DER penetrations of each of the states in Australia. Not all the states would necessarily benefit from such an approach.
- Customer engagement in a new market. It is important to understand the extent to which customers will be willing to embrace/engage with a new market.
- Interactions between ancillary and distribution-level services. Coordination and/or prioritisation should exist between the markets or entities requesting the services to avoid issues/conflicts.
- Extent of liquidity (volume of DER services) needed to make a market viable. A market needs enough on offer to work. However, the more local a network problem is (for instance, an LV transformer), the less houses and, therefore, the less DER will be available to help. The viability of distribution-level markets needs to be considered by assessing the different voltage levels in distribution networks.
- Role of network augmentation and other conventional approaches. Despite the potential benefits from distribution-level markets, network augmentation and other conventional approaches still need to be considered when assessing the cost-effectiveness of potential alternatives to solve network problems.

6.8. Australian Capability Assessment

The Australian capability of delivering/solving each research question is based on the performed reviews, the expertise of the team at The University of Melbourne, and the feedback from the Australian and international stakeholders (see section 6.1).

The Australian capability is classified into lead, collaborate, and learn; definitions are provided below. The results are shown in Table 17. A total of three ticks (✓) are allocated for each research question to represent the relative weightings.

- Lead: Expertise within Australia is of the capacity to answer these research questions and deliver the outcomes within reasonable timeframes.
- Collaborate: Expertise from other countries, in combination with Australian expertise, are of the capacity to answer these research questions and deliver the outcomes within reasonable timeframes.
- Learn: Australia does not have the expertise to answer these questions and should learn from the experts in other countries.

In general, as it can be seen in Table 17, Australia is considered to be in a position to answer (lead) most research questions. Nonetheless, even in those cases there are opportunities to collaborate with international organisation and potentially increase the quality and timeliness of the corresponding outputs; hence, the mixed classifications. Only RQ4.1 was perceived as one where there is already significant, ongoing research abroad (in particular, Europe) and, therefore, Australia could gain speed and expertise from being a collaborator that also learns from its partners.

6.9. Prioritisation of Research Questions

The prioritisation of research questions is based on the performed reviews, the expertise of the team at The University of Melbourne, and the feedback from the Australian stakeholders, in particular the Australian Workshop (see section 6.1.3). Note that the present prioritisation considers the latest version of the research questions (second refinement).

While all the research questions are considered a priority for Australia, the relative urgency to address a given question with respect to the others has been used to classify each of them into *very high*, *high* and *medium*. The results are shown in Table 18. There is no sub-ranking within each classification.

As expected, given the DER visibility challenges already faced by AEMO, RQ0.1 was considered to have very high priority. The questions associated with regulation (RQ5.1 and RQ5.2) were also given very high priority as they were considered to provide the foundations for what might be possible in terms of DER orchestration and markets. DER standards were also deemed very urgent as they can play a major role in enabling DER orchestration. On the other side of the spectrum, RQ2.1 was considered, relative to the other research questions, as the one with the lowest priority. This is partly because there are already communication standards/protocols adopted by industry, as well as they can evolve and be adapted (relatively) rapidly.

Table 17. Australian Capability Assessment for Each Research Question

(Area 0) DER Visibility for Whole-System Operations	Lead	Collaborate	Learn
RQ0.1 What data flows (DER specs, measurements, forecasts, etc.) are needed to ensure AEMO has enough DER/net demand visibility to adequately operate a DER-rich system in different time scales (mins to hours)?	✓✓	✓	
(Area 1) Control Architecture of DER	Lead	Collaborate	Learn
RQ1.1 For each of the potential technical frameworks for orchestrating DERs in Australia (e.g., based on the OpEN Project), what is the most cost-effective DER control approach to deal with the expected technological diversity and ubiquity of DERs?	✓✓	✓	
RQ1.2 For each DER control approach, what is the most adequate decision-making algorithm (solution method)?	✓✓	✓	
RQ1.3 What is the role of DER standards in concert with the future orchestration of DERs?	✓	✓✓	
(Area 2) Communication Requirements for Monitoring and Control of DER	Lead	Collaborate	Learn
RQ2.1 For each of the potential technical frameworks for orchestrating DERs and the corresponding decision-making algorithms, what is the most cost-effective communication and control infrastructure?	✓✓	✓	
(Area 3) Ancillary Services Provided by DER	Lead	Collaborate	Learn
RQ3.1 What are the most cost-effective ancillary services that can be delivered by DERs considering the expected technological diversity and ubiquity of DERs?	✓✓	✓	
(Area 4) Influence of DER on System-Level Planning	Lead	Collaborate	Learn
RQ4.1 What are the minimum requirements for a DER-rich distribution network equivalent model to be adequate for its use in system planning studies?		✓✓	✓
RQ4.2 What is the minimum availability of ancillary services from DERs at strategic points in the system throughout the year and across multiple years?	✓	✓✓	
(Area 5) Overcoming Institutional Challenge	Lead	Collaborate	Learn
RQ5.1 What are the necessary organisational and regulatory changes to enable the provisioning of ancillary services from DERs?	✓	✓✓	
RQ5.2 What are the necessary considerations of establishing a distribution-level market (for energy and services)?	✓	✓✓	

Table 18. Prioritisation of Research Questions

Research Question	Priority
RQ0.1 What data flows (DER specs, measurements, forecasts, etc.) are needed to ensure AEMO has enough DER/net demand visibility to adequately operate a DER-rich system in different time scales (mins to hours)?	**Very High**
RQ1.1 For each of the potential technical frameworks for orchestrating DER in Australia (e.g., based on the OpEN Project), what is the most cost-effective DER control approach to deal with the expected technological diversity and ubiquity of DERs?	**High**
RQ1.2 For each DER control approach, what is the most adequate decision-making algorithm (solution method)?	**High**
RQ1.3 What is the role of DER standards in concert with the future orchestration of DERs?	**Very High**
RQ2.1 For each of the potential technical frameworks for orchestrating DER and the corresponding decision-making algorithms, what is the most cost-effective communication and control infrastructure?	**Medium**
RQ3.1 What are the most cost-effective ancillary services that can be delivered by DERs considering the expected technological diversity and ubiquity of DERs?	**High**
RQ4.1 What are the minimum requirements for a DER-rich distribution network equivalent model to be adequate for its use in system planning studies?	**Very High**
RQ4.2 What is the minimum availability of ancillary services from DERs at strategic points in the system throughout the year and across multiple years?	**High**
RQ5.1 What are the necessary organisational and regulatory changes to enable the provisioning of ancillary services from DERs?	**Very High**
RQ5.2 What are the necessary considerations of establishing a distribution-level market (for energy and services)?	**Very High**

7. Research Plan

This section presents the proposed timeline of the Research Plan as well as the Key Research Activities and Key Research Outputs for each of the refined Research Questions presented previously. It also includes potential information/data needs, risks associated with the Research Plan, and reflections on the key stakeholders required to undertake this Research Plan.

Based on the refined research questions, the Australian capability assessment and the prioritisation of the research questions done in the previous sections, the proposed timeline of the Research Plan is presented in Table 19. To illustrate the timeline of the research activities and the potential implementation of the corresponding outputs/findings, the horizon of 10 years (as defined for this Research Plan, section 1) is assumed to start in 2022. In practice, due to funding processes, contracts, etc., the start date might occur in 2023 or later.

The main aspects of Table 19 and the following sections are described below:

- Priority. Although all research questions are considered relevant to Australia, to distinguish their relative urgency, three priority levels (*Very High*, *High* and *Medium*) are assigned to the research questions as discussed in section 6.9.
- Start Year. Although 6 research questions could start in parallel in 2022, 4 research questions have prerequisites due to strong dependencies with other tasks or Topics. In particular, RQ1.1, RQ1.2 and RQ2.1 would need to wait for the DER orchestration frameworks to be agreed/defined to some extent (potentially by Topic 7 “Architecture”) for these research questions to be investigated (as discussed in section 6.1.3). In the case of RQ1.2 and RQ4.2, partial outputs/findings from other research questions would be needed to start the corresponding investigations.
- Research Activities. To answer each research question, several activities of different types and durations have been identified (further details in sections 7.2 to 7.11). Given the very technical and practical nature of many of the research questions, some activities can benefit from carrying out trials and some from relatively short pieces of work. These activities have been classified into the following three types (and used as ‘tags’ in sections 7.2 to 7.11).
    - [Short-Term Research]. 1 to 2 years of work that can be done by research organisations and/or consultancy companies.
    - [Trial]. 2 to 3 years of work devoted to actual field trials to test concepts, technologies, implementation aspects, etc. and that are led typically by key stakeholders such as AEMO and/or DNSPs.
    - [Long-Term Research]. 3 to 4 years of in-depth research work typical of a PhD project (or equivalent) and, thus, done by research organisations.

  The total duration of the combined activities per research question has been adjusted to reflect the feedback from the stakeholders (section 6.1.3).
- Buffer. Given that research questions can have activities that can take longer than others, a buffer was created to illustrate that shorter activities can start later if needed.
- Implementation. This corresponds to the time it might take for the outputs and findings from the research activities for each question to be implemented/adopt by industry and/or Government. In particular, RQ1.3 and RQ5.2 are those considered to take longer due to the nature of standards and rule changes. The duration for each research question has been tuned according to the feedback from the stakeholders (section 6.1.3).

It is important to highlight that the priorities and timelines provided in Table 19 do not necessarily mean that research funding would need to be allocated to research questions with *Very High* priority first. The timeline can also be used to prioritise research questions based on, for instance, how immediate the implementation/adoption of outputs would be.

Finally, for the 10 identified Research Questions to be successfully answered in the context of Australia, it is crucial that the corresponding research activities (presented in sections 7.2 to 7.11) are carried out considering:

- States and Territories Characteristics. Different States and Territories in Australia have (and might continue to have) different DER uptakes, different demand/population growth, different monitoring infrastructures at the distribution level (particularly in terms of smart meters), etc. The research activities need to be carried out considering those differences.
- DER is not only solar PV. As discussed in presented in section 3.1, rooftop solar PV will continue to be the most prominent DER technology in terms of installed capacity for the next 10 years. Within this period, batteries will increasingly provide more opportunities. However, given that the uptake of EVs is expected to be very high from 2030 onwards, EVs should be considered throughout the research activities to ensure that our electricity system is prepared accordingly.

Table 19. Timeline of the Research Plan

Long-term Research, Trial, Short-term Research, Prerequisite, Buffer, Implementation, Letters = Research Activity

<table>
<tr><th>Priority</th><th>Research Questions</th><th>2022</th><th>2023</th><th>2024</th><th>2025</th><th>2026</th><th>2027</th><th>2028</th><th>2029</th><th>2030</th><th>2031</th><th>2032</th></tr>
<tr><td rowspan="14">Very High</td><td rowspan="3">RQ0.1 What data flows (DER specs, measurements, forecasts, etc.) are needed to ensure AEMO has enough DER/net demand visibility to adequately operate a DER-rich system in different time scales (mins to hours)?</td><td colspan="4">B, E, F, G</td><td colspan="2" rowspan="3">Implementation</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="3">D</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">A, C, D, H, I</td><td colspan="2"></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="3">RQ1.3 What is the role of DER standards in concert with the future orchestration of DERs?</td><td colspan="4">A, B</td><td colspan="5" rowspan="3">Implementation</td><td></td><td></td></tr>
<tr><td colspan="3">C</td><td></td><td></td><td></td></tr>
<tr><td colspan="2">C</td><td colspan="2"></td><td></td><td></td></tr>
<tr><td rowspan="3">RQ4.1 What are the minimum requirements for a DER-rich distribution network equivalent model to be adequate for its use in system planning studies?</td><td colspan="4">B, C</td><td colspan="2" rowspan="3">Implementation</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="3">E</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">A, C, D, E</td><td colspan="2"></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">RQ5.1 What are the necessary organisational and regulatory changes to enable the provisioning of ancillary services from DERs?</td><td colspan="3">A, B</td><td colspan="2" rowspan="2">Implementation</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">A, B, C, D</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="3">RQ5.2 What are the necessary considerations of establishing a distribution-level market (for energy and services)?</td><td colspan="4">B, C, D, E</td><td colspan="5" rowspan="3">Implementation</td><td></td><td></td></tr>
<tr><td colspan="3">C, E</td><td></td><td></td><td></td></tr>
<tr><td colspan="2">A</td><td colspan="2"></td><td></td><td></td></tr>
<tr><td rowspan="11">High</td><td rowspan="3">RQ1.1 For each of the potential technical frameworks for orchestrating DERs in Australia (e.g., based on the OpEN Project), what is the most cost-effective DER control approach to deal with the expected technological diversity and ubiquity of DERs?</td><td colspan="2" rowspan="3">Agreement on Frameworks (Topic 7)</td><td colspan="4">A, B, D, F</td><td colspan="2" rowspan="3">Implementation</td><td></td><td></td><td></td></tr>
<tr><td colspan="3">C, F, G</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">E, G</td><td colspan="2"></td><td></td><td></td><td></td></tr>
<tr><td rowspan="3">RQ1.2 For each DER control approach, what is the most adequate decision-making algorithm (solution method)?</td><td colspan="2" rowspan="3">Agreement on Frameworks (Topic 7)</td><td colspan="4">A, B, C</td><td colspan="2" rowspan="3">Implementation</td><td></td><td></td><td></td></tr>
<tr><td colspan="3">B, C, D, E</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">D, E, F</td><td colspan="2"></td><td></td><td></td><td></td></tr>
<tr><td rowspan="3">RQ3.1 What are the most cost-effective ancillary services that can be delivered by DERs considering the expected technological diversity and ubiquity of DERs?</td><td colspan="4">E</td><td colspan="2" rowspan="3">Implementation</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="3">A, B, D, E, F, G</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">A, B, C, D, F</td><td colspan="2"></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">RQ4.2 What is the minimum availability of ancillary services from DERs at strategic points in the system throughout the year and across multiple years?</td><td colspan="3" rowspan="2">Partial outputs/findings from RQ3.1, RQ5.1</td><td colspan="4">B, D</td><td colspan="3" rowspan="2">Implementation</td><td></td></tr>
<tr><td colspan="2">A, C</td><td colspan="2"></td><td></td></tr>
<tr><td rowspan="3">Medium</td><td rowspan="3">RQ2.1 For each of the potential technical frameworks for orchestrating DERs and the corresponding decision-making algorithms, what is the most cost-effective communication and control infrastructure?</td><td colspan="3" rowspan="3">Agreement on Frameworks (Topic 7) and Partial outputs/findings from RQ1.2</td><td colspan="4">A, D</td><td colspan="3" rowspan="3">Implementation</td><td></td></tr>
<tr><td colspan="3">A, B, D</td><td></td><td></td></tr>
<tr><td colspan="2">B, C</td><td colspan="2"></td><td></td></tr>
</table>

7.1. Links with other Topics

While the Research Plan timeline presented in Table 19 considers that RQ1.1, RQ1.2, and RQ2.1 have explicit links with Topic 7 "Architecture", there are other research questions that also require interactions with other Topics. Figure 3 illustrates the links between some of the research questions and the other Topics (the thickness of the arrows indicates the relative degree of the linkage).

