RACE for 2030
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Theme N3 Opportunity Assessment
LOCAL DER NETWORK SOLUTIONS
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What is RACE for 2030?

Reliable, Affordable Clean Energy for 2030 (RACE for 2030) is an innovative collaborative research centre for energy and carbon transition. We were funded with $68.5 million of Commonwealth funds and commitments of $280 million of cash and in-kind contributions from our partners. Our aim is to deliver $3.8 billion of cumulative energy productivity benefits and 20 megatons of cumulative carbon emission savings by 2030.

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Project partners

Curtin University

University of Technology Sydney

Royal Melbourne Institute of Technology

Griffith University

Monash University

CSIRO
Australian Power Institute

AGL Energy Services Pty Limited

Ausgrid

Climate-KIC Australia

Department of Energy and Mining (South Australia)

Sydney Water Corporation

Clean Cowra

Executive Summary

The future energy systems will be more decentralised. With over 2 million photovoltaic systems already installed across Australia by 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 the energy storage technologies, in particular the batteries. As the prices of batteries come down, the number of these solar households with batteries will also increase. Using batteries will give customers more excellent choice and flexibility about how they consume the energy they generate and how they potentially export their power to others. Furthermore, the existing distribution networks of the grid are experiencing severe problems due to high penetration of distributed renewable energy sources. However, these challenges can be overcome through the use of novel power system models such as micro-grids, smart-grid technologies and business and ownership models.

This opportunity assessment project researches on 43 research questions related to microgrids, community batteries, virtual power plants and their combinations. These research questions encompass four broad areas of research, as consumers and regulatory framework, business models, designing and planning, and demonstrations. Based on the findings of the literature survey and the stakeholder consultations, research opportunities are explored to prepare the research roadmap.

The main research opportunities that are identified for further research by the RACE 2030 CRC are listed below:

- Regulatory, Business Models Ownership: The inclusion of microgrids, community batteries and virtual power plants will require regulatory reforms. The financial viability in terms of their ownership, revenue models and tariffs also need to be determined.
- EVs in Electricity Grids: The increasing uptake of EVs can stress the electricity grid. Moreover, it is likely that many employers and large business districts will have EV charging stations. Therefore, the impacts that EVs can have, while operating in G2V and V2G modes need further investigations.
- Large-Scale Utilization of Energy Storages: The requirement of energy storages becomes a crucial issue as the penetration level of renewable energy increases. The different energy storage types, e.g., batteries, fuel cells, supercapacitors, etc. need to be evaluated, along with its grid integration through power converters.
- Machine Learning and Cybersecurity: In the “Smart Grid” framework, modern power grids are increasingly using ICT devices. At the same time, other technologies such as peer-to-peer energy transactions, blockchains, machine learning and cybersecurity are being developed for the efficient operation of power grids.
- Renewable Energy in Urban Areas: It is expected that existing distribution networks will be converted into smart, self-healed, renewable energy zones in the near future. Therefore, this will require in-depth studies, where other power conditioning devices can be integrated for voltage control and load balancing.
- Stakeholders’ Engagement: Finding what the stakeholders need and meeting those expectations are very important for the installations of VPP, MG or CB.
- Microgrids: One of the most important aspects of microgrid projects is the protection against faults. This area has not been thoroughly explored but needs urgent attention. The other area of importance is to investigate a network of microgrids as the future distribution systems may contain several microgrids.
- Designing Local Networks: A local network needs to be designed in such a way that CBs and MGs can meet the community needs and also provide reliable operation under extreme weather conditions like bushfires and floods.

The report also presents the barriers to the implementation of novel local network solutions to propagate DER integration and possible impacts to the reduction of greenhouse gases, consumer energy bills etc. Finally, the report proposes some research projects that could pave the way to investigate all the identified research opportunities.

Research Roadmap (See Section 6.1)

	Time Frame		
Research Priorities	Short Term (up to 3 years)	Medium Term (up to 5 years)	Long Term (up to 8 years)
Governance and Regulatory (RO1)	Regulatory reforms required for the uptake of MGs, CBs and VPPs.		Performance, safety, and equity of access to MGs, CBs and VPPs.
Revenue Streams (RO2)		Financial feasibility of MGs, CBs and VPPs.	
Ownership and Access (RO3)	Ownership and aggregation models to implement MGs, CBs and VPPs.	Revenue models and tariff reforms to encourage investments.	
Electric Vehicles (RO4)	Estimating the available capacity of the grid for EV charging (G2V mode).	Maximizing the available capacity of the grid for EV operating in both G2V and V2G modes.	
Storage Options (RO5)	(1) Evaluation of different battery technologies (e.g., lithium, flow, and supercapacitors) and fuel cells from power networks POV. (2) Techno-economic feasibility of other large-scale storage options, e.g., pumped-hydro, mass-gravity, heat conversion, hydrogen, and liquid air.	(1) Converter technologies and control for best utilization of storages. (2) Converter control to provide virtual inertia to compensate for the intermittency of renewable generators and other power transients.	(1) Recycling battery energy storages and super capacitors. (2) Development of gravity-based energy storage options. (3) Viability of the production and storage of hydrogen.
Advanced Technologies (RO6)	Integration of energy forecasting, Blockchain and IoTs in local DER network solutions.	Machine learning techniques for condition monitoring of renewable energy generating systems.	Cyber security for the safe and resilient operations of MGs and VPPs.
Urban Renewable Energy Zones – UREZ (RO6)	Developing algorithms to transform existing distribution networks to a smart, self-healing, renewable energy zones to include PVs, EVs and smart meters.	Network compensating devices (DSTATCOM and DVR) in UREZ's to ensure stable operation under high renewable penetration.	
Stakeholder Engagements (RO7)	Surveys of stakeholders' expectations vis-à-vis MG and VPP.	Addressing the challenges of meeting stakeholders' expectations.	
Microgrids in Distribution Networks (RO8)	(1) Frequency control and associated smart load control. (2) Transition from CBs to MGs.	(1) Protection and fault mitigation in microgrids. (2) Natural disaster mitigation using microgrids.	Network of microgrids in distribution networks.
Custom Design of Local Networks (RO9)	Siting and sizing of CBs and MGs to meet community needs.	Innovative approaches for sustained operation under extreme weather conditions.	

Proposed Research Projects (See Section 6.2)

Urban Renewable Energy Zones

The main objective of this project is to facilitate maximum penetration of renewable energy in existing grid distribution networks to avoid or delay highly expensive network augmentations. This is achieved through employing smart grid technologies such as smart metering, communication and multi-layer control to enable coordinated power flow in the distribution networks. It will fully utilize the emerging EV storage capacities, behind the meter batteries, community batteries to mitigate network problems such as line and transformer overloading, line overvoltage, phase imbalance, neutral line currents etc. The intelligently controlled UREZ will not only minimize curtailments of distributed generation it will also facilitate participating in VPPs. This project will consist of two stages. In the first stage an urban renewable energy zone is designed in detail and a laboratory hardware model is built. The laboratory tests are conducted to verify the effectiveness and to make further improvements. In the second stage, UREZ will be implemented at an urban area with highest RE penetration and strongest community interest. At this stage, in addition to the technical implementation of the UREZ model of control, it will research on the acceptance of it by various stakeholders such as prosumers, aggregators, DNSPs, regulators and investors.

Machine-Learning for Condition Monitoring and Forecasting of DERs

This project will incorporate advanced technologies such as the Internet of Things (IoT), Blockchain and Machine learning techniques. The short-term research tasks include effective monitoring of local DER and sharing the associated information with VPPs ensuring integrity. Monitoring of DERs at the low voltage level and making comprehensive condition assessments based on the perceived information are challenging. For different DERs, their condition is subject to diverse chemical, mechanical, and electrical measurement and historical data sets, which is barely traceable through conventional monitoring approaches and techniques such as smart meters, DC-AC Inverters and Supervisory control and data acquisition (SCADA) systems. Therefore, in this project, IoT-enabled intelligent monitoring devices with embedded Spatio-temporal gradient-based hybrid sensors will be leveraged to monitor the health, performance and hosting capacity of DERs at the prosumer premises. Considering the large volume yet heterogeneous raw data captured by these intelligent devices, extracting representative attributes (features) consisting of useful information and insights is also necessary. Therefore, this project will apply a novel feature selection algorithm based on maximal relevance and minimal redundancy criterion from sensor-perceived data. Since such information is sensitive and, at the same time, requires to be accessible for efficient decision-making, the project will extend the concept of blockchain to ensure its integrity while sharing with respective bodies and control systems. Moreover, as part of mid-term research tasks, the project will develop a self-supervised Machine Learning model for cooperative control of networked DERs. It will incorporate two modules. The first module will correlate the health condition of each asset in a DERs network and the Spatio-temporal feature of their operating environments to estimate the performance of DERs. The second module will contain a deep neural network to predict the renewable power generation rate of DERs depending on environmental parameters such as weather, temperature and wind pattern. Collectively both modules will determine the reachable regions of DERs based on different norm-based measures under various classes of performance and renewable power generation and will construct control protocols to optimise the network load while serving and integrating the DERs to the primary grid. Finally, the IoT-enabled DERs monitoring framework and proposed ML models will be consistently refined through pilot testing in a real-world testbed as the long-term research tasks, which will eventually result in an end-to-end software solution for DERs management in a microgrid.

Evaluation of Storage Options and their Utilization

The objectives of this project are: Evaluation of battery technologies for grid support; Techno-economic feasibility studies of large-scale storage options; and Smart converter controller design. Lithium-ion batteries are prevalent currently, especially for EVs. However, there are other technologies that are evolving rapidly, such as, lithium sulphur batteries, solid state batteries and vanadium redox flow batteries etc. At the same time, supercapacitors can be added to batteries to enhance their speed of response. Moreover, the cost of hydrogen fuel cells is decreasing. Therefore, it is imperative that these different technologies need to be evaluated based on their cost, speed of response and maximum charge/discharge cycles (longevity). Furthermore, the possibility of green hydrogen generation and storage options are evolving, and it is expected that they will be available by 2030. In addition, other large scale storage options like pumped hydro, compressed air etc. can be viable options. However, some of these are depended on geographical locations. Therefore, the techno-economic feasibility of these large-scale storages need to be studied. A power converter can be operated in grid feeding, grid forming or grid supporting modes. These modes are application-specific and will depend on the network structure. Moreover, their siting is also crucial from the point of view voltage rise issues, voltage balancing and reverse power flow issues. Furthermore, the converters can be operated as virtual synchronous generators to compensate for the intermittency of renewable generators. All these issues need to be studied in detail through practical demonstration projects.

Microgrid in Distribution Networks (3-5 years):

Microgrid research and demonstration are in advanced stages. However, there are several unanswered questions that need to be addressed. Microgrid frequency control is well understood. When a microgrid gets islanded from a distribution grid, it has to manage its local loads using some form of primary control, such as droop control. However, if the power generation in a microgrid is not able to cater to its local load, then small load shedding strategies need to be designed. Some of the loads can have higher priority than some other loads. Therefore, circuit breaker coordination will be required to trip the non-critical loads, as and when required. While the operation and control of microgrid is well researched, microgrid protection area has been largely neglected, as the protection system evolves with distribution systems. However, standard distribution system protection cannot be used for microgrids since it must cater for reverse power flow and the fault level changes due to plug-and-play energy resources. Directional overcurrent relays can be an option, but the converter-interfaced generators generally cannot supply sustained fault current levels. Therefore, a holistic approach will be required for microgrid protection design. The other important issue that needs attention is the natural disaster mitigation using microgrid. When several microgrids are placed in a distribution system forming a network of microgrids, smart islanding strategies will be required in case of any natural disaster that can result in a large-scale power failure. However, a microgrid can also help in restoring the power network through black start. Therefore, both microgrid networks and disaster mitigation aspects need to be studied.

Partner Preferred Themes and Projects

Based on partner preferences the following list of themes have been highlighted for incorporation into future CRC projects as a priority:

- Regulatory reforms required for the uptake of MGs, CBs and VPPs.
- Financial feasibility of MGs, CBs and VPPs.
- Revenue models and tariff reforms to encourage investments.
- Recycling battery energy storages and super capacitors.
- Cyber security for the safe and resilient operations of MGs and VPPs.
- Developing algorithms to transform existing distribution networks to a smart, self-healing, renewable energy zones to include PVs, EVs and smart meters.
- Network compensating devices in UREZ's to ensure stable operation under high renewable penetration.
- Natural disaster mitigation using microgrids.
- Network of microgrids in distribution networks.

Based on partner preferences the following recommended projects received the strongest interest:

- Urban Renewable Energy Zones, and
- Machine-Learning for Condition Monitoring and Forecasting of DERs.

Contents

1 Introduction

1.1 Project Scope

This project investigates local Distributed Energy Network solutions which is theme N3 in RACE for 2030 for Networks, providing analysis for cost effective embedded and islanded microgrids (sub-theme N3a) and investigation of storage as a service, particularly for distributed community batteries (sub-theme N3b)[1].

In more detail, analysis for cost effective embedded and islanded microgrids aims to develop economic and technical analysis supporting cost-effective adoption of islanded and embedded microgrids. This 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 as well as frequency support. Moreover, community storage interacts with both customers and other market participants through a range of regulatory constructs as well as business models. This sub-theme covers all these interactions while centrally positioning the consumer interest and perspective.

These two sub-themes represent extensive areas of investigation. Through a process of consultation with stakeholders and the industry reference group, a set of focused problems and five recommended projects has been established.

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 1 following. The research partners for the project were from Curtin University, UTS, RMIT, Griffith, Monash 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 as follows:

- **SG1** - April 14th, covering project scope, timelines and expected involvement.
- **SG2** - May 26th, covering materials for the first IRG meeting, to review initial research findings for topics in the 'Research Roadmap', and associated CRC projects to follow to gauge partner interest.
- **SG3** - July 21st, providing an update on progress and sharing the intended pathways for the first implementation project.
- **SG4** – is combined with IRG 2nd meeting and held on October 27th as the final partner meeting.

Table 1: IRG Membership (*non-CRC industry partner, people listed where nominated).

AGL Energy Services (Simeon Baker-Finch)	Australian Power Institute (David Pointing)	Ausgrid (David Dawson)	Ausnet Services*
AEMO*	Clean Cowra*	Climate-KIC (Chris Lee)	EV Energy*
Elexsys Energy*	Energy Consumers Aus.	Horizon Power	NSW Planning & Environment (A. Lowe)

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[1] This scope section is paraphrased from the Theme N3 Opportunity Assessment Call for Proposals published by RACE 2030.

Powerlink	SA Energy and Mining (Joanne Galley)	Sydney Water (Phil Woods)	Victoria Environment Land Water & Planning

Industry Reference Group meetings were held as follows:

IRG 1 – June 1, discuss common scope, where the IRG was presented with a list of key questions around community batteries, microgrids and VPPs as well as integrated solutions for consideration in the research roadmap and to develop project proposals that have strong industry support.

IRG 2 – was held on October 27, providing an end of project summary and seeking advice on the research roadmap and implementation projects.

For both SGs and IRGs participants were provided with materials well ahead of meetings and write ups of key conclusions thereafter. In IRG meetings particularly, researchers were encouraged to listen more than present.

1.3 Research Methodology

RACE for 2030 provided an initial forty-three research questions. These were grouped by researchers, and during SGs and IRGs into four work packages:

1. Consumers and Regulatory Framework
2. Business Models
3. Microgrid and VPP research projects
4. Embedded Microgrids

For each work package researchers explored the relevant literature as well as industry reports. Through this process and in consultation with industry representatives the initial research questions were condensed into nine research questions with the most potential:

- Governance and Regulatory Challenges
- Revenue Streams
- Ownership and Access
- Electric Vehicles
- Storage Options
- Advanced Technologies and Urban Renewable Energy Zones
- Stakeholder Engagements
- Microgrids in Distribution Networks
- Custom Design of Local Networks

From here, and again in consultation with industry partners, five recommended projects were generated.

1. EVs in Regional Microgrids
2. Urban Renewable Energy Zones
3. Evaluation of Storage Options and their Utilization
4. Microgrid in Distribution Networks
5. Machine-Learning for Condition Monitoring and Forecasting of DERs

The Literature review concentrated on industry reports due to fast moving nature of this domain, where the latest information is best obtained from practitioners and industry.

2 Literature Review

2.1 Consumers and Regulatory Framework

The focus of this stream 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 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.

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

To address this question, it is necessary to have a basic understanding of the current legal and regulatory framework which forms the background to any community/consumer engagement in microgrids and also neighbourhood batteries. Microgrids, regardless of whether standalone or grid connected, are usually comprised of generation and network assets and supply directly to end-users. In the Australian national electricity market (the NEM), the strict unbundling rules apply (note – this is different in WA and NT, which are not part of the NEM). This means that the same entity cannot operate the microgrid, generate and retail electricity.

Are community expectations different in embedded semi-connected vs edge of grid versus standalone microgrids?

