RACE for 2030
RELIABLE
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N3 Opportunity Assessment

Local Distributed Energy Resource Network Solutions

Final Report

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What is RACE for 2030?

RACE for 2030 CRC is a 10-year co-operative research centre with AUD350 million of resources to fund research towards a reliable, affordable and clean energy future. racefor2030.com.au

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EXECUTIVE SUMMARY

Background

In 2023, over 3.36 million photovoltaic systems have already been installed across Australia, with a combined capacity of over 29.7 gigawatts. Future energy systems are becoming more decentralised, and many traditional electricity users are no longer just power consumers, they are prosumers. This transition implies that conventional electricity users will no longer just be buying power from the grid—they will also sell power, either to the grid, their neighbours or their retailer. The backbone of such a transition has been energy storage technologies, in particular batteries. As prices of batteries come down, the number of solar households with batteries will increase. Using batteries will offer customers greater choices and flexibility in how they consume the energy they generate and how they potentially export their power to others.

At the same time, existing distribution networks of the grid are experiencing severe problems due to the high penetration of distributed renewable energy sources. These challenges can be overcome through the use of novel power system models such as microgrids, smart-grid technologies, and innovative business and ownership models. This opportunity assessment aimed to identify the knowledge gaps in relation to the growth of renewable energy in local distribution networks that require attention from the research community.

Consumers and regulatory frameworks

Understanding social and legal aspects in propagating microgrids, virtual power plants (VPPs) and community batteries is instrumental to the successful implementation of such technologies. Such options, either individually or collectively, cannot be successfully deployed without the active participation of stakeholders such as customers, prosumers, distribution system operators (DSOs), private investors, energy retailers, network companies and governments. This will include consideration of applicable law and regulation to identify unsolved questions, and, where applicable, a global comparison of policy and regulatory settings of successful examples of microgrid integration.

Business models

Accelerating the adoption of distributed energy system solutions requires innovative business models. Energy market deregulation brings in a host of challenges, many of which are yet to be addressed. Affordable IoT technologies facilitate new business model realisations such as VPPs, aggregators and blockchain-mediated transactions in the energy sector. Questions explored in this work package included the relationship between incumbent retailers and distribution networks, the most appropriate mix of ownership structures for microgrid assets and community batteries, financing models for development and operation, and how VPPs and microgrids can both be facilitated when they overlap.

Planning and design

Realising the best economic and social benefits from local distributed energy resource (DER) network solutions is heavily dependent on how well the state-of-the-art technology is integrated in the planning and design of new power systems. Some of the key questions investigated included identifying regions and areas most suitable for microgrids and VPPs with and without community batteries, finding ways to fuse new data technologies (such as machine learning and artificial intelligence (AI)) within novel power systems, understanding the capability limits of inverter-based generators, and maximising the benefits of existing grid network through the use of smart-grid technologies.

Demonstration and operation

The demonstration and operation of both embedded and isolated microgrids has been implemented in many countries. In Australia, net zero energy projects have been implemented by various universities and industry. However, rapid uptake of local DER solutions can only be promoted at a faster pace through innovative approaches applied on top of the current best practice. This report investigates the best practice that needs to be adopted in accelerating the growth of renewable energy to meet local consumer energy needs.

Methodology

During the projects scoping stage, the RACE for 2030 CRC contributed an initial 43 research questions to the opportunity assessments design. These questions were categorised and assigned to four work packages (Consumers and regulatory framework, Business models, Planning and design, Demonstration and operation) which delved deep and identified the most pertinent current research gaps. In each work package, researchers explored the relevant literature as well as industry reports. The literature review made use of a wide spectrum of reference materials, concentrating predominantly on industry technical reports and technical websites. This reflects the fast-moving nature of this domain, where the latest information is best obtained directly from practitioners and industry. The genre composition of the 256 references utilised in this opportunity assessment is provided in Figure 1 below.

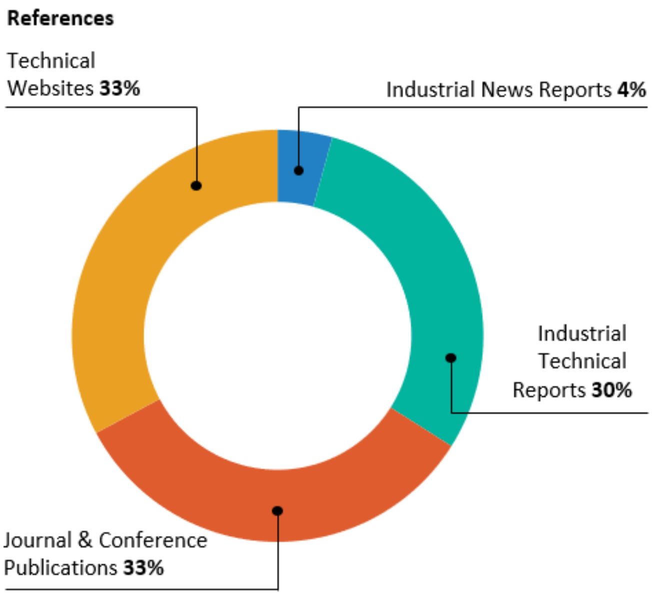


Figure 1. Composition of the references used during literature review

Research questions identified through the literature survey were consolidated and shortlisted to develop research opportunities and identify barriers and impacts. This consolidation of research questions considered feedback received from the project's industry reference group, which met periodically throughout the opportunity assessment. Through this consultative process, the research roadmap and priority projects were developed to address the most urgent research questions identified.

Results and discussion

The opportunity assessment produced a total of 72 key research questions (full list available in the Appendix) under the original four work packages. A brief summary of the four research areas (i.e. work packages) is given below.

Consumers and regulatory frameworks

Stakeholder engagement is essential to achieve an effective energy scheme. Research found that such a scheme cannot succeed without establishing a proper level of trust among the players. Information is lacking about the degree of trust among the energy community's key players. An empirical, research-based trust assessment should be conducted to examine and verify the current trust level and identify potential factors to enhance such faith.

Another important consideration is to initiate an analysis of consumers' responses to, and interest in, participating in various community energy configurations, such as community batteries. Establishing an associated database can address the lack of information symmetry among various types of users, increasing participation in local energy DER programs. Regulatory and governance barriers must also be identified and properly handled to implement efficient community energy configurations.

Business models

Innovative business models are required to accelerate the adoption of distributed energy system solutions. Energy market deregulation brings a host of challenges, many of which are yet to be addressed. Service delivery at the grid-edge is an exciting topic as it should yield benefits to all stakeholders. That said, setting practical criteria, and identifying the individual or organisation best placed to deliver such services remains challenging. Also, establishing efficient mechanisms for the adoption of distributed energy system solutions can assist communities to get greater benefits from various offerings of distributed energy resources. A priority area of future research would be to devise methods that would support the establishment of such mechanisms through financial institutions.

There is widespread consensus that microgrids can play a critical role in efficiently integrating distributed energy resources, supplying local demands, and reducing reverse power-flow. Appropriate financial models need to be developed to implement the successful operation of DER.

Planning and design

A key to handling the ever-increasing penetration of distributed energy resources is employing a range of energy storage systems, such as batteries. The features and capabilities of each storage type should be adequately evaluated for their suitability to different applications. This requires identifying the critical performance indicators on which to base an accurate comparison between such systems at different time scales.

Grid integration of storage systems should best be done using smart power electronics interfaces. More efficient interfaces, with flexible configurations, are required for bidirectional power flow during the charging/discharging of energy storage systems of different sizes. These interfaces should also be equipped to handle interaction energy among different energy storage devices in large-scale utilisation scenarios and would support increased penetration levels of community batteries.

Australia has the highest per capita rate of residential rooftop solar installations; however, a lack of communication and coordination between solar inverters was identified as a major barrier to the further rise of such distributed generators. Implementing VPPs and microgrids can be an efficient method to address such hurdles. This research has identified some significant concerns to address prior to implementing microgrids and VPPs. Among them is establishing efficient control levels for the reliable operation of microgrids.

Additionally, a sensitivity analysis should be conducted to evaluate the impact of applying different levels of control and monitoring on the operation and capital requirements of microgrids. This is because commercial and industrial participants are expected to employ different monitoring and analytics from various manufacturers which may have differing operational and capital requirements. Correct operation scheduling of microgrids and VPPs depends on the forecasting and control schemes employed. Developing a selection guide for forecasting methods and control strategies would help in the selection of the most appropriate combination of strategies.

In addition to technical matters, energy market-related facilitations should be considered to ease the implementation of various business models, such as peer-to-peer (P2P), microgrid as a service (MaaS) and energy as a service (EaaS). Generally, community batteries and power banks are for energy arbitrage in Australia. It is found that the use of blockchain can be very efficient in fulfilling such models. The realisation mechanism of blockchain in the future energy market of Australia is yet to be evaluated.

Demonstration and operation

Smart metering and demand-side management are essential features of a smart grid, maximising penetration of renewable energy in distribution networks to avoid or delay highly expensive network augmentations. Smart metering systems can also increase the possibilities for more communities to access community batteries as a solution. Adequate development would be required to employ smart meters and demand-side management techniques to handle peak load within microgrids. Devising such mechanisms in collaboration with community batteries would be beneficial.

There is also a need to study possible methods for establishing trust-based, house-to-house energy interaction within microgrids. Such collaboration can be extended to utilising community battery systems within or at the microgrids. Integration and harnessing of electric vehicle storage require efficient methods of handling uncertainties with charging location and the security operation centre (SOC) of the vehicles.

Findings and recommendations

Research opportunities

The research roadmap begun development by exploring possible research opportunities under nine areas, identified as follows –

- Governance and regulation (RO1)
- Revenue streams (RO2)
- Ownership and access (RO3)
- Electric vehicles (RO4)
- Storage options (RO5)
- Advanced technologies (RO6)
- Consumer expectations (RO7)
- Microgrids in distribution networks (RO8)
- Balancing interests (RO9)

Research opportunities RO1 to RO9 are shown in Figure 2 below to reflect their broad interrelationships. Five of the nine overarching research opportunity areas cover non-technical aspects such as governance and regulation (RO1), revenue streams (RO2), ownership and access (RO3), consumer expectations (RO7) , and balancing interests (RO9). These aspects of research are commonly applicable to all the technological solutions covered in microgrids and VPPs (RO8), advanced technologies (RO6), energy storage (RO5) and electric vehicles (RO4).

As illustrated in Figure 2, microgrids and VPPs are central to the new power system concepts. Advanced technologies can make revolutionary changes to the performance, cost and benefit of these solutions. Energy storage is an integral component of future power systems. As such, knowledge of the capabilities and limitations of different available options is vital for reduction of system costs and improving performances. Finally, the anticipated spread of electric vehicles (EV) used in these power systems present both challenges and opportunities, and future research must consider their presence in these modern power systems.

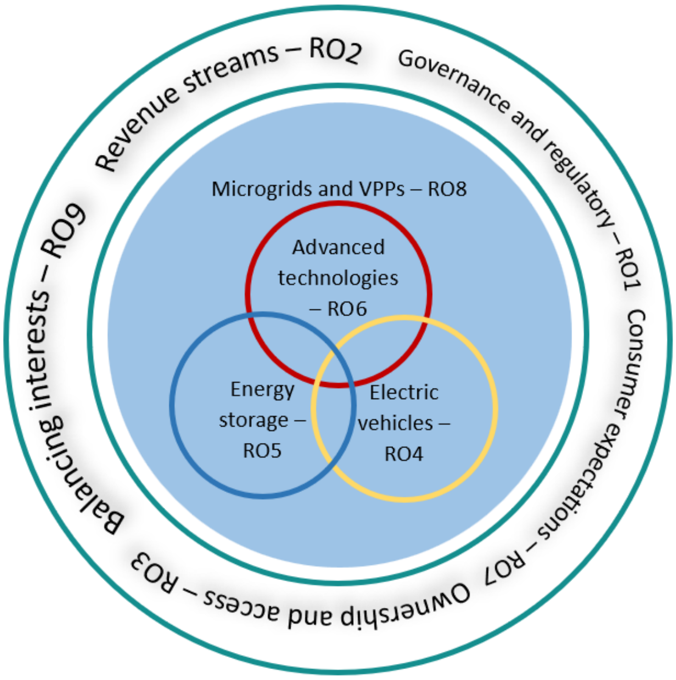


Figure 2. Interrelationship of research opportunities

Research questions

Consolidation of the opportunity assessments 72 key research questions (full list available in the Appendix) took place within the original four work packages of Consumers and regulatory framework, Business models, Planning and design, and Demonstration and operation. Research questions within these packages were then mapped against the nine research opportunities developed by the team as shown in Table 1 below. The mapping of research questions into research opportunities then informed the proposal of research concepts.

Table 1. Mapping of research questions into research opportunities (ROs)

	Research questions by work package (WP)			
Research opportunities	Consumer and regulatory framework (WP1)	Business models (WP2)	Planning and design (WP3)	Demonstration and operation (WP4)
Governance and regulation (RO1)	1.1, 1.2.1.4, 1.7, 1.8	2.3, 2.4, 2.5, 2.7, 2.8, 2.9, 2.10	3.11, 3.12, 3.17, 3.18, 3.19, 3.33, 3.34, 3.35, 3.36	
Revenue streams (RO2)		2.5, 2.9, 2.15	3.9, 3.11, 3.12, 3.13, 3.31, 3.32, 3.38, 3.40	4.2
Ownership and access (RO3)		2.4, 2.6, 2.8, 2.14, 2.15	3.13	4.2
Electric vehicles (RO4)				4.7, 4.8, 4.9
Storage options (RO5)	1.6, 1.9	2.2, 2.12	3.2, 3.3, 3.4, 3.23, 3.30	4.1
Advanced technologies (RO6)	1.3, 1.4, 1.6, 1.8	2.11,2.13	3.3, 3.6, 3.7, 3.10, 3.14, 3.22, 3.24, 3.25, 3.26, 3.27, 3.37	4.3, 4.4, 4.6
Consumer expectations (RO7)	1.1, 1.2, 1.3, 1.5	2.10, 2.14	3.8, 3.9, 3.36	
Microgrids in distribution networks (RO8)	1.5	2.1, 2.2, 2.13	3.5, 3.6, 3.7, 3.8, 3.15, 3.16, 3.20, 3.21, 3.22, 3.24, 3.25, 3.26, 3.28, 3.29, 3.31, 3.35, 3.37, 3.39, 3.41	4.4, 4.5, 4.6, 4.8
Balancing interests (RO9)	1.9	2.1, 2.11, 2.12	3.5, 3.15, 3.16, 3.19, 3.20, 3.23, 3.27	

Research concepts proposed within each of the nine research opportunities are outlined in Table 2. The concepts presented cover more than one research task as the final research projects will need to be practical and therefore should be treated as interrelated and cumulative.

Table 2. Research concepts developed from the N3 Opportunity Assessment: Local DER Network Solutions

#	Research Opportunity	Research Concept	Research Activity	Timeframe
1	Governance and regulation (RO1)	An assessment of the potential future regulatory framework for community batteries, microgrids and VPPs	1. A desktop assessment of the current regulatory frameworks in Australia 2. A comparative study with the international best cases 3. A mixture of in-depth, qualitative interviews and focus groups to examine the motivations, attitudes and values of various stakeholders 4. Cross-check the findings against the innovative ownership models introduced in other CRC research themes, such as N4 DSO & Beyond 5. Empirically examine institutional arrangements that could enhance trust and participation by the stakeholders.	N/A
2	Revenue streams (RO2)	Feasibility study for valuation of different revenue streams for community batteries, microgrids and VPPs	A techno-economic feasibility project to understand the theoretical revenues for different value streams under various regulatory and operating scenarios.	N/A
3		A virtual net metering market (interaction between VPP/DER aggregators and microgrids)	A virtual net metering market allows for the trading of energy credits between multiple entities, often using a third-party platform to facilitate transactions. This project aims to create a business model to understand interactions between microgrids and virtual power plants based on a virtual net metering market.	
4		EVs business model in islanded microgrid operation mode	This project aims to evaluate the possible ways of representing the behaviours of the EV owners/drivers as well as propose a proper business model and encourage EV owners to contribute to the reliability and stability of microgrids. Forecasting driver behaviour, and controlling the bi-directional charging/ discharging processes, are challenging.	N/A
5	Ownership and access (RO3)	A multi-stakeholder participatory approach for community energy systems development	1. Develop a framework for assessing the social fabric of the community 2. Develop a tool to identify the optimal business model based on learning from the social dynamics of the community 3. Develop a sand-boxing tool to assess the impact of various network capacity constraints and regulations on the community energy system's performance 4. Develop a multi-objective, design-operation optimisation framework for a system that satisfies the range of the community's needs, expectations and constraints	N/A

			5. Establish a community energy trial to test the accuracy, credibility, and reliability of the analyses of community energy benefits at normal operational conditions as well as during natural disasters.	
6	Electric vehicles (RO4)	Harnessing fluctuating EV storage	1. Build a temporal-spatial model of where and when people charge their EVs and use this to predict the available battery capacity for storage or generation 2. Derive techniques to maximise the available battery capacity of EVs 3. Propose methods to nudge desirable behaviour by EV owners to maximise the amount of EV storage available to the grid, VPPs and community batteries; this may include financial or other incentives, disincentives and regulatory levers.	2024-25
7		EV trial project	1. Work with charging providers and EV owners/users to provide real-world verification and calibration of the research models and proposals 2. The trial(s) will seek to understand four areas: a) How people charge their vehicles when there are incentives b) How well models of the system predict the EV charging behaviour compared to the data c) The extent to which live data on EV capacity is available from chargers or over-the-air telemetry d) Survey and interview data to gain insights into effective incentives for desirable behaviour and vehicle-to-grid (V2G) technology uptake.	2026-27
8	Storage options (RO5)	Storage technologies feasibility study for community storage	1. A desktop study project investigates the techno-economic feasibility of using other storage technologies, such as ultra-batteries and/or vanadium flow batteries, for community storage applications 2. Develop storage system dynamic models and simulations for different combinations of community battery services (value streams) and their associated lifecycle analysis 3. Design a long-term community battery trial embedding technical evaluations and proof-of-concepts of alternative storage technologies.	2024-27
9		Assessment of the energy storage capability of closed mines	1. Prepare a map of recently closed mines suitable for energy storage purposes by considering the geographical location close to load centres, proximity to transmission lines, height, area of the pits, etc. 2. Propose a method of ranking of closed mines for different large energy storage options such as pumped-hydro, hydrogen, compressed air and gravity battery 3. Estimate the energy storing potential of closed mines.	2026-28

10		Green hydrogen powered remote area microgrids	1. Survey the energy portfolio of remote communities 2. Assess the reduction of carbon emissions by replacing fossil fuels by green hydrogen 3. Compare the technological options suitable for electrolyser, fuel cells and storage 4. Trial the implementation of green hydrogen based remote area microgrids.	2028-31
11		Design of reconfigurable self-healing battery packs for central batteries	1. A desktop study of practical problems with large battery arrays 2. Design novel switching algorithms among cells and strings to achieve self-healing, adjustable voltage/current battery packs 3. Compare the electrical characteristics of different cell types and use electronic control to achieve replacement of batteries with different chemistry 4. Design battery energy management techniques considering battery degradation models.	2025-27
12	Advanced technologies (RO6)	Urban renewable energy zones (UREZ)	1. Develop algorithms, control systems and communication methods to transform existing distribution networks in urban areas to smart embedded microgrids with high penetration of photovoltaics (PVs), EVs and smart meters 2. Develop the roadmap of transition of urban distribution areas into embedded microgrids that are self-sufficient in energy needs 3. Investigate the social, business and regulatory transformations needed to realize urban renewable energy zones 4. Procure/develop 3D dataset of information for each building and urban precinct for case studies 5. Test the methodologies to assess and generate rooftop irradiance potential 6. Trial urban renewable energy zones with developed technologies, novel business models and social engagements.	2023-26
13		Synthetic inertia measurement/estimation for inverter-interfaced distributed generators	1. A broad study will be conducted to identify potential challenges with inertia estimation for different combinations of distributed generators under various operating and control schemes 2. Both software and hardware analysis and implementations will be fulfilled to reveal the most accurate methods for estimating inertia caused by inverter-interfaced generators 3. An accurate designing tool will be developed to facilitate the installation of renewable energy resources capable of providing a certain level of synthetic inertia.	2025-26

14		Context-aware network capacity assessment for DER deployment	1. Develop spatio-temporal gradient-based hybrid sensors for monitoring network capacity at the low voltage level 2. Develop a novel feature selection algorithm based on maximal relevance and minimal redundancy criterion from sensor-perceived data to predict the load of a network to host further DERs 3. Develop a self-supervised machine learning model for cooperative control of networked DERs to balance and optimise loads of microgrids.	2023-24
15		Robust prediction of solar energy generation by DER	1. Develop an automated cloud movement and a shadow sequence estimator system 2. Real-time analysis of cloud images to predict the time horizon over a geographical area 3. Quantify anomalies in existing weather models in alignment with the capacity, price and demand-supply models 4. Integrate the sequence estimator, image analyser and uncertainty quantifier into a comprehensive solar power forecasting software system for pilot testing and real-world deployment.	2026-28
16		Automated health assessment of DER in rural regions	1. IoT-enabled monitoring of performance, throughput, and usage patterns of DER 2. Estimate ageing-driven performance drifting of DER in rural areas where frequent repair is costly and time-consuming 3. Develop data-driven techniques for predicting the operating lifespan of DER and a context-aware recommendation system for their better health management.	2028-30
17		Ransomware prevention for DER	1. Assess vulnerabilities in DER pertinent to the financial aspect, data transmission channels and modes of communication in an urban region 2. Development of a consortium blockchain to ensure data integrity during peer-to-peer energy trading of DER produced power 3. Develop adaptive attack prevention for DER to protect the digital identity of prosumers 4. Develop a fault-tolerant policy to restore the functionality of the DER management system following an unprecedented cyber attack.	2029-31
18	Consumer expectations (RO7)	Customer trust and information transparency models (socio-techno-economic framework)	Research is necessary to fully comprehend the aspirations and expectations of customers, and to improve the level of trust between service providers and customers in the energy sector. The key to a successful and sustainable energy future is to place the interests of customers at the forefront and ensure that their needs are met.	N/A

19	Microgrids in distribution networks (RO8)	Analysis for cost-effective embedded and stand-alone microgrids	1. Technical and economic feasibility study for implementing grid-connected microgrids as well as stand-alone power systems to reduce costs for customers, including developing technology, planning, operating methods (pricing, incentives, soft and control) 2. Assess barriers to microgrids including regulatory, technical, financial and other; develop and prototype algorithms for forecasting and control of DER resources at grid edge and islanded microgrids 3. Pilot projects, develop business models, investment planning and operational tools to support decision making by networks and end users 4. Pilot and implement microgrids where cost effective to reduce costs for customers. Develop technology and planning and operation methods and algorithms 5. Provide innovative approach and technology for microgrids to realise swift frequency and voltage regulations in a reliable manner.	2023-26
20		Consistent microgrid design and operation framework	1. Survey the existing standards for interconnecting DER with the grid and microgrids 2. Establish a consistent framework for designing and operating microgrids in Australia, addressing requirements for grid-forming inverters and hydrogen storage systems 3. Facilitate knowledge sharing and experience exchange, enabling stakeholders to effectively tackle challenges and limitations and improve the accuracy and functionality of microgrid design and operation over time.	2026-27
21		Open-source decision-support tool for designing and operating microgrids	The existing microgrid decision-support tools focus on investment and operation decisions but do not support power flow analysis or represent the detailed model of network/feeder. Microgrid projects require a tool that combines optimal power flow in steady-state and dynamic domain, investment and operation stages, and social and environmental aspects. The project aims to develop such software tools, which can be built on top of the power flow tools using an open-access, high-level programming language.	2029-31
22		Power electronics dominated power system	This project aims to understand the operation of grid-forming resources under faults, both balanced and unbalanced. Additionally, the ability of the grid forming resources to energise transformers and the motor load is to be studied. Protection of power systems are heavily based on the detection of current. With increasing DER and inverter-based generation in power systems, existing protection methods need to be re-assessed and replaced wherever necessary.	2023-24

23		Innovative control architecture	Proper selection of control techniques and settings is essential to ensure microgrid stability, and performance requirements and standards should be considered. Flexibility in control architecture design is important to avoid complexity and instability. Researchers are exploring solutions such as droop control and grid-forming inverter-based DERs to address these challenges. The objective of this study is to enhance the control architecture of microgrids by incorporating negative sequence control strategies. The proposed approach could potentially contribute to the widespread application and functionality of renewable energy microgrids.	2027-28
24		Network and grid impact of VPPs	1. Network impact assessment: emulate the behaviour of VPP under different network conditions and comparing them to non-VPP cases 2. Dynamic local network operating envelopes: investigate the impact of dynamic local network operating envelopes for DER on the ability of VPPs to provide network and system services 3. Reliability analysis: Analyse the reliability of services provided by VPPs, and identify the factors that impact reliability.	2025-27
25		Virtual power plants and microgrids	Balance load through large scale batteries in a microgrid containing behind-the-meter rooftop PVs and batteries a) How can a microgrid operate under a VPP? b) How can each microgrid operate as a single entity in a VPP regime where the VPP controls a large geographical area? c) How can primary and secondary controllers be designed for networked microgrids and what is the function of the tertiary controller in this scheme? d) How can demand response and cyber security be embedded for stable and safe operation of the system?	2026-29
26	Balancing interests (RO9)	Optimal siting and sizing of microgrids and community batteries	1. A thorough study will be conducted to identify the most critical economic, social and technical factors influencing the best location for community batteries and various types of microgrids. 2. Conducting interactive surveys among different stakeholders will help determine the key sizing and siting factors. 3. An accurate decision-making tool will be developed to find the optimum location and scale of microgrids and community batteries.	N/A

Research recommendations and roadmap

As shown in Figure 2, the regulatory, ownership, social and business aspects covered in RO1, RO2, RO3, RO7 and RO9 overarch all technical aspects covered in RO4, RO5, RO6 and RO8. Therefore, it is recommended that all research projects have one or more technical aspects at the centre of focus yet integrate some or all of the non-technical aspects in each of these projects. The research opportunities outlined below and in Table 3 are proposed as a roadmap for research projects in the RACE for 2030 'Opportunity Assessment: Local DER Network Solutions'.

Research opportunities identified for use in the research roadmap

RO4. Electric vehicles and RO5. Energy storage — Concept numbers 6–11

RO6. Advanced technologies — Concept numbers 12–17

RO8. Microgrids and VPPs — Concept numbers 19–25

Priority research concepts to be developed

Within this research roadmap these research concepts have been identified as high priority for the research theme and the RACE for 2030 CRC.

1. **RO4. Electric vehicles and RO5. Energy Storage**
    a. Harnessing fluctuating EV storage (No. 6) combined with
    b. Storage technologies feasibility study for community storage application (No. 8)
2. **RO6. Advanced technologies**
    a. Urban Renewable Energy Zones (No. 12) combined with
    b. Context-aware network capacity assessment for DER deployment (No. 14)
3. **RO8. Microgrids and VPPs**
    a. Analysis for cost-effective embedded and stand-alone microgrids (No. 19) combined with
    b. Power electronics dominated power system (No. 22)

Table 3. Research roadmap for N3 Local DER Network Solutions Opportunity Assessment

Expected Start		RO4 Electric Vehicles and RO5 Energy Storage	RO6 Advanced Technologies	RO8 Microgrids and VPPs
Priority (2023-2024)		6. Harnessing fluctuating EV storage + 8. Storage technologies feasibility study for community storage application (3 years)	12. Urban Renewable Energy Zones + 14. Context-aware network capacity assessment for DER deployment (3 years)	19. Analysis for cost-effective embedded and stand-alone microgrids + 22. Power electronics dominated power system (3 years)
Mid term	2025	11. Design of reconfigurable self-healing battery packs for central batteries (2 years)	13. Synthetic inertia measurement/estimation for inverter-interfaced distributed generators (1 year)	24. Network and grid impacts of VPP (2 years)
	2026	7. EV Trial project (1 year) 9. Assessment of the energy storage capability of closed mines (2 years)	15. Robust prediction of solar energy generation by DER (2 years)	20. Consistent microgrid design and operation framework (1 year) 25. VPPs and microgrids (3 years)
	2027			23. Innovative control architecture (1 year)
	2028	10. Green hydrogen powered remote area microgrids (3 years)	16. Automated health assessment of DER in rural regions (2 years)	
Long term	2029		17. Ransomware prevention for DER (2 years)	21. Open-source decision support tool for designing and operating microgrids (2 years)
	2030			

The findings and outcomes from the research proposed in this roadmap will pave the way to transition the local distribution networks in Australia to host high percentage of DER while minimising the negative impacts of DER to the power systems. Furthermore, the holistic and inclusive approach of project formulation ensures the transition in technical solutions are equally facilitated in parallel by the necessary transformations in regulatory, business and social aspects. Thus, the projects will have wide-ranging positive impacts to all the relevant sectors during Australia's fast-paced journey towards net zero future.

CONTENTS

1. INTRODUCTION

1.1 Project scope

This project investigates local distributed energy resource network solutions, which is a Theme in RACE for 2030's Networks program, providing analysis to support the development of cost-effective embedded and islanded microgrids and investigating storage as a service, particularly for distributed community batteries.

Analysis to support the development of cost effective embedded and islanded microgrids aims to develop economic and technical options for supporting cost-effective adoption of islanded and embedded microgrids. This project investigation covers microgrids that operate autonomously or semi-autonomously from the main grid through to stand-alone microgrids (also known as stand-alone power systems — SAPS, and remote area power systems — RAPS). Consumer benefits and participation, and community engagement, are also central to this sub-theme.

Storage as a Service - distributed community batteries will analyse how, and in which contexts, community-scale batteries on the low and medium voltage network can deliver outcomes superior to both large, centralised batteries and small, household-scale batteries. The investigation covers the benefits of community batteries across all parts of the supply chain (low voltage network, medium voltage network and sub-transmission,) and their operation, as well as their interaction with the large-scale generation fleet. In this context, they provide potential benefits in areas such as voltage management and frequency support. Moreover, community storage interacts with both customers and other market participants through a range of regulatory constructs and business models. This sub-theme covers all of these interactions while positioning consumer interests and perspectives at its centre.

These research themes represent extensive areas of investigation. Consultation with stakeholders and the projects industry reference group produced a set of focused problems and recommended priority research concepts for future development.

1.2 Stakeholder engagement

The project was well represented by both CRC industry partners and a wider group of non-CRC partners who augmented the industry reference group. These are listed in Table 4. The research partners for the project were from Curtin University, UTS, RMIT, Griffith, Monash University and CSIRO. Stakeholders were engaged through three steering group (SG) meetings, which involved researchers and core CRC industry partners, as well as two industry reference group (IRG) meetings. Steering group meetings were held over 2022 as follows:

- **SG1** (April 14 2022) covered project scope, timelines and expected involvement
- **SG2** (May 26 2022) covered materials for the first IRG meeting, reviewed initial research findings, identified potential topics for inclusion in the research roadmap, and proposed research concepts to gauge partner interest
- **SG3** (July 21 2022) provided an update on progress and sharing the intended pathways for the first implementation project
- **SG4** (Oct 27) was combined with IRG Meeting 2 as the final partner meeting

Table 4. IRG Membership (*non-CRC industry partner)

AGL Energy Services	Australian Power Institute	Ausgrid	Ausnet Services*
AEMO*	Clean Cowra*	Climate-KIC	EV Energy*
eleXsys Energy*	Energy Consumers Australia	Horizon Power	NSW Department of Planning & Environment
Powerlink	SA Department of Energy and Mining	Sydney Water	Victoria Department of Environment, Land Water & Planning

Industry reference group meetings were held as follows:

IRG 1 (June 1 2022) discussed common scope and presented the IRG with a list of key questions around community batteries, microgrids and virtual power plants (VPPs), as well as integrated solutions for consideration in the research roadmap and to develop project proposals that have strong industry support.

IRG 2 (Oct 27 2022) provided an end-of-project summary and sought advice on the research roadmap and implementation projects.

1.3 Research methodology

During the projects scoping stage, the RACE for 2030 CRC contributed an initial forty-three research questions to the opportunity assessments design. These questions were categorised and assigned to four work packages (Consumers and regulatory framework, Business models, Planning and design, Demonstration and operation) which delved deep and identify the most pertinent current day research gaps that need further attention.

Work Package 1: Consumers and regulatory framework

Understanding social and legal aspects in propagating microgrids, VPPs and community batteries is instrumental to the successful implementation of such technologies. Such options, either individually or collectively, cannot be successfully deployed without the active participation of stakeholders such as customers, prosumers, distributed system operators (DSOs), private investors, energy retailers, network companies and governments. This will include consideration of applicable law and regulation to identify unsolved questions, and where applicable, a global comparison of policy and regulatory settings of successful examples of microgrid integration.

Work Package 2: Business models

Accelerating the adoption of distributed energy system solutions requires innovative business models. Energy market deregulation brings in a host of challenges, many of which are yet to be addressed. Affordable IoT technologies facilitate new business model realisations such as VPPs, aggregators and blockchain-mediated transactions in the energy sector. Questions explored in this work package included the relationship between incumbent retailers and distribution networks, the most appropriate mix of ownership structures for microgrid assets and community batteries, financing models for development and operation, and how VPPs and microgrids can both be facilitated when they overlap.

Work Package 3: Planning and design

Realising the best economic and social benefits from local distributed energy resource (DER) network solutions is heavily dependent on how well the state-of-the-art technology is integrated in the planning and design of new power systems. Some of the key questions investigated included which regions and areas are most suitable for microgrids, VPPs with and without community batteries, finding ways to fuse new data technologies such as machine-learning and AI within novel power systems, understanding the capability limits of inverter-based generators, and maximising the benefits of existing grid network through the use of smart-grid technologies.

Work Package 4: Demonstration and operation

Both embedded and isolated microgrids have been implemented in many countries. In Australia, net zero energy projects have been implemented by various universities and industry. However, rapid uptake of local DER solutions can only be promoted through innovative approaches applied on top of the current best practices. This report investigated the practices that need to be adopted to accelerate the growth of renewable energy to meet local consumer energy needs.

The literature review drew on a wide spectrum of reference materials, concentrating predominantly on industry technical reports and technical websites. This reflected the fast-moving nature of this domain, where the latest information is best obtained directly from practitioners and industry. Research questions identified through the literature review were consolidated and shortlisted to develop research opportunities and identify barriers and impacts. The consolidation of research questions considered feedback received from the project's industry reference group, which met periodically throughout the opportunity assessment. This consultative process identified the most impactful research questions to be addressed by the research roadmap and priority projects.

For each work package, researchers reviewed the relevant literature as well as industry reports. Through this process, and in consultation with industry representatives, the initial set of topics was condensed into nine:

1. Governance and regulation
2. Revenue streams
3. Ownership and access
4. Electric vehicles
5. Storage options
6. Advanced technologies and urban renewable energy zones (UREZ)
7. Stakeholder engagement
8. Microgrids in distribution networks
9. Custom design of local networks

The research roadmap was then formed by proposing research concepts with detailed activities, start years and durations under each research opportunity.