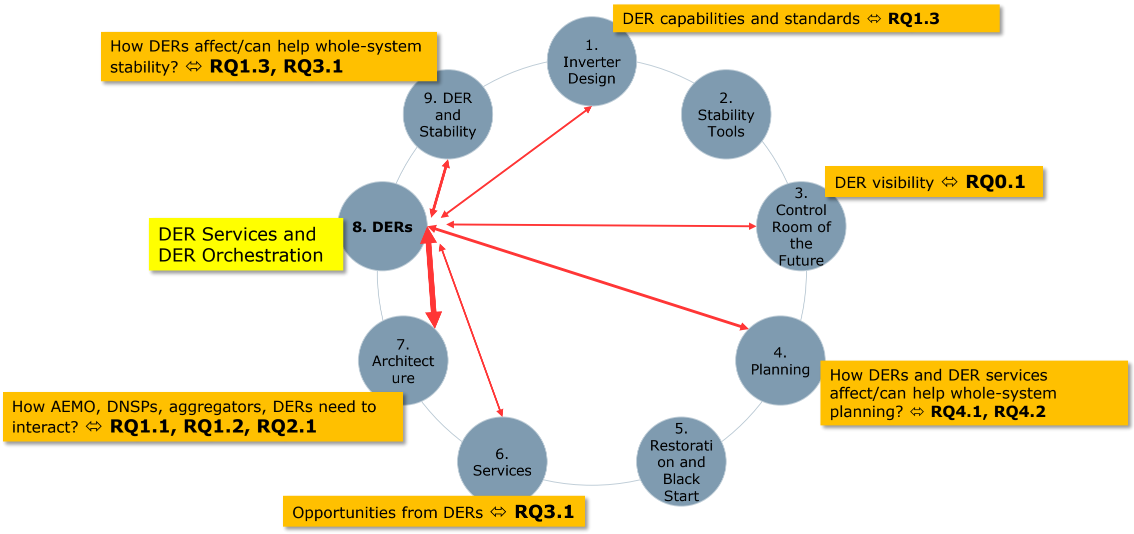

Figure 3. Links with other Topics

More details about the interactions with Topics 1, 3, 4, 6, 7, and 9 are provided below.

- Topic 1 "Inverter Design" and **RQ1.3**. Some of the activities of RQ1.3 explore the use of standards to extract different types of services (and, potentially, new services) from DER as well as the definition of future-proof standards that can help with the transition to DER orchestration. This means that those activities need to liaise with Topic 1 to ensure that those standards are not only realistic but also do not create conflicts with other functionalities of the inverters.
- Topic 3 "Control Room of the Future" and **RQ0.1**. Some of the activities of RQ0.1 are related to the quantification of net demand and the different data flows that might be required. Consequently, it is important for those activities to liaise with Topic 3 given that the associated data might need to be visualised in AEMO's control room.
- Topic 4 "Planning" and **RQ4.1, RQ4.2**. The activities of RQ4.1 and RQ4.2 aim to produce models and methods that help carrying out different system-level planning tasks. Consequently, these activities need to be coordinated with Topic 4 to ensure that the outputs and findings from RQ4.1 and RQ4.2 can be used in a timely manner.
- Topic 6 "Services" and **RQ3.1**. Given that the activities of RQ3.1 will explore different (existing and new) services that DER could provide, it is important to liaise with Topic 6 to ensure that there is a close match between what DER could do and what might be required in the future by AEMO.
- Topic 7 "Architecture" and **RQ1.1, RQ1.2, RQ2.1**. As mentioned previously, RQ1.1, RQ1.2 and RQ2.1 need the potential DER orchestration frameworks (e.g., as those define by the Open Energy Networks Project [3]) to be agreed upon before the corresponding activities

can start. Consequently, close collaboration with Topic 7 will be required to ensure that their interim or full outputs/findings are made available in a timely manner.

- Topic 9 “DER and Stability” and **RQ1.3**, **RQ3.1**. Some of the activities of RQ1.3 and RQ3.1 explore the use of standards to extract different types of services (and, potentially, new services) from DER as well as the definition of future-proof standards that can help with the transition to DER orchestration. This means that those activities need to liaise with Topic 9 to ensure that those standards are not only realistic but also do not create conflicts with other functionalities of the inverters.

In addition to the links described above, there other links that could be explored. In particular, some of the activities of RQ4.1 related to equivalent distribution network models could benefit from liaising with Topic 2 “Stability Tools” as well as with Topic 9 “DER and Stability”. There could also be closer interactions between RQ4.2 (and the quantification of future DER services) and Topic 6 “Services”.

7.2. RQ0.1: Activities and Outputs

This section presents the key research activities and corresponding outputs needed for this Research Question. This has been produced based on the *key aspects* discussed in the Refined Research Questions and Prioritisation section, specifically, section 6.2 (Area 0) DER Visibility for Whole-System Operations.

***RQ0.1** What data flows (DER specs, measurements, forecasts, etc.) are needed to ensure AEMO has enough DER/net demand visibility to adequately operate a DER-rich system in different time scales (mins to hours)?*

7.2.1. Key Research Activities

The following key research activities need to be carried out to answer this research question:

A. Definition of the characteristics of an adequate DER/net demand visibility. This requires defining the most important parameters and their characteristics needed to consider DER/net demand visibility as adequate (accurate) by AEMO. [Short-Term Research]
B. Assessment of the effects of mixed DER standards on the quantification of net demand. This requires a time-varying quantification (e.g., hourly for different types or days and seasons) that considers the effects of mixed DER standards on the net demand. It should be done for different penetrations of DER, different types of DER, and different levels of mixed DER standards. Furthermore, the interactions of DER standards with the local connection point (particularly for standards or requirements related to voltages and/or export limits) should be captured directly (using distribution network models) or indirectly (using estimations). [Long-Term Research]
C. Assessment of the benefits from existing metering infrastructure. This requires exploring all the different opportunities to increase DER/net demand visibility solely using existing infrastructure from DNSPs as well as DER operators/aggregators/solution providers. This needs to be done for each Australian state separately given their different characteristics in terms of metering infrastructure and DER uptake. Furthermore, this should also consider privacy, ownership and cybersecurity aspects associated with the provision of this data, particularly when involving end users/customers. [Short-Term Research]

D. Investigation of potential data coordination schemes. This requires assessing the cost-effectiveness of the potential data coordination schemes that could be adopted for DER orchestration. This involves defining the spectrum of schemes and the corresponding roles and data flows of the different entities that might be involved (e.g., DNSPs, aggregators, DER operators, data concentrator). This needs to be done for each Australian state separately given their different characteristics in terms of metering infrastructure and DER uptake. [Short-Term Research] [Trial]
E. Assessment of the effects of distribution networks on the quantification of net demand. This requires a time-varying quantification (e.g., hourly for different types or days and seasons) that considers the effects of distribution networks (e.g., power losses, network constraints, etc.) on the net demand seen at relevant locations (e.g., transmission-distribution interface or zone substations). These effects should be captured using distribution network models and different types of networks (urban, rural, etc.) as well as different uptakes of DER. [Long-Term Research]
F. Approaches to improve and extend DER visibility. This requires exploring the potential benefits, such as increased accuracy or reduced need for measurement devices/data, from adopting different advanced approaches (statistical, machine learning, etc.) that improve and extend DER visibility. For instance, better accuracy is an improvement, whilst advanced approaches extend DER visibility since measurements and models of LV feeders are not widespread and readily available for DNSPs. [Long-Term Research]
G. Assessment of the effects of DER managed by aggregators on net demand. This requires a time-varying quantification (e.g., hourly for different types or days and seasons) that considers the flexible and non-flexible parts of the demand to demonstrate the effects of the former (managed by aggregators) on the DER/net demand visibility. These effects should be captured considering different levels of consumers engaging with aggregators, different uptakes of DER. This analysis can be expanded to involve DER orchestration strategies such as the use of operating envelopes (to ensure distribution network integrity). This would require more advanced modelling involving distribution networks. [Long-Term Research]
H. Assessment of the benefits from targeted forecast (e.g., per zone sub) of DER/net demand. This requires quantifying the trade-offs between added accuracy and complexity/cost from using more geographically granular forecasts (next hour, next day), particularly in areas with high DER uptakes. [Short-Term Research]
I. Assessment of the value of DER/net demand visibility. This requires investigating and quantifying the potential economic impact of not having an adequate DER/net demand visibility so it can be used as a proxy for its value. An estimation of the potential benefits to society from an open approach to the corresponding data (i.e., making it freely available to different stakeholders) is also needed. Both quantifications will help inform decisions related to the necessary investments. [Short-Term Research]

7.2.2. Key Research Outputs

The successful completion of the key research activities should lead to the following key outputs:

- A list of minimum parameters and their characteristics for an adequate visibility of DER/net demand.
- A method to embed/estimate the effects of mixed DER standards on the quantification of net demand.

- An estimation of the benefits from exploiting the existing metering infrastructure available in each Australian state.
- A ranking (cost-benefit analysis) of the potential data coordination schemes for each Australian state.
- A method to embed/estimate the effects of distribution networks on the quantification of net demand.
- A ranking (cost-benefit analysis) of the approaches that can be used to extend DER visibility.
- A method to embed/estimate the effects of DER managed by aggregators on net demand.
- A ranking (cost-benefit analysis) of different granularities that can be used to improve the forecasts necessary to estimate net demand (next hour, next day).
- An estimated valuation of DER/net demand visibility.
- An estimation of the societal benefits if DER/net demand data is made freely available.

7.3. RQ1.1: Activities and Outputs

This section presents the key research activities and corresponding outputs needed for this Research Question. This has been produced based on the *key aspects* discussed in the Refined Research Questions and Prioritisation section, specifically, section 6.3 (Area 1) Control Architecture of DERs.

As mentioned in section 6.3, **it is crucial that there is an agreed position on the DER orchestration frameworks (which is linked to Topic 7 “Architecture”) before RQ1.1 can be addressed.**

RQ1.1 *For each of the potential technical frameworks for orchestrating DER in Australia (e.g., based on the OpEN Project), what is the most cost-effective DER control approach to deal with the expected technological diversity and ubiquity of DER?*

7.3.1. Key Research Activities

The following key research activities need to be carried out to answer this research question:

A. Definition of the spectrum of potential DER control approaches. This requires defining the different types of control approaches (e.g., centralised, distributed, local, hierarchical, etc.) that could be adopted in each of the different technical frameworks for DER orchestration. [Long-Term Research]
B. Assessment of the feasibility, adequacy, reliability, and adaptability of potential DER control approaches for each type of service. This requires investigating how feasible it is, in practice, to implement each of the potential DER control approaches identified. Such an investigation needs to consider aspects such as the scale (size) and unbalanced nature of distribution networks, the number and diversity of DER devices, practical limitations related to what can and cannot be controlled, interactions among the different stakeholders (depending on the DER orchestration framework), etc. Furthermore, this also requires investigating the extent to which each of the potential DER control approaches can adequately and reliably deliver the different types of services (in the corresponding time scales) procured by AEMO. Finally, this requires evaluating the ability of each control approach to adapt to changes in the DER uptake in terms of numbers and technologies. [Long-Term Research]
C. Assessment of data transfer and communication infrastructure requirements. This requires determining the minimum data transfers and corresponding communication infrastructure needed by each potential DER control approach to deliver the different types of services. This also involves determining the most adequate communication standards to be used to

increase cost-effectiveness. Furthermore, cybersecurity aspects associated with each potential DER control approach must also be considered. [Trial]

D. Assessment of the effects of electrical network model accuracy and/or availability. This requires quantifying the extent to which DER control approaches can produce adequate or acceptable results considering existing inaccuracies in electrical network models or even the lack of models (e.g., LV circuits). [Long-Term Research]

E. Definition of metrics that capture the interests and concerns of all stakeholders. This requires defining technical, economic, and societal metrics that can be used to compare the potential DER control approaches considering the different stakeholders, including the impacts/effects on end consumers (e.g., electricity bill, performance of DER, etc.) and their acceptance of/engagement with the DER control approach. These metrics should also consider the ability of a potential DER control approach to stack services, hence, reducing the need for different DER control approaches for different types of services. [Short-Term Research]

F. Comparison of the potential DER control approaches. This requires quantifying and comparing the different metrics for each of the potential DER control approaches considering each of the different types of services procured by AEMO as well as future distribution-level services. [Trial] [Long-Term Research]

G. Incorporation of findings from real-world trials. This requires running actual trials and/or exploring and extracting key findings from completed Australian and international trials that can be used as additional inputs to the key research activities listed above. [Short-Term Research] [Trial]

7.3.2. Key Research Outputs

The successful completion of the key research activities should lead to the following key outputs:

- A list of the potential DER control approaches for the different DER orchestration frameworks.
- An analysis of the feasibility, adequacy, reliability, and adaptability of the potential DER control approaches for each type of service.
- A ranking (cost-benefit analysis) of the data transfer and communication infrastructure requirements for each of the potential DER control approaches.
- A quantification of the effects of electrical network model accuracy and/or availability on the outcomes/performance from each DER control approach.
- A list of metrics that capture the interests and concerns of all stakeholders, including consumers.
- A ranking (cost-benefit analysis) of the potential DER control approaches.