Firstly, there is confusion and only a limited understanding of the different types of microgrids (MGs) and their implications (Shakya et al., 2019). Further, the extant literature focuses primarily on the technical and economic aspects of MGs and the optimisation and balancing of demand and supply rather than stakeholder engagement (Gui et al., 2017). While several papers touch on stakeholder engagement in MGs and trust 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 MGs are preferred, from both a financial and technical perspective. Kaundinya et al. (2009) identify several disadvantages to standalone systems, not least community concerns about long-term economic viability, a key component in the decision to utilise grid connected or ‘standalone' energy systems. While standalone 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 DERs 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, while 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 MGs. Projects in rural and remote communities are also viewed more positively by communities because they have the most to gain.

Anecdotal evidence of projects in Australia indicate that initial stakeholder engagement should include an explanation and education of the technical options. This serves to empower community thinking beyond simply MGs and embrace other DER options. It was also important for communities to understand that MGs were an all-encompassing solution and could impact all parts of the community.

Some key areas for further research:

- Energy Consumers Australia does regular surveys/research on consumer expectations more generally (e.g., their 2019 report[1]). But there has been very little research undertaken so far which expressly explores community expectations comparing different types of microgrids. Arguably, all of them want reliable, green and local supply, but existing literature has shortage in this context.
- Are there different community expectations for different microgrids and if so, how can the regulatory system facilitate this?

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

RACE (for everyone) 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 Morgon (2020)'s study has shown that electricity retailers rank among the least trusted brands in Australia (22 out of 25). The current regulatory framework (stream 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 MGs, 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.

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 in their project. 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 DERs 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 MG projects to the community, but entitle 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 MGs 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 MGs and understanding the environmental and financial benefits have proven challenging for local consumers, particularly in relatively isolated areas where many MG 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 MGs (Soshinskaya et al., 2014).

Some key areas for further research:

- 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

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; start recruitment of CLOs early in the project; and local engagement requires a dedicated full-time role, particularly in the initial months of projects c commencement; celebrate successes i.e., 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 MGs remains rare. Warneryd et al. (2020) propose two additional dimensions when considering community energy and more specifically MGs.

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 MG 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.

Provance et al. (2011) suggest that community involvement also assists both the political and social–institutional dynamics in the business model and ownership structure. To conclude, this is a rapidly evolving landscape with many MG projects at the feasibility stage. Community education is a critical early component of these projects in 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 MGs and accelerate the transition.

Some key areas for further research: How are communities currently included in the development of MG projects and are these participatory models sufficient?

Consumer participation in Community Battery uptake

How do different types of consumers participate in, and benefit from community scale batteries? Residential vs SME and C&I customers will have 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 these solar households with batteries will also 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 battery (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 CSBs is that they may irradicate inequalities in the energy system by providing an opportunity to build customers' engagement with and building trust in the energy sector. The CSBs may also help peak shaving of the entire electricity system via integrating distributed energy resources. The CSB/CES is expected to increase peak load and an increasingly unpredictable peak load. They may increase peak exports from household prosumers (e.g., solar photovoltaic (PV) generation). Together, these challenges could cause demand and voltage management issues in the distribution network. The community-scale batteries should be explored as a viable solution to these challenges. 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 backup 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-scaled batteries. Even if these consumers will not 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 are 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-scaled 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-scaled batteries is currently scarce due to research mainly focusing on residential consumers. One study that however focuses entirely on energy storage for commercial renewable integration was performed by ElectraNet (2021). It was shown that the benefits of using the community-scaled 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 were needed, thereby increasing in levels of safety for workers. It was also shown 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 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 not only participate but 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 in 2020 found that current regulations do not need significant changes to be seen as current achievable options. However, what most communities will need is some type of discounted local network tariff to make them financially viable. Policies regarding competitive basis can also impact the participation of different customer types (ANU, 2020a). The ownership model is also essential to consider 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. Based on a survey of the literature (Parra et al., 2017), highlight 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.

Some key areas for further research:

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.

- Asymmetry of information among various users (i.e., households, SMEs and C&Is). This problem is stated in the existing literature and needs to be addressed properly.

For this purpose, there is an essential serious need to establish a new database for objectively analysing the participation of different types of users.

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 and sometimes with a broad objective of DERs and does not focus on community-scaled batteries (Ambrosio-Albalá et al., 2020; Kalkbrenner, 2019). Hence, the topic is not investigated enough to answer if there are demographic differences in preferences. However, some specific cases such as the UK survey from Ambrosio-Albalá et al. (2020) have showed that consumers would rather have government and municipally owned and managed community-scaled 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-scaled batteries and run them for non-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-scaled 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-scaled 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 their 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 comprised of serval aspects, which is especially important for consumers such as network providers. It is an essential input to understand how commercial arrangements should be setup (ElectraNet, 2021). However, the point that different groups emphasise different benefits highlights the inherently political nature of model selection - any selection of 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 so as to reveal which models are most likely to benefit all energy consumers.

Also, based on the Analysis done 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 researches showed that a range of models is possible as an "ideal" optimization 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. As customers opt for time use management and incorporate storage, the network tariff should be set to motivate customers to do so. According to the Council of European Energy Regulators (CEER), the new tariffs must recover the cost, to be cost-reflective, non-discriminatory, non-distortionary, simplistic, transparent, and predictable. In addition, Customers have to be explained 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's important to stress that the results from the literature review only show 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.

Some key areas for further research:

- Is there an ideal model for consumer interaction with a neighbourhood battery and how can different consumers (from active to passive) be supported.
- designing an algorithm to optimise the benefits of battery technology for trading excess supply in real time for passive prosumers using smart meters facilities.

How do customers' understandings of how the neighbourhood battery obtains value impact their interest and acceptance of the technology?

A study exploring acceptance and community-scaled batteries through a UK survey showed that initial customers' attitudes were positive. However, this study also showed that the level of awareness of DES 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 justice and injustice better. They found that several participants were not sure why community-scaled batteries would be the best technology to obtain the value needed for 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).

Some key areas for further research:

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: 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 recent relevant studies including of public health and natural disaster events and their management (NNDA, n.d., Publications), critical infrastructure and critical supply chains (ProductivityCommission, 2021). These highlight that Australia is vulnerable in many ways but that there is an especially strong dependence on mobile telecommunications systems. These systems, for example, are the foundation of operational control redundancy and resilience (i.e., "backup" to SCADA) in the electricity system. Shortfalls in the depth of backup power supply for telecomms facilities is a major recognized problem (DITRDC, n.d., 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 harmonize with power supply assurance to critical infrastructure are clear. One may also look to islanded operation of community energy (CE) for maintaining electricity supply when conventional infrastructure is impacted by events. Certainly, 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 for making 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 with can reduce fire risk and community vulnerability (EngageVictoria, 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 much from electricity transmission and distribution businesses. CE is both a problem and a solution in this context. Electricity transmission and distribution are subjected to much regulation which seeks to reduce the occurrence of bushfire ignitions from the power system. This spans 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 fire starts. CE 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 recognize the problem). Less conventional and distributed energy assets are by no means free of ignition risk (ABCNews, 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 CE 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 occurs in distribution network planning but (i) parts of the documentation can be commercial in nature and not public, and (ii) the analysis of CE solutions can be under-informed and immature because knowledge is scarce. The latter exacerbates the former because CE options can be dismissed early in options analysis due to the costs, benefits, uncertainties and risks being inadequately understood. The cause of CE, and particularly the quantification of its benefits pertaining to resilience to natural hazards, will be strongly assisted by the establishment of recognised 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.

Some Key Areas for Further Research: How do we bring accuracy and credibility to analyses of the benefits of community energy with respect to natural disasters resilience; and what can we say about the net rate of bushfire ignitions when community energy augments or replaces conventional electricity distribution?

2.2 Business Models

For the acceleration of adoption of distributed energy system solutions, innovative business models are required. Energy market deregulation brings in a host of challenges, much of which is yet to be addressed. The affordable IoT technologies facilitate new business model realizations such as Virtual Power Plants, Aggregators, and Blockchain mediated transactions in energy sector. In this stream, many related 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, how the VPPs and microgrids both be facilitated when they overlap will be explored. Note that this stream will build on the results of a N4 Fast Track on DER Business Models.

Introduction and Definitions

The proposal for this RACE for 2030 Opportunity Assessment on Local DER Solutions stated that it "looks at both, standalone and grid-connected microgrids and, in the latter category, also distinguishes microgrids for rural and SWER connected communities from peri-urban and new developments". However, a key initial question raised by the researchers prior to working on the questions here was "what definition best constitutes what is meant by a 'microgrid' or 'community battery'?' While there are a small number of highly cited examples for microgrids (such as the US Department of Energy one cited below), they usually take a network-centric – rather than customer or community centric-view. 'Local DER Network Solution' also infers such a perspective.

US Department of Energy – microgrid definition:

A group of interconnected loads and distributed energy resources with a clearly defined electrical boundaries that acts 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 whereas they are often deployed as non-network solutions which don't offer direct benefits for the community/neighbourhood at all. Local Energy Solutions are a term that could be used to encompass microgrids (embedded and islanded), community batteries, and standalone power systems (SAPS). The definition used by the RAMPP (Regional Australia Microgrid Pilot Program) provides a more flexible approach to defining a microgrid than that assumed commonly in the literature.

For the purpose of the (Regional Australia Microgrid Pilot) Program the term microgrid is used to include the following technical configurations (source: 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.
- Standalone 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 rather than 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.

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

(i) What is the relationship between incumbent retailers and local distribution networks? (ii) 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 above 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., SIPS). Currently, battery providers are not allowed to deliver all of these services. In the Australian National Electricity Market, strict separation between any network providers (transmission and distribution) and retail is enforced. DNSP can therefore only provide distribution services. They usually have no consumer contact. So-called ring-fencing, which requires administrative and legal separation of network and retail activities, ensures that that natural monopoly network providers cannot abusing their position of power by preferring associated upstream (generation) or downstream (retail) businesses.

Ring-Fencing Guideline – Ring Fencing Definition: Ring-fencing refers to 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 governs the extent to which DNSPs can provide contestable services.

Box 3: Ring-fencing definition (AER, 2021)

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). Innovation at the 'edge of the grid', such as smart grids, microgrids, batteries and EV, requires 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 on the US example that utilities can behave anti-competitively towards new entrants, such as DER providers to protect their traditions business model. On the other hand, the ACCC (2018) report in 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.

Some Key Areas for Further Research:

-Who should deliver services at the grid edge in a way that encourages innovation and benefits to all stakeholders? Should there be a role created for a dedicated a microgrid operator? What is the role of community retailers? Who is best placed (criteria?) to facilitate these kinds of solutions?

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

- 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 could support a solution that fairly distribute the costs and benefits of microgrids. Assessments should include consideration of whether models suit rural and urban micro-grid environments equally.

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 renewable, 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 is still unknown which ownership structures and business models that will emerge as dominant, as has been the case with the more mature solar, wind renewable, and cogeneration sectors (Bolton & Hannon, 2016, Burger & Luke 2017, Wright et al 2022). There is also additional complexity 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 the 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 2: 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) represents 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, distribution network services).

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

Table 3: 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 delivered via a form of legally defined organisation or organisations. There are three broad types of profit models by which such an organisation would operate, as described in the table below.

Table 4: 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 Sou Resilience in regional and remote areas is a key driver for microgrids. A map and short summary of seventeen Western Australian Microgrid projects can be found at Microgrids Australia (MicroGridsAustralia, n.d., Microgrid Projects in Western Australia). Two examples responding to this need examples are from Western Power in Kalbarri (WesternPower, n.d., Kalbarri microgrid) and Horizon Power in Onslow (HorizonPower, 2021). In NSW Endeavour Energy is developing a microgrid for Bawley Point and Kioloa on the Coast in response to issues related to bushfires, storms and peak loads (EndeavourEnergy, n.d., community microgrid for NSW South Coast).

Some Key Areas for Further Research:

- 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)?

- 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?

- How can you ensure that where ownership is given to others that a customer/community-centric approach is followed? And what is the role of policy and regulatory reform to help remove the barriers that hinder certain

What role can local governments play in supporting the transformation?

Australia is divided into 537 local government areas (LGAs) with 55% of these 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 such events 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, it 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 them 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 projects, especially where they have already invested in capital works, 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 scalability for microgrid projects which are demonstrated to be feasible, viable, and desirable for implementation. Bodies representing Local Government (Regional Organisations/Joint Organisations, Local Government Association, Cities Power Partnership) would be a good entrance point with which to engage this important stakeholder group.

Some Key Areas for Further Research:

- 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. 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 5: 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 & 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 projects. 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; resource 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	Higher cost of capital. May be difficult to balance investor expectations with social purpose.	Simply Energy VPP Thrive Renewables Community Bridge

	emerging; Potentially responsive to emerging new opportunities.		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 exists a growing number of 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 from this is slow and the financing mechanisms are not always transparent. Further examination to better understand the linkage between accelerating the adoption of local energy solutions facilitated by sustainable finance 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 as detailed in the previous question a3-2. Wright et al. (2022) and Langham et al. (2021) discuss a number of sources of capital for financing microgrids.

Table 6: Sources of capital for financing microgrids

Sources of capital	Description
Government grants	Government funding in the Australian context has mainly been provided to date 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/ 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 derisking 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 their 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 SolarShare 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)

Some examples of finance and ownership examples relevant for microgrids or other local energy solutions are given in the following table.

Table 7: Financing and ownership options with examples

Type	Benefits	Disadvantages	Examples
Customer owned and financed	Customers understand purchasing products they own to deliver personal benefit.	Limited to products on customer premises, and restricts access to those with capital; generally, leaves risk of performance with the customer.	Integrated solar & storage smart energy products in Yackandandah.
Community owned and financed	Create opportunity to build social capital through co-owned assets on community or business sites.	Capital raising takes time; Harder to make generation projects stack up financially 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 [#6], Pingala crowd-funded solar on Sydney breweries, Enova Energy, Hepburn Wind, Solar Share. Sapphire Wind Farm community co-investment campaign
Network business (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, etc; Most suitable for local distribution elements of the microgrid.	Limited likelihood outside of remote locations; Limited flexibility to develop community interests not expressly focussed on grid benefits; May not represent best value to community (hard to invoke competition benefits).	Western Power's microgrid projects: Kalbarri, Perenjori, Bremer Bay and Ravensthorpe projects. AusNet Services' Mooroolbark Mini Grid
Government (ownership not likely; only financed)	Only likely in Heyfield case as source of grant funding or low interest debt finance (i.e., low cost of capital) or in a partnership model with a community energy group to lease land and purchase electricity	Long funding cycles and reporting guidelines may detract from purpose. See also comments above under 'network business' regarding limited flexibility.	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 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)

Some Key Areas for Further Research:

- What does “best mean” – what should the criteria be?

- 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?

To answer the question of what is the best financing models for microgrid development and operation, more attention needs to be paid to what does “best” mean? With the infancy of the microgrid market, the risk profile means that obtaining finance is found to be challenging (Wright et al, 2022). Additional grant funding from the federal government has been assigned to microgrids for remote and regional communities but what is the impactful way in which to apply this? Should it be to turn mildly uneconomic projects into economic ones? Or should it be leveraged in some other way that can move the needle on microgrids and maximising their benefits to consumers and other stakeholders? Until more microgrids are implemented there will be a lack of knowledge on microgrid operation. The Commonwealth’s RRCRF (Regional and Remote Community Reliability Fund) committed $50m to fund feasibility studies for microgrids across Australia and runs from 2020 to 2024, already supported almost two dozen projects. The ARENA RAMP (Regional Australia Microgrid Pilots) program has committed $50 million to support microgrid pilots 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 be additive while potentially leveraging off them.

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

Local storage assets can be considered a component of microgrids. Question2.2.1.2 covers the best ownership models for microgrids, and 2.2.1.4 covers financing and operation models for microgrids, so the content in those two areas largely covers this question, through the lens of the storage component of microgrids. As noted in those questions we are in the early stages of implementing, operating, and financing storage assets and there are not yet established models of best practice.

Further, to 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 (see a3-2 on microgrids)
- Lowest operational cost (see a3-4)
- Lowest cost for end consumers (lower than buying off the grid conventionally)
- Sustainability rating
- Reliability of supply
- What is possible given the regulatory envelope

Answering these questions would be best done by interview and survey with each stakeholder group to assess the priority of each of these aspects, as well as examining the current practice in pilot implementations. The PowerBank community battery is an interesting case as it’s facilitated by Western Power and Synergy and customers subscribe to it. The 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:

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 so won't be repeated here. On the specific issue of trust during the ownership and operation phases, the lack of pilot or early commercial microgrid projects in Australia does infer 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) states 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 to ensure trust in the ownership and operation phases by encouraging the building of trust through the earlier microgrid and community battery project development phases.

The RACE for 2030 Opportunity Assessment on Trust Building in the Energy Sector is an excellent reference source for which the conceptual pillars for E1 (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 in which exploring ownership and operation models is desired. It could also be offered to ARENA who will be playing a major role in the funding of microgrid pilots through the RAMP program. Further dialogue between RACE for 2030 and ARENA is recommended.

Some Key Areas for Future Research:

- 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 1: Conceptual Pillars for Trust building

Source: Russell-Bennett et al. (2021).