2. LITERATURE REVIEW

2.1 Work Package 1: Consumers and regulatory framework

The focus of this work package is to identify research opportunities in social and legal aspects of promoting the propagation of local DER network solutions such as microgrids, VPPs and community batteries. Such options, either individually or collectively, cannot be successfully deployed without the active participation of stakeholders such as customers, prosumers, DSOs, private investors, energy retailers, network companies and governments. A key research question is how to ensure an appropriate role for communities and consumers as part of the transformation of local power networks. This includes consideration of applicable law and regulation to identify futures areas of research, and where applicable, a global comparison of policy and regulatory settings of successful examples of microgrid integration.

The following questions raised in the projects scoping document formed the basis for the literature survey in this work package:

How do we put communities and consumers first in the potential transformation to a microgrid or embedded microgrid opportunity**?**

1. *Are community expectations different in embedded semi-connected microgrids compared with edge-of-grid or stand-alone microgrids?*
2. *What are the current trust levels between different actors in this environment?*
3. *What are good participatory models for developing microgrids and their associated business models?*

How do we encourage consumer participation in community battery uptake?

1. *How do different types of consumers (e.g. residential, small and medium-sized enterprises (SME) and commercial & industrial (C&I)) participate in, and benefit from, community-scale batteries?*
2. *How do consumers want to interact with the battery, and what are their expectations from participation?* For instance, are there demographic differences in preferences? What do consumers consider to be the 'ideal' optimisation strategy for neighbourhood batteries and a fair distribution of benefits?
3. *How does a customer's understanding of value created by neighbourhood batteries impact their interest in and acceptance of the technology?*
4. *What happens in case of a disaster (bushfire, storm, etc.)? Social and regulative perspective*s

To address these questions, it is necessary to have a basic understanding of the current legal and regulatory framework that forms the background to any community/consumer engagement in microgrids and neighbourhood batteries. Microgrids, regardless of whether stand-alone or grid-connected, usually comprise of generation and network assets and supply directly to end users. In the Australian national electricity market (the NEM), strict unbundling rules apply (Note: this is different in Western Australia (WA) and the Northern Territory (NT), which are not part of the NEM). This means that the same entity cannot operate the microgrid while generating and retailing electricity.

Putting communities and consumers first - How do we put communities and consumers first in the potential transformation to a microgrid or embedded microgrid opportunity?

Are community expectations different in embedded semi-connected microgrids compared with edge-of-grid or stand-alone microgrids?

Firstly, there is confusion and only a limited understanding among the community of the different types of microgrids and their implications (Shakya et al., 2019). Further, the extant literature focuses primarily on the technical and economic aspects of microgrids and the optimisation and balancing of demand and supply rather than stakeholder engagement (Gui et al., 2017). While several papers touch on stakeholder engagement and trust in microgrids as a part of this engagement, few focus on community expectations, and none compare these expectations across different configurations.

The literature suggests that grid-connected microgrids are preferred from both a financial and technical perspective. Kaundinya et al. (2009) identify several disadvantages to stand-alone systems, including community concern about long-term economic viability, which is a key component in the decision to utilise grid-connected or stand-alone energy systems. While stand-alone systems and energy autonomy are often desirable and feasible for communities, they are usually more expensive and hence avoided (Krajačić et al., 2011). Rae and Bradley (2012) note that grid-connected systems bring a host of socio-economic benefits, but ultimately the highly context-specific nature of such projects means that the degree of autonomy targeted is likely to be dictated by local factors. This is supported by Del Rio and Burguillo (2009), who stress the need to understand and analyse social impacts of DER at a site-specific, local scale and ensure that those who contribute to, and accommodate, community energy projects also reap the financial and social benefits they can bring, such as an increased sense of community and a more positive connection with renewables.

Studies in the UK have found that positive expectations are amplified by strong community involvement. Shamsuzzoha et al. (2012) found public willingness for smaller local development to be approximately twice as high as the willingness to accept large-scale development. This appears to compound the need for stakeholder involvement and the sharing of the benefits between stakeholders across all types of microgrids.

Anecdotal evidence of projects in Australia indicates that initial stakeholder engagement should include an explanation and education of the technical options. This would empower community thinking beyond simply microgrids to embrace other DER options.

Energy Consumers Australia conducts regular surveys/research on consumer expectations in general (e.g. ECA, 2019), but very little research so far has expressly explored community expectations related to different types of microgrids. Arguably, all consumers want reliable, green and local supply, but there is a shortage on pre-existing literature in this area of research.

Key areas for further research:

1.1 Do community expectations differ for different microgrids, and if so, how can the regulatory system account for this?

What are the current trust levels between different actors in this environment?

RACE for 2030 has already developed two reports fully dedicated to the issue of trust for collaborative win-win solutions, particularly for customers (Russell-Bennett et al., 2021). Roy Morgan's (2020) study has shown that electricity retailers rank among the least trusted brands in Australia (22 out of 25). The current regulatory framework (Work Package 4) identifies retailers as the point of contact consumers have with the electricity system.

Cultural and social aspects of energy and technology are reflected in the way communities react to the introduction of microgrids, with locality, ownership, trust, symbolic, affective and discursive aspects affecting the behaviour of people in relation to energy (Walker et al., 2010). These multiple factors can lead to unexpected conflicts if not addressed properly. Central to gaining an understanding of a community to prevent conflicts is the issue of trust. Trust - among stakeholders, institutions and society - enables the community to work collectively, consensually and effectively towards a common goal. An ideal cohesive community can be enrolled in strongly participatory and cooperative projects, improving their levels of social capital (Walker et al., 2010).

Projects where the community is actively engaged tend to be more successful (Walker et al., 2010). Warneryd et al. (2020), writing specifically on community microgrids, have shown that community involvement across all stages of the project enhanced trust. This aligns with work on community energy projects, and more generally shows that active community engagement and buy-in enhances the success of energy projects (e.g., Walker & Cass, 2007). This, in turn, requires communities to actively participate and be heard in the decision-making processes. Arguably, microgrid projects, which usually integrate individual community members' energy resources (e.g., rooftop solar), will require especially high levels of trust. These findings are largely mirrored on the ground at a project level. Trust building takes time and involves ongoing communication and sometimes education, for example when introducing technology options for DER in local communities. When problems arise, they need to be dealt with swiftly and openly. Individualised, face-to-face communications and working with community champions have proved particularly effective in trust and rapport building (Dwyer et al., 2020).

In summary, case studies indicate that handing over microgrid projects to the community and entitling them with the ownership, management and responsibilities of the project can only be achieved when the community is participating actively in the process of decision making and selecting the relevant aspects of the technology to be deployed. The customers become familiar with the technology as well as how to relate the components to their local context. The novelty and complexity of microgrids and accompanying visual and infrastructural changes have meant that planners and designers have struggled to gain the trust of local consumers to enable implementation. Moreover, integrating the various components of microgrids, and understanding the environmental and financial benefits, has proven challenging for local consumers, particularly in relatively isolated areas where many microgrid opportunities exist. Involving them in the decision-making is critical to build trust and cohesion with other stakeholders like manufacturing companies, DSOs, and power producers. Building a cooperative relationship with the DSO/utility is important for grid-connected microgrids (Soshinskaya et al., 2014).

Key areas for further research:

1.2 There is a need for some empirical research for assessment of trust in the existing community energy options (Research is needed to identify the drivers of trust or mistrust) and quantify its objective and subjective components.

What are good participatory models for developing microgrids and their associated business models?

Lessons learned from CLEAN Cowra and Heyfield suggest some key ingredients for good participatory models:

- Communities should be included as early as possible in the engagement process.
- Mapping stakeholders and applying the full range of community engagement tools and measures are of great importance to ensure the needs and aspirations of the community are reflected.
- A community-focussed pre-feasibility study (preceding a full feasibility study) gives a head start to the project by building an early understanding of the vision of the community and perspectives of the different stakeholders, qualifying the need for a more comprehensive and technical feasibility study. Community support gathered during the prefeasibility phase also helps attract engagement to drive the project idea forward.
- Community Liaison Officers (CLOs) play an important role in the technology deployment and community engagement, providing an important interface between the project team and the community.
- Community Reference Groups (CRGs) are an essential component. Recruit early, establish processes and procedures, address concerns early, recruit diversely and representatively, meet and communicate regularly and clarify roles and tasks.

Other key lessons include the importance of two-way information flows, the recruitment of CLOs early in the project, and that local engagement requires a dedicated full-time role, particularly in the initial months of projects commencement. Other lessons are to celebrate successes (i.e. with a launch event) and manage the media communications. It is evident that no one model fits all, and that local context and requirements play an important role. This is supported by the literature, which identifies a variety of participatory approaches and business models (Vanadzina et al., 2019; Martin-Martínez et al., 2016). However, Gui et al. (2017) remind us that research into business models and institutional design for microgrids remains rare. Warneryd et al. (2020) propose two additional dimensions when considering community energy and more specifically microgrids.

The first is the process dimension (i.e. who is the project being developed by, how will it operate and who has influence)? The second is an outcome dimension (i.e. how are the outcomes from the microgrid spatially and socially distributed, or who benefits economically and socially)? Significant institutional barriers remain globally, while in Australia limited government ambition has meant that community projects have been driven largely by end users or consumers, grappling with the problem of discovering an appropriate business model and a need to seek-out third-party investors, resulting in limited community benefit.

To conclude, this is a rapidly evolving landscape with many microgrid projects at the feasibility stage. Community education is a critical early component of these projects, building trust and knowledge to inform planning. Participatory models are also at an emergent phase and remain strongly influenced by local contexts. More empirical research is required across all of these elements to inform our thinking about microgrids and accelerate the transition.

Key areas for further research:

1.3 How are communities currently included in the development of microgrid MG projects, and are these participatory models sufficient to ensure success?

Consumer participation - How do we encourage consumer participation in community battery uptake?

How do different types of consumers participate in, and benefit from community-scale batteries? Residential, SME and C&I customers all have a different context.

The future energy market will be more decentralised. With over 2 million photovoltaic systems (more than 100 kilowatts (kW) capacity) already installed across Australia (Ransan-Cooper, 2020), many traditional electricity users are no longer just power consumers; they are prosumers. This transition implies that conventional electricity users will not just be buying power from the grid—they will be selling power into the grid or to their neighbours or their retailer. The backbone of such a transition has been battery technologies. As the prices of batteries come down, the number of solar households with batteries will increase. Using batteries will give customers more prudent choice and flexibility about how they consume the energy they generate and how they potentially export their power to others.

However, only a few studies have evaluated the social benefits and costs of community-scale batteries (CSB) or community energy storage (CES). Such studies address fundamental questions about renewable electricity's haves and have-nots. One of the potential benefits of CSB is that they may eradicate inequalities in the energy system by providing an opportunity to build customers' engagement with, and trust in, the energy sector. CSB may also help peak shaving of the entire electricity system by integrating distributed energy resources. CSB/CES is expected to help manage an increasingly unpredictable peak load. They may also increase peak exports from household prosumers (e.g. solar photovoltaic generation). Together, community-scale batteries should be explored as a viable solution to both voltage management and demand management issues. Technical benefits of this storage scale arise from a higher level of reliable control associated with managing a more significant asset than the management of many household batteries and providing regulation and contingency services such as voltage management and back-up islanded power supply. Another bundle of benefits surrounds the potential of the battery to reduce carbon emissions by enabling more renewable generation for both electricity consumption and electrical vehicle charging (Ransan-Cooper et al., 2022).

Ransan-Cooper et al. (2022) also suggest that direct consumers without their own electricity production create the most profit for community-scale batteries. Even if these consumers don't contribute to private capital such as technology connected to the community-scaled battery, they should be considered just as important. Hence, encouraging direct consumers to participate through financial incentives is shown to be of importance. For battery prosumers, Ransan-Cooper et al. argues that the initial investment should justify their profit share (Ransan-Cooper et al., 2022). Hence, sharing economy business models is important to create a profitable solution for all consumers that participate in this solution. Further, Ambrosio-Albalá et al. (2020) found that residential consumers are more supportive of community-scale batteries if the benefits could be transferred to local projects within their community (Ambrosio-Albalá et al., 2020).

Information about SMEs and C&I participation and benefits connected to community-scale batteries are currently scarce as research is mainly focusing on residential consumers. However, one study that focuses entirely on energy storage for commercial renewable integration was performed by ElectraNet (2021). It showed that the benefits of using the community-scale battery during power outages were significant in more ways than reducing the duration of the loss of energy supply. ElectraNet could, for example, schedule outages during regular hours; hence no overnight work with live lines techniques was needed, thereby increasing in levels of safety for workers. The study also showed that ElectraNet benefited through i) enhancing their local reliability of supply, ii) using the battery for fast frequency response, iii) network support, iv) frequency control ancillary services, and v) energy arbitrage (ElectraNet, 2021). Economic benefits from community-scale batteries arise from the efficiencies of flexibly sharing the power and energy capacity of the battery among customers and reducing the number of system communication and control components. It can also be challenging for prosumers to utilise all electricity generated for self-consumption (Ransan-Cooper et al., 2022). Various reports showed that community-scale batteries are cheaper than household batteries, regardless of ownership (network, retailer, or community group; Shaw et al., 2020).

To further understand how different consumer types would like to interact with the battery, current regulations and network tariff strategies need to be investigated. A conclusion from the study of the Australian National University (2020) found that current regulations do not need significant changes for community batteries to make them achievable options. However, what most communities will need is some type of discounted local network tariff to make them financially viable. Competitive policies can also impact the participation of different customer types (ANU, 2020a). The ownership model must also be considered, and how that will impact the participation of different customers. The consumer who benefits the most from the battery's operation will be likely to participate to a greater extent (Shaw et al., 2020).

CES should not be ignored. A survey of the literature (Parra et al., 2017) highlighted a number of advantages that CES could bring over single-home systems, including enhanced performance of battery systems due to smoother electricity demand profiles resulting from the aggregation of household loads, a reduction in the required energy and power ratings of the storage system in terms of kWh/home and kW/home, and potential economies of scale from to the use of larger systems.

Apart from difficulties in monitorisation of social costs and benefits of CSBs or CES, there are various ethical issues regarding property rights and trust among various stakeholders that need to be thoroughly discussed.

Key areas for further research:

1.4 There are discrepancies in the amount of existing information about how different users of community energy storage (i.e., residential, SMEs and C&Is) participate that needs to be addressed.

How do consumers want to interact with the battery, and what are their expectations from participation? Are there demographic differences in preferences? What do they consider to be the 'ideal' optimisation strategy for neighbourhood batteries and a fair distribution of benefits?

A study from Ransan-Cooper et al. (2022) shows that consumers do not represent a homogenous viewpoint on their preferences and views. Each community has special preferences that are yet to be explored further. We can also see that the literature available often discusses residential customers only, sometimes with a broad objective of DER, and does not focus on community-scale batteries (Ambrosio-Albalá et al., 2020; Kalkbrenner, 2019). Hence, the topic has not been investigated enough to answer whether there are demographic differences in preferences. However, some specific cases such as the UK survey from Ambrosio-Albalá et al. (2020) have shown that consumers would rather have government and municipally owned and managed community-scale batteries than incorporate a private company. A battery storage and integration program initiative by the Australian National University also showed a strong preference for local governments to own community-scale batteries and run them not-for-profit. Consumer expectations are also likely to be sceptical if they cannot get clear information on how this type of energy storage will benefit the local community (ANU, 2020a).

Kalkbrenner (2019) discusses studies related to consumer preferences regarding ownership structures of energy storage systems such as community-scale batteries. He argues that results from current studies are ambiguous, and that no consensus or broad understanding of how consumers want to interact with the storage system exists.

Another study from Kloppenburg et al. (2019) also discussed community-scale batteries and participation models. According to their study, the role of communities connected to battery storage should not be seen as active or aware enough to do most of the work around the battery storage. Instead, the work should be carried out by professionals, especially when it comes to the installation and maintenance of the battery system. This means that consumer participation should not entirely have the responsibility of the monitoring and management (Kloppenburg et al., 2019).

For C&Is, ElectraNet's final report from its development in 2021 presents the importance of understanding and considering how the battery is intended to be used. For example, auxiliary loads and losses can be especially important for some consumers such as network providers. It is an essential input to understand how commercial arrangements should be setup (ElectraNet, 2021) should be. However, the point that different groups emphasise different benefits highlights the inherently political nature of model selection, and many models will reflect a particular set of values and may come at the expense of another group in the energy system. Therefore, a 'community battery' will depend on a range of considerations including how householders are engaged in the design and how the benefits are distributed. As such, any proposed regulatory changes must take this into account and provide a pathway to explore different models to reveal which models are most likely to benefit all energy consumers.

Also, based on analysis undertaken by ANU, there are some differences between the expectations of the general public and energy sector professionals about future models of community batteries. The main factor is around questions of ownership, in which the general public envisions a minimal role for large retailers and networks. The research also proved that householders are not simply concerned about energy affordability but have a range of values and expectations for future energy systems. Community batteries are in line with values of sustainability and energy sovereignty, so long as the entity delivering the community battery can demonstrate these same values (Ransan-Cooper, 2020). Different research has showed that any one of a range of models is possible to use as an 'ideal' optimisation strategy for neighbourhood batteries, all with different value propositions and different regulatory barriers if the regulation of community batteries is adaptable and flexible. In addition, communities will have different goals in terms of what they want the battery to achieve and are also differentiated in terms of their composition of solar owners and non-solar owners. Finally, local and state governments have their own carbon reduction objectives and are also highly differentiated in terms of their strategies around storage investments (ANU, 2020a).

To make customers more engaging and to empower them, the distribution network tariff system also needs to be changed. For example, a network tariff structure with multiple options to select would encourage customers to select the most suitable option with the necessary knowledge of their load consumption patterns. According to the Council of European Energy Regulators (CEER), the new tariffs must recover the cost, be cost-reflective, non-discriminatory, non-distortionary, simple to understand, transparent and predictable. In addition, customers have to understand the importance of their role in the future grid. Customers can be motivated to invest in batteries by giving them extra monthly incentives if they reduce their peak demand consumption (Gautam, 2017).

Lastly, it is important to stress that the results from the literature review show only a few specific cases that cannot be used as a representation to explain the demographic differences in preferences for different consumers. However, the results can be used as learning and information on how to conduct further studies to gain more knowledge in this area.

Key areas for further research:

1.5 Is there an ideal model for consumer interaction with a neighbourhood battery and how can different consumers (from active to passive) be supported?

1.6 Can we design an algorithm to optimise the benefits of battery technology for trading excess supply in real time for passive prosumers using smart meter facilities?

How does a customers' understanding of value created by neighbourhood batteries impact their interest and acceptance of the technology?

A UK survey exploring acceptance of community-scale batteries showed that initial customers' attitudes were positive. However, this study also showed that the level of awareness of decentralised energy storage for residential customers in the UK is still low. Further, residential customers are shown to have very strong expectations of the technology, especially when it comes to its benefits and management (Ambrosio-Albalá et al., 2020). Ransan-Cooper et al. (2022) focused on creating a survey with participation from diverse participants to understand justification of deployment better. They found that several participants were not sure why community-scale batteries would be the best value technology or their community. Further, this study showed that participants need a clear justification why this technology and scale would be the best option available for the community and themselves (Ransan-Cooper et al., 2022). Based on the Community Energy Model (CEM) Project run by The Australian National University (ANU), all participants were open to the idea of local, community-scale storage in the energy system. However, all raised concerns or challenges based on the two categories: practical challenges, which often relate to the material-technical aspects of battery installation/maintenance (some aspects of which require a regulatory response), and governance and regulatory issues (perceived and real), which relate to ways in which community batteries may require changes to the current institutional frameworks to be viable (Ransan-Cooper, 2020).

Key areas for further research:

1.7 What practical, governance and regulatory challenges need to be overcome for community- scale energy storage?

The issue of disaster (bushfire, storm, etc.) and community energy: a social and regulative perspective

Community energy and supply resilience. Natural disasters (fire, cyclone and flood) in Australia in recent times have particularly highlighted telecommunications vulnerabilities and specifically the power supply for telecommunications facilities across the landscape (i.e. towers and stations). There have been several relevant recent studies, including of public health and natural disaster events and their management (NNDA, n.d., Publications), and critical infrastructure and critical supply chains (Productivity Commission, 2021). These highlight that Australia is vulnerable in many ways, especially so in mobile telecommunications systems. These systems, for example, are the foundation of operational control redundancy and resilience (i.e. back-up to supervisory control and data acquisition (SCADA)) in the electricity system. Shortfalls in the depth of backup power supply for telecommunications facilities is a major recognised problem (DITRDCA, 2021, Telecommunications in emergencies and natural disasters). How community energy (microgrids and so on) could usefully and reliably support such facilities may be an open and complex technical question. However, the driver and opportunity for community energy to support and harmonise with power supply assurance to critical infrastructure are clear. One may also look to islanded operation of community energy for maintaining electricity supply when conventional infrastructure is impacted by events. This has been a driver for community energy in parts of the United States (Hirsch et al., 2018). There may be a cost premium for technology supporting islanded operation compared to network-integrated operation, and Australian safety/fire-safety regulations will come into play. Proponents will need guidelines and tools to make decisions around the benefits of resilience afforded by islanded operation versus the technology costs and potential additional models of failure/maloperation. It is laudable that a major program of community consultation has been undertaken in Victoria to understand community views of the benefits (and downsides) of non-conventional solutions for electricity supply that can reduce fire risk and community vulnerability (Engage Victoria, 2022). This study may inform benefits quantification work in the future.

Safety, fire safety and non-network solutions. Electrical safety regulations including bushfire safety regulations are extensive and require strict compliance by electricity transmission and distribution businesses. Community energy is both a problem and a solution in this context. Electricity transmission and distribution are subject to much regulation which seeks to reduce the occurrence of bushfire ignitions from the power system. This ranges from vegetation management (clearance standards) to required upgrades to electrical protections systems (e.g., telemetry-fitted and fast-acting automatic circuit reclosers) and structural changes (e.g. compulsory undergrounding of assets), to corporate and individual obligations to maintain safety and avoid fires. Community energy in the form of community batteries and microgrids must operate under the same instruments of safety regulation (even if legislators and regulators might not quite yet recognise the problem). Less conventional and distributed energy assets are by no means free of ignition risk (ABC News, 2021). Quantitative representations of the likelihoods/risks are not presently available to industry, but there will be urgency in the demand for these as ‘serious’ investment cases are brought forward in bushfire prone areas in particular. This will be especially true if the motivation and support for an investment in community energy is significantly predicated on bushfire avoidance by removal or non-use of electricity distribution powerlines through bushland.

Regulatory tests and resilience benefits. Within the national electricity rules there is an obligation for regulated investment proponents to consider non-network solutions (AER, 2013). This applies to the planning of distribution networks but (i) parts of the documentation can be commercial in nature and not public, and (ii) the analysis of community energy solutions can be under-informed and immature because knowledge is scarce. The latter exacerbates the former because community energy options can be dismissed early in options analysis due to the costs, benefits, uncertainties and risks being inadequately understood. The cause of community energy, and particularly the quantification of its benefits pertaining to resilience to natural hazards, will be strongly assisted by the establishment of proven methods and datasets for assessment. These can bring credibility to the benefits side of the equation as well as delineate the true and perceived risks around safety and performance.

Key Areas for Further Research:

1.8 How do we bring accuracy and credibility to analyses of the benefits of community energy with respect to natural disasters resilience?
1.9 What can we say about the net rate of bushfire ignitions when community energy augments or replaces conventional electricity distribution?

2.2 Work Package 2: Business models

Accelerating the adoption of distributed energy system solutions requires innovative business models. Energy market deregulation brings a host of challenges, many of which are yet to be addressed. Affordable IoT technologies such as virtual power plants, aggregators, and blockchain-mediated transactions facilitate new business models in the energy sector. This work package will explore questions such as the relationship between incumbent retailers and distribution networks, the most appropriate mix of ownership structures for microgrid assets and community batteries, financing models for development and operation, and how to facilitate both VPPs and microgrids when they overlap. Note that this work package builds on the results of the project on DER Business Models.

Introduction and definitions

The proposal for this RACE for 2030 'Opportunity Assessment: Local DER Solutions' stated that it "looks at both stand-alone and grid-connected microgrids and, in the latter category, also distinguishes microgrids for rural and single wire earth return (SWER) connected communities from peri-urban and new developments." A key initial question, therefore, was "What definition best constitutes what is meant by a 'microgrid' or 'community battery'?" The small number of highly cited examples for microgrids (such as that of the US Department of Energy cited below) usually take a network-centric rather than customer or community-centric view. 'Local DER network solutions' also infers such a perspective.

US Department of Energy microgrid definition:

"A group of interconnected loads and distributed energy resources with clearly defined electrical boundaries that act as a single, controllable entity with respect to the grid. A microgrid can connect and disconnect from the grid to enable it to operate in both grid-connected and island mode" (Smith & Ton, 2013).

Conversely, 'community/neighbourhood battery' infers a community-centric perspective although they are often deployed as non-network solutions which don't offer direct benefits for the community/neighbourhood at all. 'Local energy solutions' is a term that could be used to encompass microgrids (embedded and islanded), community batteries and stand-alone power systems (SAPS). The definition used by the RAMPP (Regional Australia Microgrid Pilot Program) provides a more flexible definition of a microgrid than that assumed commonly in the literature.

For the purpose of the RAMPP, the term microgrid is used to include the following technical configurations (ARENA, 2021e)

- Embedded microgrid: An electricity supply arrangement that coordinates and optimises the use of connected, locationally proximate distributed energy resources (DER) to provide secure and reliable electricity within the microgrid and is able to provide value to the major grid. This could include energy market participation, provision of system flexibility, systems services and deferral of network investment.

- Stand-alone power systems (SAPS): An electricity supply arrangement that can demonstrate temporary or permanent operation when not physically connected to a major grid. SAPS encompasses supply to single and multiple customers where
    - Customers currently connected to a major grid can move to a SAPS or
    - A SAPS is installed in place of a new grid connection.
- Remote isolated microgrid: An electricity supply arrangement that already operates as an isolated SAPS and will continue to do so. These systems are often in very remote locations and managed by state government-owned corporations.

Acknowledging the diversity of potential microgrid configurations, ARENA may also consider projects that do not fit the microgrid technical configurations above.

Business and ownership models – What are the range of business models and ownership models for funding and operating microgrids?

What is the relationship between incumbent retailers and local distribution networks? What are the regulatory issues and technical problems that need to be solved to enable the full value stack of services a community battery can provide to the local community and consumers AND the bulk power system?

Both research questions are addressed in the below response.

Batteries can deliver a number of services to the electricity system, including generation, network and system services (e.g. System Integrity Protection Scheme (SIPS)). Currently, battery providers are not allowed to deliver all these services. In the Australian national electricity market, strict separation between network providers (transmission and distribution) and retailers is enforced. Distribution network service providers (DNSPs) can therefore only provide distribution services. They usually have no consumer contact. Ring-fencing, which requires administrative and legal separation of network and retail activities, ensures that network providers cannot abuse their position of power by preferring associated upstream (generation) or downstream (retail) businesses.

Ring–fencing Guideline definition: “the separation of regulated services provided by a DNSP (for example, installation/maintenance of poles and wires) from the provision of contestable services by a DNSP (for example, the installation of smart meters) or an affiliated entity.”

The Ring-fencing Guideline (AER, 2021) governs the extent to which DNSPs can provide contestable services. This means that, in principle, a DNSP cannot operate all functions of a microgrid. In particular, it cannot provide contestable services such as control and operate any embedded generation assets and the retail supply to consumers. Exemptions (waivers) from this strict separation are available under the Ring-fencing Guideline under Specific Conditions.

The NEM has especially strict unbundling requirements separating retail and distribution. While most countries do unbundle transmission networks from generation, requirements to separate distribution from supply/retail are less common (Kallies, 2021). Innovations at the ‘edge of the grid’, such as smart grids, microgrids, batteries and EvsS, require close interaction between distributors and retailers. Authors such as Sanyal & Ghosh (2013) and Jamasb & Pollitt (2008) have associated strict unbundling with a lack of innovation. Rønne (2012) poses that smart grid will require “proper planning and coordination… covering all elements of the supply chain and not only the particularly unbundled activity.” However, Wara (2017) shows, using the US example, that utilities can behave anti-competitively towards new entities such as DER providers to protect their traditional business model. On the other hand, the ACCC (2018) report on retail electricity pricing in Australia has shown that the state with the highest competition in retail, Victoria, also had the highest retail cost as percentage of the consumer electricity bill.

In Australia so far, strict ring-fencing has arguably stymied the roll out of innovative solutions such as microgrids and community/neighbourhood batteries, even where there is a clear commercial case. The experiences with embedded networks, which has seen consumers locked into uncompetitive electricity rates, also provides a cautionary tale. At the same time, the market bodies have now adopted a SAPS model which allows DNSP to manage these systems. Overall, the literature and experience so far present a mixed view on the ideal degree of competition at the grid edge and the future role of distribution network providers in actively managing microgrids.

Key Areas for Further Research:

2.1 Who is best placed to deliver services at the grid edge in a way that encourages innovation and benefits to all stakeholders? What criterion should be used to determine this?

2.2 Should the full stack of services a community battery can provide be delivered by a single entity, and if so, who could this be?

2.3 An in-depth study is required of the advantages and disadvantages of different governance models (e.g., retailer-led, DNSP-led, independent grid operator, etc.) for community microgrids in both urban and rural areas that considers the fair distribution of costs and benefits.

What is the best mix of ownership structures for microgrid assets?

The market for microgrids is still in its infancy, despite a recent increase in interest due to concerns over energy affordability, reliability, and resiliency, the falling cost of renewables, storage, and supporting technologies, and increased support from state and federal governments to fund feasibility studies and pilots (Chartier et al., 2022). Because of the lack of commercial microgrid projects in Australia and around the globe, it remains to be seen which ownership structures and business models will emerge as dominant. This has been the case with the more mature solar, wind, renewable and co-generation sectors (Bolton and Hannon, 2016; Burger and Luke, 2017; Wright et al., 2022). Additional complexity stems from the fact that microgrids are characterised by a complex mix of technologies, the diverse categories of microgrid that exist (off-grid versus on-grid, facility versus community), their existence at very different scales (kWs to MWs), and the local context—from socio-economic demographics and climate, to frameworks relating to legal, regulatory and institutional concerns (Borghese et al., 2017; Wright et al., 2022). Wright et al. (2022), citing Lowitzsch (2020), identifies three types of ownership model which are described in the table below.

Table 5. Ownership models for microgrids

Ownership model	Description
Operating company with shareholders (strategic investors, local co-investors and trustees who act on behalf of consumers)	The operating company sources the loan and strategic investment (e.g. energy retailer, plant equipment supplier) and operates the microgrid. The trustees (can be a limited partnership or energy cooperative) represent the consumers/participants shareholding and can vote on issues pertaining to governance of the microgrid. Co-investors (such as the local government or local businesses) also have a number of shares. This is one of the simpler arrangements and is suitable for strategic investors who have longer term interests in the project.
Holding company as owner/manager (single)	Instead of an operating company, a holding company is the owner and manager of the microgrid. It secures the financing and controls the operating company. The strategic investors have a stake in the operating company while the co-investors and trustees' interface with the holding company. This is a more complex arrangement and is more suited to a strategic investor who has a shorter-term interest in the project.
Holding company as owner/manager (multiple)	This is a the most complex arrangement where the holding company controls would control more than one microgrid or renewable energy project company. This would be pursued when trying to achieve scalability and economies of scale and is more suitable for accommodating different types of strategic investors who have different short-term or long-term interests (e.g. providing management services, capital, aggregation and flexibility, storage, servicing and distribution network services).

In each of these cases, the owner could be a variety of different entities, as shown in the following table.

Table 6. Ownership options for microgrids

Owner type	Description
DNSP-owned	The microgrid is owned by the distribution network service provider
Retailer-owned	The microgrid is owned by the energy retailer
Third party-owned	The microgrid is owned by a third party
Customer-owned	The microgrid is owned by the customer
Community-owned	The microgrid is owned by the community
Shared ownership	The microgrid is owned by a combination of any of the above

Source: Langham et al., 2021

Irrespective of the ownership model or who the owner is, microgrids must be administered via a defined organisation. There are three broad types of profit models by which such an organisation would operate, as described in the table below.

Table 3. Organisational profit models for microgrids

Type	How it would work for a microgrid	Examples (may or may not be a microgrid)
For Profit	The microgrid is run for profit by a commercial entity.	Huntlee grid-connected microgrid
For Profit (Bounded, e.g. a cooperative)	The microgrid is run for profit with benefits able to be distributed to a specific group in support of local outcomes.	Hepburn Wind
Not for Profit	The microgrid is run with all profits going towards servicing community or social goals.	Australian Energy Foundation (AEF)
Hybrid	The microgrid combines any of the above models.	Indigo Power and Totally Renewable Yackandandah community battery

Source: Langham et al., 2021

The energy resilience in regional and remote areas is a key driver for microgrids. Two examples responding to this need are from Western Power in Kalbarri (Western Power, n.d., Kalbarri microgrid) and Horizon Power in Onslow (Horizon Power, 2021). In New South Wales, Endeavour Energy is developing a microgrid for Bawley Point and Kioloa on the South Coast in response to issues related to bushfires, storms and peak loads (Endeavour Energy, n.d., Community microgrid for NSW South Coast).

Key Areas for Further Research:

2.4 How can we determine the best mix of ownership structures for microgrid assets to deliver the desired impact and outcomes? What does “best” mean – what should the criteria be in terms of the desired impact, outcomes, and the necessary balance of benefits and costs for the different stakeholder groups (whether community, networks, businesses, government, etc)?

2.5 How can the appropriate institutional and financial mechanisms be put in place to help communities that want to make energy work better for them and seek the benefits that microgrids offer?

2.6 How can the customer/community-centric focus be retained when microgrids are owned by third parties? How can you ensure that where ownership is given to others that a customer/community-centric approach is followed?

2.7 And what is the role of policy and regulatory reform to help remove the barriers that hinder certain promising ownership models?

What role can local governments play in supporting the transformation?

Australia is divided into 537 local government areas (LGAs) and 55% of these are regional, rural or remote councils (ALGA, n.d., The Australian Local Government Association). Local government, or councils, represent the third tier of government and vary widely in geographical size and population, and therefore resources. State and territory governments have constitutional responsibility for local government and so their roles can vary accordingly.

Local government responsibilities can include:

- Infrastructure and property services (e.g. local roads)
- Provision of local amenity facilities (e.g. swimming pools, sports halls)
- Community services (e.g. community care, aged care and accommodation)
- Building regulations and developments

- Provision and management of services (e.g. airports, parking)
- Cultural facilities (e.g. libraries, museums)

With a remit for the health and wellbeing of their communities, many local governments have been active in helping support energy efficiency programs over the last 20 years, and over the last 10 years have been involved in the installation of small-scale PV on public buildings for self-supply (Mey et al., 2016). More recently, some have become highly active and visible in supporting the uptake of electric vehicles in their local government areas and for their fleets (Dwyer et al., 2021). Local governments maintain various local government facilities and public buildings, including those that support critical systems. Those in disaster- prone areas are already involved in implementing various strategies to reduce the likelihood or severity of events such as bushfires and floods, providing support to the emergency services in some of these cases. In East Gippsland Shire (Victoria), for example, they operate district relief centres to provide critical information and services for use during extreme bushfires. In future, the shire sees itself as having a role in ensuring that any existing buildings are adapted to be resilient and future proof amidst the trend towards an increasing number of climate related disasters.