7.4. RQ1.2: Activities and Outputs

This section presents the key research activities and corresponding outputs needed for this Research Question. This has been produced based on the *key aspects* discussed in the Refined Research Questions and Prioritisation section, specifically, section 6.3 (Area 1) Control Architecture of DERs.

Similar to RQ1.1, **it is crucial that there is an agreed position on the DER orchestration frameworks (which is linked to Topic 7 “Architecture”) before RQ1.2 can be addressed.**

***RQ1.2** For each DER control approach, what is the most adequate decision-making algorithm (solution method)?*

7.4.1. Key Research Activities

The following key research activities need to be carried out to answer this research question:

A. Definition of the spectrum of potential decision-making algorithms. This requires defining the different types of decision-making algorithms or solution methods (e.g., using optimisation, rules, etc.) that could be adopted in each of the DER control approaches (within each of the technical frameworks for DER orchestration). This spectrum should include rule-based algorithms (practical but not necessarily the most efficient or adaptable when complexity increases), optimisation-based algorithms (efficient but not always scalable), and data-driven algorithms (that can exploit smart meter or other available data to capture aspects that could simplify the implementation of DER control approaches); all considering, to the extent that is possible, the potential uncertainties brought by DER and demand behaviours. [Long-Term Research]

B. Exploration of the objectives of the decision-making algorithm for each type of service. This requires exploring the trade-offs between efficiency (of the service being provided) and fairness (to end consumers/DER) that different objectives will have for each type of service procured by AEMO. Although the objective to be used is likely to be decided by the rule maker (AEMC), the advantages and disadvantages of different options need to be understood. [Long-Term Research] [Trial]

C. Assessment of the feasibility and adaptability of potential decision-making algorithms for each type of service. This requires investigating how feasible it is, in practice, to implement each of the potential decision-making algorithms identified. Such an investigation needs to consider aspects such as the scale (size) of the problem (controllable devices, networks, etc.), the required input data, and the timescales of each type of service procured by AEMO. This also requires evaluating the ability of each decision-making algorithm to adapt to changes in the DER uptake in terms of numbers and technologies as well as to future improvements in capabilities (e.g., data, network modelling, computing power). [Long-Term Research] [Trial]

D. Assessment of the effects of electrical network model accuracy and/or availability. This requires quantifying the extent to which decision-making algorithms can produce efficient results considering existing inaccuracies in electrical network models or even the lack of models (e.g., LV circuits) which, in turn, might require the adoption of conservative considerations to cater for those limitations/challenges. [Short-Term Research] [Trial]

E. Definition of metrics that capture the interests and concerns of all stakeholders. This requires defining technical, economic, and societal metrics that can be used to compare potential decision-making algorithms considering the different stakeholders, including the impacts/effects on end consumers (e.g., electricity bill, performance of DER, etc.) and their acceptance of the algorithm. [Short-Term Research] [Trial]

F. Comparison of the potential decision-making algorithms. This requires quantifying and comparing the different metrics for each of the potential decision-making algorithms considering each of the different types of services procured by AEMO. [Short-Term Research]

7.4.2. Key Research Outputs

The successful completion of the key research activities should lead to the following key outputs:

- A list of the potential decision-making algorithms (or solution methods) for the different DER control approaches.
- An analysis of the objectives of the decision-making algorithm for each type of service.
- An analysis of the feasibility and adaptability of potential decision-making algorithms for each type of service.
- A quantification of the effects of electrical network model accuracy and/or availability on the outcomes from each decision-making algorithm.
- A list of metrics that capture the interests and concerns of all stakeholders.
- A ranking (cost-benefit analysis) of the potential decision-making algorithms.

7.5. RQ1.3: Activities and Outputs

This section presents the key research activities and corresponding outputs needed for this Research Question. This has been produced based on the *key aspects* discussed in the Refined Research Questions and Prioritisation section, specifically, section 6.3 (Area 1) Control Architecture of DERs.

***RQ1.3** What is the role of DER standards in concert with the future orchestration of DER?*

7.5.1. Key Research Activities

The following key research activities need to be carried out to answer this research question:

A. Assessment of the benefits from services extracted via DER standards vs procured via DER orchestration. This requires quantifying the extent to which it is cost-effective (as well as secure and reliable) to continue using DER standards to extract services (such as under/over frequency response during contingencies) instead of procuring them in a competitive market via DER orchestration. This should consider that as DER orchestration is allowed to grow and evolve, there will be more and better capabilities for frequency and other types of responses than the standards. However, the presence of the standards can prevent/sterilise this growth and evolution. Finally, this assessment should also embed the effects of DER standards on consumers and their ability to use their DER to provide services. [Long-Term Research]

B. Defining future-proof DER standards for the extraction of services. This requires investigating the use of standards (and associated infrastructure) for the extraction of services such as under/over frequency response during contingencies that allow the remote change of parameters to adapt to the changing characteristics of the system in the coming years. This should be done in coordination with DER orchestration; depending on the ability of DER orchestration to help/provide frequency services, DER standards might be changed or even disabled. Finally, this should also consider the ability or appetite of Australian/international manufacturers to implement these future-proof DER standards as well as alignment with the international community. [Long-Term Research]

C. Defining DER standards for communications and control. This requires defining the most suitable (in some cases, existing) communication and control standards for the potential DER orchestration frameworks to be adopted in Australia. This should also consider the ability or appetite of Australian/international manufacturers to implement these communications/control standards as well as alignment with the international community. [Short-Term Research] [Trial]

7.5.2. Key Research Outputs

The successful completion of the key research activities should lead to the following key outputs:

- A quantification of the benefits from services extracted via DER standards vs procured via DER orchestration.
- An analysis of future-proof DER standards for the extraction of services.
- An analysis of DER standards for communications and control.

7.6. RQ2.1: Activities and Outputs

This section presents the key research activities and corresponding outputs needed for this Research Question. This has been produced based on the *key aspects* discussed in the Refined Research Questions and Prioritisation section, specifically, section 6.4 (Area 2) Communication Requirements for Monitoring and Control of DERs.

***RQ2.1** For each of the potential technical frameworks for orchestrating DER and the corresponding decision-making algorithms, what is the most cost-effective communication and control infrastructure?*

7.6.1. Key Research Activities

The following key research activities need to be carried out to answer this research question:

A. Definition of the spectrum of potential communication and control infrastructures. This requires defining the different types of communication and control infrastructures required to transfer the data and signals for each of the identified decision-making algorithms, DER control approaches and DER orchestration frameworks. This should consider the role of existing and new DER standards for communications and control in the Australian context, as well as legacy aspects (i.e., older DER installations and associated standards). Furthermore, this spectrum should include advanced techniques that can reduce the need for data and/or communication infrastructure, such as state estimation or data analytics. In addition, depending on the DER orchestration framework and the controllable elements involved, this should consider coordination with existing infrastructure (e.g., DNSP's control of network elements such as OLTCs or capacitor banks, DNSP's management of smart meter, etc.). Finally, cyber and cyber-physical security aspects associated with each potential communication and control infrastructure must also be considered. [Long-Term Research] [Trial]

B. Assessment of the adequacy and reliability for each type of service. This requires investigating how feasible it is, in practice, to implement each of the potential communication and control infrastructures identified. Such an investigation needs to consider aspects such as the required input data, the reliability of the infrastructure, and the time scales (e.g., real-time, near real-time, etc.) of each type of service procured by AEMO. [Short-Term Research] [Trial]

C. Definition of metrics that capture the interests and concerns of all stakeholders. This requires defining technical, economic, and societal metrics that can be used to compare the potential communication and control infrastructures considering the different stakeholders, including the impacts/effects on end consumers (e.g., additional costs, ability to use existing/legacy DER) and their acceptance of/engagement with the technology. [Short-Term Research]

D. Comparison of the potential communication and control infrastructures. This requires quantifying and comparing the different metrics for each of the potential communication and control infrastructures considering each of the different types of services procured by AEMO. [Long-Term Research] [Trial]

7.6.2. Key Research Outputs

The successful completion of the key research activities should lead to the following key outputs:

- A list of the potential communication and control infrastructures for the different decision-making algorithms, DER control approaches and DER orchestration frameworks.
- An analysis of the adequacy and reliability of the communication and control infrastructures for each type of service.
- A list of metrics that capture the interests and concerns of all stakeholders.
- A ranking (cost-benefit analysis) of the potential communication and control infrastructures.

7.7. RQ3.1: Activities and Outputs

This section presents the key research activities and corresponding outputs needed for this Research Question. This has been produced based on the *key aspects* discussed in the Refined Research Questions and Prioritisation section, specifically, section 6.5 (Area 3) Ancillary Services Provided by DERs.

***RQ3.1** What are the most cost-effective ancillary services that can be delivered by DER considering the expected technological diversity and ubiquity of DER?*

7.7.1. Key Research Activities

The following key research activities need to be carried out to answer this research question:

A. Assessment of the capabilities of DER technologies for each type of service. This requires determining whether a DER technology and corresponding associated infrastructure (such as communications and control) is capable of meeting the technical specifications (e.g., response time, duration of the response, etc.) of each type of service procured by AEMO. This assessment should consider that the technical specifications of the services can be made agnostic of the DER technology (to encourage DER innovation) and that DER could also benefit from stacking multiple services. This assessment can be expanded for new types of services not yet defined by AEMO. [Short-Term Research] [Trial]

B. Assessment of the effects of end-user behaviour and availability on the provision of ancillary services. This requires a time-varying quantification (e.g., hourly for different types or days and seasons) of the effects that end-user/consumer behaviour has on the ability of DER technologies to provide certain services. This should also consider the willingness of consumers to engage with the provision of multiple services through third-party aggregators. [Short-Term Research] [Trial]

C. Assessment of the effects of distribution networks on the provision of ancillary services. This requires a time-varying quantification (e.g., hourly for different types or days and seasons) that considers the effects of distribution networks (e.g., power losses, network constraints, etc.) on the provision of services when seen at relevant locations (e.g., transmission-distribution interface or zone substations). These effects should be captured using distribution network models and different types of networks (urban, rural, etc.) as well as different uptakes of DER and types of services. [Short-Term Research]

D. Assessment of the effects of value on the provision of ancillary services. This requires investigating how the valuation of the different types of services procured by AEMO affects the availability and quantity of services that could be provided by DER. This valuation should consider that DER could benefit from stacking multiple services. [Short-Term Research] [Trial]
E. Assessment of the effects of distribution-level services on the provision of ancillary services. This requires investigating the potential effects that distribution-level services (with different valuations) might have on the ability of DER to provide ancillary services. This should also investigate coordination and/or prioritisation aspects that might be necessary between the entities requesting the services (e.g., AEMO and DNSPs) to avoid issues/conflicts. [Long-Term Research] [Trial]
F. Comparison of the ancillary services that can be delivered by DER. This requires a techno-economic quantification and comparison of the ability of DER to provide the different types of services procured by AEMO considering the different aspects discussed above. [Short-Term Research] [Trial]
G. Comparison of medium-to-large scale DER vs small-scale DER. This requires a techno-economic comparison between the ability of small-scale DER to provide services procured by AEMO and the ability of established medium-to-large scale DER technologies (such as large-scale batteries). [Trial]

7.7.2. Key Research Outputs

The successful completion of the key research activities should lead to the following key outputs:

- An analysis of the capabilities of DER technologies for each type of service.
- A method to embed/estimate the effects of end-user behaviour and availability on the provision of ancillary services.
- A method to embed/estimate the effects of distribution networks on the provision of ancillary services.
- An analysis of the effects of value on the provision of ancillary services.
- An analysis of the effects of distribution-level services on the provision of ancillary services.
- A ranking (cost-benefit analysis) of the ancillary services that can be more cost-effectively delivered by DER.
- A ranking (cost-benefit analysis) of the medium-to-large scale DER technologies that might be more beneficial to procure ancillary services from.

7.8. RQ4.1: Activities and Outputs

This section presents the key research activities and corresponding outputs needed for this Research Question. This has been produced based on the *key aspects* discussed in the Refined Research Questions and Prioritisation section, specifically, section 6.6 (Area 4) Influence of DERs on System-Level Planning.