Accessing 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. The Perth trial uses a 464kWh battery which is tiny compared to the SA battery (Energymagazine, 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 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.

Some Key Areas for Future Research:

- 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?

Inverters and virtual 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?

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 dispatch-ability.

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

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 "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) find 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 the majority of battery revenues in Australia currently originates from participation in the ancillary markets. At the same time, the authors note 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." (Csereklyei et al., 2021).

Estimating the economic value of batteries, including community batteries especially resulting from ancillary market operations, requires taking into account the development of ancillary market prices, as well as the ability of batteries to prevent blackouts, thus avoiding "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 an area requiring further research."

Some Key Areas for Future Research:

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

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

2.3 Planning and Design

This stream focuses on identifying the most impactful research projects through which microgrids, community batteries, and VPPs could be planned and designed using the state-of-the-art knowledge. Identifying regions and areas most suitable for micro-grids, VPPs or combination of them with and without community batteries, integration of these power system components to work in unison to minimize grid impacts, identify the potential of integrating microgrids, VPPs and community batteries are key research questions focused on this Stream.

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 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. The growth of the DPV is already a double-digit figure (IEA, 2022). This trend shall impose an excessive stress on the distribution networks. Curtailments of the distributed photovoltaic will be inevitable, unless effective remedial actions are taken soon, such as deploying storage systems to release congestion the distribution networks. On the other hand, storage systems can be served as a non-wire alternative to differ, reduce, or avoid the need of conventional network augmentation investments (Lowder & Xu, 2020). Li ion battery storage systems in the above are already playing a key role at the present. Thermal- and mechanical energy storage systems are good 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 also increasingly being deployed to optimise the cost, performance, response time, and aging factor of different storage types (McDermott et al., 2022; EIA, 2021; IEA, 2021; Nedd et al., 2020; METI, 2021).

The Swiss city of Ticino's 110-meter-tall skyline construction is one example of an existing gravity-based energy storage system. Energy Vault, the Swiss company that built the structure, has already begun a test program that will lead to its first commercial deployment in the coming years. Another start-up, Gravitricity, plans to build a 4MWh gravity-based storage facility on a UK brownfield site upon successful completion of a 250kW 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-scaled pumped hydro complex is under construction in Walpole, Western Australia. This hybrid energy storage system with a capacity of 1.5MW/30MWh 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 (WesternPower, n.d., Walpole pumped-hydro microgrid project).

Liquid air energy storage (LAES) systems deployed across distribution networks is also a key alternative storage system that can be used to enhance the hosting capacities of a distribution network. Owing 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 small scale that the distribution feeders can absorb. 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 1.75MW/10MWh 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 5MW/10MWh 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 500kWh of energy produced by a 300kW 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, Liquid air energy storage systems could be placed in anywhere in the distribution medium voltage network, owing to their non-dependability of geographic constraints. Pumped hydro energy storage systems have evolved during past few decades. Closed loop small/micro-scale pumped hydro storage systems are also another alternative storage type that can be deployed in urban areas by utilizing the height difference of the high-rise buildings. Combined deployment of these alternative storage systems with battery storage systems would be a promising solution to lower the cost while reducing the carbon footprint in the coming decades. In this context, it is important to find the answers to the following questions through research.

Some Key Areas for Future Research:

- What are the most critical performance indices that should be considered in comparing energy storage in different time scales? Ex. Seconds, minutes, hours, days etc.

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

- How the value of an energy storage degrades, or upgrades based on the geographical location? Ex. 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.

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

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 might 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 has an emphasis on North American experience. It does however note that the customer-centric reliability/resilience value proposition relative to impacts of natural extremes is driving North-eastern US investments. Similarly (MonashUniveristy, 2019) surveys benefits and value streams for microgrids (re Sect 6.1.1 in particular) but it 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 (ABCNews, 2019) provide anecdotal evidence of community support and value for microgrids. A significant contribution can be found in Section 7.2 of Parra et al. (2017). however it is UK and Europe-centric. Further literature search and/or primary research is required in order to bring to light additional structured primary-source information of customer views about microgrids in an Australian context.

The Community Microgrids and Sustainable Energy Program (CMSE) run by DELWP and Ausnet in Victoria has been undertaking extensive community consultation regarding micro-grids or particular areas (Corryong, Mallacoota and Omeo) (EngageVictoria, 2022). Energy reliability and bushfire risk reduction are the prominent motivations. 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 "on paper" across Australia due to the nexus between remote rural energy resilience and fire prevention.

Some Key Areas for Future Research:

- 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 microgridable regions?

There are three types of microgrid projects that are prevalent. These are:

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

Usually, rural areas are electrified through diesel/gas generators. Obviously, the cost of diesel (or gas) is high due to the transport cost. Furthermore, both transport and use of fossil fuels in generators produce greenhouse gases and 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 farm) and battery backups. Diesel generators can be used as a backup. The cost of PVs, 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 electrify such areas using PV and battery energy storage systems (BESS) will be less than using diesel.

The semi-urban town that are at the fringe of grid experience power quality problems such that 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 is evolving that is termed as No-wire Alternative (NWA) (Deboever et al., 2018). The main objective of NWAs is to use distributed energy resources (DERs) and microgrids that can defer, reduce and/or avoid grid expansion. This can be beneficial from both economic and environmental point of view. The increased loading on transmission and distribution infrastructure can be avoided using NWA and climate related events such as excessive heats resulting wild bushfires can be avoided using DERs and microgrids that are restricted within specified regions. The NWA can be extended to urban power distribution systems, especially in those in the new development areas and in those areas where the infrastructure is very old and needs replacement. Moreover, using this new paradigm, the older thermal generation units can be retired. Therefore, substantial financial savings can be made if new generation plants are not constructed, new transmission/distribution lines are not erected and old lines are not replaced.

Some Key Areas for Future Research:

- At remote rural areas, microgrids can be economic and be fire risk beneficial for relatively isolated communities such as those in the Victorian Alps, especially once distribution infrastructure has become life expired or has been heavily impacted by fire events as in 2019-2020 (Engage Victoria, 2020). Indeed, existing government programs are active around these issues.

- It is well established that Australian distribution networks are required to consider non-network solutions to solve challenges such as capacity issues whether in urban or rural settings (AER, 2013). Microgrids are clearly amongst these solutions and can be 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 Vic Energy Safety Regs Amended 2016, which apply in these locations. Microgrids have potential economic favourability for maintaining supply to clusters of (currently HV) rural customers (residential and other) which are sited beyond the urban fringe, enabling heavily-loaded (and/or high proportion underground cable) urban fringe zone substations to accommodate (or avoid) REFCL protection demands.

What are the technical aspects of these regions?

Rural, off-grid microgrids require backup power generation. Even in the sun-rich sites, it is possible to have several cloudy days, especially during the rainy seasons. Therefore, the microgrid planning in such areas must consider storage at least sufficient to meet the demand continuously for three days. Thus, the microgrid sizing must be considered carefully. Furthermore, the backup diesel generation also needs to be considered in case of contingencies. The operation strategies of such microgrids are simpler as they can be controlled by local controllers, where elaborate communication infrastructure is not required.

The strength of a grid is defined by the short circuit ratio, which defines 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 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 resynchronization processes are biggest technical challenges for such microgrids. The DERs in a microgrid are usually controlled by primary controllers. In relatively large size microgrids, secondary controllers are used as microgrid energy management systems. Again, secondary controllers can be centralized or decentralized or distributed. The major technical challenge, apart from sizing of these microgrids, the design of secondary controllers. A centralized controllers may need extensive communication system, whereas the requirement of communication system 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. However, 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. Therefore, a retrofitted microgrid needs to coordinate with these prosumer-owned resources with additional generation and storages to balance the system operation. Another important research area is on the distributed control of the microgrid power flow by dividing to number of layers. Such control methods can also be applied to control grid-connected high renewable energy zones too.

Some Key Areas for Future Research:

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

What is the interaction between virtual power plants/DER aggregators and microgrids in their varieties?

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

The future of emerging renewable energy-based businesses depends on providing valued services in this new dynamic environment. This can be developed based on a clear insight into energy consumers' various requirements, preferences and priorities. That is, genuinely endeavour to find out what consumers want, not what the businesses think they want. Adjusting consumption patterns and employing behavioural change to optimise the outcome requires consumers' engagement. Consumer expectations can vary based on the current situation and experiences. Generally, three main expectations would be enhanced reliability, reduced energy cost, and addressing some environmental concerns (Debouza et al., 2022). Microgrid and VPP share various aspects but differ mainly due to the grid connection form. As such, microgrids can probably better handle reliability concerns. As an example, residents of Kalbarri, a coastal town in Western Australia, used to experience power outages several times, mainly during hot months, since the city is connected to the grid via a 140km long rural feeder line from Geraldton (WesternPower, n.d., Kalbarri microgrid). Reliability improvement was the main expectation of the residents that was addressed by installing the Kalbarri microgrid with a capacity of 5MW. This grid-connected microgrid can immediately respond to any fault in the upstream system to minimise disruptions. The consumers are notified by text messages when a disconnection occurs to possibly get involved by decreasing their demand. When there are negligible concerns with reliability, VPP would be preferred to coordinate the integration of green DERs and provide access to a broader energy market (Bhuiyan et al., 2021).

The consumer expectations and engagement pathways in relation to VPPs and microgrids can be most accurately captured by conducting surveys in relevant areas. It would be critical to identify the incentives that would motivate consumers to enhance their engagement in MG and VPP implementations. Furthermore, surveys of consumers would also provide highly useful insight on the consumer expectations of VPPs and Microgrids and the best ways of educating consumers on what each network solution can deliver to them.

Some Key Areas for Future Research:

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

- What incentives can be offered to increase customer engagement?

- 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 both overlap on customers?

The business model could be defined in terms of the firm’s value proposition and market segments, the structure of the value chain required for realizing the value proposition, the way 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, financial),
- network (key partners like energy utility, energy producers, commercials, industries, municipalities, gas suppliers and infrastructure owners),
- customers (it is a type of end-user (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 VPP's and microgrids can be categorised based on their architectures in order to provide different services as follows:

- Managing Prosumers' DERs: In this VPP and Microgrid architecture, a prosumer's assets are optimally managed by the cooperation of multiple agents considering demand response program (AGL, 2020).
- Provide Ancillary Services: This VPP and Microgrid structure delivers a tool for distribution system operator (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 DR revenue streams based on the same loads previously viewed as a problem, 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 are 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: Optimized market bids enabled by creation of a merit order based on the marginal costs and forecast availability of each asset (ARENA, 2021a).
- Technical Virtual Power Plant (TVPP): The technical VPP is utilised mainly in the same geographical area at the transmission and distribution level. To provide different technical benefits, for example management of local network restrictions, supply-demand balances, management of 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): DERs are considered as commercial entities in this structure and participate in the market considering the price and quantity of energy they can provide, thus optimise and maximise the return. The production and consumption of energy is forecasted based on the weather condition and demand profiles (AGL, 2020).

Some Key Areas for Future Research:

- What is a recommended framework for a business model to ensure the economically viable option of deploying VPP's at a commercial scale?

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

- 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 of microgrids

How does implementation of Energy Efficiency improve or change the microgrid business case and solution characteristics?

Where energy efficiency (EE) has been pursued amongst microgrid consumers it is reasonable to expect that the emergent (and un-constrained) load and generation profiles (over time) of consumers/nodes will be different to otherwise: and, of course, that the total load is reduced because energy productivity has been raised. The business case for a microgrid will be parameterized 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 CRC Energy Productivity OA, energy efficiency especially in industrial and commercial settings requires monitoring, control, analytics and other innovations to be rolled out (which can be thought of as Industry4.0 if desired). It is therefore reasonable to expect that microgrids covering parties proactive in EE will be more technically capable around 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 (therefore, lower risks associated with energy supply shortfalls or high energy import prices). Under most circumstances this will strengthen micro-grid business cases because capital requirements and operational cost spikes may be diminished. However, some business cases may be dependent 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.

Some Key Areas for Future Research:

- How the capital requirements and future operation of a microgrid are affected by the degree to which advanced monitoring, control and analytics (i.e. Industry4.0 technologies) are adopted by commercial and industrial participants?

What is the interaction between planning and operational frameworks for microgrids and embedded microgrids?

IEEE (2019), (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 DERs, 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 to have near instantaneous of balance of power supplied and load demand and to have 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.

Some Key Areas for Future Research:

- What are critical aspects of planning of a microgrid?

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

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

As per the response to 2.3.1.2, non-network solutions must be considered when network capital investments are being proposed (AER, 2013), and microgrids are amongst these. How such consideration can be given is the key question here, that is, what are the methods and tools available to network owners/operators and their service providers which can be used to establish apples-to-apples comparisons. A holistic and complete structure is needed or the systematic evaluation of benefits (and disbenefits) from microgrids. LV/MV network solutions proponents, regulators and other stakeholders need to be able to make repeatable and reliable assessments relative to this, and to build expertise in doing so across a series of projects so that efficiencies and accuracy/correctness can emerge. The structure implied within (MonashUniversity, 2019) would offer an excellent starting point which is already suitably tuned to the Australian context. Methodological repeatability/familiarity and estimation accuracy in cost and benefit assessments will be a major enabler of investor and regulatory acceptance of microgrid proposals.

An ability to integrate network and microgrid technical evaluation (including power systems simulation) is a necessity for DBs and other technical parties. This evaluation must be able to quantitatively estimate the reliability impact for consumers (residential, commercial and industrial). Naturally the tools for this must be able to explore the extreme conditions and events which are the sources of many reliability challenges.

Questions of network operations and microgrids intersect when microgrids are integrated and not isolated with distribution systems. Relevant literature includes Islam et al. (2021), Madani et al. (2017) and Flores-Espino et al. (2020). Operational questions span from the active control of load, embedded generation, voltage and network switching for maintaining supply and power quality, to 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.

Some Key Areas for Future Research:

- 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?

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

- 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 for the operations of VPP's and Microgrids?

Scheduling the operation of VVPs and Microgrids is essential to minimising the operation costs to ensure the feasibility of VPPs and Microgrids subject to meet the design requirements (e.g., stability, reliability, power quality and security). Therefore, optimal scheduling and energy management systems (EMS) play a significant role for this purpose. To optimise the scheduling for the operation of VVPs and Microgrids, a well-defined objective function is needed subject to a set of constraints considering the environmental impacts and social acceptance (ARENA, 2021c). Therefore, this can be considered as a multi-objective problem from one aspect, which required computational methods and algorithms to optimise their operation scheduling. The selection of the proper computational method and algorithm can be based on trade-off between the simplicity, accuracy, and computational burden. Several computational methods and algorithms to formulate optimal operation scheduling of VPPS and Microgrids have been used in the literature. These methods and algorithms could be categorised based on the way of handling the optimisation problem into classical and artificial intelligence (AI) methods. The classical methods require explicit models and formulations to provide the optimal scheduling of the operation. Although the classical methods and algorithms are most used in the practical projects such as in Advanced VPP Grid Integration Project (ARENA, 2021a), they have several simplifications, which are arising from lack of critical visibility of the data and assumptions leading to grossly incorrect results. In addition, these methods are required long computational burden, which may negatively affect the digitalisation of the VPPs and Microgrids.

Therefore, 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 system. AI methods and algorithms are showing promising results in the academic research, which can be an added value to the improve the results of scheduling the operation of VVPs and Microgrids as well as response faster to the operators and market signals and communicate with the control devices accordingly (Makhadmeh et al., 2019). The AI methods and algorithms can be classified as optimisation-based methods (e.g., heuristic, and meta-heuristic methods) and learning-based methods (e.g., machine-learning, and deep-learning methods).

Here, the heuristic techniques aim to achieve a specific result for a problem that is tested by considerable experiments making a trade-off between the solution 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-heuristics approaches are high-level procedures designed to solve various types of optimization problems without special knowledge requirements 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 are implemented including Point Estimate Method (PEM) to optimize the scheduling of a VPP operation connected to a wind-photovoltaic storage system, Particle Swarm Optimization (PSO) to optimise the operational scheduling of a VPP as a single-objective optimization considering costs and GHG emission, Binary Particle Swarm Optimization (BPSO) for scheduling microgrids where integrated VPP focusing on energy saving, and 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 an acceptable margin error within a short computation cost and speed compared with the classical methods.

Moreover, machine-learning, and deep-learning methods and algorithms are promising in various science branches as significant expertise is not vital to use these approaches compared with the classical methods. Due to facing big data challenges in modern power systems, besides the complexity, velocity, and computational burden of conventional optimization methods, learning-based methods and algorithms have been broadly utilized in scheduling problems. Three main categories of machine-learning methods and algorithms, including supervised learning, unsupervised learning, and Reinforcement Learning (RL). In addition, deep-learning methods and algorithms have recently been prevalent in optimizing 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 as well as they do not require explicit models, but their accuracy depends on the volume of the provided data.

Some Key Areas for Future Research:

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

- 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?

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

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

The proliferation of renewable energy-based Distributed Energy Resources (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 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. It is to be noted that the main features commonly observed in the existing system evolution are interoperability, systems integration, and the significantly increasing level of data connectivity (Razon et al., 2020).