The opportunity for local governments may be for microgrid solutions for:

- Council facilities/precincts with critical power needs
- Recovery/relief centres in disaster (severe storm, flood, bushfire) prone areas
- Communities at the fringes of the grid
- Other local government use cases will exist, but further discussions with those local governments and their joint organisations/regional organisations and other representatives (Cities Power Partnerships, Local Government Associations) are recommended.

The role of local government today is highly relevant for microgrid technologies and can help support the deployment of pilots and early projects. Some of the more innovative local governments would make suitable partners for RACE for 2030 projects, especially where they have already invested in capital works and equipment, have close connections with communities and place, and have pending projects that fall marginally short of a positive business case. With over 500 LGAs and more than half of these in regional or remote areas, there is a good opportunity for scaling microgrid projects that are demonstrated to be feasible, viable, and desirable for implementation. Bodies representing local government (regional organisations/joint organisations, local government associations, Cities Power Partnership) would be a good entrance point with which to engage this important stakeholder group.

Some Key Areas for Further Research:

2.8 How can we directly involve local governments and their representative bodies in the scoping and implementation of subsequent projects and pilots within this RACE for 2030 theme?

What are the best financing models for development and operation? Are they different models for the two stages?

Given the immaturity of the microgrid market, the financing models for the development and operation of microgrids are still being tested. The table below makes a high-level comparison of the benefits and disadvantages associated with six broad type of ownership and financing model, including some examples for illustration. It is important to note that ownership and financing can be separate, such as when customers, third parties, or communities use loans or debt facilities.

Table 4. Financing options

Type	Benefits	Disadvantages	Examples
Customer-owned and financed	Easy to understand by customers	Limited to products on customer premises, and restricts access to those with capital; generally leaves risk of performance with the customer	Integrated solar and storage community energy project in Yackandandah
Community-owned and financed	Creates an opportunity to build social capital through co-owned assets on community or business sites	Capital raising takes time; harder to achieve financial viability as projects may only get 5-10c/kWh for exports instead of offsetting 20-30c/kWh retail power costs; capital raising takes time	Indigo Power, planned Newstead community solar farm, Pingala crowd-funded solar on Sydney breweries, Enova Energy, Hepburn Wind, Solar Share Sapphire Wind Farm community co-investment campaign
Network business-owned (with government or private debt finance)	High level of technical knowledge and expertise already exists within utility; potentially easier to protect against risks of bushfire infrastructure loss; most suitable for local distribution elements of the microgrid	Limited suitability outside of remote locations Limited flexibility to develop community interests not expressly focused on grid benefits; may not represent best value to community	Western Power microgrid projects: Kalbarri, Perenjori, Bremer Bay and Ravensthorpe AusNet Services' Mooroolbark Mini Grid
Government-owned and financed (ownership not likely in unregulated markets; only finance via grants or low interest debt finance, or in partnerships with community energy groups to lease land and purchase electricity)	Grants don't need to be paid back; access to low-cost finance	Limited availability of grants; resources required for grant application process, long funding cycles and reporting requirements	Primarily rural electrification in developing markets for actual development funding Innovation grants/ investment examples include Huntlee; partnership examples include Lismore Community Solar, Clean Cowra and the Bendigo Sustainability Group
Third party-owned and/or financed	High level of innovation with new financing structures emerging; potentially responsive to emerging new opportunities	Higher cost of capital May be difficult to balance investor expectations with social purpose	Simply Energy VPP Thrive Renewables Community Bridge Huntlee housing development
Governance without ownership	Retain benefits of more mainstream legal and capital raising structures	Few global precedents at this time	Riversimple Six Custodians Model

Source: Langham et al., 2021

Local energy solutions such as microgrids and community batteries are still in the very early stages of deployment. However, there are increasing examples of financing options being trialled and tested (as shown in table above), with growing interest and activity in sustainable finance in general. While the trials are helpful, the pace of learning is slow, and the financing mechanisms are not always transparent. Better understanding how sustainable finance could potentially accelerate the adoption of local energy solutions facilitated could help unlock an opportunity often prevented by the upfront cost barrier. Microgrids are capital intensive to develop and implement, and thus securing finance is a critical component. The ownership structure influences the financing models. Wright et al. (2022) and Langham et al. (2021) discuss a number of sources of capital for financing microgrids.

Table 5. Sources of capital for financing microgrids

Sources of Capital	Description
Government grants	Government funding in the Australian context has to date mainly been provided by grant funding to reduce innovation risk, or as innovation investment or low interest finance such as via ARENA or the Clean Energy Finance Corporation (CEFC)
Commercial loans	More favourable rates may be able to be secured by way of the climate/corporate social responsibility (CSR) commitments of lenders
Debt/equity (private/public investors)	Allows the owner to manage cash flows through stipulating when investors are repaid following debt settlement
Venture capital/private equity	Attracting funding for innovative applications and often supported by government grants to de-risking their investment
Community co-operatives	Community investment in local energy projects has become increasingly popular in Europe and Australia is starting to follow suit. Hepburn Wind raised $9.8m from almost 2,000 co-operative members for its community wind project. Community solar projects have also started to gain traction, with crowd-funded examples such as Pingala and Clear Sky Solar Investments raising equity for small scale projects, and Solar Share doing the same for larger-scale projects. This has also encouraged community-funded energy retailers to become involved directly with communities, with examples including Enova, Indigo, and DC Power.
Energy agreement (ESA/PPA)	Energy services agreements or power purchase agreements can be established to simplify the customer proposition and create a more stable revenue stream for owners and strategic investors.

Source: Wright et al., 2022

Key Areas for Further Research:

2.9 What criteria should be used to in determining the best financing models for the development and operation of microgrids? Are there different models for these two stages?

2.10 How can RACE for 2030 leverage off the existing Commonwealth microgrid feasibility funding and ARENA RAMPP microgrid implementation funding to increase knowledge of microgrid development and operation?

To identify the best financing models for microgrid development and operation, more attention needs to be paid to what 'best' means. With the infancy of the microgrid market, the risk profile means that obtaining finance is challenging (Wright et al., 2022). Additional grant funding from the federal government has been assigned to microgrids for remote and regional communities, but how can this be applied to greatest impact? Should it be used to make only marginally economic projects viable? Or should it be leveraged in some other way that can move the needle on microgrids and maximise their benefits to consumers and other stakeholders? Until more microgrids are implemented, these questions will remain. The Commonwealth's RRCRF (Regional and Remote Community Reliability Fund) committed $50 million to fund feasibility studies for microgrids across Australia and runs from 2020 to 2024. It has already supported almost two dozen projects. The ARENA RAMPP (Regional Australia Microgrid Pilot Program) has committed $50 million to support microgrid pilot projects from 2021 to 2026. RACE for 2030 could look to these projects for more insights on microgrid development and operation and consider how an additional pilot(s) could leverage these while adding value.

What is the best mix of ownership and operation of local storage assets?

Local storage assets can be considered a component of microgrids. Ownership models for microgrids, and financing and operation models for microgrids is largely addressed throughout Work Package 2. The content in this work package largely addresses research questions through the lens of the storage component of microgrids. As noted in the projects research questions, we are in the early stages of implementing, operating, and financing storage assets and models of best practice which are yet to be established.

To further answer the question, we need to unpack what 'best' means for each of the stakeholders. Stakeholders include residential and commercial customers, vendors of local storage solutions (e.g. Tesla), incumbent utilities, new players such as Enova (the first Australian community-owned energy company) and regulators. Best could mean:

- Lowest cost capital cost
- Simplest or cheapest financing
- Lowest operational cost
- Lowest cost for end consumers (lower than buying off the grid conventionally)
- Sustainability rating
- Reliability of supply
- What is possible given the regulatory envelope

The priority of each of these options could best be explored by interview and survey with each stakeholder group, as well as examining the current practice in pilot implementations. The PowerBank community battery is an interesting case as it is facilitated by Western Power and Synergy and customers subscribe to it. The Australian Labour Party (ALP) has announced its plans to roll out this model nationally as Power to the People. A different ownership model is being investigated in Victoria's Neighbourhood Battery Initiative, which has now produced its Battery Initiative Industry and Community Consultation Report. Initial findings from that report showed that community respondents identified many roles for government in establishing neighbourhood batteries, including

- the provision of well-researched models
- provision of funding for a range of trials, including cost-benefit analysis for different models
- provision of online sessions, education and resources
- regulatory reform and network tariff reform (to reduce the incidence of double-charging), and
- the development of guidelines for equitable distribution of available stored energy when demand exceeds availability.

What role does trust play in ownership and operation?

The issue of trust between different actors is clearly detailed in Work Package 1, Question a1.2, and won't be repeated here. On the specific issue of trust in the context of ownership and operation, the lack of pilot or early commercial microgrid projects in Australia suggests that answering this question in the short-term is challenging. However, based on a thorough review of around 20 ARENA-funded DER projects, Dwyer et al. (2020) note that "Building trust, including ensuring fairness (or social equity), through design and implementation, will help protect future projects from customer backlash and move the sector closer to a customer-centred energy future." Therefore, much can still be done by encouraging the building of trust through the earlier microgrid and community battery project development phases.

The RACE for 2030 'Opportunity Assessment: Trust Building in the Energy Sector' is an excellent reference source from which the conceptual pillars for E1 (see Figure 3 below) can be adapted and used as a common trust-building framework for any projects proposed by this theme, especially in any pilot seeking to explore ownership and operation models. It could also be offered to ARENA, which will be playing a major role in the funding of microgrid pilots through the RAMPP. Further dialogue between RACE for 2030 and ARENA is recommended.

Key Areas for Future Research:

2.11 How can the outcomes of the RACE for 2030 Opportunity Assessment on Trust Building be applied to future projects and pilots under this theme?

Figure 3. Conceptual pillars for trust building
Source: Russell-Bennett et al., 2021

Value in community batteries – How do we access the value of community batteries?

How can community batteries provide bulk power systems support when enabled by 'Grid-forming inverters' and 'virtual synchronous machine' software?

Grid forming refers to restarting the grid after a blackout (EE&RE, 2021), while Virtual Synchronous Machines simulate the ability of a large spinning generator or large electric motor to momentarily absorb excess grid power (seen as an increase in frequency in the grid) or to momentarily provide energy if needed (seen as a decrease in frequency in the grid) (Glassmire, n.d., A virtual synchronous generator approach to resolving microgrid and battery protection challenges; SINTEF, n.d., Virtual synchronous machine). It can also be viewed as synthetic inertia. In a completely renewable grid without conventional generators and with sufficient storage, grid stability can be provided in other ways and eventually, the concept of frequency control become irrelevant. Grid scale batteries have been shown to be useful and profitable in providing such grid services, notably the SA battery at Hornsdale (Parkinson, 2020).

AEMO provides an extensive discussion of the approach in its document Application of Advanced Grid Scale Inverters in the NEM (AEMO, 2021a). And ARENA has recently sought projects to fast track the technology (ARENA, 2021d). In June 2022 AEMO published the 2022 Integrated System Plan for the NEM which specifically mentions the need for grid forming inverters to eventually replace Virtual Synchronous Machines and sets out the engineering challenges that need to be met (AEMO, 2022). As community batteries begin to be deployed in Australia, the question now is whether batteries at this scale can be useful in providing these grid services and profitable to the owners of the batteries. A trial in Perth, WA used a 464kWh battery which is tiny compared to the SA battery (Energy Magazine, 2020). This is an involved technical question. In the newly published Research Roadmap on Grid-Forming Inverters, Lin et al. (2020), researchers from National Laboratories, universities, and the U.S. Department of Energy (DOE) Solar Energy Technologies Office (EE&RE, n.d., Solar Energy Technologies Office) outline a plan to use renewable energy to jump-start the grid by taking advantage of an essential piece of connection equipment known as an inverter (EE&RE, n.d., Solar Integration: Inverters and grid services basics).

According to NREL: Inverters provide the interface between the grid and energy sources like solar panels, wind turbines, and energy storage (EE&RE, n.d., Solar Integration: Solar Energy and Storage Basics). When there is a large disturbance or outage on the grid, conventional inverters will shut off power to these energy sources and wait for a signal from the rest of the grid that the disturbance has settled, and it is safe to restart - known as 'grid-following.' As wind and solar account for increasing shares of the overall electricity supply, it is becoming impractical to depend on the rest of the grid to manage disturbances. Grid-forming inverters are an emerging technology that allows solar and other inverter-based energy sources to restart the grid independently (ElectraNet, 2020).

The new roadmap highlights recent innovations in grid-forming inverter technology. It identifies the challenges for researchers and operators of the small, isolated grids or microgrids where this technology could be piloted, and which is more applicable to community scale batteries. In the short term, research opportunities exist for creating new grid-forming hardware, software, and controls, redesigning regulatory and technical standards, and

Key Areas for Future Research:

2.12 Is there enough battery capacity in community batteries to provide useful services to bulk power systems if their connection to the grid supports such services?

2.13 Inverters and virtual synchronous machine software can enable batteries to provide grid services traditionally supplied by non-renewable sources and already do so for large assets. Will a collection of smaller assets be useful in the same way?

developing advanced modelling techniques. Building on these, the authors envision a future where grid-forming inverters are integrated into electric grids of steadily increasing size and complexity over the next 10–30 years.

What is the economic value of different service stream that community batteries can provide?

Quantifying the societal/ economic value of community batteries over and above the profitability of the battery (value to the owner) is required. This includes estimating the value of avoided loss load due to community battery involvement, their value to ancillary system services (and overall system operations), the value of resulting deferred network investment and lowered network congestion. Battery storage has the potential to improve the efficiency of overall energy system operations by providing a wide range of services (Forrester et al., 2017; Csereklyei et al., 2021). Community and utility-scale batteries can support the increasingly challenging operational requirements of energy system predictability and dispatchability.

Csereklyei et al. (2021) notes that IRENA (2019b) and Anuta et al. (2014) compiled the following potential categories for utility-scale battery services:

1. Services for variable renewable generators, such as curtailment reduction and firming capacity provision
2. Services for overall energy system operations, such as frequency regulation, flexible ramping, black start and ancillary services
3. Services for allowing deferral of network investment, including capacity reserves for generation and congestion relief for transmission and distribution (virtual power lines).

While community batteries are less widespread than their utility-scale counterparts, they can provide similar services, also in a localised context. Csereklyei et al. (2021) note that:

“The services batteries can provide, especially in system services, are becoming increasingly valuable for the market, too, especially with increasing value on rapid response, dispatchability and flexibility, as electricity systems grapple with the integration of increased renewable generation. As costs decline, significant utility-scale battery additions are projected in many countries.”

In Australia, batteries can provide a range of revenue-generating services in various markets. The bulk of battery revenues currently stems from participating in ancillary and in wholesale markets (ARENA, 2019c; for more details see Csereklyei et al., 2021). Areas with potential future revenue streams for utility-scale and community of batteries include services as virtual transmission lines or avoided transmission investment too (Csereklyei et al., 2021). Apart from the immediate financial viability of batteries (which has been continuously improving due to the substantial decrease in their capital and operational costs, see Lazard (2021), a number of studies focus on the economic value of their services.

Csereklyei et al. (2021) note that the key strand of economic papers around battery storage currently focus on evaluating the economics of the technology in competitive markets, as well as the welfare impacts of battery usage (Siddiqui et al., 2019; Schill & Kemfert, 2011; Sioshansi, 2011; Sioshansi, 2010). Many of these studies (e.g. Siddiqui et al., 2019) have concluded that battery operations may in fact reduce social welfare in competitive markets if they act in a profit-maximising manner. Csereklyei et al. (2021) note, on the other hand, that most battery revenue in Australia currently originates from participation in the ancillary markets. At the same time, the authors observe that “batteries displace gas generator bids on the wholesale market, resulting in wholesale-market outcomes with potentially lower peak prices than outcomes without batteries would have.”

Estimating the economic value of batteries, including community batteries especially resulting from ancillary market operations, requires considering the development of ancillary market prices, as well as the ability of batteries to prevent blackouts, thus avoiding financial losses due to lost load (de Nooij et al., 2007; Carlsson & Martinsson, 2008 and Carlsson et al., 2011). The economic and social benefits batteries may provide in deferring network investments, lowering network congestion, and thus network costs to customers are areas requiring further research.

Key Areas for Future Research:

2.14 What is the societal/economic value of community batteries over and above the profitability of the battery's value (to the owner)?

2.15 How can communities access suitable tools to be able to understand and explain the complexity of whether a community battery is economically of interest to them?

2.3 Work Package 3: Planning and design

This work package focuses on identifying the most impactful research projects through which microgrids, community batteries and VPPs could be planned and designed using state-of-the-art knowledge. Key research objectives were to identify regions and areas most suitable for microgrids and VPPs singly or combined and with and without community batteries, integrate these power system components to minimise grid impacts, and identify the potential of integrating microgrids, VPPs and community batteries.

Microgrid selection – How do we determine what should be 'micro-gridded'?

Beyond PV/win/battery: Holistic framework for DER including various generation and storage technologies

While the vast share of distribution-level (small-scale) energy storage requirements is currently being met by battery storage systems, other emerging alternative storage technologies are increasingly being deployed in pilot studies around the world. Distributed rooftop photovoltaics (DPV) is a major driving force of the rapid growth of the renewable energy addition, and already in double-digit figures (IEA, 2022). This trend will pose excessive stress on the distribution networks. Curtailment of the DPV will be inevitable unless effective remedial actions are taken soon, such as deploying storage systems to release congestion in the distribution networks. On the other hand, storage systems can serve as a non-wire alternative to reduce or avoid the need for conventional network augmentation investments (Lowder & Xu, 2020). Li-ion battery storage systems are already playing a key role here. Thermal and mechanical energy storage systems are viable alternative options to a market dominated by electrochemical technologies. The use of hydrogen as a storage system is also increasing on other continents. Hybrid energy storage systems are increasingly being deployed to optimise the cost, performance, response time and aging rates of different storage types (McDermott et al., 2022; EIA, 2021; IEA, 2021; Nedd et al., 2020; METI, 2021).

A 110-meter-tall infrastructure construction by Energy Vault at the Swiss city of Ticino is one example of an existing gravity-based energy storage system. Energy Vault has begun a test program that will lead to its first commercial deployment in the coming years. Another start-up, Gravitricity, plans to build a 4 MWh gravity-based storage facility on a UK brownfield site upon successful completion of a 250 kW demonstrator test run in collaboration with Huisman (ReNews, 2022) at the industrial area of Port of Leith, Edinburgh, Scotland (More, 2021). A similar concept employing rail cars is planned for use in California, USA (CAISO et al., 2021). A PV and battery-powered, small-scale pumped-hydro complex is under construction in Walpole, Western Australia. This hybrid energy storage system with a capacity of 1.5 MW/30 MWh utilises two farm dams located on two elevation levels adjacent to each other. A solar PV-charged battery system supplies the power for the pumping action with the interconnection to the grid. This system is part of a microgrid and serves about five hundred local customers (Western Power, n.d., Walpole Pumped-hydro Microgrid Project).

Liquid air energy storage (LAES) systems deployed across distribution networks are also key alternative storage systems that can be used to enhance the hosting capacities of a distribution network. Due to the non-dependability of the geographic location and the compact system arrangement, a LAES can be placed anywhere in the distribution network on a scale sufficiently small to match the power ratings of distribution feeders. Studies are underway to co-locate LAES systems with data centres as a potential cooling load (Arrell et al., 2022).

Compressed Air Energy Storage (CAES) technology has gained much attention in the recent past and the focus now has been moved to Advanced-CAES. A 1.75 MW/10 MWh Advanced CAES (A-CAES) system plant was recently completed by Hydrostor in Canada and has been contracted to provide the local system operator with peaking capacity and ancillary services. The same company has also recently announced a 5 MW/10 MWh A-CAES system expected to be online in coming years in South Australia and contracted to provide load levelling, frequency regulation, and system inertia (ARENA, 2019a). The Los Angeles Department of Water and Power is developing a hydrogen project at the existing intermountain coal power plant site, which will be retired in 2025. The coal power plant will be replaced with a new power plant that can run on natural gas and hydrogen. The plant will transition to run on 100% hydrogen in 2045. Green hydrogen will be produced by utilising the power generated from the wind power plants and stored at the caverns in the region (CAISO et al., 2021). The Clean Energy Innovation Park (CEIP) being built by ATCO at Jandakot, Australia, stores 500 kWh of energy produced by a 300 kW capacity solar PV farm in batteries. The surplus renewable energy is used to power an electrolyser. Hydrogen produced must be stored or pumped into the microgrid as a sole fuel or combined with natural gas (ATCO, n.d., Clean energy innovation hub).

Emerging energy storage technologies like gravity-based storage systems or liquid air energy storage systems could be placed anywhere in the distribution medium-voltage network owing to their geographic flexibility. Pumped-hydro energy storage systems have evolved during past few decades. Closed loop small/micro-scale pumped-hydro storage systems are another alternative storage type that can be deployed in urban areas by utilising the height difference of the high-rise buildings. Combined deployment of these alternative storage systems with battery storage systems could lower their cost while reducing the carbon footprint in the coming decades.

Key Areas for Future Research:

3.1 What are the most critical performance indices that should be considered in comparing energy storage in different time scales (e.g., seconds, minutes, hours, days, etc.)?

3.2 How are the cost and performance of different storage technologies predicted to evolve in the next 10-to-15-year horizon?

3.3 How does the value of an energy storage system degrade, or upgrade based on the geographical location (e.g., urban, suburban, and remote)?

3.4 What is the best way to combine the performance indices considering the variety of types, time scales, implementation years, locations etc.?

Customer views on benefits, desirability and risks of micro-gridding

Social research following the 2009 bushfires in Victoria identified that consumers were prepared to fund electrical bushfire prevention measures through power bills to a value of around $100 per annum:

"… customer research indicates that customers want increased safety with minimal cost increases. It revealed that customers, on average, are only willing to pay 8 per cent more (or $25 per quarter for an average household) with no deterioration in the reliability of the electricity supply…" (PBST, 2011)

This provides valuable insight not into the microgrid concepts and technologies specifically, but into the premium of cost (or supply risk) that consumers may be prepared to pay for microgrid benefits with respect to bushfire prevention. It also highlights that reliability may always be a strong concern (positive or negative) for microgrids, at least when looking at the question of augmenting or displacing conventional supply.

The survey paper by Hirsch et al. (2018) largely takes a system rather than customer-centric view of microgrids and emphasises the North American experience. It notes that the customer-centric reliability/resilience value proposition relative to impacts of natural extremes is driving north-eastern US investments. Similarly, Monash University (2019) surveys benefits and value streams for microgrids but essentially covers what rational customers should come to value, not what customers and potential customers are actually saying. Much of the literature on microgrids follows suit. News articles such as (ABC News, 2019) provide anecdotal evidence of community support and value for microgrids. Further literature searches and/or primary research are required to bring to light additional primary-source information of customer views about microgrids in an Australian context.

The Community Microgrids and Sustainable Energy Program (CMSE) run by the Department of Environment, Land, Water and Planning (DELWP) and Ausnet in Victoria has been undertaking extensive community consultation regarding microgrids in particular areas (Corryong, Mallacoota and Omeo) (Engage Victoria, 2022). Energy reliability and bushfire risk-reduction are the prominent motivation. The results of this consultation, which concluded in January 2022, are not yet public but would be of extreme interest to the CRC. The customer proposition relating to these microgrids is amongst the strongest in Australia due to the nexus between remote rural energy resilience and fire prevention.

Key Areas for Future Research:

3.5 How can DELWP and AusNet's findings in relation to community microgrids be used in RACE for 2030 research projects? Are existing studies such as DELWP and Ausnet's findings in relation to community microgrids sufficient, or are new studies needed?

What are the economic aspects of micro-griddable regions?

Three types of microgrid projects are prevalent:

1. Rural microgrids. These are microgrids in remote areas which are far from power grids.
2. Microgrids at the fringe-of-grid. There are several sites in WA where grid connections are very weak. These are typically mining towns.
3. Urban microgrids. These are microgrids that are connected to or embedded in urban electric supply systems.

Usually, rural areas are electrified through diesel/gas generators, and the cost of diesel (or gas) is high due to transport costs. Furthermore, both transport and use of fossil fuels in generators produce greenhouse gases that are detrimental to the environment. In Australia, there are numerous such areas where the population density is very low. However, most of these areas are rich in solar power. Therefore, it is possible to electrify such small communities through rooftop PVs (or small solar farms) and battery back-ups, using diesel generators as back-up. The cost of PVs, battery energy storage system (BESS) and associated power electronic converters will rapidly decline, whereas the volatility of fuel prices will be more severe in the near future. Therefore, over a period of 20 years, the overall cost of electrifying such areas using PV and BESS will be less than using diesel.

The semi-urban towns that are at the fringe of grid experience power quality problems such as temporary voltage sag/swell, harmonics, overvoltage/undervoltage, voltage flicker and temporary or sustained interruptions. Usually mining towns/sites also have captive generation using diesel generators and their power consumption levels can be high. Therefore, any microgrid planning for these areas must consider solar and windfarms to cater to the mining load demand. Unlike in the case of rural microgrids, the cost-benefit analysis for such microgrids must be carried out, considering the environmental impacts and the cost of poor power quality.

Recently, a new paradigm has begun to evolve that comprises a no-wire alternative (NWA) (Deboever et al., 2018). The main objective of NWAs is to use distributed energy resources (DER) and microgrids that can defer, reduce and/or avoid grid expansion. This can be beneficial from both economic and environmental points of view. Non-wire alternatives can avoid increased loads on transmission and distribution infrastructure, and climate-related events such as heat waves resulting wildfires can be avoided using DER and microgrids that are restricted to specified regions. The NWA can be extended to urban power distribution systems, especially those in new development areas and in areas where the infrastructure is old and requires replacement. Moreover, using this new paradigm, the older thermal generation units can be retired. Substantial financial savings can be made from the avoided construction of new generation plants and the erection of new transmission/distribution lines.

In remote rural areas, microgrids can benefit isolated communities such as those in the Victorian Alps, especially once distribution infrastructure has reached expiry or has been heavily impacted by fire events, as was the case in 2019-2020 (Engage Victoria, 2020). Where Australian distribution networks are required to consider non-network options to solve challenges such as capacity issues in urban or rural settings (AER, 2013), microgrids clearly factor amongst these solutions and can become economic alternatives.

Urban distribution systems in growth areas at the (expanding) urban fringe are not infrequently at, or beyond, design capacity limits. This can be exacerbated by technical requirements on HV distribution electrical protection systems for bushfire prevention (e.g., Rapid Earth Fault Current Limiting–REFCL), as per Victoria's Energy Safety Regulation Amendment 2016, which applies in these locations. Microgrids provide an economical solution for maintaining supply to clusters of (currently HV) rural customers beyond the urban fringe, enabling heavily loaded (and/or high proportion underground cable) urban fringe zone substations to accommodate (or avoid) REFCL protection demands.

Key areas for future research:

3.6 How can the maintenance of microgrid assets in rural and remote areas be assured to prevent any fire risks?

What are the technical aspects of these regions?

Rural off-grid microgrids require back-up power generation. Even sun-rich sites experience series of cloudy days, especially during the rainy seasons. Therefore, microgrid planning and sizing in such areas must consider storage sufficient to meet demand continuously for at least three days, and back-up diesel generation needs to be considered in case of contingencies. The operational strategies of such microgrids are simpler than grid-connected regional microgrids. This is because they can be controlled by local controllers without the use of elaborate communication infrastructure.

The strength of a grid is defined by the short-circuit ratio, which determines the voltage stiffness of a grid. Usually, synchronous generators or condensers are good sources of system strength, while power converter-based resources are weak sources. A strong system can return to normal operation quickly following a fault or large disturbance. A microgrid that is connected to the fringe of a grid can face a large voltage disturbance following a fault on the grid side. Therefore, it needs to isolate quickly and operate in standalone or autonomous mode. The islanding and resynchronisation processes are the biggest technical challenges for such microgrids. The DER in a microgrid is usually controlled by primary controllers. In relatively large size microgrids, secondary controllers are used as microgrid energy management systems. Again, secondary controllers can be centralised, decentralised or distributed. The major technical challenge, apart from sizing of these microgrids, is the design of secondary controllers. A centralised controller may need an extensive communication system, whereas the requirement of communication systems is much reduced in distributed control, where each DER is required to interact with only its neighbouring DER.

For urban microgrids, two options are possible – (1) greenfield microgrids that can be installed in new area developments, and (2) retrofitted microgrids in existing residential areas. It is also possible to have grid-connected urban microgrids in large office blocks or shopping centres. A greenfield microgrid is somewhat easier to develop since it can be planned at the design stage. Retrofitting a microgrid is a challenging task due to the presence of inbuilt prosumer-owned rooftop PVs and/or battery storage units that are already present in the distribution networks. A retrofitted microgrid needs to coordinate with these prosumer-owned resources, with additional generation and storages to balance the system operation. Another important area for further research is the distributed control of power flow in a microgrid by using hierarchical control layers. Such control methods can also be applied to control grid-connected, highly renewable energy zones.

Key areas for future research:

3.7 What level of controllers is required for each type of microgrid so that it operate reliably irrespective of the environmental conditions?

Interactions in local DER network solutions – What kind of interactions take place between virtual power plants/DER aggregators and microgrids in their different forms?

Are the consumer expectations and engagement pathways the same or different for VPPs and microgrids?

The future success of emerging renewable, energy-based businesses depends on the value of the services provided in this dynamic new environment. This value can be developed based on a clear understanding of the various requirements, preferences and priorities of energy consumers. The objective must be to discover what consumers genuinely want rather than what businesses think they want. Adjusting consumption patterns and employing behavioural change in search of optimised DER requires consumers' engagement. Consumer expectations can vary based on their current situation and experiences. Three main expectations are likely to be enhanced reliability, reduced energy cost, and addressing of some environmental concerns (Debouza et al., 2022). Microgrids and VPPs share some aspects but differ in how they connect to the grid. As such, microgrids can probably better handle reliability concerns. As an example, residents of Kalbarri, a coastal town in Western Australia, used to experience repeated power outages (mainly during hot months) as the city is connected to the grid via a 140 km long rural feeder line from Geraldton (Western Power, n.d., Kalbarri microgrid). Installing the

Kalbarri microgrid with a capacity of 5 MW satisfied the main expectation of residents, which was improved reliability. This grid-connected microgrid can immediately respond to any fault in the upstream system to minimise disruptions. When a disconnection occurs, consumers are notified by text messages and encouraged to decrease their demand. In other situations, where reliability concerns are negligible, VPP would be preferable to coordinate the integration of green DERs and provide access to a broader energy market (Bhuiyan et al., 2021).

Consumer expectations and engagement pathways in relation to VPPs and microgrids can be most accurately captured via surveys in relevant areas. Identifying incentives that would motivate consumers to enhance their engagement in microgrid and VPP implementation is critical. Consumer surveys would also provide highly useful insights into consumer expectations of VPPs and microgrids and the best ways of educating consumers about what each network solution can deliver.

Key Areas for Future Research:

3.8 What are the consumer expectations and engagement pathways for VPPs and microgrids, and how are they influenced?

3.9 What incentives can be offered to increase customer engagement?

3.10 How can using digital visual systems and developing mobile apps enhance customer engagement, mainly in VPP-related activities?

What are the different business models for VPPs and microgrids and how can they be harmonised when they overlap?

A business model could be defined in terms of a firm's value proposition and market segment, the structure of the value chain required for realising the value proposition, the means of value capture that the firm develops, and how these elements are connected in an architecture. To make a critical comparison, and to demonstrate a holistic view of business models, six components were considered:

- Strategy (the goal of foundation or creation of VPP and microgrids)
- Resources (the type of DER and their number, total capacity and other resources such as software, human and financial)
- Network (key partners like energy utility, energy producers, commercials, industries, municipalities, gas suppliers and infrastructure owners)
- Customers (e.g. residential and commercial)
- Value propositions (a proposition of added value for owners and consumers, e.g. energy security and lower energy cost), and
- Revenue (the sources of revenue, e.g. typical services such as storage and energy reserve, and revenue streams) (Ropuszyńska-Surma & Węglarz, 2019).

The business models for VPPs and microgrids can be categorised based on their architecture in order to provide different services as follows:

- Managing prosumers' DER. In this VPP-and-microgrid architecture, a prosumer's assets are optimally managed by the cooperation of multiple agents considering a demand-response program (AGL, 2020).
- Provide ancillary services. This VPP-and-microgrid structure delivers a tool for distribution system operators (DSO) in order to provide ancillary services by the participation of customers, distributed resources, microgrids, and energy storage systems (ARENA, 2021a).

- EV and batteries fleet management. VPPs and microgrids can help control unnecessary electricity costs by moderating load surges from fleet charging while creating new DER revenue streams based on the same loads previously viewed as a problem. This is a win-win scenario. Uncontrolled EV loads drive up peak demand, increasing costs for the host site and across the entire utility service territory or balancing region (ARENA, 2022a).
- Aggregating buildings. In this VPP-and-microgrid architecture, several building energy resources are aggregated by using a reliable communication system which interconnects the energy management system of a VPP and a building energy management system (Asmus, 2019).
- Peak-demand management. As peak demand occurs for a few hours in a year, and all network infrastructure is built to meet that maximum demand, it is generally very expensive. The conventional solution to supply peak load is to build higher network and generation capacity which incurs significant capital cost. This issue can be addressed by using VPPs (ARENA, 2022a).
- Auto-grid VPP-data driven VPP. Optimised market bids are enabled by the creation of a merit order considering the marginal costs and forecasted availability of each asset (ARENA, 2021a).
- Technical virtual power plant (TVPP). The TVPP is utilised mainly in the same geographical area as the transmission and distribution level to provide different technical benefits (e.g. management of local network restrictions, supply-demand balances, energy flows, etc.). The main barrier of implementing TVPP is that it requires the detailed knowledge of a network's structure and operating conditions (ARENA, 2021a).
- Commercial virtual power plant (CVPP). DER are considered commercial entities in this structure and participate in the market on the basis of the price and quantity of energy they can provide, thus optimising and maximising the return. The production and consumption of energy is forecast based on the weather condition and demand profiles (AGL, 2020).

Key Areas for future research:

3.11 What business model framework can ensure that economically viable VPPs are deployed at a commercial scale?

3.12 Which business model can reduce the payback period of large-scale batteries to increase the investment in VPPs and microgrids?

3.13 What are the preferred criteria for defining the owner-occupier/tenant split by location to better inform opportunities for DER participation in a business model?

Planning for microgrids – How do we streamline assessment process for local DER network solutions

How does implementation of energy efficiency improve or change the microgrid business case and solution characteristics?

Where microgrid consumers look for energy efficiency, it is reasonable to expect that the emergent (and un-constrained) load and generation profiles (over time) of consumers/nodes will change over time, and that the total load will continue to reduce because the local energy production has been increased. The business case for a microgrid will be parameterised by total load, imported and exported energy, and the costs of various capacities of microgrid elements. Changes to these parameters will change the business case, but whether the case is weakened or strengthened will be specific to the situation.