***RQ4.1** What are the minimum requirements for a DER-rich distribution network equivalent model to be adequate for its use in system planning studies?*

7.8.1. Key Research Activities

The following key research activities need to be carried out to answer this research question:

A. Mapping of the types of equivalent models used for planning studies and existing practices. This requires defining the spectrum of planning studies conducted by AEMO (e.g., economic, security, reliability) and characterising the corresponding equivalent models currently used for each of them. This also involves examining current practices (including limitations and potential issues) in the production of the equivalent models. [Short-Term Research]

B. Assessment of the effects of DER uncertainty on the equivalent models. For short and mid-term system-level planning applications, this requires a time-varying quantification (e.g., hourly for different types or days and seasons) to capture the effects of DER variability (due to weather conditions as well as consumer behaviour) on the different types of equivalent models. This should also consider the effects from having different DER uptakes and technologies as well as a mix of DER standards. This assessment should consider the effects that the provision of services from DER can have on the equivalent models. For long-term system-level planning applications, the investment and operational strategies of DNSPs and how this affects DER, needs also to be captured. [Long-Term Research]

C. Assessment of the effects of distribution networks on the equivalent models. For short and mid-term system-level planning applications, this requires a time-varying quantification (e.g., hourly for different types of days and seasons) that considers the effects of distribution networks (e.g., power losses, etc.) and the changing states of controllable elements (e.g., OLTCs, capacitor banks, switches) on the equivalent models. These effects should be captured using distribution network models and different types of networks (urban, rural, etc.) as well as different uptakes of DER. For long-term system-level planning applications, however, the expansion and different types of investments done on the distribution networks, needs also to be captured. [Short-Term Research] [Long-Term Research]

D. Definition of the minimum technical specifications and accuracy needed for the equivalent models. This requires investigating the trade-offs between the accuracy needed for the equivalent models (considering the aspects discussed above) and the minimum technical specifications (and the associated cost/time/effort of the parties involved) to achieve them. This should also consider the limits that might exist on the scale of the equivalent models due to the simulation tools used by AEMO to do the planning studies. [Short-Term Research]

E. Definition of the process to produce the equivalent models. This requires defining the most suitable locations, type of measurements, timing (e.g., critical times during the day/week/season), and regularity (e.g., every 6 months) needed to produce the different equivalent models according to the minimum technical specifications. Furthermore, this should also consider the potential roles and specific tasks that AEMO and the corresponding DNSPs must have to ensure the homogenous production of equivalent models. [Short-Term Research] [Trial]

7.8.2. Key Research Outputs

The successful completion of the key research activities should lead to the following key outputs:

- A list of the types of equivalent models used for planning studies and existing practices.
- A method to embed/estimate the effects of DER uncertainty on the equivalent models.
- A method to embed/estimate the effects of distribution networks on the equivalent models.
- A list of the minimum technical specifications and accuracy needed for the equivalent models.
- A process to produce the equivalent models.

7.9. RQ4.2: Activities and Outputs

This section presents the key research activities and corresponding outputs needed for this Research Question. This has been produced based on the *key aspects* discussed in the Refined Research Questions and Prioritisation section, specifically, section 6.6 (Area 4) Influence of DERs on System-Level Planning.

***RQ4.2** What is the minimum availability of ancillary services from DER at strategic points in the system throughout the year and across multiple years?*

7.9.1. Key Research Activities

The following key research activities need to be carried out to answer this research question:

A. Mapping of the planning studies that involve ancillary services. This requires defining the spectrum of multi-month and multi-year planning studies conducted by AEMO (e.g., economic, security, reliability) that involve any type of ancillary services. This also entails examining current practices (including limitations and potential issues) in the estimation of the different ancillary services that DER might be able to provide. [Short-Term Research]

B. Assessment of the effects of DER uncertainty on the provision of ancillary services. This requires a time-varying quantification (e.g., hourly for different types of days and seasons) to capture the effects of DER variability (due to weather conditions as well as consumer behaviour) on the provision of different types of ancillary services seen at strategic points in the system (e.g., transmission-distribution interface, zone substations). This should be done considering short, mid, and long-term DER uptake forecasts (which might include new technologies and capabilities). For the long-term, this assessment should also consider distribution network expansion, future operational strategies, the existence of DER orchestration, and the provision of distribution-level services. [Long-Term Research]

C. Assessment of the effects of distribution networks on the availability of ancillary services. This requires a time-varying quantification (e.g., hourly for different types of days and seasons) that considers the effects of distribution networks (e.g., power losses, constraints, etc.) on the ability of DER to provide different ancillary services seen at strategic points in the system. These effects should be captured using distribution network models and different types of networks (urban, rural, etc.) as well as different uptakes of DER. [Short-Term Research]

D. Quantification of the minimum availability of ancillary services from DER. This requires estimating across multiple months and years (depending on the type of planning study) and considering the aspects discussed above, the minimum volume of the different ancillary services that DER might be able to provide at strategic points in the system. [Long-Term Research]

7.9.2. Key Research Outputs

The successful completion of the key research activities should lead to the following key outputs:

- A list of the types of the planning studies that involve ancillary services and existing practices.
- A method to embed/estimate the effects of DER uncertainty on the provision of ancillary services.
- A method to embed/estimate the effects of distribution networks on the availability of ancillary services.
- An estimation of the minimum availability of ancillary services from DER throughout the year and across multiple years.

7.10. RQ5.1: Activities and Outputs

This section presents the key research activities and corresponding outputs needed for this Research Question. This has been produced based on the *key aspects* discussed in the Refined Research Questions and Prioritisation section, specifically, section 6.7 (Area 5) Overcoming Institutional Challenges.

***RQ5.1** What are the necessary organisational and regulatory changes to enable the provisioning of ancillary services from DER?*

7.10.1. Key Research Activities

The following key research activities need to be carried out to answer this research question:

A. Assessment of potential frameworks for orchestrating DER. This requires investigating frameworks that define the interactions and roles among AEMO, DNSPs, and aggregators to facilitate the provision of services (to AEMO and DNSPs) from DER. This assessment should consider the added technical complexity as well as potential new responsibilities (or liabilities) that each framework might bring to the different stakeholders, including the consumer and the aggregators, as well as the different characteristics (DNSPs, metering and communications infrastructure, DER uptake, etc.) of the states across Australia. This should use as starting point the frameworks already defined by the Open Energy Networks Project [3] and aim to produce refined frameworks that allow the development of transparent business models across all parties involved and, ultimately, the cost-effective orchestration of different types of DER technologies. [Short-Term Research] [Trial]

B. Investigation of consumer-centric approaches/processes to ensure engagement. This requires investigating the different opportunities in which consumers (their interests and concerns) can be placed at the centre of the technical and regulatory discussions to ensure that, ultimately, there will be adequate consumer engagement/participation in the provision of ancillary and other services from DER as well as in DER orchestration. [Short-Term Research] [Trial]

C. Investigation of the new incentives and/or directions needed by AEMO and DNSPs to incorporate DER at the core of their businesses. This requires investigating the mechanisms needed for AEMO to embrace DER in a holistic manner. Similarly, this requires investigating the most adequate OpEx and/or CapEx considerations for DNSPs to adequately recover the additional investments needed to truly facilitate the provision of ancillary services from DER. [Short-Term Research]

D. Investigation of knowledge sharing mechanisms. This requires investigating new ways in which the know-how, expertise, and tools that have resulted from multiple projects funded by ARENA, DNSPs, AEMO and many other organisations can be adequately shared and, ultimately, incorporated in the businesses of key stakeholders. [Short-Term Research]

7.10.2. Key Research Outputs

The successful completion of the key research activities should lead to the following key outputs:

- A ranking (cost-benefit analysis) of the potential frameworks for orchestrating DER.
- A list of potential consumer-centric approaches/processes to ensure engagement/participation in the provision of ancillary and other services from DER.
- A list of potential new incentives and/or directions for AEMO and DNSPs to incorporate DER at the core of their businesses.
- A list of potential knowledge sharing mechanisms.

7.11. RQ5.2: Activities and Outputs

This section presents the key research activities and corresponding outputs needed for this Research Question. This has been produced based on the *key aspects* discussed in the Refined Research Questions and Prioritisation section, specifically, section 6.7 (Area 5) Overcoming Institutional Challenges.

***RQ5.2** What are the necessary considerations of establishing a distribution-level market (for energy and services)?*

7.11.1. Key Research Activities

The following key research activities need to be carried out to answer this research question:

A. Investigation of the potential level of consumer engagement in a new market. This requires investigating the extent to which consumers will be willing to embrace/engage with a new market that can be perceived as adding complexity and cost to how things are done today. This should also consider the investigation of strategies to educate consumers and achieve adequate engagement levels. [Short-Term Research]

B. Assessment of the minimum volume of services from DER (liquidity) needed to make a market viable. This requires quantifying for each of the potential services to be procured by a DNSP (or by a Distribution Market Operator [DMO]) the minimum volume of services that must be provided by DER for such a distribution-level market to work. This quantification should consider the different voltage levels in distribution networks to determine the most adequate match between DER liquidity and the potential local network problems it can help mitigate. [Long-Term Research]

C. Investigation of the potential coordination strategies between ancillary and distribution-level services. This requires investigating the potential coordination and/or prioritisation strategies that should exist between the ancillary services market (managed by AEMO) and the distribution-level market (e.g., managed by a DMO) to avoid issues/conflicts in which a service procured by one entity is compromised by those procured by the other. [Long-Term Research] [Trial]

D. Investigation of the long-term role of non-market approaches. This requires comparing the long-term cost-effectiveness from using a distribution-level market with the adoption of conventional approaches to solve operational and planning issues. This should include network augmentation, bi-lateral contracts, and DER orchestration (e.g., use of dynamic limits, operating envelopes, etc.). [Long-Term Research]

E. Assessment of the potential benefits across Australia. This requires quantifying the potential benefits for consumers and the whole power system considering the aspects discussed above and the different characteristics (DNSPs, metering and communications infrastructure, DER uptake, etc.) of the states across Australia. [Long-Term Research] [Trial]

7.11.2. Key Research Outputs

The successful completion of the key research activities should lead to the following key outputs:

- An estimation of the potential level of consumer engagement in a new market.
- A list of potential educational strategies to ensure adequate consumer engagement.
- An estimation of the minimum volume of services from DER (liquidity) needed to make a market viable.
- A list of the potential coordination strategies between ancillary and distribution-level services.
- An analysis of the long-term role of non-market approaches.
- A cost-benefit analysis of distribution-level markets for each Australian state.

7.12. Potential Information, Data, and Resource Needs

To successfully carry out the different research activities (classified into Short-Term Research, Trials and Long-Term Research) that have been identified for each of the Research Questions, it is crucial that relevant information, data and resources are made available to those organisations doing the corresponding work.

The characteristics of the information, data and resources required by each research activity will depend on the boundaries and depth, which must be defined when first procuring the services to carry out those research activities (e.g., a call for proposals). Nonetheless, the following provides a general overview of the potential needs.

- Information. Most of the research activities will require significant inputs, mostly from AEMO and the DNSPs. This information includes know-how, non-public reports, ongoing/planned activities, etc. Similarly, some research activities will benefit from such information from DER manufacturers, DER solution providers, and aggregators. Finally, those activities that are oriented towards regulation will need significant inputs from Government and regulatory agencies. Overall, these interactions will help accelerate both research and implementation, improve coordination, and avoid the duplication of efforts.
- Data. Many research activities rely on regional DER uptakes, DER and demand models, distribution network models, etc. This, in turn, can require large amounts of data from the corresponding regional DNSPs and other organisations that keep track of DER-related data. Nonetheless, this can be a significant challenge as the transfer of such detailed data is not common in Australia (or around the world). Furthermore, for some DNSPs, detailed network and customer data might not even exist. For example, individual demand behaviour of customers (smart meter data), low voltage networks (topology, impedances), etc.

- Resources. Beyond funding aspects, most (technical) research activities that do not involve trials would be carried out using advanced power system simulations (e.g., power flows, dynamic responses, etc.) as well as communication equipment testing and simulations, (e.g., hardware-in-the-loop simulations with real communication devices within a laboratory environment). This is, however, common for most research organisations as well as consultancies. In terms of funding, activities that involve Trials are likely to require multi-million dollar support (which can go up to $65 million, as reported in section 4) due to the need for infrastructure, equipment, etc. On the other side of the spectrum, Short-Term and Long-Term research activities will be significantly cheaper as they predominately cover the time of experts and researchers. Nonetheless, the investment required will depend on the specifics of the corresponding research activity.

Based on the above, it is very important to bear in mind that the success of most research activities will depend on ensuring high levels of collaboration with AEMO, DNSPs and other organisations.

7.13. Risks Associated with the Research Plan and Mitigation Strategies

Based on the feedback from stakeholders (section 6.1.3), the links to other Topics, as well as some of potential challenges related to data and resources, the following risks associated with the Research Plan have been identified:

- Timeliness of Research Outputs. It is conceivable that some of the research outputs might be available at a time when some decisions could have already been made by industry and/or Government. Making those outputs irrelevant. The chances of this occurring could increase if the start of the research activities is much later than 2022 or 2023.
- Readiness of Research Outputs. Certain research outputs, such as methods, might not be readily implementable by industry and/or Government, which can hinder or delay their adoption. This also extends to the recommendations or cost-benefit analyses, which might not be in a form that could be readily used by decision makers.
- Changes in DER Uptake. Depending on external factors, such as Government policies or technological developments, DER uptake can dramatically change (increase or decrease), thus changing the relative urgency and relevance of the different Research Questions.
- Dependencies with Other Topics and Research Questions. Delays (or, even, failures) of other Topics and/or research activities within Topic 8 can significantly affect the timelines of other research activities that depend on them.
- Data and Collaborations. Limited access to data considered critical for certain research activities can have a serious impact on the usefulness of the research outputs. Similarly, limited or ineffective collaborations with key stakeholders can affect the access to important information, creating delays and jeopardising the value of the research outputs.
- Resources. The diversity, extent, and quantity of the identified research activities mean that significant funding will be required to cover the whole Research Plan. Limited funding would lead to the re-prioritisation of research questions (and activities) which, in turn, will result in delays for those not funded (potentially, losing their timeliness and making them irrelevant).