A DERMS can fulfil the aggregation of a large number of DER, 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 DER along with the coordination of their operation and optimise their output. Aggregation of 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 DERs to present them as more manageable aggregated virtual resources for the appropriate location
- Simplifying data complexity of DERs 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 DERs to present them cohesively to the upstream calling entity. It is to be noted that individual DERs are of different types and scales and may speak other languages.

The techno-economic value DERMS-based interconnection of PV generators to distribution feeder is analysed in Peppanen (2020) The effectiveness of using DERMS to avoid system upgrades due to thermal overloads is evaluated 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 (HorizonPower, 2021). Horizon Power has implemented the project with PXiSE Energy Solutions and reported promising outcomes.

Some Key Areas for Future Research:

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

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

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

Integrating Microgrids, VPP and Community Batteries

How do you combine the value of microgrids, VPP's 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 spread in a geographically vast area in order to ensure technical and commercial requirements concerning the stakeholder's needs (Venegas-Zarama et al., 2022).

Despite contrasting objectives, microgrids and VPPs may still overlap (Yavuz et al., 2019). An embedded microgrid is mainly characterised by a confined network boundary, getting connected to the grid via a single point of connection, and the possibility of disconnecting from the grid to operate autonomously. Microgrids are formed to mainly create self-sufficiency and improve the reliability of the targeted area by incorporating various types of DERs and promoting demand response potentials. Also, MGs can participate in the retail market through possible interaction with upstream, but the main goal is providing self-adequacy. In contrast, VPPs can stretch over much wider geography 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.

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

Some Key Areas for Future Research:

- 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?

- How the VPP coordinator can 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?

Economic value of renewable capacity firming when supply and demand can be optimized by aggregation of 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, a concrete economic value in such system has many variables such as the different types of DERs interconnected, the location and to what degree is it receiving renewable power, the interconnection of the microgrid; is it embedded or islanded, the sizing of the community battery and the MG battery, and more. Therefore, the economic value and potential of profitability can only be estimated based on current projects and their findings.

The first Australian Community Battery (CB) trial by Synergy (WesternPower, n.d., Our community battery storage trials) took place in Meadow Springs, WA. A total of 44 residents has virtually stored excess solar power during the day and consumed it later on, having access to a community PowerBank battery. The results from the trial displayed an average of 7.3kWh of energy stored a day and 5.2kWh consumed back, for each participant. Selling the remaining 2.1kWh to the grid, each of whom has saved an average of $228, with more than $11,000 saved on power bills across the entire trial, making it cheaper to use than home batteries. The trial not only proven that community battery saves money, but also supports the grid, making it a viable option for future applications.

According to a research conducted by ARENA, microgrid (MG) initiatives that utilize solar power and batteries have installation costs of less than $4 million per megawatt of capacity. While the initial investment required is high, the saving potential is largely feasible. The levelized cost of energy (LCOE) for microgrids, according to the International Renewable Energy Agency, IRENA, falls within the range of 10-15 cents per kWh (SolarBay, 2020). Which, based on a research done by IRENA, is 50% less than the cost of electricity produced by diesel generators, about 40 cents per kWh (SolarBay, 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 CB and MG projects have proven to substantially cut costs of electricity and power consumption compared to the existing power grid. Yet, in order to grasp a more accurate economical value, the interconnection of the two systems must be further studied.

Some Key Areas for Future Research:

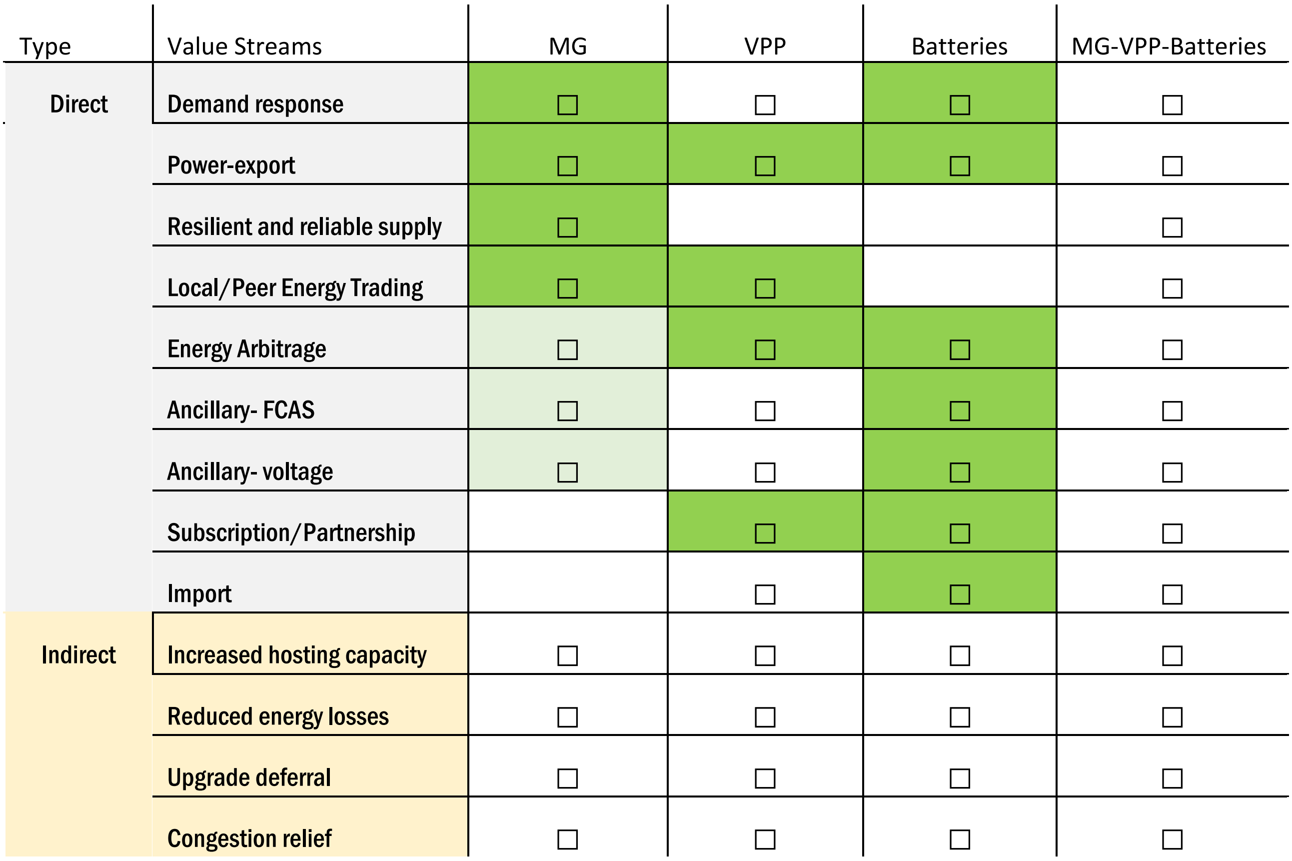
- Could the economic value of battery storage within a microgrid be increased by decentralizing in the way of CBs? This needs to be investigated by taking into account the change in technical performance as well.

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

- 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?

What are the economic value streams?

Table 8: Summary of economic value stream offered by MG, VPP and Batteries individually and integrated



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

- **MG:** Microgrids offer the key 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; MonashUniversity, 2019; Wright et al, 2022).
- **VPP:** 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:** 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).
- **MG-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. It is expected that an integrated system will 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.

Some Key Areas for Future Research:

- Do value streams exist that can be used for these technologies individually as well as combined?

- There is limited or no evidence from theoretical and actual projects on to what extent and how these different value streams impact/contribute to the overall microgrid, VPP and Community battery revenue/profit for the owner/operator and its customers, and whether any individual or combined system is the most viable energy solution (business model), particularly as compared to other related energy business models e.g., standalone solar PV and battery systems.

- What is each value stream's significance (impact) on the economic viability of individual systems (VPP, MG and Batteries) 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.

- 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?

There is a need for policy and regulatory reform in Australia to exploit the full potential of microgrids, VPPs and Community Batteries systems individually and integrated. Key constraints associated with each system and their specific value streams are summarised as follows:

Microgrid Constraints (MonashUniversity, 2019, Wright et al., 2022)

- Microgrid System Policy Constraints: Essential Service and Service Performance: There is a need for clear and transparent policies for the authorisation and governance of microgrids, particularly addressing the provision of essential service and protections and service performance to provide choice, affordability, and supply reliability to microgrid participants. Moreover, policies defining the status and authorisation of microgrid owner or operator, the appropriate form of legal and contractual relationships between the parties, and microgrid customers' rights are needed. Network Transformation and Access: Also, there is a need for network transformation to provide the right to connect MG resources to the existing network and 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: Microgrid needs a dedicated (owner and) operator who needs an exemption or licence to engage in distribution and retail activities. Licensing is a compulsory requirement for the microgrids utilising existing supply networks with many residential customers (10 customers on a single site). In addition, some of the 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, the power export (selling) in the national electricity market (NEM) can be through a virtual power plant (VPP)/small-generation aggregator (SGA) or requires registration with NEM to become a wholesale market participant.
- Other Constraints: Microgrids in Australia is in the pre-feasibility and early trial stages. Therefore, there is limited or no evidence from real projects on to what extent and how these different value streams impact/contribute to the overall microgrid revenue/profit for owner/operator and its customers, and whether microgrids are the most viable energy solution, particularly as compared to other related energy business models, e.g., standalone solar PV and battery systems. In addition, there are also technical challenges mainly; there is a lack of tested enabling technologies.

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

Community Batteries Regulatory and Policy Constraints (ANU, 2020b; Shaw et al., 2020; McKell, 2021) Network Charges: There is a need to establish a mechanism to determine the network cost for community batteries. Notably, the price 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 and proving supply during contingencies and maintenance, providing congestion relief and capacity reserve, itedious task and has not been attempted yet. Operation in Disaggregated Market: Several trial projects are underway in Western Australia (WA), 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. Therefore, there is a need to relax the regulation for community battery trial projects to determine and introduce the necessary regulatory framework changes. There is a lack of clarity on managing the life cycle impact of batteries. Moreover, policy needs to address the possible risk of increasing inequality between community batteries and other electricity users.

Integrated MG, VPP and Batteries: Embedded microgrid customers could participate in VPP 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. The customers' 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, without any conflict or violation of the contractual obligations.

Some Key Areas for Future Research:

- 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?

- 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?

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

- Microgrid: Since the microgrid has a predefined geographical boundary and common 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 VPP 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 (distribution feeder or substation) can subscribe to 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, power import and export.

Some Key Areas for Future Research:

- 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?

- 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 network and community scale batteries in one economic model?

Various types of business models are available at 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 are gaining the attraction of the industry in the recent past. The customer owned model is solely relying on the private sector investment while MaaS/EaaS, P2P and PAYG models are relying on the direct interaction between the private sector and the utility. These models require supportive government policy and regulatory reinforcement for the rapid expansion (Xu et al., 2021).

While the customer owned microgrids had gained popularity in the past decade, there are new upcoming business models, that are gaining much attention in the industry, such as MaaS/EaaS that 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. 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).

With the P2P business model, prosumers can share the benefit of the 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. Sustainable Energy Development Authority in Malaysia is piloting a P2P electricity trading project, launched in November 2019 and many pilot projects of P2Ps are currently being implemented in many continents of the world. P2P platform operators can also enable peers to provide grid ancillary services by transforming the local micro grids into Virtual Power Plants (VPP) (IRENA, 2020; IRENA, 2019a; IRENA, 2019b; Tushar et al.,2021).

Success of the deployment of the P2P business model is solely dependent on the factors like, reliability of the trading platform, the availability of 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. An extensive research and studies on the performances of the virtual layers are required Integrating and combining business models like P2P and EaaS/MaaS. The use of blockchain has rapidly emerged into the P2P energy trading and the use of the same has not been fully industrialized due to lack of exploration of the pros and cons in the P2P context (Wu et al., 2022).

Some Key Areas for Future Research:

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

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

- 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 to be considered for a combined microgrid-community battery system?

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

MGs comprise a collection of loads, along with small energy generation units, combined together as a single entity which is controllable and responsible to meet the thermal and electric demands of its local population (Mashhour & Moghaddas-Tafreshi, 2009). Akin to an MG, VPP is a collection of DGs along with BESS and loads which can be controlled. Also, VPP and MG both are able to integrate demand response programs (Ramos & Canha, 2019). However, VPP is a wider concept as compared to MG. The main differences between MG and VPP are:

- Design: MG focuses more on self-management through the use of DGs and controllable loads. On the other hand, VPP is aggregated on the basis of participation, which strives to implement collective control of DGs, controllable loads, and BESS devices. The major shift in focus is inherent as the VPP is not geographically bounded like the MG. This helps VPP to participate in energy markets.
- Interface: MG utilizes a coupling switch for connecting to the grid. VPP is a virtual collection and uses an open protocol to get connected to the grid. VPP is virtually existing and therefore does not require specific hardware for its connection to the grid. VPP, being a collection of sources, can participate in operations of power systems.
- Area: MG's physical presence depends on DGs, transmission lines, load, etc., which are its parts. This indicates that the physical spread of an MG is dependent on the geographical placement of its components (Wang & Blaabjerg, 2019). However, in the case of VPP, which is cloud-based, the spread depends on the utilization of communication networks and technology, making it have a large presence geographically.
- Functions: The MG is supposed to enhance the power quality, reliability, security, etc., of the system. VPP acts in a different way and 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 MGs are usually used as substitutes for integrating DERs in the power system. Still there exist 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 is a continuous participant in its operation. On the other hand, MG can operate in grid-connected mode, as well as islanded mode, and can thus be out of the grid at times. Another difference appears on the basis of the capacity. MG has a lower capacity as it is bounded by physical boundaries, whereas VPP commands a higher capacity.

Microgrids and VPPs typically require some form of on-site generation, with solar able to fill this role. This is due to it often being 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 or more commonly coupled to some form of energy storage (typically a battery) to optimize the use of on-site energy and maximize benefits. Together, a well-designed solar and storage solution can provide a high degree of flexibility to maximize savings, revenue generation, and emissions reduction.

Some Key Areas for Future Research:

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

- 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?

2.4 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 at a faster pace 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 framework and business models.

Demonstrate through trial (either emerging or support new development) in each of the settings:

Table 9: Key findings and implications of demonstrated microgrids and community battery implementations

Key Findings	**Implications**
Roseworthy Campus (WA) Hybrid Energy Storage System, developed by Synergy, Lend Lease and Development WA – Completed, 2021.	

– 1.2MW solar farm and a Tesla lithium-ion battery/UET vanadium flow battery with a digital MG controller choosing when to best charge/discharge the batteries.
– The goal was 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 TOU tariff; to test direct load control devices on A/C.
– 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 to test the feasibility of a new servicing model; delivered economic and non-economic benefits to participants, Synergy as the electricity retailer and Lend Lease as the property developer; and 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 are as follows:
	  – Promote and install Advanced Metering Infrastructure (AMI).
	  – Have regular and transparent collaboration with stakeholders and counterparties.
	  – Utilise larger sample sizes and asset capacity.
	  – Make customer engagement and information transparency key.
	  – Explore 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.	
– This initiative sought to cut energy bills for residents and help the community achieve their 100% RET. – The MG trial considered pathways to improve a 'single wire earth return' (SWER) network common in rural end-of-grid locations. Involving 32 metered households. 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).	– 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

– 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 CO2 heat pumps typically timed to come on during solar generation.
– Key learnings were as follows:
  – 80% of total cost savings are derived from solar generation, with the remainder from BESS.
  – Heavy consumers enjoyed most of the savings, esp. those who could use daytime generation for heating water, water pumps, and A/C.
  – Users with a combination of solar panels, 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).
	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 have 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 gives light to the main project for the district, the 100% Feasibility Study. This aims 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 heavily related to the concept of islandability for a micro grid, 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 per person. Majority of systems pay themselves off within 3-5 years, and as a result residents have found this a good incentive to act with haste and install the systems sooner rather than later. (Totally RE, n.d.,Community-scale energy generation & storage)[90]

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

– 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.
– Key project objectives were to:
  – 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
	– 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 DERs.
	– 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

– 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
– The following outcomes were achieved:
  – The BESS entered commercial operation on 14 December 2018 providing both network and market services.
  – 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
	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.	
– The aim of the project was to optimise energy use and reduce energy costs in the retail sector by investigating, trialling and accelerating learnings related to microgrids – 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. – Overall, customers benefit financially because usage tariffs are lower and the tariff structure benefits day-time consumers of energy like small businesses. – 6 customers experienced 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 are consuming 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 to August, simply because its microgrid tariff rates are on average slightly lower 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 – Due Completion late 2022	
– 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	– Virtual storage and power sharing across households appears to offer reduced electricity costs to end users while optimising storage and relieving pressure on

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.
– Objectives of the project are:
  – To provide insights into customer behaviour, appetite for a front-of-the-meter battery solutions, 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.
– During the first 12 months of the Meadow Springs trial:
  – Daily storage subscription fee of ca. $1.20.
  – $11k saved in electricity usage by households
  – 44 h'holds each saved $228, daily av storage of 7.38 kW, 5.23kW consumed, surplus sold to grid.
  – 95% of h'holds saved money on their electricity bills.
  – Alleviated network pressure during peak demand.
	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- Due Completion Date not provided

A prospective trial of minigrids on a small scale, Mooroolbark aims 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 give ideas as to 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 will hopefully give good insight into the possibility of more micro grids 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))	
– Highlight current limitations and future opportunities/issues of DERs. Limitations include legal and regulatory uncertainty, interconnection of DERs to the grid, utility regulation and opposition to DERs. Future issues cover competing smart grid paradigms and evolving market structures and business models. – Focusing on institutional role in supporting community microgrids, authors emphasise need for regulatory reform, driven by increasing need to balance renewables on the grid. Despite different regional drivers, institutions similar around the world - MG tariffs and performance-based regulations on utilities are being implemented in US; EU 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, emphasizing P2P markets and concepts such as 'citizen utilities'; In Asia, MG are state-driven, evolving regulatory framework to enable local energy systems and MGs. – 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 (BMs) for DER deployment. First, the analysis highlights that BMs are deeply embedded in myriad policy and regulatory frameworks. Second, current DER BMs are driven more by regulatory and policy factors than by technological factors. Third, the small set of mature BMs 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 BMs will likely look very different. Finally, DER BMs compete within archetypes for market share in providing a limited set of electricity services.	– In this formative phase for DERs, the formal institutional barriers to community MGs 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 MGs need a viable business model and rely on other investors. This has resulted in less 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 MG development, esp. 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 DERs matures and stabilises.