As is being identified in the RACE for 2030 'Opportunity Assessment: Energy Productivity', energy efficiency, especially in industrial and commercial settings, requires monitoring, control, analytics and other innovations to be rolled out (which could be thought of as Industry 4.0). It is therefore reasonable to expect that microgrids covering parties proactive in energy efficiency will be more technically capable with respect to energy management and energy demand/supply prediction. This provides more 'levers' for microgrid operational management (therefore, greater flexibility and optimality), and more certain operational decision-making due to better real-time analysis capability. It also lowers the risks associated with energy supply shortfalls or high energy import prices. In most circumstances, greater proactivity in energy efficiency will strengthen micro-grid business cases because capital requirements and operational cost spikes may be diminished. However, some business cases may depend on higher energy consumption levels for the capital investments to be attractive, especially when the available generation or storage nameplate capacities are of discrete sizes and can exceed the needs of an energy efficient microgrid.

Key areas for future research:

3.14 How are the capital requirements and future operation of a microgrid affected by the degree to which advanced monitoring, control and analytics (i.e. Industry 4.0 technologies) are adopted by commercial and industrial participants?

How do planning and operational frameworks interact for microgrids and embedded microgrids?

IEEE Recommended Practice for the Planning and Design of the Microgrid (2019) presents a set of guidelines for microgrid planning. According to this standard, the main tasks are to determine the configuration of the DER, electrical network structure and the automation system configurations. Also, the load profile. Energy demand and demand growth should be considered at the planning stage. There are five critical aspects that should be considered at the planning state. These are:

- Planning objectives in terms of economic benefits, reliability, and environment. While economic benefits and environment are self-explanatory, the reliability aspect must consider the rate of load loss, demand not supplied, as well as customers requiring uninterrupted power.
- Load forecasting that can contain peak load demand, peak growth demand, load classification and load modelling.
- Power generation forecasting that can contain resource analysis and power output forecasting based on historical weather data or forecasting.
- System configuration that has near instantaneous of balance of power supplied and load demand and has strategically placed generators and resources to meet this requirement. The other types of generation and storages can also be considered such combined heat and power (CHP), which is not critical for most parts of Australia and compressed air or pumped hydro storages.
- Safety of general public and microgrid system operators.

Key Areas for Future Research:

3.15 What are the critical aspects of planning of a microgrid?

3.16 Is there a general guideline that can be followed, irrespective of the type of microgrid?

How can low-voltage/medium-voltage (LV/MV) network planning and operations be enhanced to support overall consumer needs and economic efficiency in the presence of microgrids?

As mentioned earlier, non-network solutions such as microgrids must be considered when network capital investments are being proposed (AER, 2013). The key question here concerns the methods and tools available to network owners/operators and their service providers that can be used to establish apples-to-apples comparisons. A holistic and complete structure is needed to systematically evaluate the benefits (and downsides) of microgrids. To aid this evaluation, LV/MV network solutions proponents, regulators and other stakeholders need to be able to make repeatable and reliable assessments, and to build expertise in doing so across a series of projects to build efficiency and accuracy. The structure outlined in a white paper by Monash University (2019) would offer an excellent starting point which is already suitably tuned to the Australian context. Methodological repeatability/familiarity and accuracy in cost and benefit assessments will be a major enabler of investor and regulatory acceptance of microgrid proposals.

Analysing the ability to integrate network and microgrid technical evaluations (including power systems simulation) is a necessity for DBs (Distribution Business) and other technical parties. Such evaluations must be able to quantitatively estimate network reliability for consumers (residential, commercial and industrial). The tools used must be able to explore the extreme conditions and events that challenge reliability.

Questions of network operations and microgrids intersect when microgrids are integrated with, and not isolated from, distribution systems. Relevant literature includes Islam et al. (2021), Madani et al. (2017) and Flores-Espino et al. (2020). Operational questions span the active control of load, embedded generation, and voltage and network switching for maintaining supply and power quality. They also include microgrid and network coordination to maximise the operational robustness to rare events including equipment failure, unexpected load and generation excursions from predictions, and the bushfire prevention performance of rural and peri-urban sections of the network.

Key Areas for future research:

3.17 What role might the CRC have in establishing systems and tools to estimate microgrid benefits that are suitable for supporting regulated investments in the Australian electricity system?

3.18 What role might the CRC have in informing or proposing changes to AEMC rules that are relevant to microgrid operations?

3.19 Should the CRC, in collaboration with international partners such as NREL, pursue operational decision support tools/systems for both the DB and microgrid sides of interconnected distribution network and microgrid systems?

What new computational methods and algorithms are needed to operate VPPs and microgrids?

Scheduling the operation of VPPs and microgrids is essential to minimising the operational costs and to ensure that VPPs and microgrids meet the design requirements (e.g. stability, reliability, power quality and security). Optimal scheduling and energy management systems (EMS) play a significant role in this. To optimise the operational scheduling of VPPs and microgrids, a well-defined objective function is needed that is subject to a set of constraints considering environmental and social factors (ARENA, 2021c). This can be considered a multi-objective problem that requires computational methods and algorithms to optimise the VPPs/microgrids' operation scheduling. Choosing the best computational method and algorithm will comprise a trade-off between the simplicity, accuracy, and computational burdens.

Several computational methods and algorithms to formulate optimal operation scheduling of VPPs and microgrids have been used in the literature. Based on the way of handling the optimisation problem, these methods and algorithms could be categorised into classical and artificial intelligence methods. The classical methods require explicit models and formulations to provide the optimal scheduling of the operation. Although the classical methods and algorithms are mostly used in practical projects such as in the Advanced VPP Grid Integration Project (ARENA, 2021a), they lack critical visibility of the data and assumptions, leading to grossly incorrect results. In addition, these methods require long computations, which may negatively affect the digitalisation of the VPPs and microgrids. Therefore, there is a need for faster and more accurate methods and algorithms to be able to adapt the operation of VPPs and microgrids with the digitalisation of power systems.

Artificial intelligence methods and algorithms are showing promising results in academic research. They can improve the operational scheduling of VVPs and microgrids, respond faster to the operator's and market signals, and communicate with the control devices accordingly (Makhadmeh et al., 2019). AI methods and algorithms can be classified into optimisation-based methods (e.g. heuristic and meta-heuristic methods) and learning-based methods (e.g. machine-learning and deep-learning methods). Heuristic techniques aim to achieve a specific result for a problem that is tested extensively experimentally, creating a trade-off between the solution's accuracy and the computation cost and speed. Although the final answer cannot be guaranteed as the optimal solution, the computational burden is reduced compared with mathematical methods.

Meta-heuristic approaches are high-level procedures designed to solve optimisation problems without specific knowledge about the problems by combining multiple heuristic methods to reach an optimal or near-optimal solution (Fiorini & Aiello, 2019). Several new heuristic and metaheuristic methods and algorithms can be implemented including:

(a) Point Estimate Method (PEM) to optimize the scheduling of a VPP operation connected to a wind-photovoltaic storage system

(b) Particle Swarm Optimization (PSO) to optimise the operational scheduling of a VPP as a single-objective optimization considering costs and GHG emission

(c) Binary Particle Swarm Optimization (BPSO) for scheduling microgrids where integrated VPP focusing on energy saving, and

(d) Genetic Algorithm (GA) for selecting the best solution to day-ahead scheduling of VPPs.

Therefore, further research is needed to evaluate the effectiveness of the heuristic and meta-heuristic methods and algorithms in providing good solutions with acceptable margins of error within a short and speedy computation compared with the classical methods.

Machine-learning and deep-learning methods and algorithms are showing promise in various science branches as no significant expertise is necessary to use these approaches compared with the classical methods. Due to the big data challenges provided by modern power systems in addition to the complexity, velocity, and computational burden of conventional optimisation methods, learning-based methods and algorithms have been broadly utilised in scheduling problems. Three main categories of machine-learning methods and algorithms include supervised learning, unsupervised learning, and reinforcement learning (RL). In addition, deep-learning methods and algorithms have recently been prevalent in optimising operation scheduling. Deep-learning-based techniques, including convolutional neural network (CNN) and recurrent neural networks (RNN), have indicated remarkable capability in feature extraction, function approximation and representation learning (Rouzbahani et al., 2020). These methods and algorithms can save both time and effort in scheduling the operation of VPPs and microgrids. While they also do not require explicit models, their accuracy depends on the volume of the provided data.

Key Areas for future research:

3.20 What methods for scheduling the operation of VPPs and microgrids in Australia should be recommended, given the limited visibility and uncertainty of DER?

3.21 What is the optimal/least-cost mix of data and modelling required to optimise the scheduling of the operation of VPPs and microgrids with sufficient accuracy?

3.22 What are the most appropriate combinations of forecasting methods and control strategies to digitalise the operation scheduling of VPPs and microgrids?

What are the benefits of DER Management Systems (DERMS) for flexible DER integration in a microgrid setting?

The proliferation of renewable energy-based DER can cause issues such as sustained over-voltage and significant voltage fluctuation. Such concerns can be addressed by implementing a flexible interconnection enabled by a distributed energy resources management system (DERMS) to allow more DER connections with a minimal reduction in productivity for the owners (Peppanen, 2021). Basically, DERMS can apply proper dispatch and curtailments to the DER output to ensure containment in the time-varying hosting capacity. The main features commonly observed in the existing system evolution are interoperability, systems integration, and a significantly increased level of data connectivity (Razon et al., 2020).

A DERMS can fulfil the aggregation of many DERs, including power sources and demand response. Implementation issues, recommendations, functionality, and the interoperability requirements of a DERMS with its environment are discussed in IEEE (2021). The DERMS aims to aggregate and dispatch several DERs, along with the coordination of their operation and optimisation of their output. Aggregating DER can be a practical approach to successfully integrating DER into the planning and operation of power networks. A DERMS would require a reliable communication infrastructure to establish secure, real-time communications to all DER to direct them to satisfy the network requirements (Albertini et al., 2022).

The essential functions of a DERMS that can characterise it are listed as follows:

- Aggregating many individual DER to present them as more manageable aggregated virtual resources for the appropriate location
- Simplifying data complexity of DER to provide grid-related services
- Optimising the DER and the existing infrastructure utilisation in different physical locations to obtain the optimal outcome at a minimum cost with the best performance and quality

- Translating different languages of DER to present them cohesively to the upstream calling entity. It is to be noted that individual DER are of different types and scales and may speak other languages.

The techno-economic value DERMS-based interconnection of PV generators to distribution feeders is analysed in Peppanen (2020), who evaluates the effectiveness of using DERMS to avoid system upgrades due to thermal overloads to demonstrate the economic value of such an arrangement for different PV system capacities. Onslow's microgrid is one of the first DERMS-based pilot projects to energise remote communities by harnessing solar power (Horizon Power, 2021). Horizon Power has implemented the project with PxiSE Energy Solutions and reported promising outcomes.

Some Key Areas for Future Research:

3.23 What are the benefits of DERMS in terms of improving network performance and hosting capacity compared to network solutions and augmentation?

3.24 What are the interoperability considerations and communication protocols for DERMS in microgrids with heterogeneous resources? What should be the failsafe settings for DERMS?

3.25 How would DERMS incorporate network export/import dynamic limits?

Integration of local DER network solutions – How do we integrate microgrids, VPPs and community batteries?

How do you combine the value of microgrids, VPPs and community batteries?

Microgrids can generally be defined as a combination of distributed generators and interconnected loads that can be considered a single controllable entity from the grid point of view due to distinct electrical boundaries (Cox et al., 2016). A VPP is an optimal integration of various types of power generators, energy storage systems and loads of different sizes and complexities that can cover a geographically vast area in order to meet the stakeholder's technical and commercial requirements (Venegas-Zarama et al., 2022).

Despite their different objectives, microgrids and VPPs may still overlap (Yavuz et al., 2019). An embedded microgrid is mainly characterised by a confined network boundary, connection to the grid via a single point of connection, and the possibility of disconnecting from the grid to operate autonomously. Microgrids are formed mainly to create self-sufficiency and improve the reliability of the targeted area by incorporating various types of DER and promoting demand response potentials. Microgrids can participate in the retail market, but the main goal is adequate self-supply. In contrast, VPPs can span a much wider area and resize depending on real-time market conditions (Khan, 2022). VPPs are always grid-tied and have been introduced to smoothen the integration of renewables without compromising the grid stability. VPPs can reduce their own energy costs while also contributing to the reliability of the larger utility grid.

A microgrid has the option of participating in a VPP as a single entity. In other words, VPPs can see a microgrid as one of several prosumers to be coordinated along with the other participants. The VPP coordinator would act as the tertiary-level controller of the microgrid/cluster of microgrids to address the optimum value of power flow through the microgrid point of connection. The primary and secondary level control of microgrids would be done internally to properly share the demand among the local DER. Such a scenario is yet to be proposed and evaluated. Various other combinations and scenarios can also be developed and elaborated upon.

Some Key Areas for Future Research:

3.26 What is a holistic business model for a hybrid VPP/microgrid/community battery system? What additional technologies and energy management strategies are required for such a system?

3.27 How can the VPP coordinator act as a tertiary-level controller for a microgrid given that a tertiary-level controller also needs to consider other additional aspects, such as weather forecasting, markets and line capacity limits?

Economic value of capacity firming using renewable energy when supply and demand can be best matched by aggregating microgrid and community battery operation.

Economic value is a calculation of the profits an asset has produced or may produce in the future. It is a measure of the benefit a service or technology provides to the customer. However, the concrete economic value in such a system depends on many variables, including the different types of interconnected DER, the grid's location and to what degree is it receiving renewable power, the interconnection of the microgrid (embedded or islanded), the sizing of the community battery and the microgrid battery and others. Therefore, the economic value and potential of profitability of a system can only be estimated based on current projects and their findings.

The first Australian community battery trial by Synergy (Western Power, 2018, Our community battery storage trials) took place in Meadow Springs, WA. Forty-four residents virtually stored excess solar power during the day and consumed it in the evening or overnight via access to a community PowerBank battery. The results from the trial showed a daily average of 7.3 kWh of energy stored and 5.2 kWh consumed for each participant. By selling the remaining 2.1 kWh to the grid, each resident saved an average of $228 and more than $11,000 saved on power bills across the entire trial. This made the community battery a cheaper option compared to home batteries. The trial not only proved that community battery saves money, but it also supports the grid, making it a viable option for future applications.

According to research conducted by ARENA, microgrid initiatives that utilise solar power and batteries have installation costs of less than $4 million per megawatt of capacity. While the initial investment required is high, the savings potential is considerable. The levelised cost of energy (LCOE) for microgrids, according to the International Renewable Energy Agency, IRENA, falls within the range of 10-15 cents per kWh (Solar Bay, 2020). This is 50% less than the cost of electricity produced by diesel generators at about 40 cents per kWh (Solar Bay, 2020). Over time, the cost of electricity from a microgrid is expected to be substantially lower than the cost of the existing electric services. Both community battery and microgrid projects have proven to substantially cut costs of electricity and power consumption compared to the existing power grid. However, in order to provide an accurate estimate of economic value, the interconnection of the two systems must be further studied.

Key Areas for Future Research:

3.28 Could the economic value of battery storage within a microgrid be increased by decentralising via the implementation of community batteries in the way of CBs? This needs to be investigated by considering the change in technical performance as well.

3.29 What is the best way to determine the size of storage capacity needed to ensure the economic benefits to the prosumers are optimised?

3.30 Given that the storage, generation, and demand are fixed, how to develop an automated control system to use only the most economical energy options at a given time?

What are the economic value streams?

The economic value streams offered by MG, VPP and Batteries and integrated system are summarised in Table 10.

Table 6. Summary of economic value stream offered by microgrids, VPPs and batteries individually and integrated

Type	Value Streams	MG	VPP	Batteries	MG-VPP-Batteries
Direct value streams	Demand response				
	Power-export				
	Resilient and reliable supply		-	-	
	Local/Peer Energy Trading			-	
	Energy Arbitrage				
	Ancillary - FCAS				
	Ancillary - voltage				
	Subscription/Partnership	-			
	Import	-			
Indirect value streams	Increased hosting capacity				
	Reduced energy losses				
	Upgrade deferral				
	Congestion relief				

Microgrids offer the main value streams, including enhanced supply resilience and reliability, demand response management (price and event-based incentives and direct/indirect benefits), power export, and ancillary and network support services (Stadler et al., 2015; Monash University, 2019; Wright et al, 2022).

Virtual power plants' key value streams include subscriptions (or partnerships), energy arbitrage, local and peer energy trading, and power export participation (AEMO, 2021b).

Community batteries' key value stream includes subscription, participation in demand response management, power export and import, arbitrage, and ancillary and network support service (ANU, 2020b; Shaw et al., 2020; KPMG, 2020).

Microgrid-VPP-batteries: It is expected that the combination of microgrids, VPPs and community batteries will result in a mixture or hybrid of the individual value streams of the different technologies. An integrated system will likely lead to more efficient management of distributed storage resources and other connected assets. There are currently no known combined trial systems in operation or being tested.

Current theoretical and actual projects are providing limited or no evidence on to what extent and how these different value streams contribute to the overall microgrid, VPP and community battery revenue/profit for the owner/operator and its customers. It is not yet known whether any individual or combined system is the most viable energy solution (business model) compared to other related energy business models (e.g. stand-alone solar PV and battery systems). These streams need to be quantified theoretically and practically (through demonstration projects) for a range of current and future technology costs and operating and regulatory scenarios.

Key Areas for Future Research:

3.31 Do value streams exist that can be used for these technologies, microgrids, community batteries and VPPs individually or in combination as well as combined?

3.32 What is each value stream's significance (impact) on the economic viability of individual systems and a combined system?

There is a need to quantify these streams theoretically and practically (through demonstration project(s) for a range of current and future technology costs and operating and regulatory scenarios.

3.33 What is the cost of indirect value streams, and how do we evaluate these costs?

What are the constraints on providing services into each value streams?

Exploiting the full potential of microgrids, VPPs and community battery systems individually and in an integrated format requires a policy and regulatory reform. Key constraints associated with each system and their specific value streams are summarised below.

Microgrid constraints (Monash University, 2019; Wright et al., 2022)

Essential service and service performance. There is a need for clear and transparent policies for the authorisation and governance of microgrids, and in particular to address the provision of essential service and protections and service performance to provide choice, affordability and supply reliability to microgrid participants. Further policies are required for defining the status and authorisation of the microgrid owner or operator, the appropriate form of legal and contractual relationships between the parties, and microgrid customers' rights.

Network transformation and access. Network transformation must provide the right to connect microgrid resources to the existing network, determine the value of network services, and lower losses and wholesale prices. A carbon pollution reduction policy is required to facilitate energy efficiency and enable efficient investment in renewable energy.

Regulatory constraints. Microgrids need a dedicated owner and operator who is licenced to engage in distribution and retail activities. Licensing is a compulsory requirement for microgrids that utilise existing supply networks with many residential customers (10 customers on a single site). In addition, some regulatory constraints directly impact the microgrid-specific value streams. For instance, power export and local peer trading require an exemption or a special license. In Victoria, power export (selling) in the NEM can be through VPP/small generation aggregator (SGA) or requires registration with NEM as a wholesale market participant.

Other constraints. Microgrids in Australia are in the pre-feasibility and early trial stages. Currently, there is limited evidence from real projects on the extent to which, and how, these different value streams impact/contribute to the overall microgrid revenue/profit for the owner/operator and its customers. It also remains to be established whether microgrids are the most viable energy solution, particularly compared to other related energy business models (e.g. stand-alone solar PV and battery systems). Additional technical challenges include a lack of tested enabling technologies.

VPP regulatory and operational constraints

Currently, VPP operators can only participate in the wholesale energy market as an SGA. Operationally, AEMO requires batteries larger than 5 MW and generating systems larger than 30 MW in order to be scheduled through the central dispatch process, but it has no provision for the aggregation of resources (i.e. VPPs). AEMO's Virtual Power Plant Demonstration Project included an assessment of regulatory and operational arrangements that affect VPPs. The observations from this project have already fed into several regulatory processes (AEMO, 2021b).

Community battery regulatory and policy constraints (ANU, 2020b; Shaw et al., 2020; McKell, 2021)

Network charges. There is a need for a mechanism to determine the network cost for community batteries. This pricing mechanism should consider the local use of service (LUoS) (i.e. reduced local energy transport). Moreover, monetising the network and system operator services, such as the cost of network upgrade deferral, providing supply during contingencies and maintenance, and providing congestion relief and capacity reserve is a tedious task and has not yet been attempted.

Operation in a disaggregated market. Several trial projects are underway in Western Australia, where state-owned DNSPs and regulations allow buying and selling energy directly from/to customers, making the community battery model relatively straightforward. However, this is not possible on the east coast of Australia, where regulations governing the NEM currently do not allow buying and selling energy directly from/to customers. Here, the regulation for community battery trial projects needs to be relaxed to determine and introduce the necessary regulatory framework changes. Policy needs to address the possible risk of increasing inequality between community batteries and other electricity users, and there is also a lack of clarity on managing the lifecycle impact of batteries.

Key Areas for Future Research:

3.34 What (additional) policy and regulatory reforms are needed in each Australian state to implement the individual (microgrid, VPP and community batteries) and combined systems?

3.35 What specific regulatory reforms are needed to capitalise on multiple (maximum) value streams offered by the individual and combined system to exploit their full potential?

Integrated microgrid, VPPs and batteries

Embedded microgrid customers could participate in VPPs and community batteries to capitalise on multiple value steams offered by this system. However, practically such systems do not yet exist in Australia (and other parts of the world), and there is limited or no literature on such an integrated system's business and governance model. Customer participation in multiple systems is anticipated to increase the operation complexity, as highlighted below. Participation in integrated or multiple systems will require rules/mechanisms that allow for capitalising the numerous value streams offered by VPP and batteries while being part of the microgrid and without any conflict or violation of the contractual obligations.

How are consumers going to participate in the design and implementation of these schemes?

Microgrid: As the microgrid has a predefined geographical boundary and point of common coupling (PCC) with the grid, the participants must be in the same precinct and capitalise on all the value streams offered by the microgrid (IEEE, 2019). Microgrid participants subject to a contract with the microgrid owner/operator could opt to also participate in VPPs and community batteries within or outside the microgrid precinct.

VPPs: Several VPPs are already operating in Australia, with offers available to consumers. Consumers are typically engaged via subscription plans that may include subsidised battery and/or energy plans. The plans have eligibility requirements based on state residence and approved equipment (AEMC, n.d., VPP offers available). Consumer participation in the design and implementation of these schemes is currently limited to involvement in technology trials and associated feedback and surveys (Maisch, 2020; AEMO, 2021c). VPPs have the potential to benefit both utilities and customers, which may also impact and strengthen the relationships between utilities and their customers (Power, 2022).

Community batteries: Customers in the local area of a distribution feeder or substation can subscribe to a community battery service without being directly connected to the battery. The value streams offered by community batteries depend on the community battery owner and operator. Depending on the level of control of their asset and contract with the community battery service provider, the community battery participants may or may not have the choice to capitalise on specific value streams such as demand response or power import and export.

Key Areas for Future Research:

3.36 What regulatory reforms, beyond feedback surveys, are required to enable consumers to participate in the design and implementation of microgrid, community battery and VPP schemes?

3.37 How to enable customers′ participation in integrated- or multiple systems, and what rules/mechanisms are needed to allow this participation without conflict or violation of individual system objectives?

What business models emerge when combining microgrids/embedded networks and community-scale batteries in one economic model?

Various types of business models are available in the market to finance microgrids/embedded networks, virtual power plants and community-based battery storage systems. Out of many economic models available in the industry, models such as customer-owned, microgrid as a service (MaaS)/energy as a service (EaaS), peer-to-peer (P2P) and pay-as-you-go (PAYG) economic models have gained the attraction of industry in the recent past. The customer-owned model is solely relying on private sector investment while MaaS/EaaS, P2P and PAYG models are relying on the direct interaction between the private sector and the utility. For rapid expansion, these models require supportive government policy and regulatory reinforcement (Xu et al., 2021).

While customer-owned microgrids gained popularity in the past decade, there are new, upcoming business models that are gaining much attention in the industry. MaaS/EaaS, for example, facilitate the opportunity for utilities, developers and third-party financiers to strategically collaborate with customers to diversify from the traditional utility supply systems. Volumetric and capacity-based power purchase agreements may need to be signed between customers and third parties, backed with debt and equity financing from both sides. The PAYG model is also a proven model for small scale microgrid projects that require small scale capital investment (Borghese et al., 2017; Muhsen et al., 2022).

The P2P business model allows prosumers to share the benefit of low-cost renewable energy generation among consumers in the same community and makes renewable energy more accessible across the community. P2P trading models can be established among neighbors within local communities as well as among large scale communities with advanced monitoring and controlling platforms. The Sustainable Energy

Key Areas for Future Research:

3.38 How can optimum coordination be developed for a microgrid MG- and community battery-supported VPPs to achieve and take advantage of their salient features?

3.39 Use of blockchain could facilitate and ease the merging of the different business models like P2P, MaaS and EaaS. How can it be applied in the Australian context? Challenges and opportunities? Generally, where are community batteries and power banks used for energy arbitrage in Australia?

3.40 Other technical objectives can also be pursued when such batteries are included in a microgrid. Given that some of such item’s objectives can relatively compromise energy arbitrage, what are the best objectives to be considered for a combined microgrid-community battery system?

Development Authority in Malaysia is piloting a P2P electricity trading project launched in November 2019, and pilot projects of P2Ps are currently being implemented in countries across the world. P2P platform operators can enable peers to provide grid-ancillary services by transforming the local microgrids into VPPs (IRENA, 2020; IRENA, 2019a; IRENA, 2019b; Tushar et al., 2021).

Success in the deployment of the P2P business model is solely dependent on factors like reliability of the trading platform, the availability of a conducive regulatory framework, and the reliability of the external grid. In addition to the physical layer, the P2P business model also requires a virtual layer that consists of the trading market and the real time energy management system. Extensive research into the performances of the virtual layers is required that integrate and combine business models like P2P and EaaS/MaaS. The use of blockchain has rapidly emerged into the P2P energy trading and has not been fully industrialised due to a lack of exploration of the pros and cons in the P2P context (Wu et al., 2022).

How do VPPs operate in the additional presence of a grid-connected microgrid and/or community battery?

Microgrids comprise a collection of loads, along with small energy generation units, combined into a single entity that is controllable and can meet the thermal and electric demands of its local population (Mashhour & Moghaddas-Tafreshi, 2009). Akin to a microgrid, a VPP is a collection of distributed generators (DGs), along with BESS and loads, that can be controlled. VPPs and microgrids are both able to integrate demand-response programs (Ramos & Canha, 2019). However, a VPP is a wider concept compared to a microgrid.

The main differences between a microgrid and a VPP are:

Design. A microgrid focuses more on self-management through the use of DGs and controllable loads. On the other hand, a VPP is aggregated on the basis of participation, which seeks to implement collective control of DGs, controllable loads and BESS devices. The major shift in focus is inherent in that a VPP is not geographically bound like the microgrid. This helps VPPs to participate in energy markets.

Interface. Microgrid utilises a coupling switch to connect to the grid, while a VPP is a virtual collection and uses an open protocol to connect to the grid. A VPP exists virtually and therefore does not require specific hardware for its connection to the grid. As a collection of sources, VPP can participate in operations of power systems.

Area. A microgrid's physical presence depends on DGs, transmission lines, load, etc., which are its parts. The physical spread of a microgrid is therefore dependent on the geographical placement of its components (Wang & Blaabjerg, 2019). However, in the case of a VPP, which is cloud-based, the spread depends on the utilisation of communication networks and technology, giving it a large geographical presence.

Functions. While he microgrid is supposed to enhance the power quality, reliability, security, etc., of the system, a VPP is used to improve the controllability of the power system through frequency regulation, demand or emergency response, and ancillary services like the energy market (Wang et al. 2019).

Other. VPPs and microgrids are usually used as substitutes for integrating DER in the power system, but there are major differences between the two (Pudjianto et al., 2008). Based on the connectivity with the grid, the VPP is always connected to the grid and a continuous participant in its operation. Microgrids, on the other hand, can operate in grid-connected mode as well as islanded mode, and can thus be out of the grid at times. Another difference is based on capacity. A microgrid has a lower capacity as it has physical boundaries, whereas VPP (unbounded) commands a higher capacity.

Microgrids and VPPs typically require some form of on-site generation. Solar is able to fill this role as it is often the most affordable, cleanest, and easiest on-site generation technology available (compared to diesel, gas or wind). As solar is an intermittent source of energy, it may be coupled with other generating technologies where viable. It is commonly coupled to some form of energy storage (typically a battery) to optimise the use of on-site energy and maximise benefits. Together, a well-designed solar and storage solution can provide a high degree of flexibility to maximise savings, revenue generation, and reduce emissions.

Key Areas for Future Research:

3.41 How can we design a widely accepted business model that takes into account the interactions between the grid, connected microgrid and VPP? Can multiple interconnected microgrids be operated as a VPP?

3.42 How can we build the capacity, and increase consumers' understanding of the functions of VPPs and community battery energy storage systems and their roles in order to help address the grid challenges during peak hours?

2.4 Work Package 4: Demonstration and operation

Both embedded and isolated microgrids have been implemented in many countries. In Australia, net zero energy projects have been implemented by a number of universities and industry. However, rapid uptake of local DER solutions can only be promoted through innovative approaches applied on top of the current best practices. This will involve not only technological innovations, but also innovations in stakeholder participation, regulatory frameworks and business models.

Demonstration of Microgrids – How do we demonstrate this concept through trials and pilot projects

Table 7. Key findings and implications of demonstrated microgrids and community battery implementations

Roseworthy Campus (WA) Hybrid Energy Storage System, developed by Synergy, Lend Lease and Development WA; completed 2021	
Project: 1.2 MW solar farm and a Tesla lithium-ion battery/UET vanadium flow battery with a digital microgrid controller choosing when to best charge/discharge the batteries **Goal**: To demonstrate the benefits of community-scale BESS together with a virtual retail storage offering; to understand home energy usage and behaviour changes under a time of use (TOU) tariff; to test direct load control devices on A/C **Outcomes**: Generates 42% of the campus' energy needs, reducing peak electricity demand and increasing resilience of energy supply • The trial successfully leveraged new technologies such as battery energy storage, solar PV and smart meters in conjunction with new retail tariffs, and with the support of an educational behavioural change program. • The utilisation of the community battery storage during peak periods reduced demand on the network, which in turn provided benefits to system security and Synergy as an electricity retailer. • Participating households with access to the virtual battery collectively saved $81,376 in electricity costs over the duration of the trial. • Overall, the trial fulfilled the key objective of testing the feasibility of a new servicing model and deliver economic and non-economic benefits to participants with Synergy as the electricity retailer and Lend Lease as the property developer. It also provided learnings to shape the future of land developments with large-scale community energy storage.	• Pairing the newly created peak demand saver plan (PDS) with the virtual battery offering did not encourage participants to reduce peak household consumption. • Virtual battery products appear best suited for customers who export in the middle of the day and consume in peak times. • Large-scale community energy storage in residential developments can potentially deliver cost savings, enhanced network security and other improved outcomes for the retailer. • Key learnings included the value of ○ Promoting and installing advanced metering infrastructure (AMI) ○ Having regular and transparent collaboration with stakeholders and counterparties ○ Utilising larger sample sizes and asset capacity ○ Making customer engagement and information transparency key ○ Exploring new tariff structures.

Yackandandah Microgrid Development Trial (VIC), developed by Totally Renewable Yackandandah Inc. with Mondo Power, Solar Integrity and the Victorian Government; completed 2021

Project: This initiative sought to cut energy bills for residents and help the community achieve their 100% renewable energy target (RET).

Goal: The microgrid trial considered pathways to improve a 'single wire earth return' (SWER) network common in rural end-of-grid locations. It involved 32 metered households, and the trial hardware comprised 9 subsidised batteries with appropriately sized solar systems.

Specifically, the trial looked at improving SWER line performance by way of:

- Solar exports to the grid to manage voltage spikes (generating too much power for the property to use)
- Strategic release of power from the battery to reduce peak demand on the SWER
- Reduced overnight water heating load by shifting to efficient hot water production using CO_2 heat pumps typically timed to come on during solar generation.

Outcomes:

- 80% of total cost savings are derived from solar generation and the remainder from BESS.
- Heavy consumers enjoyed most of the savings, especially those who could use daytime generation for heating water, water pumps and A/C.
- Users with a combination of solar panels, a water heat pump and battery also enjoyed significant savings.
- Mondo Ubi Smart Energy Manager proved adept at:
    - Inverter active and reactive power release (voltage control)
    - Battery charge and discharge scheduling (reducing SWER line peaks)
    - Scheduling that can respond to network signals (DNSP service capability)
    - Flexible export control (smart exports)
- Findings can inform future planning of the electricity supply and therefore reduce costs for all electricity users.
- Improving the performance of existing network assets improves the quality of electricity supply for users and avoids the need for costly network upgrades, in effect working smarter rather than bigger.
- Smart energy capabilities, such as the Mondo Ubi, are best managed in cooperation with the DNSP (in network connected microgrids), where they can provide real-time insights and responses to network performance. However, this requires regulatory change.
- Currently, a comprehensive case study of a community on the move towards a zero emissions vision, Yackandandah has set up three micro grids on top of a community virtual power plant. The town-wide solar density is nearing 60% and a federal grant of $346,000 in July 2020 gave the green light to the main project for the district, the 100% Feasibility Study. This aimed to improve the efficiency and reliability of the towns self-sustaining electrical ecosystem in the final stage of the towns five-stage roadmap to the 100% renewable Yackandandah.
- Key areas of focus for this case study include grid resilience to natural disasters and extreme weather. This is closely related to the concept of island stability for a microgrid, which is the ability for the town to operate independent of the main grid. During bushfires, which have threatened Yackandandah three times in the last fifteen years, this will be invaluable.
- This case study also provides insight into the efficacy of solar systems, with residents saving 63% on power bills on average/ person. The majority of systems pay themselves off within 3-5 years, and residents have found this a good incentive to install the systems sooner rather than later (Totally RE, n.d., Community-scale energy generation and storage)

Energy Storage for Commercial Renewable Integration (SA) at Dalrymple on the Yorke Peninsula developed by ElectraNet, AGL and Advisian; completed 2021

Project: A 30 MW, 8 MWh battery energy storage system (BESS) to support renewable generation and provide fast frequency response to help stabilise the grid, while also working with the 90 MW Wattle Point Wind Farm and local rooftop solar to provide contingency power to households and businesses. The BESS entered commercial operation on 14 December 2018, providing both network and market services.

Goals:

- Demonstrate deployment and operation of a large-scale BESS to deliver a combination of network and market benefits
- Demonstrate a contracting and ownership model to maximise the value of a BESS
- Test the regulatory treatment for the ownership of large scale BESS by regulated transmission network service providers
- Provide price discovery for the deployment of a large scale grid-connected BESS
- Highlight and address technical and regulatory barriers in the deployment of large scale batteries. Technical and regulatory barriers were navigated, with regulatory treatment accepted and the BESS registered by AEMO.