To address the above risks, the following mitigation measures are proposed:

- Timeliness of Research Outputs. All types of research activities must, to the extent that is possible, provide regular updates (e.g., every 6 months) in terms of preliminary outputs and findings that are also adequately disseminated to stakeholders. This can increase the relevance of those outputs even if not final and, thus, make it possible for decisions makers to take them into account.

- Readiness of Research Outputs. All research activities must engage with the corresponding end-users of their outputs and findings since the start. In addition, at the time of procuring those research activities (e.g., call for proposals), the nature of the expected outputs should be clearly stated.
- Changes in DER Uptake. The Research Plan must be revised regularly to cater for the changes in Government policies and/or technological developments. Given that these do not occur immediately, the revision can take place every 2 to 4 years, depending on the characteristics of each State or Territory.
- Dependencies with Other Topics and Research Questions. All Topics and research activities from which outputs are relied upon for other Topics must have regular updates (e.g., every 6 months), considering preliminary results and findings. In addition, the recipient research activities must also have an alternative to the inputs from other Topics and/or research activities (i.e., a contingency plan).
- Data and Collaborations. Key stakeholders (AEMO, DNSPs, aggregators, DER manufacturers, DER solution providers, AER, AEMC, etc.) need to be involved, to the extent that is possible, in the procurement of the research activities (e.g., call for proposals). It is crucial that they acknowledge and commit to providing the required information, data, and support to the research activities.
- Resources. Strong engagement with the Australian Federal Government, State Governments, and the different funding agencies (such as ARENA and ARC) is required to ensure adequate funds.

7.14. Key Stakeholders Required to Advance Australian DER Research

Given the nature of the identified research activities (Short-Term Research, Trials, and Long-Term Research), different types of organisations will be required to carry out the proposed Research Plan and help Australia address the multiple challenges associated with DERs.

- Short-Term Research. This work can be done by research organisations, such as CSIRO and universities, as well as by consultancy companies.
- Trial. This work is likely to be led by AEMO, DNSPs, aggregators or DER solution providers. Furthermore, it can involve multiple parties, including research organisations and consultancy companies.
- Long-Term Research. This work, which requires in-depth research work that is typical of a PhD project (or equivalent), is done by universities.

As discussed in section 4, over the last decade, there have been several companies and research organisations involved in multiple Australian activities/projects, all demonstrating strong capabilities in tackling different DER-related challenges. Given that there is a strong pool of candidates across all Australian States and Territories, the procurement of services to undertake the research activities can successfully go through public calls for proposals.

From the perspective of international collaborations, important for certain research questions (as discussed in section 6.8), it was evident (from the review done in section 5 as well as the feedback from international stakeholders) that research organisations such as the National Renewable Energy Laboratory (NREL) and the Electric Power Research Institute (EPRI) are potential collaborators in the US. Across to Europe, given the different dynamics of research funding, there are multiple national research organisations (such as Electricite de France [EDF] R&D in France and Ricerca sul Sistema Energetico [RSE] in Italy) as well as universities that can also be potential collaborators.

References

[1] Australian Energy Market Operator (AEMO). *NEM settlement under zero and negative regional demand conditions*. Available: https://aemo.com.au/en/consultations/current-and-closed-consultations/nem-settlement-under-zero-and-negative-regional-demand-conditions

[2] International Energy Agency (IEA), "Energy Technology Roadmaps: a guide to development and implementation," 2010.

[3] Energy Networks Australia (ENA). *Open Energy Networks Project*. Available: https://www.energynetworks.com.au/projects/open-energy-networks/

[4] Australian Energy Market Operator (AEMO), "2020 Electricity Statement of Opportunities," Australia,2020, Available: https://aemo.com.au/-/media/files/electricity/nem/planning_and_forecasting/nem_esoo/2020/2020-electricity-statement-of-opportunities.pdf.

[5] Australian Energy Market Operator (AEMO), "2020 Integrated System Plan," Australia, 2020, Available: https://aemo.com.au/-/media/files/major-publications/isp/2020/final-2020-integrated-system-plan.pdf.

[6] Australian Energy Market Operator (AEMO). *Current Inputs, Assumptions and Scenarios*. Available: https://aemo.com.au/energy-systems/major-publications/integrated-system-plan-isp/2022-integrated-system-plan-isp/current-inputs-assumptions-and-scenarios

[7] P. W. Graham and L. Havas, "Projections for small-scale embedded technologies," Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia,2020, Available: https://aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/Inputs-Assumptions-Methodologies/2020/CSIRO-DER-Forecast-Report.

[8] Green Energy Markets Pty Ltd, "Projections for distributed energy resources – solar PV and stationary energy battery systems," Australia2020, Available: https://aemo.com.au/-/media/files/electricity/nem/planning_and_forecasting/inputs-assumptions-methodologies/2020/green-energy-markets-der-forecast-report.pdf.

[9] Australian Energy Market Operator (AEMO). *Distributed Energy Integration Program Electric Vehicle Taskforces*. Available: https://aemo.com.au/en/consultations/industry-forums-and-working-groups/list-of-industry-forums-and-working-groups/deip-ev-taskforce

[10] Australian Renewable Energy Agency (ARENA). *Victorian Distributed Energy Resources Marketplace Trial*. Available: https://arena.gov.au/projects/victorian-distributed-energy-resources-marketplace-trial/

[11] Australian Energy Market Operator (AEMO). *Project EDGE*. Available: https://aemo.com.au/en/initiatives/major-programs/nem-distributed-energy-resources-der-program/der-demonstrations/project-edge

[12] T. U. o. Melbourne. *Project EDGE*. Available: https://electrical.eng.unimelb.edu.au/power-energy/projects/project-edge

[13] Australian renewable Energy Agency (ARENA). *SA Power Networks Flexible Exports for Solar PV Trial*. Available: https://arena.gov.au/projects/sa-power-networks-flexible-exports-for-solar-pv-trial/

[14] Australian Renewable Energy Agency (ARENA). *Dynamic Operating Envelopes Workstream*. Available: https://arena.gov.au/knowledge-innovation/distributed-energy-integration-program/dynamic-operating-envelopes-workstream/

[15] Australian Renewable Energy Agency (ARENA). *Projects*. Available: https://arena.gov.au/projects/

[16] Australian Energy Market Operator (AEMO). *NEM Distributed Energy Resources Program*. Available: https://aemo.com.au/initiatives/major-programs/nem-distributed-energy-resources-der-program

[17] Energy Networks Australia (ENA). *Energy Networks Australia Projects*. Available: https://www.energynetworks.com.au/projects/

[18] Australian Renewable Energy Agency (ARENA). *Distributed Energy Integration Program (DEIP)*. Available: https://arena.gov.au/knowledge-innovation/distributed-energy-integration-program/

[19] Australian Energy Market Operator (AEMO). *DEIP Standards, Data and Interoperability Working Group*. Available: https://aemo.com.au/consultations/industry-forums-and-working-groups/list-of-industry-forums-and-working-groups/deip-isc/deip-sdiwg

[20] Australian Energy Market Operator (AEMO). *Review Of Standard For Power System Data Communication*. Available: https://aemo.com.au/en/consultations/current-and-closed-consultations/review-of-standard-for-power-system-data-communication

[21] Centre for New Energy Technologies (C4NET). *C4NET Projects*. Available: https://c4net.com.au/projects/

[22] Commonwealth Scientific and Industrial Research Organisation (CSIRO). *Energy Research*. Available: https://www.csiro.au/en/research/technology-space/energy

[23] Australian Energy Regulator (AER). *Assessing Distributed Energy Resources Integration Expenditure*. Available: https://www.aer.gov.au/networks-pipelines/guidelines-schemes-models-reviews/assessing-distributed-energy-resources-integration-expenditure

[24] A. E. M. C. (AEMC). *Review of the regulatory framework for metering services*. Available: https://www.aemc.gov.au/market-reviews-advice/review-regulatory-framework-metering-services

[25] Energy Security Board (ESB). *Post 2025 Electricity Market Design*. Available: https://esb-post2025-market-design.aemc.gov.au/

Appendices

Appendix A – First Refinement of Research Questions

For completeness, the research questions resulting from the "First Refinement" as well as the feedback from the stakeholders can be found here. These are the research questions discussed during the stakeholder engagement sessions. The key aspects for each research question are also included but in a concise manner due to the nature of the stakeholder engagement sessions (content was delivered using slides).

The comments presented in this section are based on the notes taken by the project team of The University of Melbourne. As such, there may be limitations to the interpretation of what was captured during the stakeholder sessions.

(Area 0) DER Visibility for Whole-System Operations

Research Question 0.1

Q0.1 *What data flows (DER specs, measurements, forecasts, etc.) are needed to ensure AEMO has enough DER/net demand visibility to adequately operate a DER-rich system in different time scales (mins to hours)?*

Key aspects to be considered:

- Effects of existing DER standards (e.g., PV's Volt-Watt, tripping) on quantification
- Effects of distribution networks on quantification (e.g., curtailment, losses, var, etc.)
- Effects of DER managed by aggregators
- Targeted forecast (e.g., per zone sub) of DER/net demand
- Role of DNSPs and aggregators in all these quantifications
- DER Register 2.0

Table 20. Summary of Stakeholder Feedback for Research Question 0.1

Discussion Points	Comments
Relevance to Australia	• All the stakeholders that discussed this area considered this research question highly relevant to Australia.
Key aspects missing or complementary	• What are the (different) visibility requirements for each stakeholder (AEMO, DNSP, aggregator, etc)? ○ DER technology, signal names (voltages, frequency, harmonics, etc), data resolution ○ Minimum requirements • Can 100% penetration of current metering technology provide adequate data? If not, do we need improved technologies? • How should cost be recovered (most likely from customers) from the deployment of metering infrastructures. • Who is the single source of truth for visibility and who should have access to this information? • What is the value of the data/visibility? Should it be free?

	• Should statistical approaches be considered to make decisions due to low visibility of networks?
Can Australia deliver?	• Strong belief from the stakeholders that Australia (industry, research, etc.) is able to deliver/answer this question within the next 10 years.

(Area 1) Control Architecture of DER

Research Question 1.1

***Q1.1** For each of the potential technical frameworks for orchestrating DER in Australia (e.g., based on the OpEN Project), what is the most appropriate DER control approach to deal with the expected technological diversity and ubiquity of DER?*

Key aspects to be considered:

- Scalability of centralised approaches (large 3f distribution networks)
- Feasibility of distributed approaches (community control of DER + remote supervision)
- Effectiveness due to a lack of LV network models
- Future-proof approaches (DER uptake, new technologies)
- Data transfer and comms infrastructure reqs of each control approach
- Metrics that capture the concerns of all stakeholders

Table 21. Summary of Stakeholder Feedback for Research Question 1.1

Discussion Points	Comments
Relevance to Australia	• All the stakeholders that discussed this area considered this research question highly relevant to Australia.
Key aspects missing or complementary	• What is the most adequate architecture for a given application? ○ Different network topology, population density, DER update in the region, etc. • What is the optimal balance between desktop-based analysis and real-world trials? • What is the impact on customers? • What is the cost to implement a given framework?
Can Australia deliver?	• Strong belief from the stakeholders that Australia (industry, research, etc.) is able to deliver/answer this question within the next 10 years.

Research Question 1.2

***Q1.2** For each DER control approach, what is the most adequate decision-making algorithm (solution method)?*

Key aspects to be considered:

- Effectiveness due to accuracy/changes of electrical network models
- Practicality of optimisation-based algorithms

- Effectiveness of rule-based algorithms
- Role of data-driven algorithms (no electrical models)
- Trade-off between fairness and efficiency
- Metrics that capture the concerns of all stakeholders

Table 22. Summary of Stakeholder Feedback for Research Question 1.2

Discussion Points	Comments
Relevance to Australia	• All the stakeholders that discussed this area considered this research question highly relevant to Australia.

Key aspects missing or complementary	• What should the algorithm prioritise, maximise generation, minimisation of costs, system robustness, or something else?
	  ○ How to consider cost
	  ○ No system, no electricity, no need for fairness
	• What decision-making algorithm is the most appropriate for each use case (frequency deviation, voltage issue, etc.)?
	• What decision-making algorithm is the most appropriate to each stakeholder/use case?
	• Can we use market mechanisms (e.g., compensate DER owners) to address fairness concerns?
	• How to consider possible conflict in decision-making algorithms?
	  ○ Single DER with multiple service aggregators
	  ○ Multiple services being requested at the same time
	• How to create decision-making algorithms that can evolve as system visibility/capabilities improves?
	• How much electrical model is necessary for the decision-making algorithm?
	  ○ Full / partial / no-model.

Can Australia deliver?	• Strong belief from the stakeholders that Australia (industry, research, etc.) is able to deliver/answer this question within the next 10 years.