Some Key Areas for Future Research: -

In Greenfield/new development, how to overcome regulatory issues?

- What business model works, and what is a cookie cutter approach?

- In existing sites, same issues but then you have to convince people to join microgrid, especially if can opt out of who their supplier is, is people are on legacy PV feed in tariffs, etc.

Demonstration of Community Batteries

Trialling community batteries in various contexts

Before considering the trialling of 'community batteries' in various contexts it is important to understand what is meant by the term 'community battery'. This term commonly used 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 reason for the early use of the term 'community' appears to be around the intention for the general public to benefit from the new technology though opportunities to own and access such options. For the purpose of this project, we seek to identify language that stands to have longevity and have created a framework below. When considering nomenclature for energy storage across an electricity grid there are three main factors, namely: 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 are typically operated by the private sector. This option is typically used to provide services to the grid rather than customers and often focus on assisting with reliability, power quality improvement and stability.
2. Distribution System Storage (Neighbourhood Scale): This typically involves medium scale energy storage systems (mid-tier storage) connected to the Distribution Grid which are typically operated by the private sector and made available to residents and businesses. Such systems can be located at strategic locations across the distribution system, which can be aggregated virtually, or within physical micro-grids. A micro-grid is a sub grid has been created within the main grid, typically with a single point of connection. Such micro-grids 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 a combination grid and micro-grid storage options which warrants 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 are typically owned by the private residents or businesses. Such options can be located in individual buildings connected to the grid or inside micro-grids.
4. Mobile Storage (Vehicle Scale): This typically involves small scale mobile energy storage systems (such as Electric Vehicles) that can be connected to a residential or commercial building and can move between such locations at will, and are typically owned by private residents or fleet operators. The mobile nature of this option creates a unique situation where the storage option as the ability to move to different locations in the grid raising questions around their management.

When considering the method of access and potential to share benefits, options include utility-controlled storage options, privately owned options and co-operative based sharing options. 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 should such storage devices be located, at what size, and how should they be managed and governed for mutual benefit. The following stages of research will consider precedent for informing answers to such questions, such as 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
- Test the efficacy of batteries in helping small-mid size electricity retailers deal with the impacts of high demand by accessing stored energy
- Be a pioneer project for the wider community and industry

Dubbed 'The Beehive Project' as its similarities to the self-sufficient ecosystem made for an easy parallel, this project will connect many homes with and without solar to a community battery and by extension 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 several key differences:

1. 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, the term shared community battery will instead mean that stored energy will be distributed amongst residences that are not necessarily close to the battery.
2. 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. This will be a virtual storage system, meaning that no physical battery connected to the house. The customer will be allocated an amount of virtual storage space based on the option selected that is best for their power consumption needs. The virtual bank will store excess generated electricity between 7 am and 3 pm, 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).

The aspect of this project that separates it from other projects is the virtual component of the power bank. This will mean that homeowners have very little upfront installation work to do, aside from signing the contract to agree on the price of excess sold to Synergy and the 'size' if the virtual bank. The only necessity 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.

Some Key Areas for Future Research:

- 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 6kwh or 8kwh (Western Power, n.d., Power Banks). A PowerBank is a community battery but with the added benefit of individual solar storage. This means that eligible households that have access to virtual storage in the battery to store their excess solar power. Worth to mention that from Western Power point of view, VPP is another type of community battery (Synergy, n.d., Project Symphony).
- There are several PowerBank trial projects 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 community batteries shortly (Western Power, n.d., Where are the community batteries located). Customers can automatically store up to 6kwh or 8kwh 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. Also, a list of Victorian community battery projects is available in (VIC.gov.au, 2022, Emerging energy technologies).

Benefits for customers:

- To receive more benefits from the clean energy customers 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.
- To improve the power quality to customers in the area and deliver services to the wider energy market.

- Makes access to battery storage more equitable and accessible for all customers, particularly those who aren't currently able to install their own household battery
- Participating customers will continue to receive an electricity bill from their retailer and still receive savings from having a solar power system. In addition, they will also receive credits from Ausgrid every quarter, for the excess electricity they virtually store with the community battery.
- Credited quarterly as per the excess generation (Ausgrid,n.d., What is a community battery?)
- There are no upfront installation costs, maintenance or replacement costs for customers.
- No maintenance costs or risk of battery failure, and
- Arbitraging - Lower energy costs (Energymatters, 2021).

Benefits for utilities:

- Supports the uptake of renewable energy in the electricity system.
- 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?).
- Avoiding or limiting reverse power flow in the network
- Big batteries will help stabilise networks and pave the way for increased renewable energy generation (Energymagazine, 2021).
- As a cost-effective option, they can defer the need for additional generation infrastructure or network upgrades to meet peak demand (Energymagazine, 2021; WA.gov.au, n.d., Energy Policy WA).
- To provide inertia support services to the electricity grid (Hornsdalepower, n.d., Interested in seeing SA's Big Battery up close?).
- Provision of network services (FCAS) such as frequency control (Parkinson, 2022).
- Flexibility and reliability improvement of energy systems (Cleanenergy, 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 (2 more sites were confirmed after initial announcement) 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:

1. 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.
2. Ability for the batteries to take a load off the network at peak times: An example given is on hot days when air conditioning is heavily relied on, United Energy will need to manage these batteries in such a manner that precludes the necessity for drawing from the main grid (United Energy, 2021).
3. 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 sort of automation of this management will produce the best results, however due to the often-random human nature this may be difficult. It will not be a priority for the system rollout, however.
4. 'Multidimensional web': This project will also comprise a similar theme to the Mooroolbark Mini Grid Project, in that the houses need the capability to produce solar power and send excess to the grid during low power consumption times to the batteries for storage and use during high consumption times (ARENA, 2021g).

Home Batteries

Home batteries have proven to be rather 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. At the neighbourhood level, the overall structure of aggregate load and generation is better regulated than at the individual level. Individual properties have a peaks and valleys in demand, but at the suburb level, that demand is smoothed out.

Neighborhood scale batteries

Key factors of value proposition for neighborhood-scale batteries:

1. Energy Security and Power Reliability: The current centralised electricity infrastructure has repeatedly demonstrated its vulnerability and unreliability. This susceptibility isn't just due to inclement weather. But can also be caused by the high fluctuations at the consumer's load (EngageVictoria, 2022).
2. Independence: Independence from the centralised electricity grid means independence from not just unpredictability, but also potential rate rises and other levies.
3. Reducing Grid Congestion: Neighbourhood-scale batteries will store energy locally, to reduce (if any) the bidirectional power flow occurring from RES exported power and Grid imported power (ABS, 2016).
4. 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 7.3kWh of energy stored a day and 5.2kWh consumed back, for each participant. Selling the remaining 2.1kWh to the grid, each of whom has saved an average of $228, with more than $11,000 saved on power bills across the entire trial, making it cheaper to use than home batteries (Western Power, 2022).
5. 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 (EngageVictoria, 2022).
6. 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 such an ESS.
7. Providing ancillary services to the grid: Additionally, batteries are demonstrating a particular aptitude for the Frequency Control Ancillary Services (FCAS) industries in the NEM. The market operator AEMO is appreciative of batteries' capacity to quickly absorb or inject power to adjust power system frequency variations from the required 50Hz (Australian Energy Market Operator) (SACOSS, 2020).
8. Offsetting network augmentation costs: Other "services" that batteries can offer include avoiding or reducing the scale of proposed network augmentation (SACOSS, 2020).

Some Key Areas for Future Research:

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

Trial business models in the lab and in real world settings.

Some Key Areas for Future Research:

- What can be done in a lab to inform and enable projects and make the process quicker.

- What if the lab was customers and companies, social laboratory? (Customer panels, focus groups, etc…) what would they buy, what would make money…

- What is right to trial in a lab compared to being implemented in real world conditions? Lab is an isolated environment used to test that the concept works technically. Perhaps some lab stuff is needed that the CRC can support… what 'should' be done in the lab?

- How can this be informed to best support practical projects? Testing tech and simulating use patterns to adjust assumptions in business case development?

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

Demonstration of "Micro-gridding" with community batteries

Mallacoota Mini Grid/Community Battery Project

This project aims to provide improved 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 islandability and energy reliability. This is with stressed 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 (EngageVictoria, 2022).

This project will also test several key innovations. One of these is the 'smart' energy system, in which a device, known as a "Mondo Ubi", which will "enable certain loads to be switched on or off in ways that improve the performance of the local electricity grid, with no noticeable impact to the property owners." Essentially, this will monitor the energy usage of the house, and 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 be used within 1 am and 5 am, power consumption can be adjusted accordingly. This is only one of the applications, as the device can 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). This device is also being trialled in the Yackandandah area with great success. Another innovation is the heat pump hot water systems in residential buildings. This will give a much more energy efficient alternative to electrical resistance water heaters. This will hopefully bypass the need for the burning of natural gas within a water heating system, and instead will rely on what should be electricity generated from a renewable source (EngageVictoria, 2022).

Western Power Microgrid Plans

A fifteen-million-dollar project, infrastructure for the largest microgrid plans in Australia currently are being put in place in Kalbarri, Western Australia. This is a high traffic tourism area, getting up to 100,000 visitors to the 1,500-population town each year (WesternPower, 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" (WesternPower, 2022). This project will focus on islandability and power reliability on a large scale, as the town is currently connected by a 140km rural feeder line that is "exposed to the elements". The microgrid is expected to eliminate 80 percent of the outages experienced by the town and hopes to reduce outage length significantly (WesternPower, 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 by the quote: "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." (WesternPower, 2020). This is valuable insight into the motivations behind the grid and shows similar intentions to the Mallacoota and Mooroolbark mini grid projects, such as improving power reliability and decreasing emissions through renewable energy usage in a 'multidimensional web' system.

Onslow Microgrid

This is an extremely exciting look into what the future for renewables could be. This microgrid powered the town of Pilbara for 80 minutes, completely on renewables, supported by battery technology. A smart system was used to manage the grid and ensure that it was being used to its maximum efficiency. Bill Johnston (previously mentioned) says that this "signifies a landmark step towards building a cleaner, brighter, renewable energy future for our state", and that this project "demonstrates how distributed energy resources can be safely integrated at a grid level (WA.gov.au, 2021, Onslow successfully powered by 100% renewable energy in trial). This is a huge step for renewable energy generation, and now Onslow can work towards the transition into a completely renewable grid system. This will however lead to important problems related to 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 such problematic weather events seen more and more in the wake of climate change.

Some Key Areas for Future Research:

1. Peak consumption management using smart networks
2. House to house interaction and trust within microgrids and community battery usage
3. Battery design and efficiency
4. Microgrid islandability and power reliability

An initial thorough review of all related projects that have occurred in Australia and internationally that are currently in train. Categorise these by the regulatory framework they work within. E.g., Fully deregulated NEM market VS monopoly retailer (WA: Western Power / Synergy) VS vertical integration (e.g., Horizon Power and parts of Ergon network)

Research Question in 2.4.1.1 covers many of the exemplar microgrid projects in Australia. Further information can also be found here.

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 (WesternPower, 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, whether they have solar or not, to share and trade rooftop solar between themselves, and access benefits from the community battery when it is needed (EnergyLocals, n.d., Residential Enova).
- Western power provides a comprehensive overview of their microgrid projects in this area (Western Power, n.d., A bright future for WA), highlighting the 5MW Kalbarri microgrid as an example.
- The Australian government provides a useful resource summarising ARENAs projects on the microgrid and VPP space here. ARENA has funded many VPP demonstrations which can be used to gain insight into the aspect that

need to be considered. The resource can be found here (The Transparency Portal, n.d., Virtual Power Plants: Empowering electricity consumers).

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. Suggested approach:

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

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

Some Key Areas for Future Research:

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

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

Operation of Microgrids

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

As the requirements and functions to operate DERs in microgrid and VPP configurations differ, it is treated as two separate approaches. For DERs to operate in microgrid configuration, several aspects have to be considered e.g., type of control scheme used in the microgrid, capabilities of the DER (what type of control signals/functions are available?), single PCC for the microgrid, grid synchronisation strategy, communication infrastructure available (will impact on the control scheme that can be implemented), stability analysis and compliance with IEEE 1547-2018 (Baghaee et al., 2018; Guan et al., 2015; Wang & Blaabjerg, 2019) When DERs 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; be able to control and manage the energy flow to and from the DER.

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 synchronization 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 VPP's?

There is a need for the development of intelligent EV charging infrastructure and managed charging strategies to accommodate customers' needs and to help EVs become interactive grid assets rather than unmanageable grid loads (Zhou et al., 2021; RACE2030-CRC, 2021). For EVs to become interactive grid assets, there is a requirement for unified charging- and connection standards. 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).

Some Key Areas for Future Research:

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

- What can a micro-grid 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?

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

3 Research Opportunities and Impact

3.1 Governance and Regulatory Challenges

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:
    1. Customer demand management
    2. Demand management for the distribution network service provider (DNSP)
    3. Network support
    4. Arbitrage from the spot market; and
    5. 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 to 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: There is no guarantee within the current regulatory context that community-scale batteries will not increase inequality between energy users. As community-scale batteries can be optimised to produce different values, there is a distinct risk that community-scale batteries 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. There are currently challenges regarding regulated network tariffs, which decrease the benefits to local energy trading in communities. This is also important to include when understanding 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. Of these, the regulatory restrictions may be explored using the new AER Regulatory Sandboxing (AER, 2022) initiative which provides temporary regulatory exemptions for trials of new services and technology. The other aspect that seems most urgent is how community batteries interwork with microgrids and VPPS, especially at 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 more generally that the future of community batteries will be influenced by the regulatory environment, which can determine who owns, operates and participates. In this regard, the wider work undertaken as part of the ESB 2025 post electricity market design has the potential to impact on the future of community batteries, with a number of system security mechanisms potentially opening up new income streams, and should be followed carefully.

Recent rule changes to 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 AER's 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 outcomes will be of importance for this project.

There are some works also done by ARENA and ANU's Battery Storage and Grid Integration Program related to implementing community-scale batteries. The main focus was on engaging stockholders to identify the benefits and challenges associated with the community batteries. They also 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. It's a 200 million investment where 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 suited to a desktop assessment of the current regulatory frameworks, as well as comparative research, enhanced by qualitative research.

A mixture of in-depth qualitative interviews and focus groups can obtain details and uncover the motivations, attitudes, and values of various stakeholders. Such a qualitative study could explore the prevalence of various views across different groups. However, the survey should not only run in a short period as many of the concerns about proposed community-scale batteries were linked to the governance of the energy system, which could require reassessing the overall utility of the system for innovative energy solutions. This topic links to other RACE2030 projects, such as N4 (DSO and Beyond), which can cross-fertilise projects considering the governance for edge of grid solutions. As concerns over ownership and distrust in the energy sector were significant public concerns, any future methodology should examine empirically institutional arrangements that could enhance trust and participation. This may likely 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.

Impacts

The outcome of this theme could support an adaptable and flexible model for the regulation and governance of community batteries. 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. Further, it can help to meet the local and state governments' carbon reduction objectives and enable them to set their strategies around storage investments.

Questions of trust and governance are crucially important for the success of any innovative solutions not readily matching the traditional model of electricity supply, such as neighbourhood batteries. Questions of regulatory frameworks, ownership models and tariff arrangements will therefore underpin the implementation of any of the solutions considered for a community battery model. It is these arrangements which will determine the potential for community batteries to play an important role in the energy transition, while keeping the grid reliable and affordable.

3.2 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, considering 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 the extent of and how 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/to other stakeholders. Therefore, different types of battery operations and behaviour may result in different societal outcomes.