Outcomes:

- The contracting and ownership model facilitated the integration of the Wattle Point wind farm to allow AGL a much wider use of the BESS MWh capacity between 10%–90%
- The AER accepted ElectraNet's proposed regulatory treatment of the BESS at Dalrymple
- Price discovery was provided for capital expenditure operational performance and market revenues were documented in four operational reports.

- Due to the complexity of developing an integrated grid and island BESS solution, it is all too easy to underestimate the time, effort, and costs involved.
- Regulatory and technical barriers to deployment persist and pose challenges for the development of DER.
- OEMs need a deep understanding of regulatory requirements, experience in the NEM and a strong working relationship with AEMO if generator modelling is to be readily accepted.
- Safety and islanding detection - network analysis and investigation of fault current requirements should be undertaken early in the projects, since complex issues invariably arise.
- Auxiliary loads and losses from the BESS will shape the business model.
- Factors seen as potential mechanisms that would improve the value of battery systems over time were increasing network constraints, potential increases in price volatility due to a decrease in dispatchable supply over time, and the introduction of five-minute settlement.

Byron Industrial Estate Microgrid Study (NSW), developed by Enova Energy, Essential Energy, Wattwatchers and UNSW; completed 2021

Project: Wattwatchers’ monitoring devices were installed at 25 sites. Under a novel ‘microgrid tariff’ modelled by UNSW researchers, customers could buy solar energy from neighbours more cheaply than they could from the wider grid while receiving a premium FiT for electricity sold to their neighbours.

Goals: To optimise energy use and reduce energy costs in the retail sector by investigating, trialling and accelerating learnings related to microgrids

Outcomes: Overall, customers benefit financially because usage tariffs are lower and the tariff structure benefits daytime consumers of energy like small businesses.

- 6 customers experienced bill increases of $1–$2/month due to increased electricity usage
- 15 customers experienced bill decreases of, on average, $74/month
- The 9 solar customers were all better off in this scenario, while all customers consumed less energy from the wider grid as they consumed more from the solar rooftop generation within the microgrid
- A clear positive relationship exists between total electricity use and the business participants bill charges, with large users experiencing the greatest reduction
- The retailer, Enova, experienced a net loss of about 20.7% in revenue with the microgrid tariff
- The DNSP, Essential Energy, experienced a loss of 4.9% over the period March–August, simply because its microgrid tariff rates were slightly lower on average than the original tariff.
- The modelling undertaken by the UNSW team demonstrated the potential for a microgrid to deliver financial benefits to customers, networks, transmission network and retailers.
- High functioning microgrids will potentially generate power more cheaply due to local generation, storage and circulation of energy, while networks and retailers will realise lower revenues from microgrid participants.
- A local use of system charge (LUoS), where costs are lower for distributing power in a microgrid area, combined with batteries, may reduce energy costs for participants.
- The construct of the microgrid tariff results in financial benefits to the microgrid customers (small businesses) and not to the network, transmission network or retailer.
- Regulatory changes (LUoS) and incentives are required to encourage networks and retailers to consider the longer term financial, social and environmental benefits of microgrids, rather than short term financial gain.

PowerBank Community Battery Trial, Western Power & Synergy; completed late 2022	
Project: Integration of utility-scale batteries across 12 metropolitan and regional locations at a network feeder level, paired with a retail offering to allow customers to 'virtually' store excess electricity generated by their solar PV, while providing network management services and deferring infrastructure investment. Takes advantage of cost efficiencies for larger battery systems and avoids installation costs. **Goals:** • To provide insights into customer behaviour, appetite for a front-of-the-meter battery solutions, and profitability • To test BESS technology and provide performance insights • To explore benefits/challenges of (dis-)charging physical batteries and impact on wholesale market • To explore possible future retail tariff models **Outcomes**: During the first 12 months of the Meadow Springs trial • Daily storage subscription fees were about $1.20 • $11 k saved in electricity usage by households • 44 households each saved $228; daily average storage of 7.38 kW; 5.23 kW consumed; surplus sold to grid • 95% of households saved money on their electricity bills • Network pressure was alleviated during peak demand.	• Virtual storage and power sharing across households appears to offer reduced electricity costs to end users while optimising storage and relieving pressure on the distribution network particularly at peak times. An additional 9 trials have now commenced to further demonstrate this potential.

Mooroolbark Mini Grid Project, AusNet Services; completion date not provided	
Project: A prospective trial of minigrids on a small scale **Goals**: To investigate three main outcomes: *Grid interactive*: Involves observing each house and its interactions with the main (or mini) grid, drawing and giving power during peak times, as well as supporting the network by improving power quality. This trial will also provide an indication of the viability of battery-powered houses in a grid-like network, with consistent charge and discharge over the week. *Customer secure power*: How each house works in an 'off-grid' mode needs to be analysed. Consumption and demand management are key factors in the success of battery optimisation and as such need to be studied further during this trial. *Community island*: This builds on the 'grid-of-grids' infrastructure that appears to be the vision for the future of the current electricity grid. Watching how the small grid stabilises during peak times without interacting with other grids should provide insight into the possibility of more microgrids in the future.	• Ausnet Services is most notably interested in the move from power being a 'one-way pipeline', and instead is a 'multidirectional web' that gives customers an opportunity to contribute to a much more decentralised system (Ausnet, 2017).

DER Literature Review 2017–2022 (Hirsch et al., 2018; Warneryd et al., 2020; Burger and Luke, 2017; Cagnano et al., 2020)

Goals: Highlighted current limitations and future opportunities/issues of DER. Limitations include legal and regulatory uncertainty, interconnection of DER to the grid, utility regulation, and opposition to DER. Future issues for DER include competing smart grid paradigms and evolving market structures and business models.

Outcomes:

- Focusing on institutional roles in supporting community microgrids, authors emphasise the need for regulatory reform driven by increasing need to balance renewables on the grid.
- The EU is updating electricity market and RE regulations to allow communities to act as aggregators of renewable generation, flexible loads and storage services to the overall grid.
- In Australia, market and consumer pressure drive institutional developments, emphasising P2P markets and concepts such as ‘citizen utilities.’
- In Asia, microgrids are state driven with an evolving regulatory framework to enable local energy systems and microgrids.
- Guidelines for practical DER implementation. Main technical and control themes summarised relating to master units and protection schemes, comms. networks, control system architecture and dynamic system assessments.
- Looks at business models for DER deployment. First, the analysis highlights that business models are deeply embedded in myriad policy and regulatory frameworks. Second, current DER business models are driven more by regulatory and policy factors than by technological factors. Third, the small set of mature business models suggests that determinants of success may include executional capabilities, culture, and other activities. Fourth, continued cost declines, technological innovation, and changing policy and regulatory landscapes mean that future business models will likely look very different. Finally, DER business models compete within archetypes for market share in providing a limited set of electricity services.
- In this formative phase for DER, the formal institutional barriers to community microgrids are still significant while the market stabilises.
- In Australia, low governmental ambition creates greater consumer desire to drive development of renewables. Since incentives are missing, community microgrids need a viable business model and rely on other investors. This has resulted in fewer benefits to the community compared to contexts where governmental ambition is higher.
- Utilities emerge as a critical actor whose attitude and level of activity influences community microgrid development, especially in the US.
- DER topology and structure strongly depend on their specific applications.
- Business models are very much evolving and likely to change dramatically as the market for DER matures and stabilises.

Community battery demonstration – How can we run effective demonstration and trial of community batteries?

Trialling community batteries in different contexts

Before considering the trialling of 'community batteries' in various contexts, it is important to properly define the term 'community battery.' The term bears similarity to the term 'community solar' that was used in the early stages of the rapid uptake of rooftop solar and then later replaced by other terms. The use of 'community' is intended to indicate that the general public would benefit from the new technology through opportunities to own and access such options. For the purpose of this project, we seek to identify language that stands to have longevity and we have therefore created a framework below.

When considering nomenclature for energy storage across an electricity grid, there are three main factors to consider — the location, size and method of access (affecting who can benefit from it). When considering location and size there are four main options:

1. Transmission system storage (grid-scale): This typically involves large scale energy storage systems such as batteries, hydro-systems, or mass-gravity systems that are connected directly to the transmission grid and operated by the private sector. This option is mostly used to provide services to the grid rather than to customers and often focusses on assisting with reliability, power quality improvement and stability.
2. Distribution system storage (neighbourhood-scale): This usually involves medium-scale energy storage systems (mid-tier storage) connected to the distribution grid, which are operated by the private sector and made available to residents and businesses. Such systems can be located strategically across the distribution system, which can be aggregated virtually or within physical microgrids. A microgrid is a sub-grid that has been created within the main grid, typically with a single point of connection. Such microgrids can either be right sized for energy customers in the precinct it services or oversized to provide value to the grid under certain conditions while also providing additional capacity for growth in local demand. It is likely that there will be combination grid and microgrid storage options that warrant consideration of both.
3. Distribution system storage (building-scale): This typically involves small-scale energy storage systems (such as home or business-scale batteries) that are connected behind the meter to residential or commercial buildings which are connected to the distribution grid and owned by private residents or businesses. Such options can be located in individual buildings connected to the grid or inside microgrids.
4. Mobile storage (vehicle-scale): This often involves small-scale mobile energy storage systems (such as electric vehicles) that can be connected to a residential or commercial building and moved between locations as necessary. These systems are typically owned by private residents or fleet operators. The mobile nature of this option creates a unique situation where the storage has the ability to move to different locations in the grid, which creates both risks and opportunities regarding its management.

When considering the method of access to storage and the potential to share benefits, options include utility-controlled storage, privately owned storage and co-operatively based storage. For the purpose of this project, a community battery is defined as 'an energy storage solution that is connected to the distribution system to provide both grid and customer services.' Hence, once the concept is clear, the next question becomes where such storage devices should be located, what size they should be, and how they should be managed and governed for mutual benefit. The following stages of research will consider precedent for informing answers to such questions and include various tariff trials involving the use of community batteries to identify what is being done, what has worked or not worked, and what still needs to be tested.

Enova community battery (the Beehive Project)

This project has three primary aims:

- For excess solar power generated by homes to be taken advantage of by the community
- To test the efficacy of batteries in helping small to mid-size electricity retailers deal with the impacts of high demand by accessing stored energy
- To be a pioneer project for the wider community and industry

Dubbed 'the Beehive Project' for its similarities to this self-sufficient ecosystem, this project will connect many homes with and without solar to a community battery and, by extension, to the grid. Small businesses will also be included in this process. Following similar principles to other community battery projects, excess electricity generated by homes with solar panels will be sold to those without solar to provide for a far more renewables-based energy system (Energy Locals, n.d., Residential Enova).

While this system has many similarities with other community battery projects, there are two key differences:

- The battery is not designed to store and discharge power for a particular building or group of buildings, or to a wind or solar farm, and the term 'shared community battery' will instead mean that stored energy will be distributed amongst residences that are not necessarily close to the battery.
- The peer-to-peer trading of electricity means that there will be more access to renewably generated power at a lower cost (Energy Locals, n.d., Residential Enova).

Synergy and Western Power 'Powerbank'

This will be household battery trial, as opposed to the larger-scale community batteries. It will comprise a virtual storage system, meaning that no physical battery is connected to the house. The customer will be allocated an amount of virtual storage space based on the option that is best for their power consumption needs. The virtual bank will store excess generated electricity between 7 am and 3 pm and then use the stored power to offset power consumption for the household during peak times. Any leftover power will then be 'exported' to the grid and sold to Synergy power provider (leaders for this project) for a contractual amount (Synergy, 2022).

A unique feature of this project is the virtual component of the power bank. This will mean that homeowners have very little upfront installation aside from signing the contract to agree on the price of excess sold to Synergy and the 'size' of the virtual bank. The only requirement is the ability for the home to generate power through solar panels. Houses without solar panels have no gain from the system, aside from a potentially subsidised electricity prices from Synergy from cheap customer obtained power.

Key Areas for Future Research:

4.1 What is an appropriate nomenclature for energy storage options at various scales?

In a real-world setting, perform a detailed investigation and demonstrate the technical and economic potential and the value proposition for neighbourhood-scale batteries

Western Power: A powerbank is a type of community battery situated in a local area that is shared by eligible customers who generate solar energy. Each powerbank customer has a storage capacity of 6 kwh or 8 kwh (Western Power, n.d., Powerbanks). Although a community battery, a powerbank has the added benefit of individual solar storage. This means that eligible households that have access to virtual storage in the battery are able to store their excess solar power. Note that, from Western Power's point of view, VPPs are another type of community battery (Synergy, n.d., Project Symphony).

Several powerbank trial projects are ongoing in WA (wa.gov.au, n.d., Energy policy). Customers can pay a daily fee so they can 'virtually' store solar exports in the battery and then draw from this storage without charge. Western Power has installed 13 community batteries so far and is evaluating installing more in the future (Western Power, n.d., Where are the community batteries located?). Customers can automatically store up to 6 kwh or 8 kwh of excess or unused power in the battery. From 3 pm to midnight, households can draw energy back from the battery to power up their homes. At midnight, any excess power still in the battery is returned to the grid, with the householder paid the standard feed-in tariff. Victoria is also running a number of community battery projects and a list is available (vic.gov.au, 2022, Emerging energy technologies).

Benefits of a neighbourhood-scale battery (powerbank) for customers:

- Customers receive more benefits from the clean energy that they themselves generate, getting more economic value and energy security from their solar investment without needing to own and maintain their own household battery system.
- Community batteries encourage greater solar uptake by households and businesses, increasing the amount of renewable energy in the system. They also improve the power quality to customers in the area and deliver services to the wider energy market.
- Access to battery storage is more equitable and accessible for all customers, particularly those who aren't currently able to install their own household battery.
- Participating customers continue to receive an electricity bill from their retailer and still receive savings from having a solar power system. They also receive quarterly credits from Ausgrid for the excess electricity they virtually store with the community battery.
- There are no upfront installation costs, maintenance or replacement costs for customers.
- Arbitraging to deliver lower energy costs (Energymatters, 2021).

Benefits for utilities:

- Supports the uptake of renewable energy in the electricity system
- Community batteries are an alternative to network expansion investment
- Offers a cheaper alternative to a traditional poles and wires network
- Can reduce peak demand helping distributors place downward pressure on energy prices (Ausgrid, n.d., What is a community battery?)
- Avoids or limits reverse power flow in the network
- Big batteries will help stabilise networks and pave the way for increased renewable energy generation. As a cost effective option, they can defer the need for additional generation infrastructure or network upgrades to meet peak demand (Energy Magazine, 2021; wa.gov.au, n.d., Energy policy WA)
- Provide inertia support services to the electricity grid (Hornsdalepower, n.d., Interested in seeing SA's Big Battery up close?)
- Provide network services such as Frequency Control Ancillary Services (FCAS) (Parkinson, 2022)
- Flexibility and reliability improvement of energy systems (Clean Energy, n.d., Energy storage)
- Smooth out the supply and demand for electricity (Synergy, n.d., Project Symphony)
- Provision of secure, affordable, and lower-emissions electricity (wa.gov.au, n.d., Energy policy WA).

United Energy's pole-mounted batteries

Nicknamed 'Electric Avenue', this initiative will install 30 kW community batteries at 42 sites in the south of Melbourne. The project follows a successful trial of two battery units installed in early 2020. The batteries will store energy for up to 2.2 hours at a time and will sustain a 99.99% power reliability for customers. The batteries have an expected lifetime of around 15 years (United Energy, 2021) (ARENA, 2021g).

The key factors of this trial system will be:

- Careful design. The placement of the batteries, including housing density and power consumption, and visual and audible amenity impacts, are major considerations in the design and placement of the batteries. Safety is also an important consideration.
- Ability for the batteries to take a load off the network at peak times. An example given is that on hot days, when air conditioning is heavily relied on, United Energy will need to manage these batteries to preclude the necessity for drawing from the main grid (United Energy, 2021).
- Battery network management. This will be a large network of batteries and as such the management systems in place will need to be comprehensive to allow for optimal use. Some automation of this management will produce the best results, but this will not be a priority for the system rollout.
- 'Multidimensional web.' This project will be similar to the Mooroolbark Minigrid Project in that the houses need the capability to produce solar power and send excess to the grid during low power consumption times and to the batteries for storage and use during high consumption times (ARENA, 2021g).

Home batteries

Home batteries have proven to be popular, with over 30,000 sold in 2021 despite their high costs (ABS, 2016). These small-sized batteries are useful for storing local energy, but a communal solution is more efficient. The overall structure of aggregate load and generation is better regulated at the neighbourhood level than at the individual level. Individual properties show peaks and valleys in demand, but at the suburb level, that demand is smoothed out.

Neighbourhood-scale batteries

Key factors of value proposition for neighbourhood scale batteries are:

- Energy security and power reliability. The current centralised electricity infrastructure has repeatedly demonstrated its vulnerability and unreliability. This susceptibility is not just due to inclement weather but can also be caused by the high fluctuations at the consumer's load (Engage Victoria, 2022).
- Independence. Independence from the centralised electricity grid means independence from not just unpredictability, but also from potential rate rises and other levies.
- Reducing grid congestion. Neighbourhood-scale batteries will store energy locally to reduce the bidirectional power flow occurring from RES-exported power and grid-imported power (ABS, 2016).
- Economic value. The first Australian Community Battery (CB) trial by Synergy (Western Power, 2022) took place in Meadow Springs, WA. The results from the trial displayed an average of 7.3 kWh of energy stored a day and 5.2 kWh consumed back for each participant. Selling the remaining 2.1 kWh to the grid, each participant saved an average of $228, with more than $11,000 saved on power bills across the entire trial. This made the community battery cheaper to use than home batteries (Western Power, 2022).
- Market services. In the wholesale energy market, neighbourhood batteries can participate in spot price arbitrage by purchasing electricity at low prices and selling it when prices are high. This puts downward pressure on all electricity rates (Engage Victoria, 2022).

- Avoiding curtailment. The surplus power caused by RES can lead to renewable curtailment, which is a deliberate reduction in renewable electricity output below levels that could be generated. This can be avoided with an ESS.
- Providing ancillary services to the grid. Neighbourhood batteries are demonstrating promise for frequency control ancillary service (FCAS) industries in the NEM. The market operator, AEMO, values the batteries′ capacity to quickly absorb or inject power to adjust power system frequency variations from the required 50 Hz (SACOSS, 2020).
- Offsetting network augmentation costs. Other services that batteries can offer include avoiding or reducing the scale of proposed network augmentation (SACOSS, 2020).

Key Areas for Future Research:

4.2 What is the value proposition for neighbourhood scale energy storage?

4.3 What can be done in a lab to inform and enable projects and make the process quicker? What is right to trial in a lab compared to being implemented in real world conditions?

4.4 What bit of tech is needed to activate a business model?

“Micro gridding” demonstration - How do we effectively demonstrate “micro gridding” with community batteries

Mallacoota minigrid/community battery project

This project aims to improve energy certainty to the community, as well as beginning to build a roadmap for future energy innovation. Similar to the Yackandandah 100% Feasibility Project, the key considerations relate to island-ability and energy reliability. This is vital especially with the context of essential businesses, such as hospitals and fire stations. The project hopes to improve infrastructure so that the town’s diesel generator supply can provide backup power for up to five days upon isolation of Mallacoota from the grid (Engage Victoria, 2022).

The project will also test several key innovations. One of these is the ‘smart’ energy system, in which a device known as a Mondo Ubi will “enable certain loads to be switched on or off in ways that improve the performance of the local grid, with no noticeable impact to the property owners.” Essentially, this will monitor the energy usage of the house, make informed decisions about the power consumption for the house and adjust the houses’ system accordingly (Mondo, n.d., Ubi - the brains for your home energy use). For example, if hot water is consistently not being used between 1 am and 5 am, power consumption can be adjusted accordingly. The device can also spot abnormalities in consumption patterns and notify homeowners accordingly, as well as responding to alerts triggered by high energy prices (Mondo, n.d., Ubi - the brains for your home energy use). The Mondo Ubi is also being trialled in the Yackandandah area with great success.

A third innovation is heat pump hot water systems in residential buildings. This will give a much more energy efficient alternative to electrical resistance water heaters and hopefully bypass the need for natural gas in a water heating system by instead relying on electricity generated from a renewable source (Engage Victoria, 2022).

Western Power microgrid plans

In a $15 million project, infrastructure for the largest microgrid plans in Australia are being put in place in Kalbarri, Western Australia. This is a high traffic tourism area, with up to 100,000 visitors to the town with a population of 1,500 each year (Western Power, 2022). While this plan will initially be used in tandem with the existing main grid power network to ensure no noticeable interruptions to appliances and systems, the Energy Minister Bill Johnston intends for this project to “pave the way in delivering greater renewable energy solutions across WA, particularly in regional areas, as we move forward in achieving net zero emissions by 2050” (Western Power, 2022). This project will focus on islandability and power reliability on a large scale as the town is currently connected by a 140 km rural feeder line that is exposed to the elements. The microgrid is expected to eliminate 80% of the outages experienced by the town and hopes to reduce outage length significantly (Western Power, 2022).

Microgrid solutions in WA are led by Janica Lucas, who wrote a supplementary article to the Kalbarri microgrid information. The key takeaway from this article was summed up as follows:

“It will help us understand more fully the costs and benefits of microgrid infrastructure, while immediately giving us a chance to improve power supply for the Kalbarri residents… These two microgrids are providing great insight in how we model other microgrids and will feed into detailed studies of other potential locations.” (Western Power, 2020).

This is valuable insight into the motivations behind the grid and shows similar intentions to the Mallacoota and Mooroolbark minigrid projects, including improving power reliability and decreasing emissions through renewable energy usage in a ‘multidimensional web’ system.

Onslow microgrid

This project provides an exciting look into what the future for renewables could be. Supported by battery technology, this microgrid powered the town of Pilbara for 80 minutes completely on renewables. The grid was managed by a smart system which also ensured that it was being used to its maximum efficiency.

“This signifies a landmark step towards building a cleaner, brighter renewable energy future for our state” and demonstrates how distributed energy resources can be safely integrated at a grid level (wa.gov.au, 2021).

In this trial, Onslow was successfully powered by 100% renewable energy. This is a huge step for renewable energy generation, enabling Onslow to now work towards transitioning to a completely renewable grid system. A challenge, however, will be solar power reliability when the sun cannot reach the solar panels. As a result, Onslow will need to seek solutions potentially in the form of large-scale batteries that can house a large amount of electricity for a long time during cloud events and other problematic weather events seen increasingly in the wake of climate change.

Key Areas for Future Research:

4.5 How do we manage peak load using smart meters and demand-side management techniques in a microgrid with and without community storage? Peak consumption management using smart networks.

4.6 How can we build the house- to- house interactions and the trust within microgrids and community battery usage?

An initial thorough review of all related projects that have occurred in Australia and internationally that are currently in train. These were categorised by the regulatory framework they work within (e.g. deregulated NEM *market versus monopoly retailer (WA: Western Power/Synergy) versus vertical integration (e.g. Horizon Power and parts of the Ergon Network).*

Research questions reviewed in section 2.4 cover many of the exemplar microgrid projects in Australia.

Relevant projects may be found in the following resources:

- Western Power community battery trials. How shared battery storage benefits customers and the grid, including PowerBank, an Australian first trial (Western Power, n.d., Our community battery storage trials).
- Ausgrid. Ausgrid has installed three community batteries across its network, the first of their kind on Australia's East Coast (Ausgrid, n.d., Community batteries).
- Enova's Project Beehive will allow households, with or without solar, to share and trade rooftop solar between themselves and access benefits from the community battery when it is needed (Energy Locals, n.d., Residential Enova).
- Western Power provides a comprehensive overview of its microgrid projects in this area (Western Power, n.d., A bright future for WA), highlighting the 5 MW Kalbarri microgrid as an example.

How can we extend the Monash ARENA-Indra Smart Energy City and its DELWP-funded microgrid energy market operator (MEMO) projects to more general settings?

Monash has not committed to this work. A suggested approach is to

- Summarise the model technically, and commercially if possible
- Communicate with energy players, old and upcoming, to look for interested party to proceed
- Also check if there is other ARENA funding for diffusing the Monash project.

Key Areas for future research:

4.7 What aspects of commercial-scale micro-gridded community batteries need to be demonstrated?

Demonstrate commercial and industry-scale precincts operating as embedded microgrids with a separate VPP or aggregator as commercial partner.

Key aspects to demonstrate are commercial viability, the ability to circumvent impediments caused by incumbents, and the technology that can orchestrate the different storage, generation and control technologies. The relationship between microgrids and VPPS also needs to be shown. Western Power provides a comprehensive overview of its microgrid projects in this area (Western Power, n.d., Microgrids: A bright future for WA), highlighting the 5 MW Kalbarri microgrid as an example. The Australian Government also provides a useful resource summarising ARENAs projects on the microgrid and VPP space. ARENA has funded many VPP demonstrations which can be used to gain insight into the aspect that need to be considered.

Operation of microgrids - What else do we need to consider in the operation of microgrids?

What new technofixes are needed to operate DER in microgrid and VPP configuration?

As the requirements and functions for operating DER in microgrid and VPP configurations differ, they are treated as two separate approaches. For DER to operate in microgrid configuration, aspects that have to be considered include the type of control scheme used in the microgrid, the capabilities of the DER (what type of control signals/functions are available?), providing a single PCC for the microgrid, the grid synchronisation strategy, available communication infrastructure (which will impact on the control scheme that can be implemented), a stability analysis and compliance with IEEE 1547-2018 (Baghaee et al., 2018; Guan et al., 2015; Wang & Blaabjerg, 2019). When DER are required to operate in VPP configuration, the VPP operator has to be able to coordinate the DER to release energy into the grid. The VPP needs to know its aggregated capacity and be able to control and manage the energy flow to and from the DER.

The following new technologies are identified as key to the successful building of microgrids and VPPs:

- DER configured to operate as a microgrid
- Control scheme
- DER capability (e.g. type of control functionality available)
- Single PCC
- Grid synchronisation strategy
- Communication infrastructure
- IEEE 1547-2018
- DER configured to operate as a VPP
- DER coordination
- Aggregated capacity
- Control scheme

How does EV charging and V2G integrate into the operation and planning of microgrids and VPPs?

Intelligent EV-charging infrastructure and managed charging strategies are needed to accommodate customer needs and to help EVs become interactive grid assets rather than unmanageable grid loads (Zhou et al., 2021; RACE for 2030 CRC, 2021). For EVs to become interactive grid assets, unified charging and connection standards are required. Similar to community batteries, a relatively small number of V2G-capable EV models can currently provide significant amounts of service, particularly for frequency control (Jones et al., 2021; Vayá & Andersson, 2016; Arani & Mohamed, 2018). Additional aspects currently affecting V2G approaches include EV battery capacity degradation, battery life reduction, and the impact of temperature variation of battery degradation (Jafari et al., 2018; Thingvad et al., 2021; Lehtola & Zahedi, 2015).

3. RESEARCH OPPORTUNITIES AND IMPACTS

3.1 Development of research concepts

The literature survey conducted under the four work packages unearthed 72 important research questions that need to be addressed to facilitate the fast transition towards net zero future. The full list of research questions is given in the Appendix. For the formation of research concepts for projects, nine research opportunities (RO) were identified as follows:

- Governance and regulation (RO1)
- Revenue streams (RO2)
- Ownership and access (RO3)
- Electric vehicles (RO4)
- Storage options (RO5)
- Advanced technologies (RO6)
- Consumer expectations (RO7)
- Microgrids in distribution networks (RO8)
- Balancing interests (RO9)

Research opportunities RO1 to RO9 are depicted in Figure 2 below to show their broad interrelationships. Five of the nine overarching research opportunity areas cover non-technical aspects such as governance and regulation (RO1), ownership and access (RO3), balancing interests (RO9), consumer expectations (RO7) and revenue streams (RO2). These aspects of research are commonly applicable to all the technological solutions covered in microgrids and VPPs (RO8), advanced technologies (RO6), energy storage (RO5) and electric vehicles (RO4).

As illustrated in Figure 2, microgrids and VPPs are central to the new power system concepts. Advanced technologies can make revolutionary changes to the performance, cost and benefit of these solutions. Energy storages are integral components of future power systems. As such, knowledge of the capabilities and limitations of different available storage options is vital for reducing system costs and improving performances. Finally, the anticipated spread of electric vehicles (EV) used in these power systems present both challenges and opportunities, and future research must consider their presence in these modern power systems.

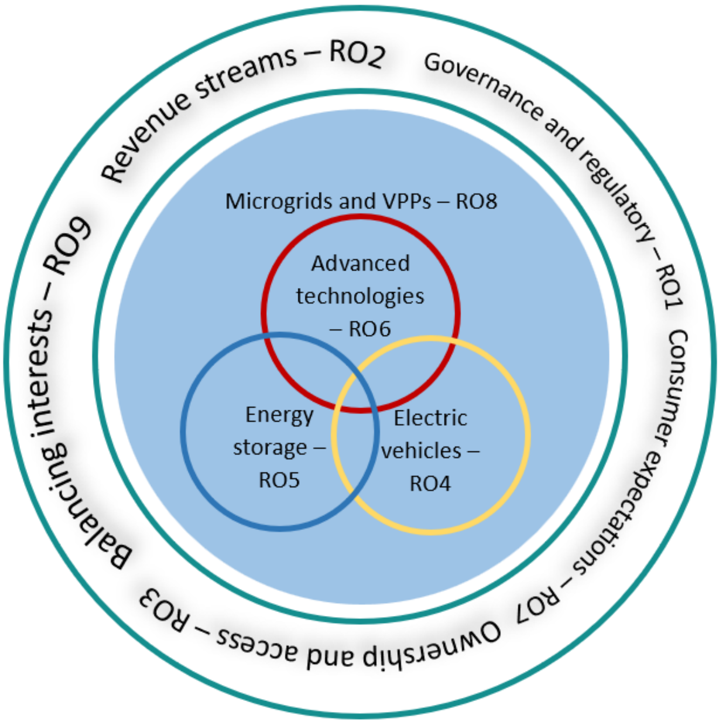


Figure 2. Interrelationship of research opportunities

Consolidation of the opportunity assessment's 72 key research questions (full list available in the Appendix) took place within the original four work packages of consumers and regulatory framework, business models, planning and design, and demonstration and operation. Research questions within these packages were then mapped against the nine research opportunities developed by the team as shown in Table 12 below. The mapping of research questions into research opportunities then informed the proposal of research concepts.

Table 8. Mapping of research questions into research opportunities (ROs)

	Research questions by work package			
Research opportunities	Consumer and regulatory framework (WP1)	Business models (WP2)	Planning and design (WP3)	Demonstration and operation (WP4)
Governance and regulation RO1)	1.1, 1.2.1.4, 1.7, 1.8	2.3, 2.4, 2.5, 2.7, 2.8, 2.9, 2.10	3.11, 3.12, 3.17, 3.18, 3.19, 3.33, 3.34, 3.35, 3.36	
Revenue streams (RO2)		2.5, 2.9, 2.15	3.9, 3.11, 3.12, 3.13, 3.31, 3.32, 3.38, 3.40	4.2
Ownership and access (RO3)		2.4, 2.6, 2.8, 2.14, 2.15	3.13	4.2
Electric vehicles (RO4)				4.7, 4.8, 4.9

Storage options (RO5)	1.6, 1.9	2.2, 2.12	3.2, 3.3, 3.4, 3.23, 3.30	4.1
Advanced technologies (RO6)	1.3, 1.4, 1.6, 1.8	2.11,2.13	3.3, 3.6, 3.7, 3.10, 3.14, 3.22, 3.24, 3.25, 3.26, 3.27, 3.37	4.3, 4.4, 4.6
Consumer expectations (RO7)	1.1, 1.2, 1.3, 1.5	2.10, 2.14	3.8, 3.9, 3.36	
Microgrids in distribution networks (RO8)	1.5	2.1, 2.2, 2.13	3.5, 3.6, 3.7, 3.8, 3.15, 3.16 ,3.20, 3.21, 3.22, 3.24, 3.25, 3.26, 3.28, 3.29, 3.31, 3.35, 3.37, 3.39, 3.41	4.4, 4.5, 4.6, 4.8
Balancing interests (RO9)	1.9	2.1, 2.11, 2.12	3.5, 3.15, 3.16, 3.19, 3.20, 3.23, 3.27	

3.2. Governance and regulation

Objectives

- Performance and safety. Grid operators must be confident that energy storage systems will perform as intended within the larger network. Also, it is essential to consider appropriate governance for network charges and billing issues.
- Lifecycle and the maintenance of batteries. From production to disposal, there are gaps in the regulation of materials production and investment in recycling and reuse schemes across different jurisdictions.
- Industry acceptance. Energy storage investments require broad cooperation among electric utilities, facility and technology owners, investors, project developers and insurers. Each stakeholder offers a different perspective with distinct concerns.
- Generating revenue by battery operators. A community battery can generate revenue from the following sources:
    - Customer demand management
    - Demand management for the distribution network service provider (DNSP)
    - Network support
    - Arbitrage from the spot market
    - Frequency control ancillary services (FCAS)

  To maximise revenue, the battery operators must make choices where maximising one revenue stream may involve reducing revenue from another. Currently, there is no clear guideline available for this practice.
- Effective ownership and access models for community-scale energy storage suitable for Australia:
    - Tariff reforms
    - Ownership models, including managing ownership of legacy infrastructure
    - Streamlined connection agreements

- Equity issue. As community-scale batteries can be optimised to produce different values, there is a distinct risk that they could increase inequality. One regulatory challenge of such is the occurrence of cross-subsidies between prosumers and consumers. Practical challenges, such as placement within the community ecosystem, will also affect the possibility of providing fair service in an environment with multiple customer preferences.

Furthermore, for community batteries to become more established, the regulatory design needs to support access to markets by communities and final consumers. Currently, challenges of regulated network tariffs have resulted in a decrease in benefits to local energy trading in communities. This is an important factor to consider when seeking to understand the practical and regulatory issues connected to data accessibility. Smart-metering on a full scale could increase the possibilities for more communities to access community batteries as a solution.

Pilots can be designed around any of these issues. The regulatory restrictions may be explored using the new AER Regulatory Sandboxing Initiative (AER, 2022), which provides temporary regulatory exemptions for trials of new services and technology. The other urgent aspect is how community batteries can work with microgrids and VPPS, especially at a precinct level. Given the number of community-battery projects currently underway, it may be prudent to pilot investigations on existing batteries or engage with planned community and precinct-scale battery installations.

Precedents

Industry partners raised that the future of community batteries will be influenced by the regulatory environment in general as it can determine who owns, operates and participates in the batteries. In this regard, the wider work undertaken as part of the Energy Security Board (ESB) 2025 post-electricity market design has the potential to impact on the future of community batteries. A number of system security mechanisms are potentially opening up new income streams and should be closely monitored.

Recent rule changes allow for a new market participant category, the integrated resource provider, which opens up options for co-locating batteries with generation.

The Australian Energy Regulator (AER) has recently released an updated Electricity Distribution Ring-fencing Guideline. The Guideline was developed through consultation with regulated network businesses, retailers and consumer groups. The Guideline provides the regulatory frameworks and controls to support two key emerging markets in Australia's transitioning energy sector:

- The deployment of batteries, including community-scale batteries
- Regulated stand-alone power systems (SAPS)

The Victorian Neighbourhood Battery Initiative is currently funding a number of different battery projects, and their outcomes will be of importance for this project.