Research Question 1.3

***Q1.3** To what extent can DER standards alone (no DER orchestration and no markets) extract valuable services for AEMO (e.g., response to frequency changes) while ensuring distribution network integrity?*

Key aspects to be considered:

- Characteristics of these DER standards
- Effects on end users/customers
- Future-proof DER standards (DER uptake, new technologies, DER orchestration)
- Readiness of DER technologies for such standards
- Quantification at different times
- Role of emergency limits in distribution (e.g., voltages)

Table 23. Summary of Stakeholder Feedback for Research Question 1.3

Key Aspect	Comments
Discussion Points	• Comments
Relevance to Australia	• All the stakeholders that discussed this area considered this research question highly relevant to Australia.
Key aspects missing or complementary	• Consider rephrasing this question to "What is the role of DER standards in concert with DER orchestration/active management." o Standard may have many limitations (time consuming, lowest common denominator, prohibits innovation) o What should the role of DER standards in terms of allowing/enabling innovations and DER integration/orchestration? • How to ensure standards are being followed with DER installations. • What is the true cost associated with implementing a standard?
Can Australia deliver?	• Weak belief from the stakeholders that Australia (industry, research, etc.) is able to deliver/answer this question within the next 10 years. This is mainly due to the associated, lengthy processes involving the production of standards, which is also tied to international processes.

(Area 2) Communication Requirements for Monitoring and Control of DER

Research Question 2.1

***Q2.1** For each of the potential technical frameworks for orchestrating DER and the corresponding decision-making algorithms, what are the minimum communication and control requirements?*

Key aspects to be considered:

- Role of advanced state estimation techniques
- Role of data analytic techniques in filling the gaps
- Role of distribution network elements (e.g., OLTCs, cap banks) in the control of DER

Table 24. Summary of Stakeholder Feedback for Research Question 2.1

Discussion Points	Comments
Relevance to Australia	• All the stakeholders that discussed this area considered this research question highly relevant to Australia.
Key aspects missing or complementary	• What is the required infrastructure to support the monitoring and control activities in real-time? • Need a standard way of communicating with DER for orchestration, what is the best? • Should statistical approaches be considered to make decisions instead of using communications?

	• How does this impact the consumer, which is best for the consumer? • What are the costs and corresponding benefits? • Should we try to achieve full DER orchestration?
Can Australia deliver?	• Moderate belief from the stakeholders that Australia (industry, research, etc.) is able to deliver/answer this question within the next 10 years. This is mainly due to the standards associated with the communication of DER and the need for other countries to face similar challenges as Australia to motivate a common and effective way of communication (standards) for DER.

(Area 3) Ancillary Services Provided by DER

Research Question 3.1

***Q3.1** What are the most reliable/available/effective ancillary services that can be delivered by DER considering the expected technological diversity and ubiquity of DER?*

Key aspects to be considered:

- Suitability of DER technologies for each of the ancillary services
- Effects of end-user behaviour and availability on the services
- Effects of distribution networks on the services (e.g., losses, var, constraints, etc.)
- Extent to which DER can be a significant provider of ancillary services
- Role of the adopted DER orchestration framework
- Role of the adopted DER control approach

Table 25. Summary of Stakeholder Feedback for Research Question 3.1

Discussion Points	Comments
Relevance to Australia	• All the stakeholders that discussed this area considered this research question highly relevant to Australia.
Key aspects missing or complementary	• What are the possible ancillary services for distribution networks? • How to measure/meter ancillary services from DER for payment/verification? • Which level of services gets priority? • How would co-optimization of multiple services work? • How should the interactions between distribution-level services and transmission services be orchestrated? • Communication infrastructure requirement for large DER versus small DER, is it viable for small DER? • What is the necessary commercial case to justify and incentivise the participation of DER in providing ancillary services? • Minimum amount of DER provided services to be worthwhile?

	• What would the benefits and drawbacks of vertical integration of the power system to enable DER providing services? • How feasible is the scalability of DER via aggregation for providing ancillary services? • Will customers agree to give these services, what price will customers participate at? • How will constraints in the distribution network / availability of DER (e.g., battery SOC) limit the volume of services that can be extracted from DER? • Some services may require a new type of DER tech (e.g., FFR and residential BESS). This of course is a big cost. Important to see the value of these services, and therefore the value and cost trade-off decided by customers and aggregators.
Can Australia deliver?	• Strong belief from the stakeholders that Australia (industry, research, etc.) is able to deliver/answer this question within the next 10 years. DER, from a technical standpoint, can deliver ancillary services (if orchestration and regulatory issues are solved by then).

(Area 4) Influence of DER on System-Level Planning

Research Question 4.1

***Q4.1** What are the minimum requirements for a DER-rich distribution network equivalent model to be adequate for its use in system planning studies?*

Key aspects to be considered:

- Different planning studies: Economic, security and reliability; steady state, dynamics.
- Minimum amount of data and accuracy needed (for each type of study)
- Location, type of measurements, and regularity needed to produce the equivalent models
- Limits on the scale of equivalent models
- Effects of uncertainty (mix of DER standards/behaviour/etc.) on the equivalent models
- Effects of distribution networks on the equivalent models

Table 26. Summary of Stakeholder Feedback for Research Question 4.1

Discussion Points	Comments
Relevance to Australia	• All the stakeholders that discussed this area considered this research question highly relevant to Australia.
Key aspects missing or complementary	• What are the new scenarios to be considered in planning? (e.g., not just peak demand, but also plan for minimum demand) • How to account for diversity in standards of DER in system-level planning? • How would distribution-level ancillary services impact system-level planning? How to cater for this in models?

	• How to account for uncertainty around consumer behaviour's influence on DER (and availability of ancillary services)? • What is the trade-off between accurate models (e.g., DNSP models to inform AEMO) and the cost to achieve it? • Uncertainty comes from diverse behaviours due to standards not being equal across DER types. • More planning around minimum demand than there is today. • Consumer behaviour needs to be accounted for in system-level planning. E.g., using EV battery for services, how many times can you use it if the customer wants battery at a certain % in the morning? Can only use a battery a few times during the day for services. • Requires an agreed consistent way of modelling in terms desired of outputs for interactions with power system operator.
Can Australia deliver?	• Moderate belief from the stakeholders that Australia (industry, research, etc.) to deliver/answer this question within the next 10 years. This is because it will be challenging due to coordination of many stakeholders to get the needed information in a standardised format.

Research Question 4.2

***Q4.2** What is the minimum availability of DER services at strategic points in the system throughout the year and across multiple years?*

Key aspects to be considered:

- DER forecast
- Effects of end-user behaviour and availability on the services
- Effects of distribution networks on the services (e.g., losses, var, constraints, etc.)
- Role of the adopted DER orchestration framework
- Role of the adopted DER control approach

Table 27. Summary of Stakeholder Feedback for Research Question 4.2

Discussion Points	Comments
Relevance to Australia	• All the stakeholders that discussed this area considered this research question highly relevant to Australia.

Key aspects missing or complementary	• What role can load-balancing from DER play? (Regulation FCAS: normal operating frequency band services)
	• 3 areas required to assess this, what is the best way to determine:
	  o DER Forecast and Uptake
	  o DER Behaviour and Availability,
	  o Distribution Network Constraints
	• What is the minimum availability of distribution-level services? (as well as system services in original RQ)

Can Australia deliver?	• Moderate belief from the stakeholders that Australia (industry, research, etc.) is able to deliver/answer this question within the next 10 years. The main challenge will be the need of DER orchestration being worked out first to then assess the minimum availability.

(Area 5) Overcoming Institutional Challenges

Research Question 5.1

***Q5.1** What are the necessary organisational and regulatory changes to enable the provisioning of ancillary services from DER?*

Key aspects to be considered:

- Potential frameworks for orchestrating DER (OpEN Project)
- Additional OpEx and/or CapEx made by DNSPs to facilitate DER services
- Ability of aggregators to manage added complexity (e.g., operating envelopes)
- Liabilities in a more complex, inter-dependent environment
- Customer acceptance of DER orchestration framework and DER control approach
- Benefits from radical changes (e.g., DNSPs becoming sole aggregators)

Table 28. Summary of Stakeholder Feedback for Research Question 5.1

Discussion Points	Comments
Relevance to Australia	• All the stakeholders that discussed this area considered this research question highly relevant to Australia.
Key aspects missing or complementary	• What is the level of transparency necessary to help all parties in developing their business models? • How should distribution level ancillary services be considered? • How should the system operator incentivise business development opportunities for DER-related services? • How can DER be included in system level markets so there is incentive by the operator? System operator (AEMO) should incorporate DER management as a critical function and become a core part of their business. • How to encourage adequate knowledge sharing across different institutions such that existing knowledge can be re-used in other projects. • How to properly use the many tools developed in projects? Often, they are made and then not us used or supported, they need to be used or prioritised. • The system operator will not be able to manage all the way down to LV level and will need help in managing DER. DNSPs would like more independence on DER management. • Certain markets already exist (e.g., FCAS), do not need to create another one for DER only.

Can Australia deliver?	• Weak belief from the stakeholders that Australia (industry, research, etc.) is able to deliver/answer this question within the next 10 years. Currently, there is not enough financial incentive for the market operators to include DER properly.

Research Question 5.2

***Q5.2** What are the necessary considerations of establishing a distribution-level market (for energy and services)?*

Key aspects to be considered:

- Extent of the potential benefits for Australia
- Extent to which local DER can provide services for DNSPs
- Extent of liquidity (volume of DER services) needed to make a market viable
- Role of network augmentation and other conventional approaches
- Role of the Distribution Market Operator (DNSP/AEMO/third party)
- Customer acceptance of a new market

Table 29. Summary of Stakeholder Feedback for Research Question 5.2

Discussion Points	Comments
Relevance to Australia	• All the stakeholders that discussed this area considered this research question highly relevant to Australia.
Key aspects missing or complementary	• How should the interactions and interdependence be catered for between the distribution market and system market? There may be conflicts. • How to future proof given the everchanging mix of technologies, standards and penetrations? • How to value the services provided by DER?
Can Australia deliver?	• Moderate belief from the stakeholders that Australia (industry, research, etc.) is able to deliver/answer this question within the next 10 years. This is because of the regulatory challenges faced by DNSPs and AEMO to manage this market. First, a DER orchestration framework needs to be defined. Once that is done, regulation/rules need to be adapted accordingly. All of this can take many years.

Appendix B – Research Question Change Log

Appendix B contains the evolution of all the research questions (i.e., original research questions, first refinement, and the second refinement). The section that follows presents the original questions identified by CSIRO along with the changes that took place.

Original Research Questions identified by CSIRO

The list below (a-h) are the original questions from CSIRO in black text. The red text under each original research question describes the changes made and indicates the new numbered item the original question is linked to.

a) Which control strategy works best with large deployments of DER considering the heterogenous local controls of DER and various existing DSO/TSO control schemes?
Question was refined and broken down into questions **1.1-1.3.**

b) How to evaluate the cost/benefit ratios of various control strategies?
Question was refined and broken down into questions **1.1-1.3.**

c) How much communications and monitoring is needed at various levels of DER deployment to ensure adequate control of the power system? It is unlikely that full communications will be possible or even necessary to hundreds of millions of DER devices.
Question was refined and became question **2.1.**

d) Which ancillary services should DER provide? (Above are only some examples) How can we audit the effective delivery of such services?
Question was refined and became question **3.1.**

e) What is the amount of ancillary services needed by from DER? (Should only a certain number of DER be required to provide these services or do all DER need to provide them?)
Question was refined and was embedded into questions **3.1** and **4.2.**

f) What are appropriate metering, monitoring and auditing approaches for integrating DER into the services market?
Question was refined and was embedded into questions **0.1** and **3.1.**

g) How can models be develop for ensembles of DERs that can be used by system planners that give appropriate response characteristics for a variety of grid conditions?
Question was refined and became question **4.1.**

h) What are the future responsibilities of TSOs and DSOs and how are those responsibilities regulated at the DSO/TSO interface where both operators rely on each other?
Question was refined and broken down into questions **5.1** and **5.2.**

First Refinement of the Research Questions (used in the Stakeholder Engagement Sessions)

The following are the refined research questions (first refinement) that were presented during stakeholder engagement sessions. The refined questions (in black text) are grouped into the respective Area and numbered accordingly. The red text under each refined research question describe the changes made following the stakeholder meetings to form the new research questions (second refinement), which is presented in the last part of Appendix B.

(Area 0) DER Visibility for Whole-System Operations

0.1 What data flows (DER specs, measurements, forecasts, etc.) are needed to ensure AEMO has enough DER/net demand visibility to adequately operate a DER-rich system in different time

scales (mins to hours)?
Question remains unchanged but was refined in terms of the key aspects.

(Area 1) Control Architecture of DER

1.1 For each of the potential technical frameworks for orchestrating DER in Australia (e.g., based on the OpEN Project), what is the most appropriate DER control approach to deal with the expected technological diversity and ubiquity of DER?
Question remains unchanged but was refined in terms of the key aspects.

1.2 For each DER control approach, what is the most adequate decision-making algorithm (solution method)?
Question remains unchanged but was refined in terms of the key aspects.

1.3 To what extent can DER standards alone (no DER orchestration and no markets) extract valuable services for AEMO (e.g., response to frequency changes) while ensuring distribution network integrity?
Question was refined and formed into a revised version of **1.3** (second refinement) and was also refined in terms of the key aspects.

(Area 2) Communication Requirements for Monitoring and Control of DER

2.1 For each of the potential technical frameworks for orchestrating DER and the corresponding decision-making algorithms, what are the minimum communication and control requirements?
Question was refined and formed into a revised version of **2.1** (second refinement) and was also refined in terms of the key aspects.

(Area 3) Ancillary Services Provided by DER

3.1 What are the most reliable/available/effective ancillary services that can be delivered by DER considering the expected technological diversity and ubiquity of DER?
Question was refined and formed into a revised version of **3.1** (second refinement) and was also refined in terms of the key aspects.