- Feasibility of Community Batteries:

Community battery feasibility depends on several factors, such as battery technology cost and value stacks associated with different services, 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- and future technology costs and operating- and regulatory scenarios. A comparative evaluation of community battery feasibility against other related business/service models, e.g., standalone, 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, including:

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 monetized. Ideally, the network (usage) cost should consider the local use of service (LUoS), i.e., 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 more details 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 as well 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 few 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 focuses on evaluating the economics of the technology in competitive markets, as well as 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) find 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 the majority of battery revenues in Australia currently originates from participation in the ancillary markets. At the same time, the authors note and 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.” (Csereklyei et al., 2021).

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 an area requiring further research.” (from page 30 of the section 2.2 of this report).

In addition, there is a lack of clarity on managing the long-term life cycle impact of batteries. There are currently no long-term studies evaluating the impact of batteries’ charge capacity and lifetime on community battery longevity. Moreover, policy needs to address the possible risk of increasing inequality between community batteries and other electricity users. Moreover, battery technology is currently used in most community battery trial projects. 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. There is also a proposed trial in Section c of this document.

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 then were 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 per cent 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-western Western Australia (WA). In Victoria (VIC), United Energy (Purtill, 2022) has been building up a network of 40 small 30 kW community batteries on power poles to support 3,000 homes, following a trial in 2020. In May, Yarra Energy Foundation (YEF) will install a 250kWh 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, owned by ElectraNet, is being trialled for market participation. This is a 30 MW/8 MWh battery. The project's initial findings suggest the battery is economically viable where the battery is used as a backup power source and for frequency stabilisation. For the third-party operator, AGL, it generates a significant income, e.g., $1M 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), where 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 mode

Table 10: 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), is required to motivate local energy exchange, and 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, 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.*"

The precedents of this research opportunity were given under the section 2.2.

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. Moreover, it will be challenging to formulate the trial project scope without getting answers to some of the initial questions. Therefore, a comprehensive yet focused techno-economic feasibility project is proposed 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 project 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 different storage system dynamic models and simulations for different combinations of community battery services (value streams) and their associated life-cycle analysis.

- Trial Project:

Based on the feasibility studies, design a real (long term – 10 years) community battery trial embedding technical evaluations and proof of concepts of parallel alternative storage technologies that allow for real-time monitoring of the battery technology storage capacity, temperature, and related chemical aging. [Ties in with WP5 Topic 5]

- Potential Stakeholders and Partners:
    - DNSPs – AGL, Horizon Power, Ausnet, and others
    - Electricity Retailers –
    - Govt Entities – DELWP/AEMO
    - Organisation/Communities – KIC
    - Service Providers – PAP and others

Impacts

This project will help all stakeholders, such as the network operators, planners, potential owners, and end-users, to better:

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

3.3 Ownership and Access

Objectives

Drawing on a review of the literature on community battery ownership and access, a number of important issues are 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 DERs matures and stabilises because of 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 DERs 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 9 summarises the key learnings from a 2020 study by ANU investigating the implementation of community-scale batteries (Shaw et al. 2020) owned either by third parties or by DNSPs.

Table 11: Insights from Shaw et al. (2020)

Community-scale1 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), 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., strong concern over battery life-cycle, promoting local energy use, reducing carbon emissions, questions of fairness and how this technology would fit in the broader energy transition to renewables

Community-scale1 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), 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., strong concern over battery life-cycle, promoting local energy use, reducing carbon emissions, questions of fairness and how this technology would fit in the broader energy transition to renewables. There is also lack of understanding connected to different perceptions towards 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 punish 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 2.4.1.1.

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, OEM manufacturers, DNSPs, asset owners, property developers, government, regulators and market operators, local tradespeople, 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, more so 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 1, 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 (tCO2-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 vs 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 vs ownership models
- Stakeholder satisfaction

3.4 Electric Vehicles

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 config 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.
- Potential to use these "batteries on wheels" to assist with issues such as low minimum demand during the day when there is high levels of solar PV export.
- Harnessing fuel price cycle behaviours 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. Could be used as a solar soak on localised sections of grid with high solar PV penetration and at grid scale.

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. EVs may also be used to provide power in emergencies such as climate extremes or grid failures.

Maximising Available Capacity

After understanding how to predict or measure the amount of storage available from EVs, the next thing is to maximise it. This means understanding how to maximise:

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 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, to develop effective financial and non-financial incentives, and 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 three 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

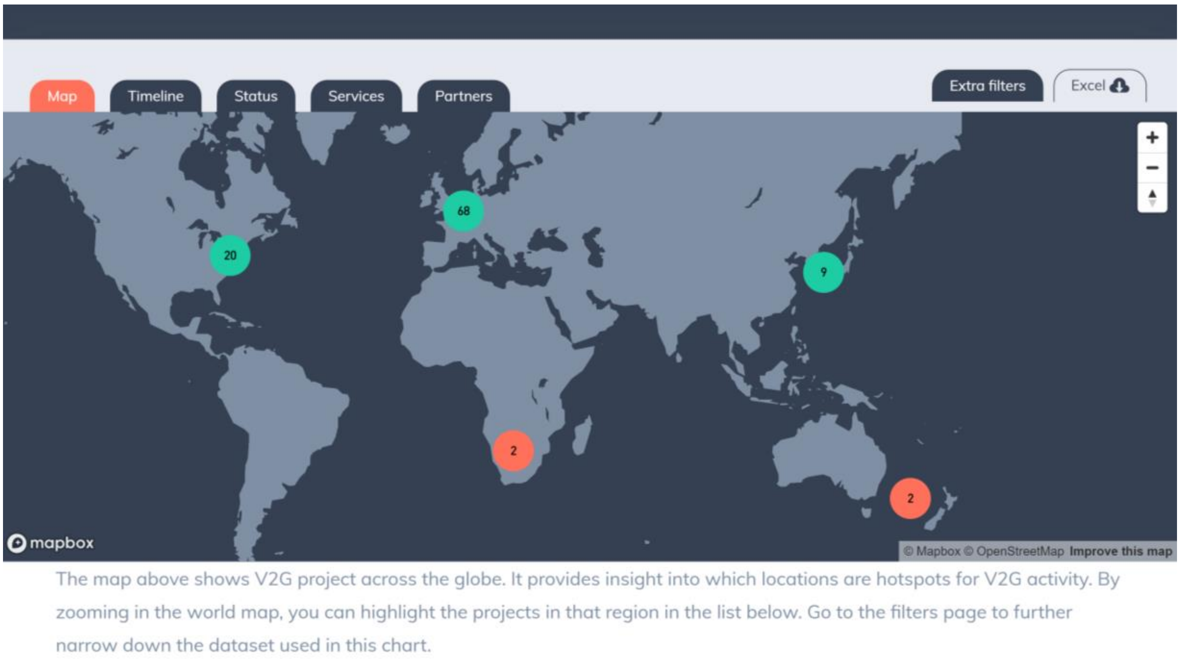
e) Survey and interview data to gain insights into effective incentives for desirable behaviour and V2G technology uptake.

When EVs as a power source will be redundant

This can be answered by understanding at what point storage technology becomes 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, 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. Access the link to see live results.



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 2: 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) 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) Realising Electric Vehicle to Grid Services. ACT based trial involving Employing 51 V2G enabled Nissan LEAF EVs in ACT Government and ActewAGL 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 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 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, 2020. 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 from Spain also having high PV potential and leading 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 valuable will be the most valuable, though G2V charging behaviour may also yield modelling insights.

2. Construct a theoretical, spatiotemporal model of charging behaviour using available published data as input initially. This will most likely be based on machine learning methods, also drawing 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 is available from charging systems and vehicle telemetry that can report on battery charge levels, location and, potentially, intended destinations (though 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. First, charging behaviour with no incentives of any kind. And second, 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, to identify blocking issues (e.g., high cost of V2G chargers), to develop effective financial and non-financial incentives, and finding 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 it, 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 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, Jemena Networks.

It is also possible to seek representation directly from EV owners through an association such as the EV Council of Australia.

Impacts

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 quality of electricity service by increasing the storage available during lulls in wind solar generation, measurable by reductions is 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 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 are paid for the storage they contribute to the grid. This benefit could be financial, or in the form of credits, or through some compelling non-financial incentive such as parking.

3.5 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 with 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 which 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 Topic 4 of this report. Also note that there is relevant material in the N3 Opportunity Assessment, Stream 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 1GWh per annum in Australia (ESN, 2022) and set to accelerate with some 27GWh of new battery storage anticipated by 2032 (AEMO, 2022), as well as new green hydrogen generation, and extensions to natural hydro storage (Snowy 2.0). However, this view needs to be evaluated and tested as technology and markets evolve to ensure we understand what the likely best fit storage options for the grid for short-term storage and long-term storage 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 if there are new approaches which 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).

1. 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 is to understand when, or 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).

2. 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 suitability for more environments such as urban and mining. A key question is at what level of storage capacity does pumped hydro become cost competitive with battery technologies? Snowy 2.0 must be considered.
3. 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 6 months, and potentially represented using a Technology Radar approach (Thought works, 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 12: 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. Vandium is expensive	Pilot, desktop research
HYBRID TECHNOLOGIES	Combines characteristics of different technologies to achieve lower cost and utility at scale	Pilot, desktop research
ULTRABATTERY	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 Ultrabattery 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 3: Hydrogen demonstration Projects in Australia. Click link in reference for live map (CSIRO, 2022)

Methodology

Key is trend analysis against the comparison criteria. As noted in Section b) 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, including monitoring uptake of different storage technologies as they move through the different technology readiness stages, drawing on extensive work in the RACE CRC's Research Theme E2: Innovative Foresighting and Planning. 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; and a

Techno-economic Performance Comparison

- Techno-economic performance comparison of different storage technologies for their applications in Microgrid, Community batteries and VPP.
  - Dynamic modelling and simulation
  - Cost and life cycle 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, as well stakeholder interviews to provide qualitative evaluations.

Stakeholders and partners: Technology vendors – good working relationships with the R and 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 during 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 use as inputs data from currently deployed systems. Direct metrics for GCH emission would be the estimated total CO2 emissions for both embodied and operating condition. Harder to measure, but still important, would be estimated of the amount of CO2 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 since the need for fuel is removed. This can be modelled right now, with inputs tuned using data from existing deployments. How much this results in a reduced price to the end customer is more complex as this depends also on transmission and distribution charged which are 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.

3.6 Advanced Technologies and Urban Renewable Energy Zones

Objectives

he most important modern technologies that needs to be trialled in future implementations of MG and VPP 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 Fast Track 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 PMUs and DSTATCOM, 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 MGs 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, there are many factors that can affect the quality of the prediction outcome, such as 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 MGs and VPPs in such solutions, the local communities and social characteristics of customers also need to be considered.

3. Digital Twins' (DTs') Models

Digitization or digital platform refers to integrating real-time data from the physical sensors with the virtual replicas of these devices. These virtual devices replicating the physical devices are called Digital Twins. (Enders & Hoßbach, 2019) Digital Twin models enables analysis of large amount of data using AI and machine learning. Digital Twins of a micro grid 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 MGs and VPPs to manage their portfolio. Thanks to the advancement of machine learning methods, it has become a crucial approach in modern engineering to improve performance. Extending the concept of Digital Twin 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

Last decade has witnessed a phenomenal growth on Industry 4.0 technologies such as Internet of Things, Cybersecurity, AI and machine learning, and hence these resulted in widespread adoption of Industry 4.0 solutions. Industry 4.0 environment consists of a large number of sensor devices capturing continuous and real-time data of various processes. Industry 4.0 supports solutions that can automate and optimize the industrial processes thereby saving cost and improved productivity. Ex. Energy 4.0 (Dexma, 2021). The electric energy sector has recently been one of the most targeted sectors by cyber-attackers. With the everyday rise in sustainable energy demand, the security of distributed controllers, services, power plants, and generators plays a vital role to prevent malfunctioning and unavailability of the 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). As a follow up, VPP and MGs security is another important aspect that needs to be integrated in future implementations.

5. Coordination, Optimization and Certification

Power flows, local density, economic, administrative, and social factors are such criteria that have to be considered for MG and VPP optimisation processes (Naughton et al., 2020). For decentralized decision support systems, it is necessary to consider data on assets size, local sustainability goals, communication efficiency or latency, and local typology (Zhang et al., 2022). Adopting a Game-theoretic-based economic model to operate VPPs so that it can dynamically adjust pricing while conducting energy trading of DERs in Microgrids under varying contexts and competitive scenarios is a possible tool that can be trialled. 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 DERs 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 optimize the inter-connection between DERs. 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 utilization of EcoStruxure Microgrid Advisor (Schneider Electric, n.d., EcoStruxure Microgrid Advisor), which allows prosumers to dynamically adjust on-site energy supplies and loads in order 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 promising microgrids to operate in 2022 (Wood, 2022) due to their innovative approach which provides a new layer of control besides the flexibility. Emera Technologies pioneered the concept utilising "BlockEnergy", a term they refer to which turns each home into a nanogrid with its own solar, batteries, and control technologies. This project was announced in 2020, and has since taken cautious steps in building the microgrid, with homes being added incrementally. The houses are then linked by a cable network system, a DC bus, that runs through the 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 a resilience oasis during energy outages as well as a decarbonization 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 since they are the most common units of organizing houses in urban and suburban areas. In 2020, researchers from Monash university, Australia, have devised a novel energy exchange system to manage DERs and assist consumers in lowering their power expenditures. Transactive Energy Market, TEM, is claimed to be a revolutionary method to energy management and trading as well as a way of facilitating the DERs 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 demonstrating how the same can be used to defer traditional network augmentations as well as to provide other services. Objectives of these projects are Supporting and enhancing voltage profile of the distribution feeders, extending the life of the networks assets like distribution transformers, understanding the customer appetite on the community batteries and to develop business models that can access many value streams that can deliver through community batteries (ARENA, 2021b; ARENA, 2020; Western Power, n.d., Where are the community batteries located; Synergy, 2021).

Active grid management system integrated at 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 optimization from the grid, rectifying power quality issues at the micro grid 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 Delihi under Horizon 2020 IElectrix program (IEC, 2022; IElectrix, n.d., Indian demonstration (Shakti); CIRED, 2020)

Stantec Inc. 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 (DERs). Their services extend to grid modernization, 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, supplying large consumers with 247 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 (Elxsys, 2022)Powerledger, n.d., Blockchain for decentralised and distributed energy markets). ElXsys 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, n.d., About us)

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

Methodology

The research methodology in this theme will include desktop studies, computer simulations, and laboratory trials before including in demonstration projects. Distributed Control System is the backbone of the research on to which other technologies are incorporated. The sizing and siting of a VPP or MG, voltage management strategy, power flow control strategy, energy management strategy incorporating energy forecasting, grid synchronization and isolation, fault ride-through and protection, retrofitting a MG in an urban area, and strategy of energy sharing with other microgrids are some relevant topics from power and energy point of view. Adopting IoT into energy systems, applying cyber security into MG and VPP controllers, 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 MG, dynamic pricing strategies in VPP and MG, data security through blockchain, data validation for renewable energy certification are some of the topics researched in computer programming and data science. Furthermore, data sensing, communication, integration and control are key points of research in control and communication field.

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 batteries, 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. The 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 MG 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 needs the guidance and support of network companies, consumer groups, regulators, renewable energy solution providers, energy investors and renewable energy certifiers. The estimated project duration is 3-5 years.

Impacts

he operation of DERs in microgrids and VPPs configurations has several impacts, which can be summarised in three main categories, such as: (i) adoption new technology and skills developments impacts; (ii) technical impacts; and (iii) economic and social impacts. The impact framework can be structured based on CSIRO and UK research excellence frameworks. Here, each category can have several sub-categories. Accordingly, the impact of each sub-category can be structured by one or multiple key performance indicator (KPI), where each KPI has at least one measuring metric. In this context, microgrids and VPP configurations can allow the adoption of new technologies by increasing the integration of renewable energy, increasing the uptake of tools for microgrid and VPPs planning, design and operation and improving the utilisation of a mix of the existed assets and the new technologies. The adoption of new technologies can be measured by the number of the new services, products, retailers that integrating renewable energy and providing green services, number of end-users utilising the microgrid and VPPs planning, design and operation tools, and number of DNSPs, and microgrid and VPPs operators using the mix model representation. In addition, skill development of the end-users is one of the impacts, where operation of DER's in microgrids and VPP configurations can provide new knowledge and local skills. Moreover, the operation of DERs in microgrids and VPPs 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 DERs. In addition, the reliability of the provided service can be increased, which can be measured by the number of power outages and its duration. Also, the CO2 emissions can be reduced by operating DERs in microgrids and VPPs, which can be measured by the GHG equivalent. Finally, the operation of DERs in microgrids and VPPs configurations can create new jobs, which can be measured by the full time equivalent.

The proposed Digital Twin-based solutions for managing DERs in microgrids can lead to a sustainable grid in relation to the 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 DERs 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 Green House Gases (GHG) emission reduction plans.