Some work related to implementing community-scale batteries has also been done by ARENA and ANU's Battery Storage and Grid Integration Program (ANU 2020b), with the main focus on engaging stakeholders to identify the benefits and challenges associated with the community batteries. The program has determined that any possible core model for community batteries should have four components, including (i) battery ownership, (ii) stakeholder participation, (iii) network tariffs, and (iv) the services the battery can provide.

There is also a current policy initiative, Power to the People, from the Australian Labor Party, which is set to install 400 community batteries across the country. This is a $200 million investment, and Labor will initially install five community batteries across Perth.

Methodology

This question involves a number of different subcategories. An assessment of the potential future regulatory framework for community batteries is best conducted via a desktop assessment of the current regulatory frameworks, as well as via comparative research enhanced by qualitative research.

A mixture of in-depth qualitative interviews and focus group research can uncover the motivations, attitudes and values of various stakeholders, and explore the prevalence of views across different stakeholder groups. However, as many of the concerns about proposed community-scale batteries are linked to the governance of the energy system, this could require reassessing the overall utility of the system for innovative energy solutions, which is not quickly addressed by qualitative surveys. This topic links to other RACE for 2030 research projects, such as the 'Opportunity Assessment: DSO and Beyond', which can inform any projects considering the governance for edge-of-grid solutions. As concerns over ownership and distrust in the energy sector are significant public concerns, any future methodology should empirically examine institutional arrangements that could enhance trust and participation. This may involve control or management of the battery by a trusted organisation. The stakeholders who need to contribute to this assessment should include electricity distribution businesses, or third parties such as community energy groups, electricity retailers, aggregators, private investors and households.

Impact

The outcome of this research could support an adaptable and flexible model for the regulation and governance of community batteries. Communities are likely to have different goals in terms of what they want the battery to achieve and also to vary in terms of their composition (solar owners and non-solar owners). Understanding these differences can help to meet the local and state governments′ carbon reduction objectives and enable them to set their strategies in relation to storage investments.

Questions of trust and governance are crucially important for the success of innovative solutions that do not conform with the traditional model of electricity supply, such as neighbourhood batteries. Exploring regulatory frameworks, ownership models and tariff arrangements will underpin the implementation of any community battery model. They will determine the potential for community batteries to play an important role in the energy systems transition, while keeping the grid reliable and affordable.

3.3 Revenue streams

Objectives

Several community battery feasibility studies and trials have been completed, and more are currently underway in different parts of Australia. Each project has specific business and service models and technical and non-technical constraints. There is a need to exploit the full potential of community batteries through a theoretical investigation and associated practical trials that consider a wide range of current and future operating scenarios and regulatory changes. The aspects to be investigated are as follows:

Stakeholders′ revenue and profit

There is limited evidence from real projects on how, and how extensively, these different value streams contribute to the overall community batteries' revenue and profit for stakeholders such as owner/operator and participating customers. The direct income of batteries must be considered hand in hand with the economic value added to other parts of the electricity system/other stakeholders.

Feasibility of community batteries

Community battery feasibility depends on several factors, such as the battery technology cost and value stacks associated with different services, as well as operating conditions and constraints. A detailed techno-economic evaluation needs to be carried out to determine the critical (minimum set of) value streams for different services, operating conditions, and constraints for community batteries to be viable businesses. The value streams need to be quantified theoretically and practically (through demonstration projects) for various current technology and future technology costs and operating and regulatory scenarios. A comparative evaluation of community battery feasibility against other related business/service models (e.g., stand-alone, grid-scale battery systems or VPP models) should also be explored.

Valuation of indirect revenue streams

Currently, there is little research to quantify the value arising from indirect value streams. Csereklyei et al. (2021), after IRENA (2019) and Anuta et al. (2014), compiled the following potential categories for e-battery services:

1. Services for variable renewable generators, such as curtailment reduction and firming capacity provision
2. Services for overall energy system operations, such as frequency regulation, flexible ramping, black start and ancillary services
3. Services for allowing deferral of network investment, including capacity reserves for generation and congestion relief for transmission and distribution (virtual power lines)

Many of these battery services are currently not valued or monetised. Ideally, the network (usage) cost should consider the local use of service (LUoS), that is, reduced local energy transport. Therefore, a new fair-price mechanism needs to be developed for community battery network charges.

In Australia, batteries can provide a range of revenue generating services in various markets. The bulk of battery revenues currently stems from participating in ancillary and wholesale markets (ARENA, 2019b; for further detail, see Csereklyei et al., 2021). Areas with potential future revenue streams for utility-scale and community batteries include services such as virtual transmission lines or avoided transmission investment (Csereklyei et al., 2021). Apart from the immediate financial viability of batteries (which is continuously improved due to the substantial decrease in their capital and operational costs; see Lazard, 2021), a few studies focus on the economic value of their services.

Cscereklyei et al. (2021) note that the key strand of economic papers about battery storage currently focuses on evaluating the economics of the technology in competitive markets, and on the welfare impacts of battery usage (Siddiqui et al., 2019; Schill and Kemfert, 2011; Sioshansi, 2011; Sioshansi, 2010). Many of these studies (e.g., Siddiqui et al., 2019) concluded that battery operations may, in fact, reduce social welfare in competitive markets if they act in a profit maximising manner. On the other hand, Csereklyei et al. (2021) note that the majority of battery revenues in Australia currently originate from participation in the ancillary markets. At the same time, the authors note that "batteries displace gas generator bids on the wholesale market, resulting in wholesale market outcomes with potentially lower peak prices than outcomes without batteries would have."

Estimating the economic value of batteries (including community batteries), especially the value resulting from ancillary market operations, requires considering the development of ancillary market prices, as well as the ability of batteries to prevent blackouts, thus "avoiding financial losses due to lost load (de Nooij et al., 2007; Carlsson and Martinsson, 2008; Carlsson et al., 2011)." The economic and social benefits that batteries may provide in deferring network investments, lowering network congestion, and thus reducing network costs to customers are areas that require further research.

In addition, there is a lack of clarity on managing the long-term lifecycle impact of batteries. Currently, no long-term studies are evaluating the impact of the charge capacity of batteries and their lifetime on community battery longevity. Policy also needs to address the possible risk of increasing inequality between community batteries and other electricity users. The feasibility of using other storage technologies, such as ultra-batteries, vanadium flow batteries or other hybrid technologies has not yet been considered. Pilot projects at a community/precinct scale can be designed around each, or combinations, of the issues raised here, and such pilots should be designed in conjunction with industry stakeholders. Further, given the growing number of community batteries and trials already underway, research can be conducted on existing implementations (also see proposed trial in Section C).

Precedents

Community batteries are primarily in the trial phase in Australia, where most trials are led by the distribution network service providers (DNSPs). In Western Australia (WA), the state utilities Western Power and Synergy recently completed a community battery trial project in Alkimos Beach, north of Perth. The trial was initiated in 2016 and involved a 1.1 MWh lithium-ion battery and 119 domestic participants (Synergy, n.d., Alkimos Beach Energy Trial). In this project, participants were paid to export power to the battery and were then charged a smaller amount to import power needed later. The participants were charged a monthly fee to access the battery service. The participants collectively saved over $81,000 on electricity costs over the five-year trial (or an average of about $36 per power bill). The battery also helped with peak-load shaving, with an 85% reduction in participants′ electricity demand from the grid at peak times. However, this project was heavily subsidised and economically not viable to continue.

Powerbank's first trial was in Meadow Springs, WA, with a 105 kW/420 kWh battery, followed by a second trial in Falcon, WA, and Ellenbrook, WA, with a 116 kW/464 kWh battery. The third Powerbank trial (Western Power, n.d., Latest battery storage trial to benefit hundreds of WA homes) is the largest trial, with nine 116 kW community batteries (Western Power, n.d., Community batteries delivering big benefits) across Perth and south-west WA. In Victoria (VIC), United Energy has been building a network of 40 small 30 kW community batteries on power poles to support 3,000 homes following a trial in 2020 (Purtill, 2022). In May 2022, the Yarra Energy Foundation (YEF) will install a 250 kWh battery in North Fitzroy, VIC. In New South Wales (NSW), Ausgrid initiated the Beacon Hill Pilot Program among 600 houses in Sydney's northern beaches with a 150 kW/267 kWh battery (Peacock, 2021). In South Australia, the ESCRI-SA grid-scale battery (ElectraNet, n.d., Boosting reliability on Lower Yorke Peninsula) in Dalrymple, SA, is being trialled for market participation. This is a 30 MW/8 MWh battery. The project's initial findings suggest that the battery is economically viable when it is used as a backup power source and for frequency stabilisation. For the third-party operator, AGL, it generates a significant income (e.g. $1 million in 2018 from energy and FCAS markets).

A cost-benefit analysis for different models of community battery ownership has been carried out by an Australian National University (ANU) team and published in recent reports (ANU, 2020b; ANU, 2020b). The following four ownership models were considered:

1. Third party-owned community battery
2. Third party-owned for-profit model
3. DNSP-owned community battery
4. DNSP-owned for-profit model

Table 9. Summary of services and revenue value streams for ongoing or completed community battery projects in Australia

Project	***Subscription***	***Export***	***Import***	***FCAS***	***Arbitrage***	***Value for Network*** *1.Demand management* *2. Upgrade deferral* *3. Congestion relief*
Alkimos Beach North						
Powerbank 1, 2 and 3						
Beacon Hill, NSW						
ESCRI-SA battery						

The findings of this study reveal that the reduced local energy transport price, and local use of service (LUoS), are required to motivate local energy exchange, and that market participation is key for community batteries to become economically viable under the current battery-and-market cost and regulatory frameworks.

While community batteries are less widespread than their utility-scale counterparts, they can provide similar services in a localised context. Csereklyei et al. (2021) note that "*The services [that] batteries can provide, especially in system services, are becoming increasingly valuable for the market, too, especially with increasing value on rapid response, dispatchability and flexibility, as electricity systems grapple with the integration of increased renewable generation. As costs decline, significant utility-scale battery additions are projected in many countries.*"

Methodology

Feasibility study for valuation of different revenue streams and trial project scope

The research aspects highlighted above cannot be addressed through a single trial project. It would also be challenging to formulate the trial project scope without getting answers to some of the initial questions. Therefore, we propose a comprehensive, yet focused, techno-economic feasibility project to understand the theoretical revenue for different value streams under different regulatory and operating scenarios. The finding of this investigatory project will then inform the trial project scope.

Storage technologies feasibility study for community storage application

This desktop study investigates the techno-economic feasibility of using other storage technologies, such as ultra-batteries and/or vanadium flow batteries, for community storage applications. This project involves the development of a number of storage system dynamic models and simulations for different combinations of community battery services (value streams) and their associated lifecycle analysis.

Trial project

Based on the feasibility studies, design a long-term (10 years) community-battery trial embedding technical evaluations and proofs-of-concepts of parallel alternative storage technologies that allow for real-time monitoring of the battery technology storage capacity, temperature and related chemical aging.

Potential stakeholders and partners:

- DNSPs – AGL, Horizon Power, Ausnet and others
- Electricity retailers – Energy Australia
- Govt Entities – DELWP/AEMO
- Organisation/communities – Climate-KIC
- Service providers – Planet Ark Power and others

Impacts

This project will help all stakeholders including network operators, planners, potential owner and end-users to better:

- Understand the community batteries' full potential and key barriers constraining its viability [Education]
- Understand the storage technologies' comparative performance in community storage applications [Education]
- Maximise the return on investment, resulting in lower electricity costs [Bill reduction]
- Maximise the return on investment through the ability to prevent possible blackouts [Grid reliability]
- Understand the potential of community batteries to displace gas generators, resulting in possible lower peak prices (Csereklyei et al., 2021) [GHG reduction]
- Understand the full value proposition that community batteries offer

3.4 Ownership and access

Objectives

Drawing on a review of the literature on community battery ownership and access, a number of important issues have been identified that can be investigated or demonstrated in a pilot project. Burger and Luke (2017) note that business models are still in the early stages of evolution and likely to change dramatically as the market for DER matures and stabilises due to declining costs, technological innovation, and changing policy and regulatory landscapes. With current access models driven as much by these regulatory and policy factors as they are by technological factors, pilots should explore the more probable determinants of success including executional capabilities and culture. Warneryd et al. (2020) reflect that in this formative phase, the formal institutional barriers to community DER are still significant, and that in Australia, low governmental ambition has created greater consumer desire to drive the development of renewables. Hence, viable business models are required that inevitably rely on other investors, unavoidably resulting in less benefit to the community compared to contexts where governmental ambition is higher. These same authors also note that while utilities emerge as critical actors, their role in projects and the extent of their influence need to be carefully considered.

Table 14 summarises the key learnings from a 2020 study by ANU that investigated the implementation of community-scale batteries owned either by third parties or by DNSPs (Shaw et al., 2020).

Table 10. Insights from Shaw et al., 2020

Community-scale batteries can increase the amount of distributed energy resources (e.g., solar panels and electric vehicles) that can be integrated into the distribution grid (i.e., increase hosting capacity).	Only DNSP-owned community-scale batteries currently require regulatory exemptions, and only if the battery is being used for anything other than regulatory network services. All other models we investigated can proceed within the current rules and regulations.
Network tariffs and market signals shape how the battery's actions contribute to hosting capacity.	Reduced local network tariffs are crucial for incentivising battery charging from locally generated solar energy and sale of energy to local customers.
Community-scale batteries are already financially viable, particularly if FCAS markets can be accessed.	Industry professionals saw significant potential benefits of community-scale batteries, including over behind-the-meter (BTM), and virtual power plant (VPP) storage. They also consider the dynamics between actors in disaggregated markets to be a major challenge.
The technical capability for implementing community-scale storage on the NEM already exists.	Householders care about more than just affordability when it comes to energy storage (e.g., there is strong concern over battery lifecycle, promoting local energy use, reducing carbon emissions, questions of fairness and how this technology would fit in the broader energy transition to renewables).

A lack of understanding is also reflected in different perceptions of electricity trade and equity in tariff structures of DER owners and non-owners. It is essential to understand how subsidies and tariff structures can benefit or disadvantage different groups in the community to consider equitable solutions for community batteries. One of many challenges is the current cross-subsidies that may accrue between prosumers and consumers. This possibility in the area of community batteries could be covered through a pilot project (Kalkbrenner, 2019).

Precedents

The precedents for this research opportunity were provided in Section 2.4.

Methodology

It is apparent that a combination of both quantitative and qualitative measures will be required to understand the full range of benefits and challenges in community battery ownership and access, and that a broad array of stakeholders will need to be involved to understand the impacts of the pilot across the entire value chain ranging from consumers, retailers, original equipment manufacturers (OEMs), DNSPs, asset owners, property developers, government, regulators and market operators, local trades people, investors and community groups.

Quantitative data will be particularly important for the technical, environmental, and economic or commercial evaluations. Similarly, qualitative evaluations will be essential for the social components of the projects given the strong community interest. Probable research tools will include a combination of surveys and one-on-one interviews involving participants from existing storage projects both planned or already underway.

Impacts

Based on a review of the outcomes of projects in Table 13, the identification of an 'effective' model of ownership and access could be partially determined through a combination of the following measures:

- Changes in total consumption (kWh/$)
- Changes in household/organisational consumption (kWh/$)
- Changes in peak demand (kWh)
- Changes in network security and reliability
- Non-economic benefits—social, environmental (tCO_2-e)
- Community satisfaction and increase in engagement
- Impact of combinations of different technologies
- Impacts of different electricity tariffs
- Impacts of different generation, export and consumption patterns
- Impacts of demand shifting
- Physical versus virtual storage models
- Inverter active and reactive power release (voltage control)
- Battery charge and discharge scheduling
- Scheduling that can respond to network signals (DNSP service capability)
- Flexible export control (smart exports)
- Compare contracting versus ownership models
- Stakeholder satisfaction

Industry Reference Group comments:

- EVs will be able to offer location agnostic network support (e.g., renewables smoothing) - the EV will just need a suitable SCADA configuration to sense grid frequency and voltage.
- The following ARENA trial may provide some useful insights on value and firmness of EV flexible energy to support energy value streams: https://arena.gov.au/projects/agl-electric-vehicle-orchestration-trial/
- EV battery storage can be considered opportunistic and would be subject to a relatively low availability factor. However, once you have a large population, statistically you will be able to rely on a percentage based on common localities visited.
- There is potential to use these "batteries- on- wheels" to assist with issues such as low minimum demand during the day when the levels of solar PV export are high.
- Harnessing fuel: price: cycle behaviours could be harnessed to move the EV battery within the distribution network.
- Surge pricing with push notifications in negative or low wholesale price events.
- It would be desirable that we don't lose, but instead harness, current bargain hunting behaviours using existing fuel pricing apps.
- EVs could be used as a solar soak on localised sections of grid with high solar PV penetration and at grid scale.

3.5 Electric vehicles

Objectives

Estimating available capacity

At any time, and for a given geographical area, we need to be able to predict or measure to a defined level of confidence the amount of available load that can be drawn (akin to firm capacity) or absorbed by the EV fleet in that geographic area. The working hypothesis is that this will be provided by the combination of a predictive model based on past behaviour, EV and owner profiles, and, wherever possible, live data from vehicles that are plugged in or can provide over-the-air telemetry. It may be thought of as a digital twin of the real system. The model will be the basis of distributed control strategies.

Note that even vehicles that can only charge can be useful as a way to absorb excess capacity, even if they can't directly send it back to the grid. Ideally, V2G-enabled EVs will be used to store excess renewables (e.g., solar) to use when renewable generation is low (e.g. at night). This is an urgent and important question to answer. Electric vehicles may also be used to provide power in emergencies such as climate extremes or grid failures.

Maximising available capacity

Once we understand how to predict or measure the amount of storage available from EVs, the next objective is maximising that storage. This means maximising

a) The number of vehicles and charging locations enabled for V2G

b) The number of people willing to allow their vehicles to be used for V2G

c) The time vehicles are plugged into chargers, especially at critical times and locations, and

d) The amount of battery storage that owners are willing to allow the grid to use

The other aspect is to develop effective incentives to encourage desirable behaviour by EV owners, fleet operators, and charging infrastructure providers. Key research questions are how to build trust, how to develop effective financial and non-financial incentives, and what are the best methods for communicating those incentives to nudge desirable behaviour. How such strategies apply to different demographics is also important. For example, just how much money does it take for someone to allow up to 20% of their EV battery to be under grid control?

Finally, we also need to understand how regulatory levers can mandate and incentivise the introduction of key technology such as two-way chargers, as well as defining standards for interoperability.

Pilot study

A pilot study could be added to an existing V2G-enabled trial such as AGL's Vehicle Orchestration Trial, which would be used to understand five things (ARENA, n.d., AGL Electric Vehicle Orchestration Trial):

a) How to people charge their vehicle when there are no incentives? (when, where, how long and how much)

b) How people charge their vehicles when there are incentives. The trial could expose different cohorts to different levels of financial incentives to understand at what point behaviour is nudged

c) How well models of the system predict the EV charging behaviour compared to the data

d) The extent to which live data on EV capacity is available from chargers or over-the-air telemetry

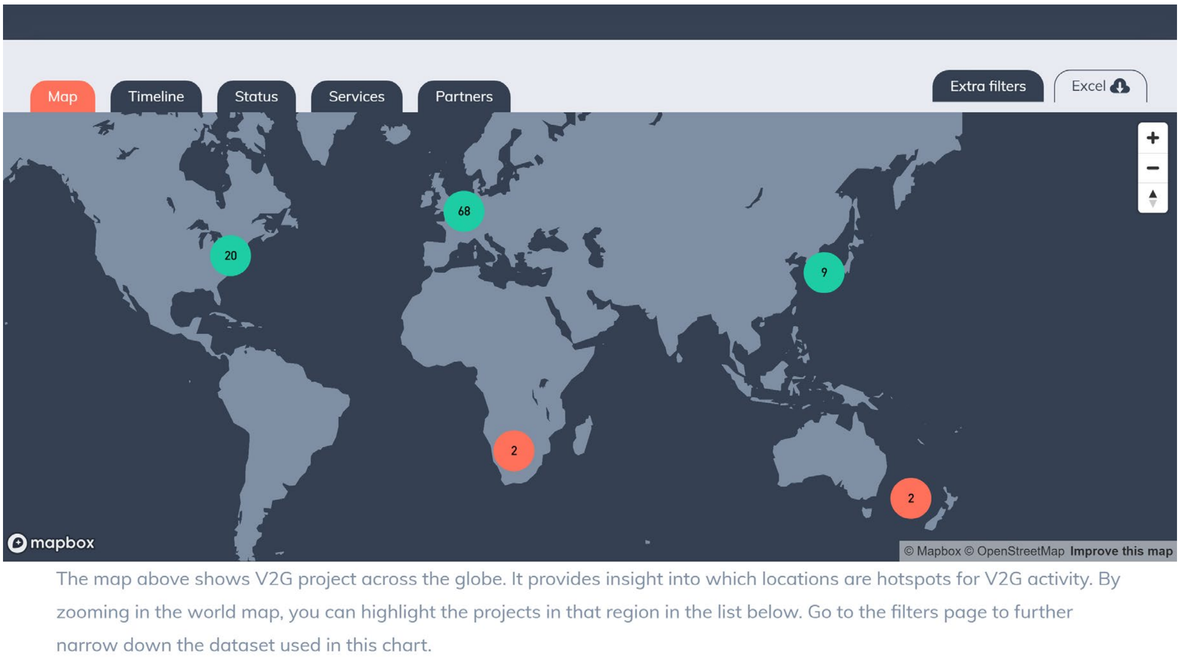
e) Survey and interview data to gain insights into effective incentives for desirable behaviour and V2G technology uptake.

When will EVs be redundant as a power source?

This can be answered by understanding at what point storage technology will become cheap enough that using the EV fleet for storage no longer has sufficient value to EV owners to participate in grid-level charging or to change their charging behaviour to assist the grid, and when the costs of managing mobile storage are no longer worthwhile for energy and storage providers. This is unlikely to happen in the next five years but may further into the future, and researching available EV capacity should take priority.

Precedents

V2G Hub (2020): The V2G hub provides a continually updated list of V2G trials globally. Note that Europe is the global leader in number of V2G trials.



The map above shows V2G project across the globe. It provides insight into which locations are hotspots for V2G activity. By zooming in the world map, you can highlight the projects in that region in the list below. Go to the filters page to further narrow down the dataset used in this chart.

Figure 3. Map of V2G projects across the globe

Utility Week (2021): Mapping out the role of V2G in energy flexibility. Article highlighting accelerated funding and collaboration for demonstrations of V2G for improving grid resilience, among changing consumer behaviour and a range of challenges to EV uptake and total utilisation.

Cenex (2021) Sciurus: Domestic V2G demonstration. Project Sciurus (at initiation the largest V2G project in the world) is demonstrating EV management and V2G in the UK to improve grid resilience, exploring options for technology and business models.

ARENA, AGL electric vehicle orchestration: AGL Electric Vehicle Orchestration Trial. A coordinated EV charging to demonstrate potential to energy and technology stakeholders and examine user behaviour.

Mitsubishi, 2020: Leveraging EV/PHEV as resources for virtual power plants commencement of trial operation of V2G business demonstration facilities, Mitsubishi. Government-initiated, pan-industry collaboration using various EV types (commuting and commercial) to form a VPP via V2G to demonstrate business models and control methods.

ARENA: Realising electric vehicle-to-grid services. ACT based trial involving employing 51 V2G-enabled Nissan LEAF EVs in ACT Government and Actew AGL fleets.

Jones et al., 2021: The A to Z of V2G: A comprehensive analysis of vehicle-to-grid technology worldwide. A comprehensive global analysis by ANU of REVS, analysing technology (hardware, statistics), business models (mechanisms, value streams) and the Australian context (standards, managers).

Lucas-Healey, 2021: Interim social report from the Realising Electric Vehicle-to-Grid Services (REVS) Trial, Battery Storage and Grid Integration Program, ANU. 35 in-depth interviews were conducted with participants from target groups involved in V2G.

Dodson & Slater, 2019: Electric vehicle charging behaviour study, Final Report for National Grid ESO (UK), Element Energy. Investigated demand for EV charging in the grid, analysing user behaviour for impacting factors.

Lee et al., 2020: Exploring Electric Vehicle Charging Patterns: Mixed Usage of Charging Infrastructure. Lee et al., *Transportation Research Part D*. A Californian study exploring EV charging behaviour, examining impact of demographics, charging location and charging level on driver choice of charging location and level.

Boström, 2021: The pure PV-EV energy system. A conceptual study of a nationwide energy system based solely on photovoltaics and electric vehicles. Boström et al., *Smart Energy*, 2021. Examining Spain's potential for an entirely PV-EV generation-storage electricity system, considering movements of EVs and demand profiles. Relevant to Australia as Spain also has high PV potential and leads Australian EV uptake.

Kester (2018): Promoting vehicle-to-grid (V2G) in the Nordic Region: Expert advice on policy mechanisms for accelerated diffusion. Advice on policy mechanisms for improving transition, suggesting focus on regulation, taxation, demonstrations, planning and information.

Methodology

Research methodology

1. Collect published data on EV-charging behaviour from the literature and current reports and trials. Ideally, charging behaviour will encompass when, where and how long EVs charge, and the typical amount of battery charge changes while connected. V2G data will be the most valuable, though G2V charging behaviour may also yield modelling insights.

2. Construct a theoretical, spatio-temporal model of charging behaviour using available published data as input initially. This will most likely be based on machine learning methods and also draw on queueing theory and other stochastic approaches which may be applicable. From this predicted charging behaviour, it should be possible to estimate the available capacity in a geographic region at a given confidence level. The model should be tested against real behaviour wherever possible for refinement.

3. Investigate what real data are available from charging systems and vehicle telemetry that can report on battery-charge levels, location and, potentially, intended destinations (although privacy concerns may be an issue). This data may then be used to improve the model and to construct a digital twin formed from prediction and real data.

4. A pilot study linked to an existing V2G trial can be used to collect real behavioural data under a variety of scenarios, including charging behaviour with no incentives of any kind, and how different kinds of incentives affect actual charging behaviour. Of particular importance are the thresholds of financial incentive that measurably nudge behaviour and attempting to uncover compelling non-financial incentives. These results will be incorporated into the model and the model then tested against future behaviour.

5. Survey and interviews to understand what EV owners, fleet operators and charging infrastructure stakeholders express around participating in a V2G system. Key research questions are how to build trust, identify blocking issues (e.g., high cost of V2G chargers), develop effective financial and non-financial incentives and find the best methods for communicating those incentives to nudge desirable behaviour. How such strategies apply to different demographics is also important.

The final stage will be to compare what people say they will do when it comes to V2G charging, how well the model predicts their behaviour, and what the real world measured data says. This will provide the best idea of how reliable capacity estimates from EVs are and how well they can be matched to fluctuating renewable energy loads or when called on in emergency situations.

Stakeholders

RACE for 2030 currently has a cohort of stakeholders engaged in V2G who would be relevant to this research. These are Icon Retail Investments Limited, AGL ACT Retail Investments, Australian National University, ACT Government, SG Fleet Australia, JET Charge, Nissan Motor Co., Icon Distribution Investments Limited and Jemena Networks. It is also possible to seek representation directly from EV owners through an association such as the EV Council of Australia.

Impact

Being able to determine with confidence the amount of capacity available from V2G-enabled EVs as storage in the grid could improve grid resilience and the quality of electricity service. Sufficient EV storage capacity would make it possible to increase the storage available during lulls in wind solar generation, measurable by reductions in service outages, and potentially lower electricity prices due to savings from less investment in stationary storage. Increasing storage in the grid will accelerate commissioning of renewable generation, reducing greenhouse gas (GHG) emissions faster than would be the case with stationary batteries alone. Financial analysis could compare various scenarios to estimate how large this effect is. This also has the effect of relieving balance sheets, freeing capital to invest more in renewable generation or charging infrastructure. EV owners could see direct financial benefits if they were paid for the storage they contribute to the grid. This benefit could be financial, in the form of credits, or through some compelling non-financial incentive such as parking.

3.6 Storage options

Objectives

Energy storage in the grid is an exciting topic with progress on many fronts. Globally, the currently dominant forms of grid storage are (pumped) hydro and stationary batteries, both grid-scale and residential, with grid-scale batteries comprising around two thirds of the total (IEA, 2022a). As identified by our industry partners, there will be a mix of storage options, including batteries (lithium-based for short term, and likely flow batteries for long term) and increasing interest and capability in hydrogen and new electrolyser and fuel cell technology. This is especially important in Australia, where we are seeing significant investment in green hydrogen. There is also an explosion of new battery chemistries, new thinking on gravity batteries and flywheels, advances in battery/supercapacitor hybrids, and Snowy 2.0, which will create significant new hydro storage for the NEMS (170-350 GWh) (Mountain, 2019). Our partners also identified EVs as likely to become a significant storage resource. EVs are forcing advances in battery technology with spill-over effects into improving grid-scale and residential batteries. EVs are considered separately in Work Package 4 of this report. Relevant material can also be found in the “N3 Opportunity Assessment, Work Package 3: Planning and design”.

Currently, it looks like the major growth in new energy storage will come mainly from batteries (short and long term) growing at 1 GWh per annum in Australia (ESN, 2022) and set to accelerate, with some 27 GWh of new battery storage anticipated by 2032 (AEMO, 2022). There will also be new green hydrogen generation, as well as extensions to natural hydro storage (Snowy 2.0). However, this view needs to be evaluated and tested as technology and markets evolve to ensure that we understand what the likely best-fit storage options for the grid for short-term storage and long-term storage are at different scales and at different points in the future, and whether there are any foreseeable major changes to our current thinking. This will need to be based on current assumptions and trends and revised as we move into the future.

Each of the storage options will ideally be evaluated across the following **comparison criteria:**

- Suitability for which environments and scale (commercial, residential, central/utility, local)
- Short-term or long-term storage
- Technology readiness level (ARENA, 2014) and estimated date till commercially viable at scale
- Energy density and current cost per MWh
- Trends (price, performance, readiness, and understanding limits of cost reductions)
- Longevity and lifecycle cost
- Operating and maintenance cost, and cost of interface to grid (AC/DC electronics)
- Safety (e.g., toxicity for vanadium flow batteries, Lithium fires, operating temperature)
- Sustainability (e.g., use of rare materials, recycling—this may prove to be a deciding factor)
- Scalability (e.g., batteries are easy, harder for hydrogen)
- Overall assessment of advantages/disadvantages.

To inform the preceding comparisons, we propose projects in the following areas:

1. Pilots of new, grid-scale battery technologies, ideally at both precinct and grid-scale. Pilots should be focussed according to industry partner priorities, with inputs from researchers.
    a. Lithium technologies (widely deployed and fast evolving)
    b. Flow batteries (currently with limited commercial deployments)
    c. Hybrid energy storages (e.g., adding supercapacitors with batteries)

    An important aspect of any pilot and study is to understand when and whether there are new approaches that will make lithium batteries attractive for long-term storage, especially as hydrogen has seen increased investment. A list of ARENA-funded battery projects can be found at ARENA (2022b).

2. Pilots of grid-scale hydrogen storage fuel cells and electrolysers, including hybrid solutions that compensate for hydrogen electrolyser's slow response time. A key question to understand is what is needed for hydrogen to compete with batteries for long-term storage, and what may be needed to use hydrogen for short-term storage (for example, using hybrid technology).

3. Estimating the potential of pumped hydro (using natural or constructed reserves). This would be desktop research based on existing geographical datasets for natural hydro storage and research into the potential of constructed hydro storage. Pumped hydro is the most mature and widely used energy storage technology in the world, and advancing hydro technologies reduce capital costs and increase their suitability for new environments, such as urban and mining. A key question is at what level of storage capacity pumped hydro becomes cost competitive with battery technologies. Snowy 2.0 must be considered.

4. Technology watch on gravity batteries, flywheels, new battery chemistries, hybrid technologies such as ultra batteries, supercapacitors, thermal storage, compressed/liquified air and others that may emerge. This would be updated every six months and potentially represented using a Technology Radar approach (Thought Works, n.d., Technology Radar) which maps technology progress from concept to commodity availability.

The following table outlines the major storage technologies we will consider and the key research and deployment questions or observations about the technology's characteristics, as well as the research approach.

Table 11. Storage technologies and key areas for research

STORAGE TECHNOLOGY	KEY RESEARCH/DEPLOYMENT QUESTION OR OBSERVATION	RESEARCH APPROACH
LION BATTERIES	Lithium supply, longevity, sustainability, expensive for long-term storage, degrades with cycles	Pilot, desktop research, stakeholder interviews
HYDROGEN FUEL CELLS	Early stage, high electrolyser cost, potential for large- scale storage	Pilot, desktop research
PUMPED HYDRO	Scale at which cost competitive, limited natural catchment	Desktop research
VANADIUM REDOX FLOW BATTERIES	Suited to long-term storage but still in limited commercial deployments, highly scalable, lower energy density, long lifespan. Vanadium is expensive	Pilot, desktop research
HYBRID TECHNOLOGIES	Combines characteristics of different technologies to achieve lower cost and utility at scale	Pilot, desktop research
ULTRA-BATTERY	Combines low cost and scale of lead-acid with fast charge/discharge of a supercapacitor	Technology watch
COMPRESSED/LIQUIFIED AIR	At large scale limited to natural features such as caverns; possible niche in the kW to MW range	Technology watch
GRAVITY	Maintenance, cost per MWh, evaluate deployed pilots	Technology watch
THERMAL	How much this can reduce overall electrical load for storage and generation. Track combination with concentrated solar power generation	Technology watch
SUPERCAPACITOR (ULTRACAPACITOR)	Practical application to protecting grid batteries, ancillary services	Technology watch

FLYWHEEL	Very expensive, high discharge rate, unlikely to be important, except in niche applications	Technology watch
NEW BATTERY CHEMISTRIES	Typically, these are early stage, and most lead nowhere; key is to be aware of emerging winners early	Technology watch

Precedents

(IRENA, 2017) IRENA Electricity Storage and Renewables: Costs and Markets to 2030

(IRENA, 2022) Renewable Technology Innovation Indicators: Mapping progress in costs, patents and standards

(AEMO, 2022) AEMO NEW Forecasting and planning-data/generation-information

(ARENA, 2014) Technology Readiness Levels for Renewable Energy Sectors

(ARENA, 2022b) ARENA Funded Battery Projects

(APH, 2021) Australian electricity options: pumped hydro energy storage, Australian Parliamentary Library

(FBICRC, 2021) Future Charge: Building Australia's Battery Industries

(Thought Works, Technology Radar) Technology Radar: An opinionated guide to technology frontiers

(Blakers et al., 2017) 100% renewable electricity in Australia

(ESN, 2022) Australia surpassed 1GWh of annual battery storage deployments during 2021

(The Conversation, 2019) Snowy 2.0 will not produce nearly as much electricity as claimed

(CSIRO, 2021) Summary of Hydrogen demonstration Projects in Australia

(CSIRO, 2019) CSIRO research and development of ultra-battery technology

(CSIRO, 2022) CSIRO Hydrogen Map (interactive)

(Wan et al., 2020) Overview of Key Technologies and Applications of Hydrogen Energy Storage in Integrated Energy Systems.