(Area 4) Influence of DER on System-Level Planning

4.1 What are the minimum requirements for a DER-rich distribution network equivalent model to be adequate for its use in system planning studies?
Question remains unchanged but was refined in terms of the key aspects.

4.2 What is the minimum availability of ancillary services from DER at strategic points in the system throughout the year and across multiple years?
Question was refined and formed into a revised version of **4.2** (second refinement) and was also refined in terms of the key aspects.

(Area 5) Overcoming Institutional Challenges

5.1 What are the necessary organisational and regulatory changes to enable the provisioning of ancillary services from DER?
Question remains unchanged but was refined in terms of the key aspects.

5.2 What are the necessary considerations of establishing a distribution-level market (for energy and services)?
Question remains unchanged but was refined in terms of the key aspects.

Second Refinement of the Research Questions (included in the Draft Research Plan)

This section presents the set of research questions from the second refinement (i.e., following the stakeholder meetings).

(Area 0) DER Visibility for Whole-System Operations

0.1 What data flows (DER specs, measurements, forecasts, etc.) are needed to ensure AEMO has enough DER/net demand visibility to adequately operate a DER-rich system in different time scales (mins to hours)?

(Area 1) Control Architecture of DER

1.1 For each of the potential technical frameworks for orchestrating DER in Australia (e.g., based on the OpEN Project), what is the most cost-effective DER control approach to deal with the expected technological diversity and ubiquity of DER?
1.2 For each DER control approach, what is the most adequate decision-making algorithm (solution method)?
1.3 What is the role of DER standards in concert with the future orchestration of DER?

(Area 2) Communication Requirements for Monitoring and Control of DER

2.1 For each of the potential technical frameworks for orchestrating DER and the corresponding decision-making algorithms, what is the most cost-effective communication and control infrastructure?

(Area 3) Ancillary Services Provided by DER

3.1 What are the most cost-effective ancillary services that can be delivered by DER considering the expected technological diversity and ubiquity of DER?

(Area 4) Influence of DER on System-Level Planning

4.1 What are the minimum requirements for a DER-rich distribution network equivalent model to be adequate for its use in system planning studies?
4.2 What is the minimum availability of ancillary services from DER at strategic points in the system throughout the year and across multiple years?

(Area 5) Overcoming Institutional Challenges

5.1 What are the necessary organisational and regulatory changes to enable the provisioning of ancillary services from DER?
5.2 What are the necessary considerations of establishing a distribution-level market (for energy and services)?

Appendix C – Australian Stakeholder Engagement

Table 30 presents the list of participants in the Australian stakeholder engagement sessions held from Thursday 10th to Tuesday 15th June 2021.

Table 30. List of Participants – Australian Stakeholder Engagement Sessions

Name	Affiliation	Position
Greg Abramowitz	AGL	Manager Market Development
Alan Reid	Reposit Power	Acting General Manager
Yogendra Vashishtha	EA Technology	Head of Future Networks
Kyriacos Petrou	ENEA	Senior Consultant
Geoff James	Pilbara Solar	Director of Technology
Josef Tadich	Tesla Energy	Senior Manager, Sales Engineering
Phil Blythe	GreenSync	Managing Director
Olav Krause	GridQube	CTO
Andres Molnar	Indra Australia	Energy Solutions Manager Australia
Martin Hablutzel	Siemens Australia	Head of Strategy
Andrew Mears	SwitchDin	CEO
Tom Langstaff	AusNet Services	Networks Planning Manager
John Theunissen	AusNet Services	Manager DER Integration
Peter Wong	Eagles Engineering Consultants Pty Ltd	Director and Principal Consultant
Christina Green	Energy Queensland	Manager Strategic Advice and Modelling
Scott Lancaster	Powercor	Senior Regulatory Analyst
Adeel Rana	TasNetworks	Future Networks Team Leader
Reza Razzaghi	Monash University	Lecturer
Gregor Verbic	University of Sydney	Associate Professor
Naomi Stringer	UNSW	Researcher
Danielle Alexander	UTS	Research Principal - Institute for Sustainable Futures
Chris Cormack	AEMO	Team Leader, Market Insights
Danny Tantri	Evoenergy	Network Planning Engineer
Chandika Dassanayake	Evoenergy	Asset Engineer
Ross Goggin	Evoenergy	Principal Electrical Engineer
Saad Akbar	Evoenergy	Principal Engineer Future Networks
Craig Chambers	ARENA	Managing Director
Liam Henderson	City of Melbourne	Energy Innovation Lead
Pierre Lelong	ENEA	Principal
Ryan Wavish	Simply Energy	General Manager
David Edwards	Horizon Power	Digital Strategy & Innovation Manager

Appendix D – International Stakeholder Engagement

Table 31 presents the list of participants in the international stakeholder engagement sessions held from Monday 26th to Friday 30th July 2021.

Table 31. List of Participants – International Stakeholder Engagement Sessions

Name	Affiliation	Position	Country
Jason Taylor	EPRI	Principal Project Manager	USA
Mark McGranaghan	EPRI	VP, Distribution and Utilization	USA
Ben Kroposki	NREL	Director - Power Systems Engineering Center	USA
Barry Mather	NREL	Senior Electrical Engineer	USA
Esther Dudek	EA Technology	Senior Consultant	UK
Christos Kaloudas	ENWL	DSO Modelling & Forecasting Lead Manager	UK
Gareth Taylor	Brunel University	Professor	UK
Gianluigi Migliavacca	Ricerca sul Sistema Energetico	Project Manager	Italy
Fabrizio Pilo	Cagliari University	Professor	Italy
Andrew Keane	University College Dublin	Professor	Ireland
Ning Zhang	Tsinghua University	Associate Professor	China

Appendix E – Australian Stakeholder Workshop

Table 32 presents the list of participants in the Australian stakeholder workshop held on Tuesday 17th August 2021.

Table 33 and Table 34 present a summary of the feedback associated with the research questions (outputs, priority, timeline) and the potential risks, respectively.

The comments presented in this section are based on the notes taken by the project team of The University of Melbourne. As such, there may be limitations to the interpretation of what was captured during the stakeholder sessions.

Table 32. List of Participants – Australian Stakeholder Workshop

Name	Affiliation	Position
Greg Abramowitz	AGL	Manager Market Development
Yogendra Vashishtha	EA Technology	Head of Future Networks
Josef Tadich	Tesla Energy	Senior Manager, Sales Engineering
Andrew Mears	SwitchDin	CEO
Peter Wong	Eagles Engineering Consultants Pty Ltd	Director and Principal Consultant
Adeel Rana	TasNetworks	Future Networks Team Leader
Reza Razzaghi	Monash University	Lecturer
Gregor Verbic	University of Sydney	Associate Professor
Danielle Alexander	UTS	Research Principal - Institute for Sustainable Futures
Liam Henderson	City of Melbourne	Energy Innovation Lead
Natalia Kostecki	AEMO	Principal Policy and Market Development Analyst
Gary Eisner	AEMO	Regulation Analyst
Jason Hart	AEMO	Senior Analyst

Table 33. Summary of Feedback Associated with the Research Questions – Australian Stakeholder Workshop*

Research Question	Key Outputs	Priority (Original)	Timeline for Research (Original)	Timeline for Adoption / BAU Implementation (Original)	Further Comments Provided by Stakeholders
RQ 0.1	**Agree**	**Very High** (Very High)	**4** (5)	**1.5** (2)	• Customer aspects (privacy, data ownership, cybersecurity, etc.) should also be considered. • How does this build on work that is already happening/have happened? • Can research and implementation overlap? • For outputs that consist of methods, how can we be sure that these methods will be accepted/adopted by industry? This is critical or, otherwise, the work will not be used. • Does this mean visibility for AEMO or other stakeholders such as DNSPs? • This needs to consider the market structure: aggregators most interested in behind the meter visibility, whereas, DNSPs may only be interested at net demand visibility.
RQ 1.1	**Agree**	**High** (Very High)	**4** (5)	**1.5** (2)	• What is the required level of customer engagement to make any model successful? • The evolution of markets and regulations will also have an impact on the chosen DER control approach. • There is a need to come to an agreement on the potential framework before spending time on a particular framework. • Longer-term research activities in this space may become out of date as businesses move quickly to implement and standardise solutions. This will likely be 'practically decided' before the research is finished. • It is important to consider equity in concert with efficiency.
RQ 1.2	**Agree**	**High** (Very High)	**4** (5)	**1.5** (2)	• Not clear why this subject would be the subject of public research? Would a number of these functions/optimisations/algorithms not be a competitive market development? I understand the need for network optimisation to be public, but is the assumption here that networks control DER? Wouldn't agree with that premise. • The decision making needs to allow for public consultation. • It is suggested that this question should be left to the market. Particularly, which strategies are allowed under different structures (and if any are blocked) is a key question. • It is a bit confusing when the adoption of outputs is quicker than some of the outputs, i.e. 2 years versus 4 years. This needs to be reconciled. • Many DER orchestration trials are already happening. The knowledge gained must be built upon when answering the research question.
RQ 1.3	**Neutral**	**Very High** (Medium)	**4** (5)	**5.5** (6)	• Alignment with manufacturers' development plans could be time consuming. • It's not clear what the question specifically means. Given that technical standards have been changed recently to provide network services with little consideration of impact on customer value, supportive of this being considered, but wouldn't support mandating frequency response from DER via technical standards, versus procuring those services in a competitive market (where consumers are rewarded). • I think the use of "standards" could be expanded to include consensus on standard approaches, i.e., that aren't so restricted by the development timelines for standards • The list of outputs does not encompass all standards that would be useful and are imbalanced towards frequency; that is not the main game. • Need more short-term research that feeds into industry implementation.

					• DER participation in FCAS R6 trial has been going for over 2 years now and MASS review is underway. The how DER work and the benefits of DER are pretty clear.
RQ 2.1	**Neutral**	**Medium** (High)	**3.5** (5)	**3** (4)	• This will depend on the degree of centralisation and the extent to which participants/customers will be able to churn between providers. • The ship seems to have sailed on comms protocols. I propose that more focussed work on local implementation in the Australian market would be more valuable than a high-level assessment of alternatives. • There should be more focus on control requirements (how to do it well, securely, providing the right data to the right parties) than just cost. Once the requirements are clear, multiple solutions can arrive to meet them. • There should be more focus on control architecture. Communication infrastructure is going through its own evolution. • Adequacy and reliability are not the only factors. There are also security factors (and others) that could be included. • In general, I feel that it is difficult to comment on outputs without understand the corresponding outcomes and impacts that are expected/associated with them (i.e., what will this be used for?). • There are communication protocols in place already in industry. Therefore, a limited literature review would suffice here.
RQ 3.1	**Agree**	**High** (Very High)	**4** (5)	**1.5** (2)	• It is difficult to answer this question without first agreeing on the market structure. • Ancillary services will be provided based on commercial considerations, not just cost benefit analysis. • Markets already exist and there are a lot of experience out there. Therefore, not of major importance in my opinion. • Note that FERC's recommendation with respect to market participation was to allow DER to participate in existing markets (i.e., ancillary services) or build new participation model where the DER can’t meet the requirements to provide that service or where the DER is best suited to provide an alternative service to the existing. This is about the entry cost, so if you can get the DER in at low cost then the service that they provide will reflect that • Behavioural factors should also be considered here, e.g., customers are less familiar with this than providing kW, so there are social elements to the availability of these services. • Cost-effectiveness is not the only goal.
RQ 4.1	**Agree**	**Very High** (Very High)	**4** (5)	**1.5** (2)	• This concept is currently not firmly embedded in system planning. • The models should include optimisation techniques. • Application of different models based on either DER size or the voltage level of connection. • Getting visibility of exiting passive DER and future controllable DER is paramount • Year 2025 is a good goal date. • It is challenging if goal dates are not possible; all these need to start asap or they will be out of date. • I like the idea of an MVP (minimal viable product).
RQ 4.2	**Agree**	**High** (High)	**4** (5)	**3** (4)	• This can add new insights about actions taken but starts after the previous questions are all implemented • This topic is transmission focus. Do you think this can be expanded to include distribution network requirements?
RQ 5.1	**Strongly Agree**	**Very High** (High)	**3** (5)	**2** (4)	• It is critical that customer-centric questions are answered before or in-tandem with earlier work proposals. Thus, it needs to happen as soon as possible as it has higher priority. • This should be fairly quick - keeping to principles rather than detailed information. This is going through industry right now, needs to be quicker. • Regulation needs to be settled first before we talk about DER control services. • Agree this is a fundamental question, propose adding outputs such as standardised communication of market signals for home-automation • Doing the regulatory due diligence first will help guide roles and responsibilities of relevant parties and determine whether proposed arrangements can be implemented under the existing framework or whether (and the extent to which) regulatory change will be required. This exercise contributes to transparency for stakeholders

					• An appropriate consumer protections framework for DER participation in markets/service, and encouraging DNSP's and AEMO to support their participation, could make or break DER participation in ancillary services markets. I propose that we know enough already to be able to significantly shorten the research time, and implementation time should also be considerably reduced. • Encourage you to review the institutional barriers identified by iGrid, which go well beyond this scope. • Regulation needs to ensure that distribution networks are incentivised to build the enabling capability for DER. • This is probably the most fundamental question because the technical solutions depend on it.
RQ 5.2	**Agree**	**Very High** (Medium)	**3.5** (5)	**5** (6)	• This question is also fundamental, like the previous one. It should be given the highest priority. • It's not just customer engagement - it is also listening to their perspective and using this to design. • This needs to be much quicker here - as the industry is moving through this right now. • This is foundational research; it should be happening now. • There hasn't been much focus on distribution-level market. It would be good to research on this topic. • I feel like the focus on engaging consumers here might be misplaced - if there is value and service provision doesn't impact amenity, then I believe that the competitive market could manage the messaging and consumer participation. This question feels more relevant for markets where there are vertically integrated monopoly utilities, where consumer engagement is trickier. A healthy, competitive aggregation market in Australia has largely solved the consumer engagement piece, provided there is value to share with consumers. • How about flexibility markets instead? • This is a policy question and must be answered first to determine the detailed design of the market arrangements, otherwise it will either develop organically or outside of market arrangements.