Similarly, the integration of blockchain for managing DERs 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 customers' data manipulation and ignorance concerning the details of their energy usage profile, particularly in P2P trading of DERs. 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-theoretic-based economic model of the project will contribute to drawing an optimal operation plan for DERs in microgrids through VPPs than allowing each consumer to operate DERs independently. Such an approach will help 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 DERs and the associated incentive schemes within the economic models will also facilitate healthy competition among the stakeholders, expediting the advancement of decarbonisation plans for DERs in microgrids.

3.7 Stakeholder Engagements

Objectives

Those terms contained under the "Local DER Network Solution" banner as "VPP", "microgrid", "community battery" are fundamentally technocratic terms and concepts that are challenging for consumers to understand, engage with, and understand what benefits they offer. 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 on the basis of 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 in more quickly and effectively identify suitable customers, provide a deeper understanding of them, and develop and communicate more compelling product offerings. This has become an accepted strategy to guide engagement by environmental and social justice organisations (e.g., as used by the Common Cause2 network). A simplified way to survey customers' values is to use a 'values modes' method. This categorises the main set of customer values into three modes: Settlers, Prospectors and Pioneers, as shown in the following figure.

Figure 4: 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.

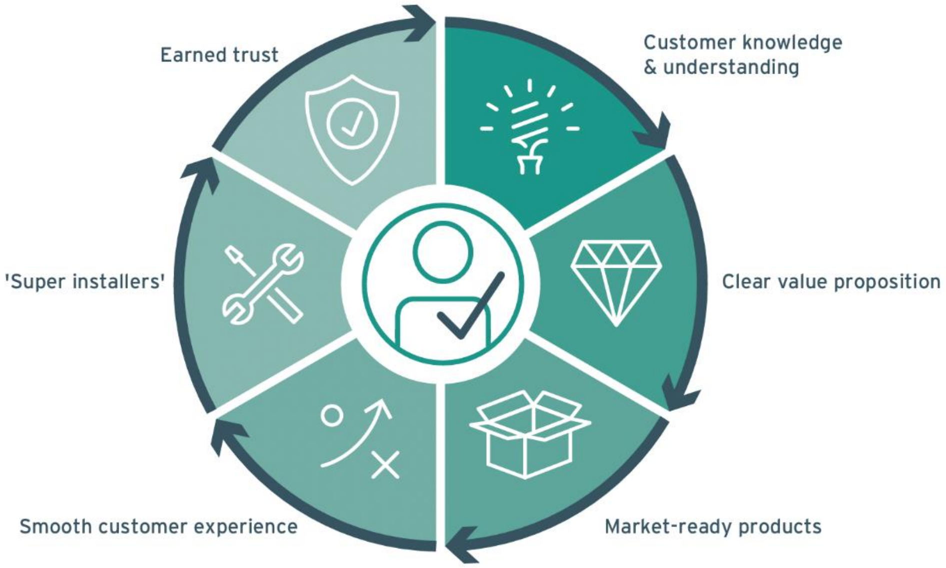


Figure 5: Figure TK: Six key ingredients to a happy DER customer (Dwyer et al 2020)

However, Local DER Solutions are still largely in the very early stages of deployment in Australia and worldwide. This means that there is still a lack of information on consumer experience 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 has been 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, community batteries. Community

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

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 in order to create a chain of trust. This can be enhanced through ensuring fairness and building social equity throughout the various phases, while helping enshrine community benefit and consumer protections. Important aspects that need to be covered in CRC projects that can be demonstrated include ensuring that suitable foundation research has been employed 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/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 attempt to answer their 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 2.4.1.1.

Methodology

Established frameworks (such as Schwartz (2012) Theory of Basic Values and Maslow's Hierarchy of Needs Maslow (1958)) 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 Schwartz says guides a person's actions based on the ordering of their preference is shown below:

- 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.

Figure 6: Figure TK: 10 Basic Universal Values (Schwartz 2012)

While these values don't explicitly refer to 'trust', it has been well document as critical for positive customer outcomes by both Alexander et al (2020) and Russell-Bennett et al (2021). The latter is an excellent reference source for 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 in which exploring ownership and operation models is desired. 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 (RAMP) program.

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

Table 13: Summary of relevant research methodologies

Methodology	How it would be used	Stakeholder/ partners
Values based approach *(Maslow, 1958; Schwartz, 2012)*	Encourage the use of a values-based approach to support those organisations that don't 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 (for example those that use machine learning and AI tailored for specific energy use cases) by those that have the capability and seek the sharing of findings where possible (noting 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 Standford University Design School in mid-20th century)	Encourage the use of journey maps, customer personas, and other tools in the planning of trials 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 (originals in participatory research in education and healthcare in 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 its use to help better understand human behaviour and how they can be shaped by individual traits, interpersonal skills, societal characteristics, community dynamics, policies, and systems.	Universities Government

Impacts

Pilots and demonstration projects involving DER rarely recruit the number of customers that are targeted initially, often facing issues that mean it 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 customer. In addition, the approaches described above can also help better prepare industry and businesses for commercial product offerings and government design more effective policy and regulation.

In terms of specifically measuring the impact for these outcomes for:

- GHG Emissions: Through being able to increase customer acquisition rates, GHG emissions will be able to be reduced by a corresponding amount. It will help future projects better achieve their targeted GHG emission savings through ensuring they meet their targeted number of participants during the trial phase, as well as through any future expansion as part of commercial deployments.
- Grid Reliability: Local DER solutions can enhance the network but often this can reply on being able to recruit a relatively high proportion customers within a relatively concentrated and small 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.
- Bills Reduction: While customers do care about saving money on their bills, what will motivate them to adopt Network DER Solutions will be a variety of reasons

Industry Reference Group Comments:

- Microgrids can add a level of reliability, but it is too early in the development to be able to quantify.
- Demonstrate capacity for responding to Commercial impacts on Network constraints/ HV network providing DER
- Quantification of the solution 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.
- Offer network resilience and improved network reliability
- Early engagement/ Appoint ENSP as part of customer agreements

3.8 Microgrids in Distribution Networks

Objectives

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

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

1. Allow parties to answer the question "*How can distribution network planning and operations be enhanced by micro-grids*" for stylized and example MGs;
2. Quantify the reliability, emissions and financial performance of specific MGs 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 MGs. However, in cases where this standard provides detail and stronger guidance, this is mainly on aspects associated with MGs' electrical systems (e.g., Section 8). The standard only provides high-level guidance on:

1. Methods for evaluating the MG value proposition for distribution network businesses.
2. MG configuration and capacity planning relative to proponents' aims for the MG.
3. The relationship between the aims for a MG, the operating practices of the MG, and the methods for MG design to match these.

4. Data models, data acquisition, and analysis methods (at design time) for assessing how a proposed MG 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 gap between IEEE 2030.9, quantitative studies in the academic literature, and Australian electricity sector practice. This "bridging" we discuss here as having 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 with the financial, emissions and energy delivery performance of MGs with sufficiently good quantitative accuracy that networks, investors/lenders, regulators and in-the-MG participants accept the findings and will act with confidence.

For distribution networks to which an MG interfaces, concerns are with the sufficiency of support that an MG might give to the network, or alternatively, the upper bounds of stresses the MG might place on the network, and the true costs to be borne. For example, if a MG is put in place to strengthen a weak end-of-line section of network, DBs need confidence that the MG 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 MG is an initiative of the DB (and therefore the DB has a significant hand to play in its facilitation) or is the product of other proponents' endeavours. *The articulated reflections of CRC partners regarding the MG value proposition strongly demonstrate the need for this kind of analysis capability.*

Most MGs will be significantly resource (capacity) constrained, e.g., by the depth of energy storage in the MG and the amount of generation capacity that is installed. Furthermore, the overall rationale for MG investment can vary markedly[3]. This variation in motivation leads to comparable variation in operational imperatives. A MG built as an alternative to network augmentation may be operated very differently to a MG that is central to a precinct's "net zero" goal. The combination of resource constraints and explicit aims means that MG operational objectives and practices (i.e., how and why operational decisions are made, and by whom) are primary not secondary concerns. MG 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 in 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 analysts and the recipients for analyses) and which results in methods which are readily understood and maximally adoptable by competent practitioners
6. Validation of the methods against data from real MGs, and where the information about validation is peer reviewed and readily accessible (i.e., for stakeholders to verify)

The third component of **cost-effective utilisation**, goes beyond this to tackle the reality that acquiring data and executing analyses can be (very) difficult and (very) expensive, as can the acquisition of the relevant human capability, and the "tooling up" needed for mastery of software packages including 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 harmonize/interoperate with existing industry-standard tools, and be

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understandable and useable by many rather than just an elite few. The methods should be flexible (i.e., modular/adaptable) and tailorable to specific types/scales of MG and to specific use-cases/aims for MGs -- so that the data and analysis needed is reflective of what is actually 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. In simple terms, microgrids can localise a lot of generation and storage which should get us more bang for our buck on the distribution network. The more you can co-locate generation and storage the better the effect will be. There will also be a lot of relief for the transmission networks. And a loosely coupled bunch of microgrids is naturally going to have more resilience than anything else as the island are self-sufficient.

Precedents

The IEEE 2030.9-2019 Standards and Working Group is clearly relevant. Work by the CRC on analysis methods development and utilisation must be able to be positioned in the context of this. This means that the CRC's methods should not be in conflict with the Standard, that the CRC's methods will reference the Standard, and that the CRC's methods 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 MGs, and Victorian Market Assessment for Microgrid Electricity Market Operators offers an excellent published starting point which is already suitably tuned to the Australian context (Monash University, 2019). Smaller-scale energy system performance estimation and design optimisation are the raison d'etre of significant branches of electrical engineering and data sciences (the latter including but not limited to workers in statistical machine learning, combinatorial optimisation, and optimal control). There is much to harvest from the relevant literature. From earlier work in this OA, some representative work is found in Fiorini and Aiello (2019), Islam et al. (2021), Madani et al. (2017) and Islam & Amin (2021)

Australian microgrid projects (at various stages of development) obviously are highly relevant, especially where the MG 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 MG examples will be critical because well-developed MG projects are precious sources of information and methods validation.

Methodology

The MG analysis methods development must be targeting what might be called "investment grade" or "regulator grade" methods. That is, we are pursuing methods that:

- Can be depended-upon and utilised-for electricity sector decision making, as standard methods requiring 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 MG 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 might prevail solely in documentation. The intended users of the methods will chiefly be in-house engineers and analysts in network businesses, 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 methods 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 MGs present fire risk, and/or where MGs 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.

Impacts

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

- A number of Australian MGs 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 CRC projects for MGs have been used;
- ... and where financial, reliability and emissions performance estimates have been met or (positively) surpassed.

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

Along this impact pathway we should see:

- Trials of MGs where partial or prototype versions of CRC's analysis/quantification methods for MGs have been used.
- Validation of the estimations of cost, emissions and reliability by way of post-hoc observations in (specific) MGs.
- Use of the CRC's methods within the business cases for MGs 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 CRC projects deliver (in partnership, most likely) will need to become the foundation for the sector's "tools of choice" in MG and MG-to-network assessment.

3.9 Custom Design of Local Networks

Industry Reference Group Comments:

- Social license.
- 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 is required to identify areas of localised constraints in networks before any discussion with stakeholders about community batteries. If parts of a network are not constrain, there isn't 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, is a key issue will be securing sites for small community batteries. These will help to stabilize 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 are as follows:

Cost and Benefit Analysis

As identified by IRG member's ECA and Climate KIC that 'Social license' and IRG member KIC that 'Consider how you develop contracts and project set up to scale', it is important for microgrids and community batteries to have a cost-friendly, benefitable for all stakeholders, legal, and effective business model. In this model, through proposing new price policies and demand side management, a considerable scale of microgrids or community batteries is identified. The maintenance of microgrids and community batteries should be also included in this cost and benefit model.

Identification of Demonstration Sites

IRG member AusNet identified that 'a need is required 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 isn't a need to put in any assets to shore up reliability'. For some communities and customers, they are eager to have reliable electricity supply during extreme weathers or to require an affordable bill. Microgrids and community batteries are suitable for them. These areas or customers should be identified. If a pilot project is built in these areas, that will benefit all the stakeholders.

Innovative Approach and Technology

It is critical for microgrids and community batteries to provide reliable, stable and affordable electricity. To achieve this goal, the innovative approach and technology are needed to be provided. For example, swift frequency and voltage regulations should be considered for microgrids and community batteries. Distributed approaches should be proposed to deal with high voltage caused by the fluctuation of solar PV generation in microgrids and to prevent the outage under extreme weathers.

Pilot projects incorporating these factors are described in Section c) on methodology, but key is a rich process of engagement with all stakeholders to understand what they believe to be 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 build 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 (EngageVictoria, 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 (WesternPower, 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 approach the logistics involved with regular charge/discharge (Synergy, 2022)
STANDALONE 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

Before building a pilot project for microgrids and community batteries, the following aspects should be investigated:

- To conduct cost and benefit analysis.
- To discuss all the stakeholders and determine the location of a pilot project.

- To optimise the scales of microgrids and community batteries, including the type and number of microgrids and community batteries, at the best benefit for all the stakeholders.
- To provide 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 outage.

There are three suggestions:

(1) A pilot project of microgrids can be conducted at Griffith University by utilising the University microgrid facilities.
(2) A pilot project of community batteries can be conducted in the site of Planet Art Power with the discussion with Planet Art Power for possibility because they have already installed solar PV panels in a few buildings and may be willing to have a trial.
(3) A pilot project of microgrids or community batteries can be conducted in regional and remote communities through Regional and Remote Communities Reliability Fund – Microgrids (Australian Government, 2022).

Impacts

This theme may include several outcomes:

- GHG reduction: Microgrids can connect a large number of renewable energy resources that use cheap renewable energy rather than traditional expensive diesel and thermal energy. Besides, if no community batteries are involved, each microgrid must be equipped with batteries to control the generation of renewable energy, the use of community batteries will reduce the numbers of batteries so that GHG reduction can also be achieved by reducing the loss of materials used to make batteries.

- Bills reduction: The project will optimise electricity prices and achieve bills reduction. Private microgrids are selfish, they will only consider individual interests when operating microgrids, which will lead to poor shared benefits in the whole area. Community batteries will consider global conditions and make an optimal choice to realise the shared benefits. These shared benefits will make the microgrids more reliable and cheaper so as to reduce the bills of customers. In addition, battery energy management system will sell or purchase the electric energy in the best interest, so as to further realise the bill reduction.

- Grid reliability: As community batteries would consider shared benefits, this investigation can design relevant strategies to eliminate the power imbalance among microgrids. In addition, microgrids and community batteries can work both island and grid-connected, which means that they are able to support customers' demand by themselves. If extreme weather makes the area must be separated from the Utility Grid, the microgrids and community batteries can 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

There is a significant intention towards proliferating community batteries, MGs, and VPP. Promoting the propagation of such local DER solutions can be highly efficient for overcoming the decarbonisation challenges. The focus of this section is to identify barriers to the uptake of local DER solutions, either individually or collectively. Successful implementation of such schemes depends on partially or entirely removing current obstacles. This will include overcoming both technical and institutional barriers to properly transforming local power networks.

A complete list of barriers is presented as follows.

4.1 Technical Barriers

Most items to be mentioned in this section are caused due to inaccurate placement, design, and uncoordinated control of local DERs systems. Lack of optimal scheduling of DERs can violate most reliability and power quality indices, increasing the overall implementation and operating costs, and reducing the hosting capacity of the network. Some technical barriers are highlighted in more detail as follows:

- It is highly likely to experience overvoltage due to the high integration of uncoordinated DER systems.
- Lack of or inefficient coordination among local DER systems can limit the hosting capacity of distribution networks
- Lack of detailed knowledge of a network's current structure and operating conditions is the main barrier to implementing local DER systems. This includes insufficient information about the current systems management of local network restrictions, supply-demand balances, management of energy flows, etc.
- There is a lack of clarity on managing batteries' long-term life cycle impact. There are currently no long-term studies evaluating the impact of batteries' charge capacity and lifetime on community battery longevity. Moreover, policy needs to address the possible risk of increasing inequality between community batteries and other electricity users.
- There is uncertainty in employing optimal placement methods for various types of DER systems. What parameters and variables should be taken into account to ensure a successful placement of such DERs?

MGs and VPPs in Distribution Networks:

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

There is insufficient information on the most optimum level of control and monitoring systems that should be adopted by the local DERs, such as MGs. Further, the successful operation of the local DER systems under various weather conditions or natural disasters is yet to be evaluated.

To what extent the future expansion scenarios should be considered in planning procedures? The long-term planning of local DER systems needs more evaluation and development.

There is a shortage of a proper evaluation on setting the most efficient technical objectives in the optimal operation of DER systems. It is unclear how those objectives can vary when switching the operation mode from individual to collaborative.

Interoperability and communication protocols are of the main concerns with the successful implementation of local DER systems, mainly VPP and MGs, with several hardware and software components usually coming from different manufacturers.

It is not clear how part of the existing interconnected network can be converted to and restructured as an MG or VPP. How should the current setting of different protection and control devices be readjusted or replaced with other components? Such transform algorithms 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.