Figure 4. Hydrogen demonstration Projects in Australia. Click link in reference for live map (CSIRO, 2022)

Methodology

The key approach is trend analysis against the comparison criteria. There are many good quality reports produced by different research agencies locally and internationally, and these provide a basis for trend estimation. We would also employ formal foresighting methods to improve the accuracy of trend analysis and to identify potential disruptions. This would include monitoring uptake of different storage technologies as they move through the various technology readiness stages, drawing on extensive work in the RACE for 2030's Research Theme E2: Innovative foresighting and planning project. For technology watch, the technology radar approach could be employed as a visualisation and insight tool (Thought Works, n.d., Technology Radar).

We would also carry out a storage technologies feasibility study (and application mapping):

- Performance characterisation for different applications and grid services
    - Dynamic modelling and simulation
    - Result analysis to make capability chart and map applications
- Techno-economic performance comparison of different storage technologies for their applications in microgrid, community batteries and VPP
    - Dynamic modelling and simulation
    - Cost and lifecycle modelling

The pilot projects will be designed based on the findings of the above desktop study projects. For pilot deployments, we will employ a combination of quantitative methods (to evaluate pilot success) and stakeholder interviews with the below groups to provide qualitative evaluations.

- Stakeholders and partners: Technology vendors – good working relationships with the R & D teams of storage technology vendors, which give visibility into the roadmaps of different storage technologies
- Energy providers (utilities, retailers, ancillary service providers) who are planning or conducting pilots
- Energy investors – providers of capital
- Consumer groups which are often under-represented

Impacts

GHG reduction and grid reliability: Wider deployment of appropriate storage will accelerate the transition to clean energy by reducing the dependence on fossil fuel sources at night and provide stability for variable generation from both wind and PVs. Storage will also make the grid more reliable in two ways. First, battery storage can respond much faster to sudden changes in demand and second, storage, especially when distributed, makes the system more resilient to generation and transmission failures. It will only be possible to measure these improvements as systems are deployed at reasonable scale, however, models can be developed which can predict the likely performance of widely deployed grid storage, and the models can be used as input data from currently deployed systems. Direct metrics for GHG emission would be the estimated total CO_2 emissions for both embodied and operating condition. Harder to measure, but still important, would be estimating the amount of CO_2 saved by the accelerated uptake of renewable generation.

Cost/price/bill reduction: Ultimately, deploying sufficient energy storage to allow a complete transition to renewable energy will dramatically lower the cost of energy production as the need for fuel is removed. This can be modelled right now, with inputs tuned by using data from existing deployments. Estimating how much this results in a reduced price to the end customer is more complex as this depends also on the transmission and distribution charged, which is distorted by historical decisions. A further factor is the extent to which local microgrids supply energy to their participants, especially if these microgrids have limited need for access to the distribution network.

3.7 Advanced technologies

Objectives

The most important modern technologies that needs to be trialled in future implementations of microgrid and VPPs are as follows:

1. Urban Renewable Energy Zones (UREZ)

As identified by IRG member Planet Ark Power:

".. voltage management is the big issue. A high penetration of DER results in the voltage being pushed above limits, this causes energy curtailment (e.g., from solar PV systems, or from a BESS in discharge mode."

Moreover, IRG member AusNet identifies "better orchestration for more optimised control" as an important area for research in this project. As proposed in the Final Report of the RACE for 2030 project on 'Demonstrating pathways for Urban Renewable Energy Zones: Barriers, opportunities and impacts of establishing a REZ', the overvoltage problems due to high renewable energy penetration in distribution lines could best be controlled by using a distributed, multi-layer power flow control system comprising of energy storage devices such as EV batteries, home batteries and community-scale batteries, voltage measurement and control devices such as phase measurement units (PMUs) and distribution static compensator (DSTATCOM), and smart energy management system controllers integrated by a dedicated communication system (Espina et al., 2020). This system can be applied in both microgrids and VPPs. It also can integrate all of the other technologies identified below as additional features. When several microgrids are connected to a utility system, a higher-level controller will be required that can manage the power flow to and from the microgrids.

2. Energy forecasting

For optimisation in the management of microgrids and VPPs, the forecasting of energy generation, demand and prices are important inputs (Nguyen Duc & Nguyen Hong, 2021). In the case of renewable energy generation, the very-short-term to long-term forecasting of weather, such as cloud coverage and wind speed, is critically important. Satellite data, sky cameras etc. can be used to manage the generation and storage portfolio most effectively (Barbieri et al., 2017). When it comes to energy demand, many factors can affect the quality of the prediction outcome, including social factors, seasonality, prediction interval, and the intrinsic physical parameters of the assets. To improve the prediction accuracy and reduce the uncertainty related to optimization of microgrids and VPPs in such solutions, the local communities and social characteristics of customers also need to be considered.

3. Digital twin (DT) models

Digitisation or digital platform refers to integrating real-time data from the physical sensors with the virtual replicas of these devices. The virtual devices replicating the physical devices are called digital twins (Enders & Hoßbach, 2019). Digital twin models enable the analysis of large amounts of data using AI and machine learning. Digital twins of a microgrid's critical assets will significantly improve operational efficiency of the grid. With the purpose of energy efficiency improvement and energy exchange minimisation, DTs are useful for empowering both microgrids and VPPs to manage their portfolio. Thanks to the advancement of machine learning methods, digital twinning has become a crucial approach to improve performance in modern engineering. The concept of a digital twin can be extended to assimilate the potentially conflicting objectives and operational dependencies of DERs in microgrids so that their performance bottlenecks and trade-offs can be simulated by VPPs prior to reinforcing any policies for optimised management.

4. Industry 4.0 technologies and cyber security

The last decade has witnessed a phenomenal growth in Industry 4.0 technologies, such as the Internet of Things, cybersecurity, AI and machine learning, and these have resulted in the widespread adoption of Industry 4.0 solutions. An Industry 4.0 environment consists of many sensor devices capturing continuous and real-time data of various processes. Industry 4.0 supports solutions that can automate and optimise industrial processes, thereby saving cost and improving productivity (e.g., Energy 4.0 - Dexma, 2021). The electric energy sector is one of the sectors most targeted by cyber-attackers. With the swift rise in sustainable energy demand, the security of distributed controllers, services, power plants and generators plays a vital role in preventing the malfunctioning and unavailability of power systems. The Australian Energy Sector Cyber Security Framework (AESCSF) has been developed through collaboration with industry and government stakeholders, including the Australian Energy Market Operator (AEMO), Australian Cyber Security Centre (ACSC), Cyber and Infrastructure Security Centre (CISC), and representatives from Australian energy organisations (AEMO, 2022). VPP and microgrid security needs to be integrated in future implementations.

5. Coordination, optimisation and certification

Power flows, local density and economic, administrative and social factors are criteria that must be considered in microgrid and VPP optimisation processes (Naughton et al., 2020). Decentralised decision-support systems require data on assets size, local sustainability goals, communication efficiency or latency, and local typology (Zhang et al., 2022). Adopting a game-theory-based economic model to operate VPPs could dynamically adjust pricing while conducting energy trading of DER in microgrids under varying contexts and competitive scenarios. Implementing a consortium blockchain spanning multiple communication layers, from smart meters to Cloud datacentres, for ensuring integrity and privacy while dealing with sensitive consumer information pertinent to DER will be critical in certifying the authenticity of renewable energy generated using platforms such as Powertracer (Enosi, n.d., Powertracer).

Precedents

Schneider Electric, alongside AutoGrid and Uplight, announced a new end-to-end grid-to-prosumer initiative to optimise the inter-connection between DER. With the industry's most comprehensive end-to-end-integrated DER management system, the new approach enhances grid flexibility (Businesswire, 2022). G2P incorporates the three pillars of DER management - grid optimisation, flexibility services, and prosumer interaction - with the utilisation of EcoStruxure Microgrid Advisor (Schneider Electric, n.d., EcoStruxure Microgrid Advisor), which allows prosumers to dynamically adjust on-site energy supplies and loads to maximise the operation of their facility. The solution integrates with existing distributed energy resources to forecast and optimise how and when to consume, generate and store energy.

A suburban neighbourhood microgrid pilot program is currently taking place in Tampa, Florida. The project was featured in an article listing 22 microgrids showing promise due to their innovative approach which provides a new layer of control besides the flexibility (Wood, 2022). Emera Technologies pioneered the concept utilising 'Block Energy', which turns each home into a nanogrid with its own solar, battery and control technologies. This project was announced in 2020 and cautious steps have since been taken to build the microgrid, adding homes incrementally. The houses are linked by a cable network system, a DC bus, that runs through the entire community, enabling the residences to share their energy resources (Wood, 2022).

Another urban microgrid project is taking place in Oakland, California (Cohn, 2019). The Oakland EcoBlock Project intends to create both a resilience oasis during energy outages, as well as a decarbonisation blueprint for communities around the country. The microgrid will be used to integrate solar and EVs at distribution levels. Retrofitting city blocks is the main focus of the project as they are the most common units of organising houses in urban and suburban areas. In 2020, researchers from Monash University, Melbourne, devised a novel energy exchange system to manage DER and assist consumers lower their power expenditures. The transactive energy market (TEM), is claimed to be a revolutionary method of energy management and trading, as well as a way of facilitating the DER integrations in existing networks (Maisch, 2020). It offers a market-based framework that enables demand and supply to actively negotiate energy exchange.

Community-battery projects in Westerns Australia and Queensland demonstrate how the same approach can be used to defer traditional network augmentations. The objectives of these projects are to support and enhance the voltage profile of the distribution feeders and extend the life of network assets such as distribution transformers. It also seeks to understand the customer appetite for community batteries, and to develop business models that can access multiple value streams through the delivery of community batteries (ARENA, 2021b; ARENA, 2020; Western Power, n.d., Where are the community batteries located; Synergy, 2021).

An active grid management system integrated into the Indra Monash Smart Microgrid Project is used as a large-scale trial to demonstrate the value of smart energy infrastructure to the various market participants. Energy use optimisation from the grid, rectifying power quality issues at the microgrid, and improving performance reliability through model predicting loads and the embedded generation are the key objectives of the project (ARENA, 2019c). Similar objectives were pursued in the Shakti Microgrid Pilot project launched in New Delhi under Horizon 2020 IElectrix program (IEC, 2022; IElectrix, n.d., Indian demonstration (Shakti); CIRED, 2020).

Stantec Inc. from Alberta, Canada is a solutions provider for DER management systems (DERMS). Their services encompass preliminary research and character development to system planning, DERMS and pilot execution (Stantec, n.d., Distributed Energy Resources (DER)). Their services extend to grid modernisation, renewable energy integration, energy storage and microgrids. Powerledger is a Perth based company that offers services such as P2P energy trading, managing grid stability and flexibility and supplying large consumers with 24/7 renewable energy with VPP. The Powerledger Energy Blockchain is a customised permissioned Solana blockchain. eleXsys Energy is the inventor and manufacturer of an award-winning solution to the voltage problem caused by clean energy producers trying to send energy back to electricity grids. This DSTATCOM-based voltage management technology was first commercialised in 2020 with the integration into a microgrid project with global retail giant IKEA (eleXsys, 2022; Powerledger, n.d., Blockchain for decentralised and distributed energy markets).

However, there is still a lack of precedents in applying distributed control, Digital Twin, Industry 4.0, energy forecasting, a dynamic economic model and blockchain simultaneously to meet the diverse challenges in this domain.

Methodology

The research methodology in this theme includes desktop studies, computer simulations and laboratory trials leading to demonstration projects. The distributed control system is the backbone of the research on to which other technologies are incorporated. The sizing and siting of a VPP or microgrid, voltage management strategy, power-flow control strategy, energy management strategy (incorporating energy forecasting, grid synchronisation and isolation, fault ride-through and protection, retrofitting a microgrid in an urban area, and strategy of energy sharing with other microgrids) are some relevant topics from a power and energy point of view. Adopting IoT into energy systems, applying cyber security into microgrid and VPP controllers, and incorporating digital twins to improve productivity of existing systems are the topics researched in IoT and embedded systems. Energy forecasting, optimal coordination of energy assets within a VPP or microgrid, dynamic pricing strategies in VPPs and microgrids, data security through blockchain, and data validation for renewable energy certification are some of the topics researched in computer programming and data science. Key points of research in the control and communication field include data sensing, communication, and integration and control.

The laboratory trials of most of these technologies can be accomplished at Green Electric Energy Park (GEEP) at Curtin University (Rajakaruna & Islam, 2011; Davis, 2013). GEEP lab is a state-of-the-art renewable energy and microgrid laboratory featuring different types of solar, wind, hydro, hydrogen and battery technologies, as well as power and weather sensing, all integrated into one system capable of remote monitoring and display. Building a microgrid with different combinations of sources and loads is easily facilitated at GEEP. New technological features such as IoT, DTs, cyber security, energy forecasting and dynamic coordination will all be incorporated within a distributed control setting for the microgrid or VPP. This project will undoubtedly require the forming of a team of researchers specialised in a variety of fields such as power and energy, instrumentation and control, data communication and integration, data analytics, software engineering, cyber security and IoT. The project depends on the guidance and support of network companies, consumer groups, regulators, renewable energy solution providers, energy investors and renewable energy certifiers, and its estimated duration is 3-5 years.

Impact

The operation of DER in microgrids and VPP configurations has several impacts that can be summarised into three main categories: (i) adoption of new technology and skills development impacts, (ii) technical impacts, and (iii) economic and social impacts. The impact framework can be structured based on CSIRO and UK research excellence frameworks. Each category can have several sub-categories. Accordingly, the impact of each sub-category can be structured by one or multiple key performance indicators (KPI), where each KPI has at least one measurable metric. In this context, microgrids and VPP configurations can allow the adoption of new technologies by increasing the integration of renewable energy, the uptake of tools for microgrid and VPP planning, the design and operation, and improving the utilisation of a mix of the existing assets and the new technologies. The adoption of new technologies can be measured by the number of new services, products and retailers that are integrating renewable energy and providing green services, by the number of end-users utilising the microgrid and VPPs planning, design and operation tools, and by number of DNSPs and microgrid and VPP operators using the mix model representation. In addition, the operation of DER in microgrids and VPP configurations can provide new knowledge and local skills and lead to the skill development of end-users. Moreover, the operation of DER in microgrids and VPP configurations can lead to several economic and social impacts, where the energy costs and network costs can be decreased. This can be measured by the reduction in the energy bills and the levelised cost of energy of DER. In addition, the reliability of the provided service can be increased, which can be measured by the number of power outages and their duration. CO_2 emissions can also be reduced by operating DER in microgrids and VPPs, which can be measured by the GHG equivalent. Finally, the operation of DER in microgrids and VPP configurations can create new jobs, which can be measured by the full time equivalent.

The proposed digital twin-based solutions for managing DER in microgrids can lead to greater sustainability in terms of grid reliability and resilience. These solutions will work as intermediaries between the physical grid model, the operational and engineering data, and engineering simulation tools, providing actionable insights into the grid. Such insights can enable VPPs to react quickly to needs in the physical grid, helping them control the operational life of critical assets and mitigate operational risks, transmission and distribution losses, and system failures. Furthermore, by virtually adding the new DER and interconnections, VPPs can use the digital twin counterparts as their testing ground, performing the 'what-if' analyses and quantifying the impacts against the decarbonisation and greenhouse gas (GHG) emission reduction plans.

Similarly, the integration of blockchain for managing DER will ensure the robustness and security of the microgrids. It will expedite the detection of non-technical losses on the microgrid and solve the issue of customer manipulation of data and ignorance regarding the details of their energy usage profile, particularly in P2P trading of DER. The smart contracts of the proposed consortium blockchain infrastructure will also serve the distributed energy prosumer (DEP) by enrolling them dynamically in the demand response program initiated by the VPPs. These smart contracts check the compliance of each DEP to the desired energy profile, calculate the associated rewards and penalties, and decide the definition of new demand response events for the VPPs, which will add further transparency while operating DERs. Additionally, the proposed game-theory-based economic model of the project will contribute to drawing an optimal operation plan for DER in microgrids through VPPs rather than allowing each consumer to operate DER independently. Such an approach will help to reduce consumer bills and develop a market structure promoting the participation of various prosumers, from end-users to enterprises. The inclusion of parameters pertinent to the use of renewables in operating DER, and the associated incentive schemes within the economic models, will also facilitate healthy competition among the stakeholders, expediting the advancement of decarbonisation plans for DER in microgrids.

3.8 Consumer expectations

Objectives

Terms contained under the Local DER Network Solution banner as 'VPP', 'microgrid' and 'community battery' are fundamentally technocratic terms and concepts that are challenging for consumers to understand and engage with. The terms have been developed, defined and refined by technology companies, academics, utilities and governments and don't speak to the benefits of what they offer consumers. These types of technocratic solutions are being offered to people and communities based on energy and/or monetary savings without fully understanding what they want and value. While the customer proposition developed around these concepts can still be made to appeal to a small number of individuals who are driving the first wave of adoption of these solutions, they have more limited appeal to other customer types and larger sections of the market.

Customer segmentation is the gold standard in understanding customer needs and wants. However, while it is used by those larger organisations that have the resources and skills to employ it, it is not universally available to all. A values-based approach can help to identify suitable customers, provide a deeper understanding of them, and develop and communicate more compelling product offerings more quickly and effectively. This has become an accepted strategy to guide engagement by environmental and social justice organisations (e.g., as used by the Common Cause 1 Network). A simplified way to survey customers' values is to use a 'values models' method. This categorises the main set of customer values into three models—Settlers, Prospectors and Pioneers—as shown in the following figure.

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[1] Common Cause helps mission driven organisations use the power of values and frames to motivate change: http://www.commoncause.com.au

Settlers are sustenance driven, needing safety, security and belonging.

Prospectors want success, including the esteem of themselves and others.

Pioneers are focused on new ideas and self-actualisation.

Figure 5. Value models (Alexander et al., 2022, citing Rose, 2011)

A values-based approach has also been used to undertake a meta-analysis of around twenty ARENA-funded DER projects between 2014 and 2020, mining almost one-hundred reports for customer insights to help inform its future projects. As part of this research, six key ingredients to a happy (DER) customer were identified as shown in the figure below.

Figure 6. Six key ingredients to a happy DER customer (Dwyer et al., 2020)

However, local DER solutions are still largely in the very early stages of deployment. This means that there is still a lack of information on consumer experiences and attitudes (although a growing base of research is emerging for VPP). What exists has been more generally researched from innovator and early adopter customer types or gleaned from projects involving households with individual solar and battery systems. More needs to be done to extend such customer insights to solutions that serve multiple households and/or businesses within a defined local area. For those local DER network solutions that serve multiple households and/or businesses, community engagement becomes critically important. Community engagement is an essential part of the planning and development of any type of infrastructure that occurs in—and impacts on—that community. This should include the infrastructure (both hardware and software) that encompasses VPPs, microgrids and community batteries. Community engagement best practice seeks to encourage the participation and empowerment of community members within each aspect of the decision-making process. As a result, solutions should be able to be co-created that meet the needs of the community and the individual.

Through participating in the project planning, implementation and operation phases, communities can express their acceptance, preferences and reservations. Close collaboration between researchers, businesses, industry, government and community leaders is needed to create a chain of trust. This can be enhanced by ensuring fairness and building social equity throughout the various phases, while helping enshrine community benefit and consumer protections. Important aspects that can be demonstrated in CRC projects include ensuring that suitable foundation research has been undertaken in order to explain why a specific customer group is being targeted, what values and motivations would drive them to participate in the project, and how communication and engagement activities should be carried out throughout the entire lifecycle of the project. A deep understanding of the customer and the community will achieve a greater uptake with less effort, and a higher level of satisfaction, leading to continued engagement and advocacy.

The pilot can also evaluate the effectiveness of the foundation research. The research can be used to design target customer groups and pilots which seek to identify customer motivations. Both during and after the pilot, customers can be surveyed to gauge how well the research has guided the pilot design.

Precedents

The precedents for this research opportunity were provided in Section 2.4.

Methodology

Established frameworks (such as Schwartz's (2012) Theory of Basic Values, and Maslow's (1958) Hierarchy of Needs) have been used to explain the values and motivators of people and their needs, regardless of the society or culture within which they belong. A values mode framework was subsequently developed by Cultural Dynamics Strategy and Marketing (CDSM) and applied by campaign strategists and market researchers, including Chris Rose, KSBR and Futerra.

The 10 basic universal values that, according to Schwartz, guide a person's actions based on the ordering of their preference are as follows (Schwartz, 2012):

- Self-direction: seeking independent thought and action
- Stimulation: seeking excitement, novelty and challenge in life
- Hedonism: seeking pleasure or gratification for oneself
- Achievement: seeking personal success through demonstrated competence
- Power: seeking social status and prestige, control or dominance
- Security: seeking safety, harmony and stability
- Conformity: seeking restraint of actions likely to harm or violate norms
- Tradition: seeking respect, commitment and acceptance of customs and culture
- Benevolence: seeking preservation/enhancement of the welfare of one's group
- Universalism: seeking to understand, appreciate and protect the welfare of all

While these values don't explicitly refer to trust, Alexander et al. (2020) and Russell-Bennett et al. (2021) have identified trust as critical for positive customer outcomes. The latter is an excellent reference source from which the conceptual pillars (see figure below) can be adapted and used as a common trust-building framework for any associated projects proposed by this theme, especially in any a pilot seeking to explore ownership and operation models. It could also be offered to others involved in funding other Local DER Solutions projects, such as ARENA who will be playing a major role in the funding of microgrid pilots through the Regional Australia Microgrid Pilot Program (RAMPP).

A summary of other relevant methodologies is provided in the table below.

Table 12. Summary of relevant research methodologies

Methodology	How it would be used	Stakeholders/ partners
Values-based approach (*Maslow, 1958; Schwartz, 2012*)	Encourage the use of a values-based approach to support organisations that do not use customer segmentation to quickly and effectively segment customers while developing more effective communication and engagement.	Universities DNSPs Start-ups Government
Customer segmentation (Smith, 1956)	Encourage the use of more advanced methods of customer segmentation (e.g. using machine learning and AI tailored for specific energy use cases) by those that have the capability and seek to share findings where possible, noting that there will be some confidentiality restrictions.	Energy retailers Universities
Trust-building framework (Russell-Bennett et al., 2021)	Encourage the use of the trust building framework in the design, planning, implementation and operation phases of any planned demonstration.	Universities DNSPs Start-ups Government Energy retailers
Human-centred design (coined by Horst Rittel, championed by Herbert Simon, developed and taught by Stanford University Design School in mid-20th century)	Encourage the use of journey maps, customer personas and other tools in trial planning to ensure that the process for acquisition and engagement has been planned to understand the individual's needs and how these can be met.	Universities DNSPs Start-ups Government Energy retailers
Community engagement (originates in participatory research in education and healthcare in the late 20th century)	Encourage best-practice community engagement through supporting participation and empowerment of community members in each aspect of the decision-making process and the co-creation of locally adequate solutions.	Universities DNSPs Start-ups Government Energy retailers Community groups
Stakeholder Theory (Freeman, 1984)	Encourage stakeholder mapping and the development of a stakeholder engagement plan to guide engagement strategies throughout the entire lifecycle of a project.	Universities DNSPs Start-ups Government Energy retailers Community groups
Behavioural Development Model (Petit, 2019)	Encourage the use of this model to help better understand human behaviour and how people can be shaped by individual traits, interpersonal skills, societal characteristics, community dynamics, policies and systems.	Universities Government

Impact

Pilots and demonstration projects involving DER rarely recruit all customers that are targeted initially, and recruitment often takes longer, or is more challenging, than anticipated. Through a better understanding of consumer expectations and values, more rapid and widespread adoption of DER network solutions will be possible. This will reduce the cost of customer acquisition through better messaging and targeting, while enabling a higher proportion of customers to be acquired through appealing to a wider section of the market and many different types of customers. In addition, the approaches described above can also help better prepare industry and businesses for commercial product offerings, and government to design more effective policy and regulation. Specifically, the impact of these outcomes can be measured by:

- GHG emissions:by increasing customer acquisition rates, GHG emissions can be reduced by a corresponding amount. This will help future projects to better achieve their intended GHG emission savings by ensuring they meet the targeted number of participants during the trial phase.
- Grid reliability: local DER solutions can enhance the network, but often this can rely on recruiting a relatively high proportion of customers within a concentrated area. This demands a highly targeted engagement approach, but with potentially rewarding outcomes for networks and customers where network augmentation can be deferred or avoided, resulting in fewer, and lower duration, supply interruptions. Without effective and targeted engagement, local DER solutions may become unviable due to customer apathy or non-acceptance.
- Bill reduction: while customers do care about saving money on their bills, a variety of reasons may motivate them to adopt network DER solutions.

Industry Reference Group Comments:

- Microgrids can add a level of reliability, but it is too early in the development to be able to quantify how much.
- We need to demonstrate capacity for responding to commercial impacts on network constraints/ HV network providing DER.
- Quantification of the solution's value to planning would enable easier incorporation into future planning.
- A research piece across multiple installations that helps establish valid value metrics would be great. These would then go into future system planning and would underpin business cases.
- Microgrids offer network resilience and improved network reliability.
- Early engagement / Appoint ENSP as part of customer agreements.

3.9 Microgrids in distribution networks

Objectives

Future CRC projects need to produce analysis methods that can be used to evaluate the reliability, emissions and financial performance of microgrids given an in-situ or proposed microgrid physical structure, network boundary conditions, microgrid operating objective(s), and (in-microgrid) customer behaviours and requirements. Armed with these methods, proponents can evaluate and articulate potential benefits for network operations and iteratively optimise microgrid designs in planning.

Analysis methods which are sufficiently accurate, comprehensive, validated and trusted can:

- Allow parties to answer the question *How can distribution network planning and operations be enhanced by micro-grids?* (for stylised and example microgrids)
- Quantify the reliability, emissions and financial performance of specific microgrid designs within planning and decision-making processes by proponents, regulators and investors.

To a certain degree, the standard IEEE 2030.9-2019 *IEEE Recommended Practice for the Planning and Design of the Microgrid* addresses relevant considerations of microgrids. However, this standard provides detail and stronger guidance mainly on aspects associated with microgrids' electrical systems (e.g. Section 8). The standard only provides high-level guidance on:

1. Methods for evaluating the microgrid value proposition for distribution network businesses
2. Microgrid configuration and capacity planning relative to proponents' aims for the microgrid
3. The relationship between the aims for a microgrid, the operating practices of the microgrid, and the methods for microgrid design to match these
4. Data models, data acquisition, and analysis methods (at the design stage) for assessing how a proposed microgrid might perform with respect to its aims and constraints around emissions, power quality, supply reliability and grid dependence.

RACE 2030 CRC projects in this area need to bridge the gaps among IEEE 2030.9, quantitative studies in the academic literature, and Australian electricity sector practice. This bridging has three components:

1. Quantitative dependability
2. Methodology validation and acceptance
3. Cost-effective utilisation by sector participants

On quantitative dependability, the eventual electricity sector practice, must result in analyses which reflect the financial, emissions and energy delivery performance of microgrids with sufficient quantitative accuracy that networks, investors/lenders, regulators and in-the-microgrid participants accept the findings and will act with confidence.

Distribution networks that interface with a microgrid are concerned about the sufficiency of support that a microgrid might give to the network (or, alternatively, the upper bounds of the stress that the microgrid might place on the network) and the true costs to be borne. For example, if a microgrid is put in place to strengthen a weak end-of-line section of the network, Distribution Business (DB) need confidence that the microgrid will perform as intended (with respect to energy supply reliability, power quality, emissions intensity etc.) over relevant conditions (especially the extremes of load and supply, weather and network stress), and that estimates of capital and operational expenditures should be free of surprises. This need for dependable performance and cost estimation holds if the microgrid is an initiative of the distribution business (and therefore the distribution business has a significant hand in its facilitation) or is the product of other proponents' endeavours. *The articulated reflections of CRC partners regarding the microgrid value proposition strongly demonstrate the need for this kind of analysis capability.*

Most microgrids will be significantly resource (capacity) constrained, for instance, by the depth of energy storage in the microgrid and the amount of generation capacity that is installed. Furthermore, the overall rationale for microgrid investment can vary markedly. This variation in motivation leads to comparable variation in operational imperatives. A microgrid built as an alternative to network augmentation may be operated very differently to a microgrid that is central to a precinct's 'net zero' goal. The combination of resource constraints and explicit aims means that microgrid operational objectives and practices (i.e., how and why operational decisions are made, and by whom) are primary not secondary concerns. Microgrid analysis methods must explicitly account for operational strategy differences, or else they simply cannot be quantitatively accurate and trustworthy.

In terms of methodology validation and acceptance, the CRC's methods will need to win the trust and confidence of all relevant parties. Achieving trust and confidence requires:

1. Inherent correctness and completeness of the methods
2. Quality in the articulation and description of the methods
3. Quality in the implementation of the methods (when software and user interfaces are involved)
4. Co-ownership that can be formed through participatory development and consultation
5. A methods design process that is user-centric (i.e., the users being both analysts and the recipients of analyses) and which results in methods that are readily understood and maximally adoptable by competent practitioners
6. Validation of the methods against data from real microgrids, and where the information about validation is peer reviewed and readily accessible (i.e., for stakeholders to verify).

The third component, cost-effective utilisation, goes beyond this to tackle the reality that acquiring data and executing analyses can be difficult and expensive, as can the acquisition of the relevant human capability, and the upskilling needed for mastery of software packages such as power system simulators. The costs, in effort, time and money, need to be justifiable relative to accuracy and fidelity gains from 'doing more' in data and analysis. Methods need to harmonise/interoperate with existing industry-standard tools and be understandable and useable by many rather than just an elite few. The methods should be flexible and tailorable to specific types/scales of microgrid, and to specific use-cases/aims for microgrids so that the data and analysis needed is reflective of what is required in each specific instance. This tailoring should be achieved without compromising assessment quality or obscuring that there is an overall approach that is trustworthy and validated.

Precedents

Work conducted by the IEEE 2030.9-2019 Standards Working Group is highly relevant to future research. Work by the CRC on analysis methods development and utilisation must be able to be positioned in the context of this standard. This means that the CRC's methods should not conflict with the Standard, that the methods will reference the Standard, and that they will address a superset of the considerations and (high-level) method recommendations that are contained in the Standard.

A holistic and complete structure is needed or the systematic evaluation of benefits from microgrids, and the Victorian Market Assessment for Microgrid Electricity Market Operators offers an excellent published starting point that is already suitably tuned to the Australian context (Monash University, 2019). Smaller-scale energy system performance estimation and design optimisation are the raison d'étre for significant branches of electrical engineering and data sciences (the latter including, but not limited to, work in statistical machine learning, combinatorial optimisation, and optimal control). There is much to harvest from the relevant literature. From the literature survey in this opportunity assessment, some representative work is found in Fiorini & Aiello (2019), Islam et al. (2021), Madani et al. (2017) and Islam & Amin (2021)

Australian microgrid projects, at various stages of development, are highly relevant, especially where the microgrid is intended to be grid connected (given the emphasis here on distribution network planning and operations). These include the Monash University Microgrid, the Community Microgrids and Sustainable Energy Program (CMSE) run by DELWP and Ausnet Services, and the Commonwealth Government's Regional and Remote Communities Reliability Fund. Integration of the CRC's activities with the research, design and operation of these and other in-practice microgrid examples will be critical because well-developed microgrid projects are precious sources of information and method validation.

Methodology

Microgrid analysis methods must target what might be called 'investment grade' or 'regulator grade' methods. That is, we must pursue methods that:

- Are dependable and can be utilised for electricity sector decision making as standard methods that require no special allowances or exceptions
- Are able to be executed methodically and correctly by competent electricity sector participants
- Are accepted by all relevant parties (including regulators, investors and lenders) as accurate and complete estimates of microgrid reliability, emissions and financial outcomes.

This implies a need to co-design and co-implement the analysis methods and their implementations with the intended analysis method users and analysis customers. This holds regardless of whether the methods may become implemented within decision-support systems or prevail solely in documentation. The intended users of the methods will chiefly be in-house engineers and analysts in network businesses, as well as energy consultants and those who will assess analyses and investment cases constructed using the methods. A co-design/co-implementation approach will inform and drive the underlying method development work by practitioners in engineering modelling and simulation, data science, and optimisation.

The co-design/co-implementation requirement could be fulfilled through adoption of techniques and methods from *User-centred Design* (UCD) (also somewhat synonymously known as *Participatory Design*). UCD is an established applied science and practice. It is often associated with optimising products and service delivery, but it is also able to be successfully applied in technical decision-making contexts (Stitzlein et al., 2019).

The stakeholders and partners' experience and capability must span:

- Legal and regulatory aspects of (distribution network) capital decision-making and operations
- Electrical safety, including bushfire safety where microgrids present fire risk, and/or where microgrids may mitigate fire risk
- Power systems engineering (including electrical protection systems)
- First-hand experience in microgrid planning, construction and commissioning
- Optimisation, as it applies to optimised energy management
- Data science (for engineered systems) including 'professional' financial analysis expertise
- Knowledge of DB planning and operations
- Energy consultancy practice
- Practitioners in user-centred design/participatory design applied to analysis methods and decision-support systems.

In many cases the stakeholders and partners will need to be actively involved in developments rather than being engaged solely in advisory/review activities.

Impact

The true longer-term 'end-state' test of impact for projects addressing this microgrid planning and distribution network impacts topic will be:

- A number of Australian microgrids installed and operated in an ongoing manner…
- … that interface with distribution networks …

- ... which are bona fide regulated-capital investments (if done to support/augment distribution networks) or wholly private capital investments (if done by non-network proponents within/adjacent-to distribution networks)
- ... for which the analysis and design methods devised by RACE for 2030 projects for microgrids have been used, and
- ... and where financial, reliability and emissions performance estimates have been met or (positively) surpassed.

It is desirable that the methods will show that microgrids are credible solutions when used for network purposes and are benign or beneficial to networks when initiated by non-network proponents. This desirability is subordinate to a need to obtain trustable, unbiased analyses.

Along this impact pathway we should see:

- Trials of microgrids where partial or prototype versions of CRC's analysis/quantification methods for microgrids have been used
- Validation of the estimations of cost, emissions and reliability by way of post-hoc observations in (specific) microgrids
- Use of the CRC's methods within the business cases for microgrids that are developed for DBs and/or non-network proponents
- Uptake and/or acceptance of the methods by many and varied electricity sector parties (i.e., internal-to-DB teams, energy consultancies, regulators, proponents and innovators).

The last point highlights an important impact requirement, which is that the methods that CRC projects deliver (most likely in partnership) will need to become the foundation for the sector's 'tools of choice' in microgrid and microgrid-to-network assessments.

3.10 Custom design of local networks

Industry Reference Group comments:

- Acquiring and maintaining social licence is a key consideration in the design of local network solutions.
- A values-driven, co-designed approach towards resilience where communities can realise the benefits during and outside extreme weather events and feel empowered by it, instead of feeling giving up autonomy/agency.
- A need to identify areas of localised constraints in networks before any discussion with stakeholders about community batteries. If parts of a network are not constrained, there is not a need to put in any assets to shore up reliability.
- Microgrids can be a cheaper means to supply remote areas, so saving community capital and operating costs.
- Community batteries will be an essential part of maintaining a stable grid once EV charging is common, but location is important. A key issue will be securing sites for small community batteries. These will help to stabilise the energy equation within each LV network.
- Consider how you develop contracts and project set up to scale.
- Interested in the narrative for how this drives community resilience.