** The columns 'Key Outputs', 'Priority', 'Timeline for Research' and 'Timeline for Adoption / BAU Implementation' are produced based on the 'average' of all responses from stakeholders.*

Table 34. Summary of Feedback Associated with Risks – Australian Stakeholder Workshop

Area	Risks	Mitigation Strategies
Area 0	• General risk around cybersecurity, and the fact that we're proposing more rapid connection, storage, data sharing from billions of connected devices with no clear idea about how to keep the device or its data secure (or the grid secure).	-
Area 1	• Control, interoperability, and cyber security are matters that must be considered and revisited at each design stage (from defining high level principles down to the detailed design aspects). Otherwise, there is the risk of designing out options. • There is a risk that the control architecture may pushes the customer out. In all cases, industry should be helping the customer to achieve what they want and providing feedback on costs of different choices. It should always be customers choosing how to use their own devices and industry / utilities helping them do that. • There is a risk of low customer adoption. • There is a risk that existing market players seek to duplicate the transmission-level architectures in a DER market. • There is a risk associated with the level of control that customers are ready/willing to give away. • There is a risk that technical standards or mandated control architectures stifle the competitive market for DER services.	• A holistic approach must be considered for DER control architecture design. • Customer-centric control architecture design.
Area 2	• Inconsistencies in smart meter rollout can be a risk.	-
Area 3	• It’s important to have at least a high-level idea or set of principles for DER participation with respect to ancillary services, as this will influence what market models are built to enable access by DER and whether the services will be the same as existing or whether different services need to be designed for. • Not having enough incentive for customers to provide these services. • Customers don't see value in VPPs single systems can't do enough. • Slow uptake of DER. there is not enough responsive DER in the market to provide services.	-
Area 4	-	-
Area 5	• It is a risk that there is a perceived reliance on a combination of customer education and goodwill to enable DER participation in ancillary services markets rather than the expectation that customers be rewarded for their participation. • Absence of clear direction may result in market participants and states making their own choices that do not lead to desirable results.	-
General	• The biggest risk to all areas is that the research will be irrelevant before it has finished as all of this will have been implemented already. The market would benefit from more granular research on DER 2.0 or post implementation improvements to systems (e.g., role of EVs, how is P2P, new markets...). • I agree with the point above. I suggest ancillary service research looks at what new services DER can provide rather than how it can fit into existing services.	-

Appendix F – Past and Ongoing Australian Activities

Legend:

Y = Project/activity is valid for the area or DER technology
“blank” = Project/activity not valid for the area or DER technology
PV = Rooftop photovoltaic systems
BESS = Small-scale battery energy storage systems
Others = It can be any other DER technology (rather than the highlighted ones), or DER technologies in general (not specified)

Table 35. Past and Ongoing Australian Activities

Project/Activity Name	DER Technologies Involved					Research Areas Mapping				
	PV	BESS	EV	DR	Others	Area 1	Area 2	Area 3	Area 4	Area 5
Addressing Barriers to Efficient Renewable Integration	Y	Y					Y	Y		
Advanced Planning of PV-Rich Distribution Networks Study	Y	Y							Y	
Advanced VPP Grid Integration		Y				Y	Y	Y		
AEMO Virtual Power Plant Demonstrations	Y	Y		Y				Y		Y
Affordable Heating and Cooling Innovation Hub (iHub)				Y				Y		
AGL Demand Response				Y				Y		
AGL Electric Vehicle Orchestration Trial			Y			Y	Y	Y		Y
AGL Virtual Power Plant		Y						Y		
AGL Virtual Trial of Peer-to-Peer Energy Trading		Y		Y	Y	Y	Y			
Allume Rooftop Solar Salvation Army Pilot Demonstration	Y							Y		
Amendment of the Market Ancillary Service Specification (MASS) – DER and General consultation					Y			Y		
Analysis of Variations in Instantaneous Weather Effects	Y							Y		
Assessing Distributed Energy Resources Integration Expenditure					Y				Y	
Bright Thinkers Power Station	Y								Y	
Charge Together Phase 2			Y					Y		
Chargefox Electric Vehicle Charging Network Project			Y						Y	Y

Climate-Based PV Performance and Reliability	Y						Y		Y	Y
Community Models for Deploying and Operating DER	Y	Y								Y
Consumer Energy Systems Providing Cost-Effective Grid Support	Y	Y				Y	Y			
Decentralised Energy Exchange (deX)	Y	Y		Y				Y	Y	Y
Decentralised Energy Exchange (deX) Program					Y		Y	Y		Y
DEIP Access, pricing and incentive arrangements for distributed energy resources					Y					Y
DEIP Dynamic Operating Envelopes Workstream					Y	Y	Y	Y		Y
DEIP Electric Vehicle Grid Integration Workstream			Y			Y	Y	Y		Y
DEIP Standards, Data and Interoperability Working Group	Y	Y	Y	Y		Y	Y			Y
Demonstration of Three Dynamic Grid-Side Technologies					Y	Y	Y			
DER 2.0: Customer Focused Design for DER Participation		Y				Y				Y
DER behaviour during disturbances	Y	Y			Y				Y	
DER Enablement Project (Phase 1)										
DER Integration and Automation Project	Y	Y				Y		Y		Y
DER integration and maintaining power system security					Y				Y	
DER Visibility and Monitoring Best Practice Guide					Y		Y			Y
Distributed Energy Market										Y
Distributed Energy Resources Hosting Capacity Study					Y				Y	
Dynamic Limits DER Feasibility Study					Y	Y	Y	Y		Y
Electricity Network Transformation Roadmap					Y	Y	Y	Y	Y	Y
Enel X Demand Response Project						Y	Y	Y		
EnergyAustralia Demand Response Program							Y	Y		
EV Integration									Y	Y
evolve DER Project						Y	Y	Y		Y
Flow Power Energy Under Control Demand Response						Y	Y	Y		
Household Battery Network Impact Assessment									Y	

Increasing the Uptake of Solar PV in Strata Residential Developments							Y			
Increasing Visibility of Distribution Networks									Y	
Indra Monash Smart City	Y	Y	Y	Y		Y	Y			
Intelligent Storage for Australia's Grid		Y				Y	Y	Y		
Intercast and Forge Demand Response				Y				Y		
Investigating Local Network Charges and Local Electricity Trading					Y					Y
Jemena Dynamic Electric Vehicle Charging Trial			Y			Y	Y		Y	
Mapping Network Opportunities for Renewable Energy					Y				Y	
Mapping of Low-Voltage Networks					Y				Y	
Medium-Scale Solar on Industrial Rooftops	Y								Y	Y
Monash University and ClimateWorks Low Carbon Study			Y							Y
My Energy Marketplace					Y		Y			
Narara Ecovillage Smart Grid	Y	Y		Y		Y	Y			Y
National Conection Guidelines					Y		Y			
National Low-Voltage Feeder Taxonomy Study					Y				Y	
Networks Renewed	Y	Y				Y	Y	Y		Y
Open Energy Networks Project					Y	Y		Y		Y
Optimal DER Scheduling for Frequency Stability					Y	Y		Y		Y
Origin Energy Electric Vehicles Smart Charging Trial			Y			Y	Y			
Pathways to Deep Decarbonisation in 2050										Y
Peak Demand Reduction Using Solar and Storage		Y				Y				Y
Pooled Energy Demonstration Project				Y			Y	Y		
Post 2025 Electricity Market Design	Y	Y	Y	Y	Y			Y		Y
Power System Data Communication Standard					Y		Y			
Power system model development	Y				Y				Y	
Powershop Australia Demand Response Program				Y			Y	Y		
Pricing and Integration of Distributed Energy Resources					Y					

Project MATCH					Y				Y	
Project SHIELD					Y		Y			
Realising Electric Vehicle-to-Grid Services			Y					Y		
REALM: Renewable Energy and Load Management	Y	Y		Y	Y			Y		Y
Renewable Energy and Load Management Phase 1	Y	Y		Y	Y			Y		
Review of the regulatory framework for metering services					Y					Y
Rheem Active Hot Water Control				Y				Y		
SA Power Networks Flexible Exports for Solar PV Trial	Y					Y	Y			Y
SA Strategic Regional Electric Vehicle Adoption Program										
Simply Energy Virtual Power Plant (VPP)	Y	Y				Y	Y	Y		Y
Smart Grids Innovation Challenge		Y			Y	Y	Y	Y	Y	
Social Licence for Control of Distributed Energy Resources					Y					
Solar and Storage Trial at Alkimos Beach Residential Development		Y							Y	
Solar Enablement Initiative					Y		Y			
Technology Collaboration Program for Demand Side Management				Y		Y	Y			
Tesla Virtual Power Plant	Y	Y				Y	Y	Y		Y
Trialling a New Residential Solar PV and Battery Model						Y	Y			Y
United Energy Distribution Demand Response				Y		Y	Y	Y	Y	
UNSW Addressing Barriers to Efficient Renewable Integration	Y	Y						Y	Y	
Victorian Distributed Energy Resources Marketplace Trial	Y	Y				Y	Y	Y		Y
Virtual Power Plant (VPP) Demonstrations		Y			Y		Y	Y		Y
Virtual Power Station 2						Y	Y			Y
Zen Ecosystems Demand Response				Y			Y	Y		

Appendix G – Key International Activities

Legend:

Y = Project/activity is valid for the area or DER technology
“blank” = Project/activity not valid for the area or DER technology
PV = Rooftop photovoltaic systems
BESS = Small-scale battery energy storage systems
Others = It can be any other DER technology (rather than the highlighted ones), or DER technologies in general (not specified)

Table 36. Past and Ongoing International Activities

Project/Activity Name (Countries Involved)	DER Technologies Involved					Research Areas Mapping				
	PV	BESS	EV	DR	Others	Area 1	Area 2	Area 3	Area 4	Area 5
Active Consumers Project (Slovenia)	Y			Y				Y		
Callia Project (Austria, Belgium, Germany, Turkey)	Y	Y		Y		Y	Y	Y		
CoordiNet Project (Austria, Belgium, Czechia, Germany, Greece, Italy, Netherlands, Spain, Sweden)					Y			Y		
Electric Access System Enhancement Project (United States of America)	Y	Y				Y	Y	Y		
Electric Nation Vehicle to Grid (United Kingdom)			Y	Y				Y		Y
Electricity Flexibility and Forecasting System – EFFS (United Kingdom)		Y		Y						Y
Energy Control for Household Optimisation – ECHO (United Kingdom)				Y			Y		Y	
European Research Project – EASY-RES (Germany, Greece, Netherlands, Slovenia, Spain, United Kingdom)	Y	Y	Y	Y		Y	Y	Y		Y

Flexible Residential Energy Efficiency Demand Optimisation and Management – FREEDOM (United Kingdom)				Y				Y		Y
FLEXIGRID Project (Belgium, Croatia, France, Greece, Italy, Spain)					Y	Y	Y			
Fusion (United Kingdom)					Y					Y
FutureFlow Project (Austria, Belgium, France, Germany, Hungary, Romania, Serbia, Slovenia)	Y	Y		Y				Y		
INTERPLAN Project (Austria, Cyprus, Germany, Italy, Poland)					Y				Y	
INTERRFACE Project (Belgium, Bulgaria, Cyprus, Estonia, Finland, Germany, Greece, Hungary, Italy, Latvia, Luxembourg, Portugal, Romania, Serbia, Slovenia, Spain)					Y	Y		Y		
Network Optimized Distributed Energy System – NODES (United States of America)	Y		Y	Y	Y	Y		Y	Y	
PGE - EPIC 2.02 – Distributed Energy Resource Management System (United States of America)	Y	Y				Y	Y			Y
PGE - EPIC Project #1.24 - Demonstrate Demand-Side Management (DSM) for Transmission and Distribution (T&D) Cost Reduction (United States of America)				Y			Y	Y		
PGE - EPIC Project 1.01 – Energy Storage End Uses, Energy Storage for Market Operations (United States of America)		Y								Y

PGE - EPIC Project 1.02 – Demonstrate Use of Distributed Energy Storage for Transmission and Distribution Cost Reduction (United States of America)				Y	Y		Y	Y		
SDG&E - EPIC-1, Project 4 Demonstration of Grid Support Functions of Distributed Energy Resources (DER) - Module 1, Pre-Commercial Demonstration and Value Assessment (United States of America)	Y	Y				Y	Y	Y		
SDG&E - EPIC-1, Project 4 Demonstration of Grid Support Functions of Distributed Energy Resources (DER) - Module 2, Pre-Commercial Demonstration of Communication Standards for DER (United States of America)		Y					Y			
SDG&E - EPIC-2, Project 5 Integration of Customer Systems into Electric Utility Infrastructure (United States of America)	Y				Y	Y	Y			
Smart Grid Vendee (France)	Y			Y	Y	Y	Y	Y		
SmartNet Project (Austria, Belgium, Denmark, Finland, Italy, Norway, Spain, United Kingdom)					Y	Y	Y	Y	Y	Y
Upgrid (France, Norway, Poland, Portugal, Spain, Sweden, United Kingdom)					Y		Y			Y