Objectives

The most important aspects that need to be covered for microgrids and community batteries in the context of custom designing a local network include:

Cost and benefit analysis

It is important for microgrids and community batteries to have a business model that is cost-friendly, legal and effective, while benefiting all stakeholders. By proposing new price policies and demand-side management, microgrids and community batteries can be developed at a substantial scale. The maintenance of microgrids and community batteries should also be included in this cost and benefit model.

Identification of demonstration sites

IRG member AusNet expressed that it saw ‘a need to identify areas of localised constraints in networks before any discussion with stakeholders about community batteries. If parts of a network are not constrained, there is no need to put in assets to shore up reliability.’ Potential demonstration sites should therefore be tested for the presence of localised constraints to be suitable for a trial installation of microgrids or community batteries.

Communities and customers may have different priorities with respect to their power supply. Where these priorities include a desire for reliable electricity during extreme weather, or affordable power bills, microgrids and community batteries could comprise suitable solutions, and a pilot project built in these areas is likely to benefit all stakeholders.

Innovative approach and technology

Microgrids and community batteries need to provide reliable, stable and affordable electricity. Achieving this goal requires innovative approaches and technology. For example, frequency and voltage regulation in microgrids with community batteries and high renewable energy generation require fast-acting control systems. Distributed approaches should be proposed to deal with high voltage caused by the fluctuation of solar PV generation in microgrids and to prevent outages in extreme weather.

Key to these pilot projects is a rich process of engagement with all stakeholders to understand their interests.

Precedents

PROJECT	LOCATION/SCOPE	GOALS/OUTCOMES
MOOROOLBARK MINI GRID	Mooroolbark, Victoria, Australia; 14 homes (AusNet, 2017)	To investigate the possibility and logistics of microgrids on a small scale
YACKANDANDAH	Yackandandah, Victoria, Australia 1811 people (ABS, 2016)	To be 100% powered by renewables by 2022 (Totally RE, n.d., Community-scale energy generation & storage)
UNITED ENERGY'S POLE-MOUNTED BATTERIES IN PV-RICH AREAS	Eastern Melbourne/Mornington Peninsula, Victoria; 40 custom-built batteries mounted on electricity poles (ARENA, 2021g)	To reduce stress on transformers during peak hours, regulate voltage, and increase the hosting capacity of solar PV in the local grid (ARENA, 2021g)
MALLACOOTA MICROGRID/COMMUNITY BATTERY	Mallacoota, Victoria 1063 people (ABS, 2016)	To improve the energy resilience of Mallacoota and build a roadmap for future energy innovation to support local people and community life (Engage Victoria, 2022)
WESTERN POWER SEEKING POTENTIAL MICROGRID REGISTRATIONS	Mid-West, Wheatbelt, or Great Southern region of Western Australia	Improve power reliability to the local community and pave the way for net zero emissions by 2050 (Western Power, 2022)
ENOVA COMMUNITY BATTERY AKA THE BEEHIVE PROJECT	Byron Bay, NSW. Expected to power 500 homes when operational (Energy Locals, n.d., Residential Enova)	To trial a shared community battery and peer-to-peer solar energy trading. Large-scale battery storage testing (Energy Locals, n.d., Residential Enova)
WESTERN POWER/SYNERGY POWER BANKS IN WA	Western Australia; 12 homes trialling the new Powerbank system (Synergy, 2022)	To assess the viability of battery-powered homes within a microgrid community, and to assess the logistics involved

		with regular charge/discharge (Synergy, 2022)
STAND-ALONE MICROGRIDS IN ONSLOW	Onslow, Western Australia 848 people (ABS, 2016)	Onslow was successfully powered by renewable energy for 80 minutes (WA.gov.au, 2021)
VARIOUS - REGIONAL AND REMOTE COMMUNITY RELIABILITY FUND - MICROGRIDS (RRCRF)	36 microgrid feasibility studies across Australia funded by grants provided by the Commonwealth (2019–2024)	To support feasibility studies into more reliable, secure and cost-effective energy supply to regional and remote communities; also seeks to increase dissemination of technology, project knowledge, and increased human capital/skills (Australian Government, 2022)

Methodology

Prior to building a pilot project for microgrids and community batteries, the following steps should be taken:

- A cost and benefit analysis
- A discussion with all stakeholders to determine the project's location
- Optimising the scale of microgrids and community batteries, including the type and number of both, to yield the maximum benefit for all stakeholders
- Providing an innovative approach and technology for microgrids and community batteries to realise swift frequency and voltage regulations with a cost-friendly and reliable manner. A smart battery energy management system should be designed to avoid power outages.

There are three suggestions:

(1) A microgrid pilot project could be conducted at Griffith University by utilising the university's microgrid facilities.

(2) A pilot project of community batteries could be conducted with Planet Ark Power (following discussions with Planet Ark Power) as they have already installed solar PV panels on a number of buildings and may be willing to partner in a trial.

(3) A pilot project of microgrids or community batteries could be conducted in regional and remote communities through the Regional and Remote Communities Reliability Fund - Microgrids (Australian Government, 2022).

Impact

This theme may produce several positive outcomes:

- *GHG reduction*: microgrids can connect a large number of renewable energy sources that use cheap renewable energy rather than traditional expensive diesel and thermal energy. Without community batteries, each microgrid must be equipped with batteries to control the generation of renewable energy. The use of community batteries will therefore reduce the numbers of batteries so that GHG can also be cut by reducing the materials used to make batteries.
- *Bill reduction*: the community microgrid/battery pilot project will optimise electricity prices and reduce energy bills. Private microgrids are selfish in that they only benefit their owners, minimising shared

benefits to the surrounding area. Community batteries consider a wider set of stakeholder's conditions and are therefore more likely to realise shared benefits. These shared benefits will make the microgrids at once more reliable and cheaper, thus reducing customer bills. In addition, a battery energy management system will sell or purchase the energy in the best interest of customers and further reduce their bills.

- *Grid reliability*: as community batteries will consider shared benefits, this pilot can implement relevant strategies to eliminate the power imbalance between microgrids. In addition, microgrids and community batteries can work both as islands and grid-connected, which means that they are able to support customers' demand by themselves. If extreme weather made it necessary for the area to be separated from the utility grid, the microgrids and community batteries could still provide stable and reliable power to this area. As microgrids and community batteries would charge/discharge batteries when there is excess/insufficient power, they will be used to peak cut and peak demand will be satisfied with less cost.

4. BARRIERS TO UPTAKE OF LOCAL DER SOLUTIONS

Due to the accelerated decarbonisation targets in energy sector, there is a growing trend towards deploying community batteries, microgrids and VPP. Promoting the propagation of such local DER solutions can contribute efficiently to overcoming decarbonisation challenges. The focus of this section is to identify barriers to the uptake of local DER solutions, either by individuals or by groups or communities. The successful implementation of such schemes depends on partially or entirely removing current obstacles (technical and institutional barriers) to properly transforming local power networks.

4.1 Technical barriers

Most items to be mentioned in this section are caused by the inaccurate placement, design or uncoordinated control of local DERs systems. A sub-optimal scheduling of DERs can lead to lower supply reliability, power quality and network hosting capacity in addition to increased running costs.

Technical barriers in DER systems may include:

- Overvoltage due to the integration of uncoordinated DER systems
- Limits to the hosting capacity of distribution networks caused by a lack of, or inefficient, coordination among local DER systems
- Insufficient information about the current systems management of local network restrictions, supply-demand balances, management of energy flows, etc., constituting the main barrier to implementing local DER systems
- A lack of clarity on managing batteries′ long-term life-cycle impact. There are currently no long-term studies evaluating the impact of the charge capacity of batteries and their lifetime on community battery longevity. Moreover, policy needs to address the possible risk of increasing inequality between community batteries and other electricity users.
- Uncertainty in employing optimal placement methods for various types of DER systems, raising the question what parameters and variables should be taken into account to ensure a successful placement of such DERs.

Technical barriers in microgrids and VPPs in distribution networks may include:

- Uncertainty as to what level of controllers are required for each type of microgrid to ensure reliable operation, irrespective of the environmental conditions.
- Insufficient information on the optimal level of control and monitoring that should be adopted by local DERs such as microgrids. Further, the successful operation of local DER systems under various weather conditions or natural disasters is yet to be evaluated.
- Future expansion scenarios: to what extent should these be considered in initial DER planning? The long-term planning of local DER systems needs more evaluation and development.
- The existing technical objectives of DER operation require thorough revision. It is unclear how those objectives can be varied when switching the operation mode from individual to collaborative.
- Interoperability and communication protocols are of concern for the successful implementation of local DER systems (mainly VPP and microgrids) as hardware and software components are usually made by different manufacturers.
- It is not clear how part of an existing interconnected network can be restructured as a microgrid or VPP. How should the current settings of different protection and control devices be adjusted or replaced with other components? Appropriate transformation procedures are yet to be developed.

Storage options and EVs

- There is a shortage of information about the current hosting potential of EV-charging systems. Likewise, the possible implications of the uncoordinated operation of EVs under G2V and V2G modes are yet to be identified. Misleading data or analysis in this area can cause a significant underutilisation of the system's potential to take full advantage of EVs.
- There is insufficient knowledge about the likely energy storage options that will dominate the grid in the future. This can highly impact the efficiency, operation, reliability, and revenue of such systems.

Advanced technologies

- There is a lack of sufficient historical data for the proper modelling and behaviour analysis of different stakeholders in near-future distribution networks. DER generation and other hardware operation modelling also suffer from a data shortage. More advanced modelling methods are required to meet these modelling requirements.
- There are serious concerns about how to deal with potential cyber security attacks in developing smart grids, including local DER systems. Insufficient capacity to address this issue can cause a partial or complete system shutdown.
- Successfully handling interoperability matters would require the development of more advanced protocols through internet of things (IoT) procedures.

4.2 Institutional barriers

As the outcome of consultation with various stakeholders and from conducting a literature review, the main institutional barriers can be summarised as follows:

Governance and regulatory barriers

- Inefficient and inconsistent regulations are among the most serious threats to the successful uptake of microgrids, community batteries and VPPs. The regulatory system needs to be able to facilitate the realisation of different community expectations from microgrids.
- The lack of common standards for the implementation of local DER solutions and their performance and safety is already alarming. The success of community-scale energy storage systems depends on overcoming the current regulatory challenges.
- There is a shortage of commonly accepted access mechanisms to installed DERs that needs to be met.
- Regulatory reforms are required to enhance the participation of consumers in different stages of DER implementation. Policy uncertainties will negatively impact the responsibilities of potential participants.

Ownership and revenue streams

- The upfront cost of designing and implementing local DER solutions is significant. This includes the cost of both the hardware and the management and control software required for the implementation of such mechanisms. Microgrids and VPPs are capital intensive to develop and implement. Likewise, community batteries require significant upfront investment.
- There is a lack of clarity for stakeholders on revenue creation through investment in local DER systems.
- Innovative business models are required to accelerate the adoption of distributed energy system solutions. There is a shortage of a holistic business model for a hybrid VPP/microgrid/community battery system.
- There is a shortage of efficient business models to ensure the financial feasibility of local DER systems. Reducing the payback period of DER solutions would encourage substantially more investment. It is unclear whether a single entity or combination of entities should be involved in running potential DERs.

Stakeholder engagement

- The deployment success of any local DER system requires the active participation of stakeholders such as customers, prosumers, DSOs, private investors, energy retailers, network companies and governments.
- There is a lack of information on various stakeholders' expectations from such DER systems. This is particularly the case for possible interactions among stakeholders in response to different operation scenarios.
- There is a shortage of studies on the potential combination of DER technologies to meet stakeholder expectations. Individual DER systems can satisfy some expectations, whereas others will require a hybrid system of various local DERs.
- Very little research has been undertaken so far to expressly compare community expectations of different types of microgrids, VPPs and community batteries.
- There is a lack of proper incentives to encourage the active engagement of various stakeholders.

5. KEY FINDINGS AND RECOMMENDATIONS

5.1 Research concepts

Research concepts proposed within each of the nine research opportunities are outlined in Table 2. The concepts presented cover more than one research task as final research projects will need to be practical and therefore should be treated as interrelated and cumulative.

Table 2. Research concepts developed from the N3 Opportunity Assessment: Local DER Network Solutions

#	Research Opportunity	Research Concept	Research Activity	Timeframe
1	Governance and regulation (RO1)	An assessment of the potential future regulatory framework for community batteries, microgrids and VPPs	1. A desktop assessment of the current regulatory frameworks in Australia 2. A comparative study with the international best cases 3. A mixture of in-depth qualitative interviews and focus groups to obtain the details and uncover the motivations, attitudes and values of various stakeholders 4. Cross-check the findings against the innovative ownership models introduced in the other CRC research themes, such as N4 5. Empirically examine institutional arrangements that could enhance trust and participation by the stakeholders	N/A
2	Revenue streams (RO2)	Feasibility study for valuation of different revenue streams for CBs, microgrids and VPPs	A techno-economic feasibility project to understand the theoretical revenue for different value streams under different regulatory and operating scenarios	N/A

3		A virtual net metering market (interaction between VPP/DER aggregators and microgrids)	A virtual net metering market allows for the trading of energy credits between multiple entities, often using a third-party platform to facilitate transactions. This project aims to create a business model to understand interactions between microgrids and virtual power plants based on virtual net metering market.	
4		EV business model in islanded microgrid operation mode	This project aims to evaluate possible ways of representing the behaviours of EV owners/drivers as well as propose a proper business model and encourage EV owners to contribute to the reliability and stability of microgrids. Forecasting driver behaviour and controlling the bi-directional charging/discharging processes is challenging.	N/A
5	Ownership and access (RO3)	A multi-stakeholder participatory approach for community-energy systems development	1. Creating a framework for assessing the social fabric of the community 2. Developing a tool to identify the optimal business model based on learning from the social dynamics of the community 3. Developing a sand-boxing tool to assess the impact of various network-capacity constraints, as well as regulations the community energy performance 4. Developing a framework for a	N/A

			system that satisfies the range of the community's needs, expectations and constraints 5. Establishing a community energy trial to test the accuracy, credibility and reliability of the analyses of the benefits of community energy under normal operation conditions as well as during natural disasters	
6	Electric vehicles (RO4)	Harnessing fluctuating EV storage	1. Build a temporal-spatial model of where and when people charge their EVs and use it to predict the available battery capacity for storage or generation 2. Derive techniques to maximise the available battery capacity of EVs 3. Propose methods to nudge desirable behaviour by EV owners to maximise the amount of EV storage available to the grid, VPPs and community batteries. This may include financial or other incentives, disincentives and regulatory levers.	2024-25

7		EV trial project	1. Work with charging providers and EV owners/users to provide real world verification and calibration of the research models and proposals 2. The trial(s) will seek understand four areas: a) How people charge their vehicles when there are incentives b) How well models of the system predict the EV-charging behaviour compared to the data c) The extent to which live data on EV capacity is available from chargers or over-the-air telemetry d) Survey and interview data to gain insights into effective incentives for desirable behaviour and V2G technology uptake	2026-27
8	Storage options (RO5)	Storage technologies feasibility study for community storage	1. A desktop study investigating the techno-economic feasibility of using other storage technologies, such as ultra-batteries and/or vanadium flow batteries for community storage applications 2. Developing different storage system dynamic models and simulations for different combinations of community-battery services (value streams) and their associated lifecycle analysis 3. Designing a long-term community	2024-27

			battery trial embedding technical evaluations and proof-of-concepts of parallel alternative storage technologies	
9		Assessment of the energy storage capability of closed mines	1. Prepare a map of recently closed mines suitable for energy storage purposes by considering the geographical location (close to load centres, proximity to transmission lines, height, area of the pits etc.) 2. Propose a method of ranking of closed mines for different large energy storage options such as pumped-hydro, hydrogen, compressed air and gravity battery 3. Estimate the energy storing potential of closed mines	2026-28
10		Green hydrogen powered remote area microgrids	1. Survey the energy portfolio of remote communities 2. Assess the reduction of carbon emissions by replacing fossil fuels by green hydrogen 3. Compare the technological options suitable for electrolyser, fuel cells and storage 4. Trial the implementation of green hydrogen-based remote area microgrids	2028-31

11		Design of reconfigurable self-healing battery packs for central batteries	1. A desktop study of practical problems with large battery arrays 2. Designing novel switching algorithms among cells and strings to achieve self-healing, adjustable voltage/current battery packs 3. Comparing the electrical characteristics of different cell types and use electronic control to achieve replacement of batteries with different chemistry 4. Designing battery energy management techniques considering battery degradation models	2025-27
12	Advanced technologies (RO6)	Urban renewable energy zones (UREZ)	1. Develop algorithms, control systems and communication methods to transform existing distribution networks in urban areas to smart embedded microgrids with high penetration of PVs, EVs and smart meters 2. Develop the roadmap of transition of urban distribution areas into embedded microgrids that are self-sufficient in energy needs 3. Investigate the social, business and regulatory transformations needed to realize urban renewable energy zones 4. Procure/develop 3D dataset of information for each building and	2023-26

			urban precinct for case studies 5. Test the methodologies to assess and generate rooftop irradiance potential 6. Trial UREZ with developed technologies, novel business models and social engagements	
13		Synthetic inertia measurement/estimation for inverter-interfaced distributed generators	1. Conduct a broad study to identify potential challenges with inertia estimation for different combinations of distributed generators under various operating and control schemes 2. Analyses and implementation of both software and hardware to ascertain the most accurate methods for estimating inertia caused by inverter-interfaced generators 3. Develop an accurate design tool to facilitate the installation of renewable energy resources capable of providing a certain level of synthetic inertia	2025-26
14		Context-aware network capacity assessment for DER deployment	1. Develop spatio-temporal gradient-based hybrid sensors for monitoring network capacity at the low voltage level 2. Develop a novel feature selection algorithm based on maximal relevance and minimal redundancy criterion from sensor-perceived data to predict	2023-24

			the load of a network to host further DER 3. Develop a self-supervised machine learning model for cooperative control of networked DER to balance and optimise loads of microgrids	
15		Robust prediction of solar energy generation by DER	1. Develop an automated cloud movement and a shadow sequence estimator system 2. Real-time analysis of cloud images to predict the time horizon over a geographical area 3. Quantify anomalies in existing weather models in alignment with the capacity, price and demand-supply models 4. Integrate the sequence estimator, image analyser and uncertainty quantifier into a comprehensive solar power forecasting software system for pilot testing and real-world deployment.	2026-28
16		Automated health assessment of DER in rural regions	1. IoT-enabled monitoring of performance, throughput and usage patterns of DER 2. Estimate age-related performance drifting of DER in rural areas where frequent repair is costly and time-consuming 3. Develop data-driven techniques for	2028-30

			predicting the operating lifespan of DER and a context-aware recommendation system for their health management	
17		Ransomware prevention for DER	1. Assess vulnerabilities in DER pertinent to the financial aspect, data transmission channels and modes of communication in an urban region 2. Develop a consortium blockchain to ensure data integrity during peer-to-peer energy trading of DER produced power 3. Develop adaptive attack prevention for DER to protect the digital identity of prosumers 4. Develop a fault-tolerant policy to restore the functionality of the DER management system following an unprecedented cyber attack	2029-31
18	Consumer expectations (RO7)	Customer trust and information transparency models (socio-techno-economic framework)	Research is necessary to fully understand the aspirations and expectations of customers, and to improve the level of trust between service providers and customers in the energy sector The key to a successful and sustainable energy future is to place the interests of customers at the	N/A

			forefront and ensure that their needs are met.	
19	Microgrids in distribution networks (RO8)	Analysis for cost effectiveness of embedded and stand-alone microgrids	1. Test the technical and economic feasibility for implementing grid-connected microgrids as well as standalone power systems to reduce costs for customers, including developing technology, planning, operating methods, including pricing, incentives, software and control 2. Assess barriers to microgrids, including regulatory, technical, financial, and other; develop and prototype algorithms for forecasting and control of DER resources at grid edge and islanded microgrids 3. Create pilot projects, develop business models, undertake investment planning and create operational tools to support decision making by networks and end users 4. Pilot and implement microgrids to reduce costs for customer; develop technology and planning and operation methods and algorithms 5. Provide innovative approaches and technology for microgrids to realise swift and reliable frequency and voltage regulations	2023-26

20		Consistent microgrid design and operation framework	1. Survey the existing standards for interconnecting distributed energy resources (DER) with the grid and microgrids 2. Establish a consistent framework for designing and operating microgrids in Australia, addressing requirements for grid-forming inverters and hydrogen storage systems 3. Facilitate knowledge sharing and experience exchange, enabling stakeholders to effectively tackle challenges and limitations and improve the accuracy and functionality of microgrid design and operation over time	2026-27
21		Open-source decision-support tool for designing and operating microgrids	Existing microgrid decision-support tools focus on investment and operation decisions but do not support power-flow analysis or present detailed models of a network/feeder A tool that combines optimal power flow in steady-state and dynamic domains, investment and operation stages, and considers social and environmental aspects is required for microgrid projects The project aims to develop such software tools, which can be built on	2029-31

			top of the power-flow tools using an open-access, high-level programming language	
22		Power electronics-dominated power systems	This project aims to understand the operation of grid-forming resources under faults, both balanced and unbalanced. It will also examine the ability of the grid-forming resources to energise transformers and the motor load The protection of power systems is heavily based on the detection of currents With increasing DER and inverter-based generation in power systems, existing protection methods need to be reassessed and replaced wherever necessary	2023-24
23		Innovative control architecture	Proper selection of control techniques and settings is essential to ensure microgrid stability, and performance requirements and standards should be considered. Flexibility in control architecture design is important to avoid complexity and instability Researchers are exploring solutions such as droop control and grid-forming inverter-based DER to address these challenges. The objective of this	2027-28

			study is to enhance the control architecture of microgrids by incorporating negative sequence-control strategies The proposed approach could potentially contribute to the widespread application and functionality of renewable energy microgrids	
24		Network and grid impact of VPPs	1. Network impact assessment: Simulating the behaviour of VPP under different network conditions and comparing them to non-VPP cases 2. Dynamic local network operating envelopes: Investigating the impact of dynamic local network operating envelopes for DER on the ability of VPPs to provide network and system services 3. Reliability analysis: Analysing the reliability of services provided by VPPs and identifying the factors that impact reliability	2025-27

25		Virtual power plants and microgrids	Balancing load through large-scale batteries in a microgrid containing behind- the-meter rooftop PVs and batteries a) How can a microgrid operate under a VPP? b) How can each microgrid operate as a single entity in a VPP regime, where the VPP control a large geographical area? c) How can primary and secondary controllers be designed for networked microgrids, and what is the function of the tertiary controller in this scheme? d) How can demand-response and cyber security be embedded for stable and safe operation of the system?	2026-29
26	Balancing interests (RO9)	Optimal siting and sizing of microgrids and community batteries	1. Thorough research will be conducted to identify the most critical economic, social and technical factors influencing the best location for community batteries and various types microgrids 2. Conducting interactive surveys among different stakeholders will help to determine the key sizing and siting factors 3. An accurate decision-making tool will be developed to find the optimum location and scale of microgrids and	N/A

			community batteries using the identified factors and their associated contributions	

5.2 Research recommendations and roadmap

As shown in Figure 2, the regulatory, ownership, social and business aspects covered in RO1, RO2, RO3, RO7 and RO9 overarch all the technical aspects covered in RO4, RO5, RO6 and RO8. All research projects should therefore focus on one or more technical aspects while also integrating some or all of the non-technical aspects. The approach below and Table 3 represents a roadmap for research projects in the RACE for 2030 'Opportunity Assessment: Local DER Network Solutions'.

1. RO6. Advanced Technologies: Concept numbers 12 to 17
2. RO8. Microgrids and VPPs: Concept numbers 19 to 25
3. RO5. Energy Storage and RO4. Electric Vehicles: Concept numbers 6 to 11

The following combined research concepts have been identified as high priority for the research theme and the RACE for 2030 CRC:

1. **RO6. Advanced Technologies**
   a. Urban Renewable Energy Zones (No. 12) combined with
   b. Context-aware network capacity assessment for DER deployment (No. 14)
2. **RO8. Microgrids and VPPs**
   a. Analysis for cost-effective embedded and stand-alone microgrids (No. 19) combined with
   b. Power electronics dominated power system (No. 22)
3. **RO5. Energy Storage and RO4. Electric Vehicles**
   a. Storage Technologies Feasibility Study for Community Storage Application (No. 8) combined with
   b. Harnessing fluctuating EV storage (No. 6)

Expected Start		RO4. Electric vehicles and RO5. Energy storage	RO6. Advanced technologies	RO8. Microgrids and VPPs
Priority (2023-2024)		8. Storage technologies feasibility study for community storage + 6. Harnessing fluctuating EV storage (3 years)	12. Urban Renewable Energy Zones + 14. Context-aware network capacity assessment for DER deployment (3 years)	19. Analysis for cost-effective embedded and stand-alone microgrids + 22. Power electronics dominated power system (3 years)
Mid term	2025	11. Design of reconfigurable self-healing battery packs for central batteries (2 years)	13. Synthetic inertia measurement/estimation for inverter-interfaced distributed generators (1 year)	24. Network and grid impacts of VPP (2 years)
	2026	7. EV Trial project (1 year) 9. Assessment of the energy storage capability of closed mines (2 years)	15. Robust prediction of solar energy generation by DER (2 years)	20. Consistent microgrid design and operation framework (1 year) 25. Virtual power plants and microgrids (3 years)
	2027			23. Innovative control architecture (1 year)
	2028	10. Green hydrogen powered remote area microgrids (3 years)	16. Automated health assessment of DER in rural regions (2 years)	
Long term	2029		17. Ransomware Prevention for DER (2 years)	21. Open-source decision-support tool for designing and operating microgrids (2 years)
	2030			

The outcomes from the research proposed in this roadmap will pave the way to transition the local distribution networks in Australia to host a high percentage of DER while minimising the negative impacts of DER to the power systems. The holistic and inclusive approach of the project structures ensures that the transition to technical solutions occurs concurrently to the necessary regulatory, business and social changes. Thus, the projects will have wide-ranging positive impacts on all relevant sectors during Australia's fast-paced journey towards a net-zero future.

6. APPENDIX

Work Package 1: Consumers and regulatory framework

1.1 Are there different community expectations for different microgrids and if so, how can the regulatory system facilitate this?

1.2 There is a need for some empirical research for assessment of trust in the existing community energies. Research is needed to identify the drivers of trust or mistrust and quantify its objective and subjective components.

1.3 How are the communities currently included in the development of microgrid projects? Are these participatory models sufficient?

1.4 Asymmetry of information among various users (i.e. residential, SMEs and C&Is). There is an essential serious need to establish a new database for objectively analysing the participation of different types of users.

1.5 Is there an ideal model for consumer interaction with a neighbourhood battery and how can different consumers (from active to passive) be supported?

1.6 Designing an algorithm to optimise the benefits of battery technology for trading excess supply in real time for passive prosumers using smart meters facilities.

1.7 What practical, governance and regulatory challenges need to be overcome for community scale energy storage?

1.8 How do we bring accuracy and credibility to the analyses of the benefits of community energy with respect to natural disasters resilience?

1.9 What can we say about the net rate of bushfire ignitions when community energy augments or replaces conventional electricity distribution?

Work Package 2: Business models

2.1 Who is best placed to deliver services at the grid edge in a way that encourages innovation and benefits to all stakeholders? What criterion should be used to determine?

2.2 Should the full stack of services a community battery can provide be delivered by a single entity and if so, who could this be?

2.3 An in-depth study of the advantages and disadvantages of different governance models (e.g. retailer-led, DNSP-led, independent grid operator, etc.) for community microgrids in both urban and rural areas, considering the fair distribution of costs and benefits.

2.4 How to determine the best mix of ownership structures for microgrid assets to deliver the desired impact and outcomes?

2.5 How can the appropriate institutional and financial mechanisms be put in place to help communities that want to take make energy work better for them and seek the benefits that microgrids offer?

2.6 How can the customer/community-centric focus is retained when microgrids are owned by third parties?

2.7 What is the role of policy and regulatory reform to help remove the barriers that hinder certain promising ownership models?

2.8 How can we directly involve local governments and their representative bodies in the scoping and implementation projects and pilots within this RACE for 2030 theme?

2.9 What criteria should be used in determining the best financing models for development and operation of microgrids? Are they different models for the two stages?

2.10 How can RACE for 2030 leverage off the existing Commonwealth microgrid feasibility funding and ARENA RAMP microgrid implementation funding to increase knowledge of microgrid development and operation?

2.11 How can the outcomes of the RACE for 2030 Opportunity Assessment on Trust Building be applied to future projects and pilots under the theme 'Local DER Network Solutions'?

2.12 Is there enough battery capacity in community batteries to provide useful services to bulk power systems if their connection to the grid supports such services?

2.13 Inverters and virtual synchronous machine software can interface enable batteries to provide grid services traditionally supplied by non-renewable sources and already so for large assets. Will a collection of smaller assets be useful in the same way?

2.14 What is the societal/economic value of community batteries over and above the profitability of the battery (value to the owner)?

2.15 How can communities' access suitable tools to be able to understand the complexity of whether a community battery is economic for them?

Work Package 3: Planning and design

3.1 What are the most critical performance indices that should be considered in comparing energy storage in different time scales (e.g., seconds, minutes, hours, days, etc.)?

3.2 How the cost and performance of different storage technologies are predicted to evolve in the next 10-to-15-year horizon?

3.3 How the value of an energy storage degrades, or upgrades based on the geographical location (e.g., urban, suburban and remote)? What is the best way to combine the performance indices considering the variety of types, time scales, implementation years, locations. etc.?

3.4 What are the likely energy storage options that will dominate the grid in the future?

3.5 How DELWP and Ausnet's findings in relation to community microgrids can be used in RACE for 2030's research projects?

3.6 How can the maintenance of microgrid assets in rural and remote areas be assured to prevent any fire risks?

3.7 What level of controllers are required for each type of microgrid so that it can have a reliable operation, irrespective of the environmental conditions?

3.8 What are the consumer expectations and engagement pathways for VPPs and microgrids, and how are they influenced?

3.9 What incentives can be offered to increase customer engagement?

3.10 How can using digital visual systems and developing mobile apps enhance customer engagement, mainly in VPP-related activities?

3.11 What is a recommended framework for a business model to ensure the economically viable option of deploying VPPs at a commercial scale?

3.12 What is the suitable business model to reduce the payback period of the large-scale batteries to increase the investments in VPPs and microgrids?

3.13 What are the preferred criteria for defining the owner occupier/tenant split by location to better inform opportunities for DER participation in a business model?

3.14 How the capital requirements and future operation of a microgrid are affected by the degree to which advanced monitoring, control and analytics (i.e., Industry 4.0 technologies) are adopted by commercial and industrial participants?

3.15 What are critical aspects of planning of a microgrid?

3.16 Is there a general guideline that can be followed, irrespective of the type of microgrid?

3.17 What role might the CRC have in establishing systems and tools for microgrid benefits estimation that are suitable for supporting regulated investments in the Australian electricity system?

3.18 What role might the CRC have in informing or proposing changes to AEMC rules that are relevant to microgrid operations?

3.19 Should the CRC in collaboration with international partners such as NREL pursue operational decision support tools/systems for both the community batteries and microgrid sides of interconnected distribution network and microgrid systems?

3.20 What is a recommended method or algorithm for scheduling the operation of VVPs and Microgrid in Australia, given limited-visibility and uncertainty?

3.21 What is the optimal/least-cost mix of data and modelling required to optimise the scheduling the operation of VVPs and Microgrids with sufficient accuracy?

3.21 What are the most appropriate combinations of forecasting methods, and control strategies to digitalise the operation scheduling of VVPs and Microgrids?

3.22 What are the benefits of DERMS in terms of improving network performance and hosting capacity compared to network solutions and augmentation?

3.23 What are the interoperability considerations and communication protocols for DERMS in microgrids with heterogeneous resources? What should be the failsafe settings for DERMS?

3.24 How would DERMS incorporate network export/import dynamic limits?

3.25 What is a holistic business model for a hybrid VPP/microgrid/community battery system? what additional technologies and energy management strategies are required for such a system?

3.26 How can the VPP coordinator act as a tertiary level controller for a microgrid since a tertiary level controller need to consider other aspects, such as weather forecasting, markets and line capacity limits?

3.27 Could the economic value of battery storage within a microgrid be increased by decentralizing in the way of CBs? This needs to be investigated by taking into account the change in technical performance as well.

3.28 What is the best way to determine the size of storage capacity needed such that economic benefits to the prosumers are optimised?

3.29 Given the storage, generation and demand are fixed, how to develop an automated control system to use only the most economical energy options at a given time?

3.30 Do value streams exist that can be used for microgrids, community batteries and VPPS individually as well as combined? What is each value stream's significance (impact) on the economic viability of individual systems and a combined system?

3.31 What is the cost of indirect value streams, and how do we evaluate these costs?

3.32 What (additional) policy and regulatory reforms are needed in each state of Australia to implement the individual (microgrid, VPP and community batteries) and combined systems?

3.33 What specific regulatory reforms are needed to capitalise on multiple (maximum) value streams offered by the individual and combined system to exploit their full potential?

3.34 What regulatory reforms beyond feedback surveys are required to enable consumers to participate in the design and implementation of microgrid, community battery and VPP schemes?

3.35 How to enable customers' participation in integrated or multiple systems and what rules/mechanisms are needed to allow this participation without conflict or violation of individual system objectives?

3.36 How can optimum coordination be developed for microgrid and community-battery supported VPPs to achieve and take advantage of their salient features?

3.37 Use of blockchain could facilitate and ease the merging of the different business models like P2P, MaaS and EaaS. How can it be applied in Australian context? Generally, community batteries and power banks are for energy arbitrage in Australia.

3.38 Other technical objectives can also be pursued when such batteries are included in a microgrid. Given that some of such items can relatively compromise energy arbitrage, what are the best objectives for a combined microgrid-community battery system?

3.39 How to design a widely accepted business model considering the interactions between the grid connected microgrid and VPP? Can multiple interconnected microgrids operate a VPP?

3.40 How to build the capacity of consumers for understanding the functions of VPPs and community battery energy storage systems and their roles in order to address the grid challenges during peak hours?

Work Package 4: Demonstration and operation

4.1 What is an appropriate nomenclature for energy storage options at various scales?

4.2 What is the value proposition for neighbourhood-scale energy storage?

4.3 What can be done in a lab to inform and enable projects and make the process quicker? What is right to trial in a lab compared to being implemented in real world conditions?

4.4 How to manage peak load using smart meters and demand side management techniques in a microgrid with and without community storage?

4.5 How to build the house-to-house interaction and trust within microgrids and community battery usage?

4.6 What aspects of commercial-scale micro-gridded community batteries need demonstrating?

4.7 How can fluctuating levels and changing locations of storage available from EVs be harnessed?

4.8 What can a microgrid or VPP depend on from EVs? Can we develop a confidence level for the amount of energy available (firm capacity), or load that can be absorbed, that is useful to the microgrid or VPP?

4.9 Can we influence charging behaviour to improve the availability of storage and capacity from EV batteries?

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