Any misleading data or analysis on this topic can cause a significant underutilisation of the system's potential to take full advantage of such vehicles.

There is insufficient knowledge of the likely energy storage options that will dominate the grid in the future. This can highly impact the efficiency, operation reliability, and also revenue of such systems.

Advanced Technologies:

There is a lack of sufficient historical data for proper modelling and analysis of different players' behaviour in the near future distribution networks. Likewise, DER generation and other hardware operation modelling suffer from the very same data shortage. More advanced modelling methods are required to meet such modelling requirements.

There are serious concerns with handling potential cybersecurity attacks in developing smart grids, including the local DER systems. Insufficient measures to address this issue can cause a partially or entirely system shutdown.

Successfully handling interoperability matters would require the development of more advanced protocols through IoT procedures.

4.2 Institutional Barriers

Governance and Regulatory:

Inefficient and inconsistent regulations can be considered the most serious threats against the successful uptake of MGs, CBs and VPPs. The regulatory system should be capable of facilitating the realisation of different community expectations from MGs.

The lack of common standards on local DER solutions' implementation, performance and safety is already alarming. Further, the success of community-scale energy storage systems depends on overcoming the current regulatory challenges.

The shortage of commonly accepted access mechanisms to the installed DERs needs to be adequately 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 quite significant. This includes the cost of both the hardware and management and control software required for a desirable implementation of such mechanisms. Microgrids and VPPs are capital-intensive to develop and implement. Likewise, CBs require significant upfront investments.

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.

The study should reflect the shortage of efficient business models to ensure the financial feasibility of local DER systems. Reducing the payback period would be highly encouraging for attracting more investments. It is unclear whether a single entity or combination of entities should be involved in running potential DERs.

Stakeholder Engagements:

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. There is very insufficient information about possible interaction among stakeholders in response to different possible operation scenarios.

There is a shortage of studies on the potential combination of DER technologies to meet stakeholders' expectations. Individual DER systems can satisfy some expectations, whereas some will require a hybrid system of various local DERs.

Very little research has been undertaken so far which expressly explores community expectations comparing different types of MGs, VPPs, and CB.

It seems there is a lack of proper incentives to encourage the active engagement of various stakeholders.

5 The Strategic EV Integration Project (SEVI)

The findings of the N3 Opportunity Assessment have been directly included in the development of a new Standard Track project in the RACE for Networks theme. The project initially focused on EVs however through the process of partner and stakeholder engagement as part of the design of the project, and the N3 Opportunity Assessment, it was clear that investigations into EVs needs to take place within the wider context of the DER transition. In practice this lead to the project exploring how EVs interact with a range of storage options in a number of configurations, such as home and work charging of fleets, home and local charging in residential precincts, and interacting with behind the business meter storage options in regional areas. The project is called the 'Strategic EV Integration Project' and will begin on the 1st of February 2023 for a period of three years. The project incorporates items from the N3 Research Roadmap and associated Commonwealth Milestones, along with similar inclusions from the N4 Opportunity Assessment.

Main Research Opportunity: RO4

Other Relevant Research Opportunities: RO1, RO2, RO3, RO5, RO7, RO9

5.1 Project Summary

Rapid growth in uptake of Electric Vehicles (EVs) will create many opportunities across the energy sector, which calls for early research efforts to be well informed, carefully evaluated, and lessons learned quickly shared. This project will investigate a selection of early-stage use cases for EVs in Fleets, Precincts, and Regions, through a process of co-design and collaborative implementation with industry partners over three years. Demonstration projects will be undertaken across multiple states and will feature a diverse mix of customer types (both fleet and private vehicles), options for managed charging (and bidirectional charging when available), a range of business and operating models, and a variety of types of interaction with co-located stationary battery systems of different scales. As part of the dissemination of project outcomes a set of 'TV Ready' short videos will be developed for each demonstration project to present the findings in an accessible format that will be suitable for broadcast on TV and via other channels.

This project will explore how EVs interact with energy storage options at grid, embedded network, and building levels, involving a range of energy storage options (as per the 'N3 Research Roadmap'), and the development of specific regulatory reform proposals (as per the 'N4 Research Roadmap'), contributing to associated Commonwealth Milestones for each. Partners also strongly supported the recommendation from the Consultation Stage that rather than designing new pilot projects, such projects should be selected from Partner projects that provide the opportunity to explore key research questions, calling for the development of the 'Partner-led Embedded Research Approach'. This approach allows researchers to directly support partners while developing a set of detailed case studies exploring specific testable hypotheses based on the key research questions in a manner that minimises duplication and captures synergies.

5.2 Project Approach

The project will be implemented in two steps:

1. *Co-Design of Demonstration Projects - up to 1 year*: The co-design stage of the project will focus involving close partner collaboration to undertake the planning and establishment of the foundations of the way in which the demonstration projects will be implemented, assessed and communicated. The key outcomes from this stage will be the selection of partner demonstration projects and the development of accompanying Companion Research Plans, to include template documents and procedures to use for each project.

2. *Collaborative Implementation of Demonstration Projects - 2 years*: The third stage will focus on the collaborative implementation of partner-led demonstration projects over a further 2 year period, focused on specific use cases, namely: EVs and Fleets, EVs and Precincts, and EVs and Regions. The key outcomes from this stage will be the execution of the 'Companion Research Plans' to enhance project outcomes and explore key research priorities. The findings will be included in the 'Australian Strategic EV Integration Report', and will include transferable frameworks, recommendations and detailed case studies to support future projects.

The project will interact with partners in one of four ways, namely:

1. *Demonstration Partners*: Partner-led projects will be selected as the basis of the research activities, with partners and researchers working closely to ensure enhanced project outcomes and rigorous research findings.
2. *Steering Partners*: Steering partners will join Demonstration Partners to form the Steering Committee to actively steer the project, meeting quarterly to receive updates, review outcomes, and assist in decision making.
3. *Industry Reference Group*: The IRG will be formed of Partners and key stakeholders receiving updates, informing the research, and assisting in dissemination, with specific groups invited to join particular meetings.
4. *International Advisory Panel*: A selection of both CRC International Partners and Key International Experts will be invited to form the International Advisory Panel to provide guidance to the project.

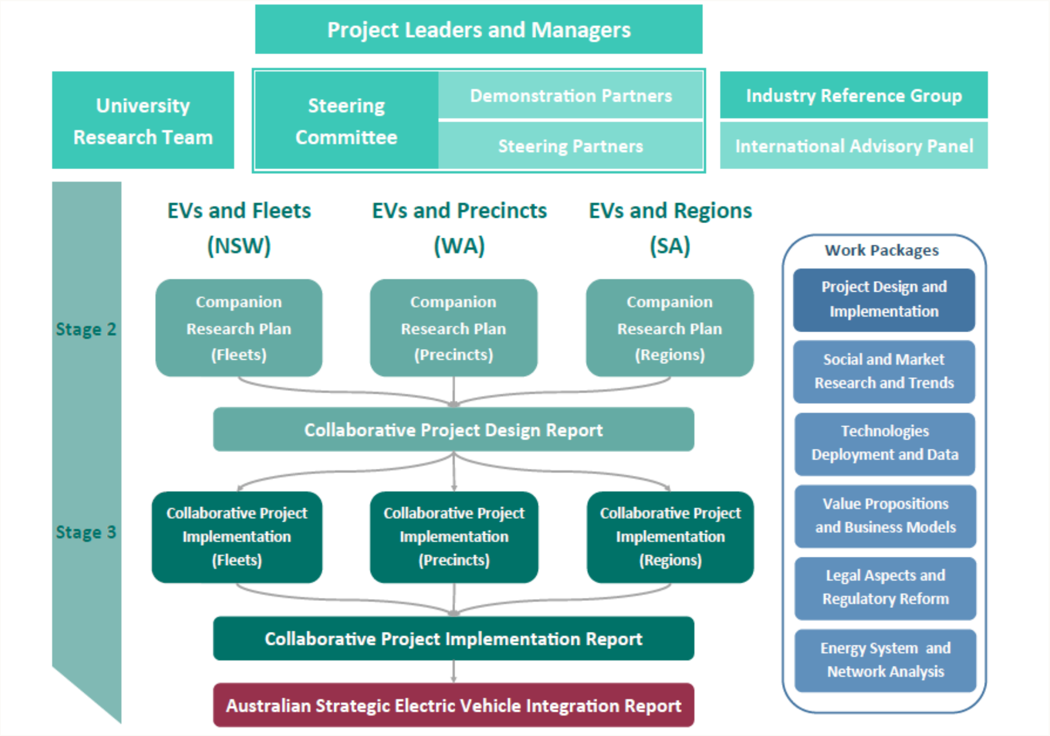

Figure 7: Project approach stages

6 Key Findings and Recommendations

6.1 Research Roadmap

The Research Roadmap recommended to the CRC under this theme is given below. The N3 Research Roadmap takes into account the short, medium and longer-term research priorities as identified in the Opportunity Assessment.

Table 14: Proposed Research Roadmap

	Time Frame		
Research Priorities	Short Term (up to 3 years)	Medium Term (up to 5 years)	Long Term (up to 8 years)
Governance and Regulatory (RO1)	Regulatory reforms required for the uptake of MGs, CBs and VPPs.		Performance, safety, and equity of access to MGs, CBs and VPPs.
Revenue Streams (RO2)		Financial feasibility of MGs, CBs and VPPs.	
Ownership and Access (RO3)	Ownership and aggregation models to implement MGs, CBs and VPPs.	Revenue models and tariff reforms to encourage investments.	
Electric Vehicles (RO4)	Estimating the available capacity of the grid for EV charging (G2V mode).	Maximizing the available capacity of the grid for EV operating in both G2V and V2G modes.	
Storage Options (RO5)	(1) Evaluation of different battery technologies (e.g., lithium, flow, and supercapacitors) and fuel cells from power networks pov. (2) Techno-economic feasibility of other large-scale storage options, e.g., pumped-hydro, mass-gravity, heat conversion, hydrogen, and liquid air.	(1) Converter technologies and control for best utilization of storages. (2) Converter control to provide virtual inertia to compensate for the intermittency of renewable generators and other power transients.	(1) Recycling battery energy storages and super capacitors. (2) Development of gravity based energy storage options. (3) Viability of the production and storage of hydrogen.
Advanced Technologies (RO6)	Integration of energy forecasting, Blockchain and IoTs in local DER network solutions.	Machine learning techniques for condition monitoring of renewable energy generating systems.	Cyber security for the safe and resilient operations of MGs and VPPs.
Urban Renewable Energy Zones – UREZ (RO6)	Developing algorithms to transform existing distribution networks to a smart, self-healing, renewable energy zones to include PVs, EVs and smart meters.	Network compensating devices (DSTATCOM and DVR) in UREZ's to ensure stable operation under high renewable penetration.	
Stakeholder Engagements (RO7)	Surveys of stakeholders' expectations vis-à-vis MG and VPP.	Addressing the challenges of meeting stakeholders' expectations.	
Microgrids in Distribution Networks (RO8)	(1) Frequency control and associated smart load control. (2) Transition from CBs to MGs.	(1) Protection and fault mitigation in microgrids. (2) Natural disaster mitigation using microgrids.	Network of microgrids in distribution networks.
Custom Design of Local Networks (RO9)	Siting and sizing of CBs and MGs to meet community needs.	Innovative approaches for sustained operation under extreme weather conditions.	

6.2 Recommended Research Projects

Based on the N3 Research Roadmap developed, following research projects are recommended to the RACE for 2030 CRC for actioning under the N3 theme in the period until 2030. These projects are in addition to the first implementation project that was outlined in Section 5.

Urban Renewable Energy Zones (3-5 years):

Main Research Opportunity: RO6

Other Relevant Research Opportunities: RO1, RO2, RO3, RO4, RO7, RO9

The main objective of this project is to facilitate maximum penetration of renewable energy in existing grid distribution networks to avoid or delay highly expensive network augmentations. This is achieved through employing smart grid technologies such as smart metering, communication and multi-layer control to enable coordinated power flow in the distribution networks. It will fully utilize the emerging EV storage capacities, behind the meter batteries, community batteries to mitigate network problems such as line and transformer overloading, line overvoltage, phase imbalance, neutral line currents etc. The intelligently controlled UREZ will not only minimize curtailments of distributed generation it will also facilitate participating in VPPs. This project will consist of two stages. In the first stage an urban renewable energy zone is designed in detail and a laboratory hardware model is built. The laboratory tests are conducted to verify the effectiveness and to make further improvements. In the second stage, UREZ will be implemented at an urban area with highest RE penetration and strongest community interest. At this stage, in addition to the technical implementation of the UREZ model of control, it will research on the acceptance of it by various stakeholders such as prosumers, aggregators, DNSPs, regulators and investors.

The project arising from the RACE for 2030 N4 Fast-Track project "Demonstrating pathways for Urban Renewable Energy Zones" will also address the research objectives of N1, N2 and N4 themes.

Machine-Learning for Condition Monitoring and Forecasting of DERs (3-5 years)

Main Research Opportunity: RO6

Other Relevant Research Opportunities: RO4, RO5, RO8, RO9

This project will incorporate advanced technologies such as the Internet of Things (IoT), Blockchain and Machine learning techniques. The short-term research tasks include effective monitoring of local DER and sharing the associated information with VPPs ensuring integrity. Monitoring of DERs at the low voltage level and making comprehensive condition assessments based on the perceived information are challenging. For different DERs, their condition is subject to diverse chemical, mechanical, and electrical measurement and historical data sets, which is barely traceable through conventional monitoring approaches and techniques such as smart meters, DC-AC Inverters and Supervisory control and data acquisition (SCADA) systems. Therefore, in this project, IoT-enabled intelligent monitoring devices with embedded Spatio-temporal gradient-based hybrid sensors will be leveraged to monitor the health, performance and hosting capacity of DERs at the prosumer premises. Considering the large volume yet heterogeneous raw data captured by these intelligent devices, extracting representative attributes (features) consisting of useful information and insights is also necessary. Therefore, this project will apply a novel feature selection algorithm based on maximal relevance and minimal redundancy criterion from sensor-perceived data. Since such information is sensitive and, at the same time, requires to be accessible for efficient decision-making, the project will extend the concept of blockchain to ensure its integrity while sharing with respective bodies and control systems.

Moreover, as part of mid-term research tasks, the project will develop a self-supervised Machine Learning model for cooperative control of networked DERs. It will incorporate two modules. The first module will correlate the health condition of each asset in a DERs network and the Spatio-temporal feature of their operating environments to estimate the performance of DERs. The second module will contain a deep neural network to predict the renewable power generation rate of DERs depending on environmental parameters such as weather, temperature and wind pattern. Collectively both modules will determine the reachable regions of DERs based on different norm-based measures under various classes of performance and renewable power generation and will construct control protocols to optimise the network load while serving and integrating the DERs to the primary grid.

Finally, the IoT-enabled DERs monitoring framework and proposed ML models will be consistently refined through pilot testing in a real-world testbed as the long-term research tasks, which will eventually result in an end-to-end software solution for DERs management in a microgrid.

Evaluation of Storage Options and their Utilization (3-5 years):

Main Research Opportunity: RO5

Other Relevant Research Opportunities: RO1, RO2, RO3, RO4, RO7

The objectives of this project are:

- Evaluation of battery technologies for grid support.
- Techno-economic feasibility studies of large-scale storage options.
- Smart converter controller design

Lithium-ion batteries are prevalent currently, especially for EVs. However, there are other technologies that are evolving rapidly, such as, lithium sulphur batteries, solid state batteries and vanadium redox flow batteries etc. At the same time, supercapacitors can be added to batteries to enhance their speed of response. Moreover, the cost of hydrogen fuel cells is decreasing. Therefore, it is imperative that these different technologies need to be evaluated based on their cost, speed of response and maximum charge/discharge cycles (longevity).

Furthermore, the possibility of green hydrogen generation and storage options are evolving, and it is expected that they will be available by 2030. In addition, other large scale storage options like pumped hydro, compressed air etc. can be viable options. However, some of these are depended on geographical locations. Therefore, the techno-economic feasibility of these large-scale storages need to be studied.

A power converter can be operated in grid feeding, grid forming or grid supporting modes. These modes are application-specific and will depend on the network structure. Moreover, their siting is also crucial from the point of view voltage rise issues, voltage balancing and reverse power flow issues. Furthermore, the converters can be operated as virtual synchronous generators to compensate for the intermittency of renewable generators. All these issues need to be studied in detail through practical demonstration projects.

Microgrid in Distribution Networks (3-5 years):

Main Research Opportunity: RO8

Other Relevant Research Opportunities: RO1, RO2, RO3, RO4, RO7, RO9

Microgrid research and demonstration are in advanced stages. However, there are several unanswered questions that need to be addressed.

Microgrid frequency control is well understood. When a microgrid gets islanded from a distribution grid, it has to manage its local loads using some form of primary control, such as droop control. However, if the power generation in a microgrid is not able to cater to its local load, then small load shedding strategies need to be designed. Some of the loads can have higher priority than some other loads. Therefore, circuit breaker coordination will be required to trip the non-critical loads, as and when required.

While the operation and control of microgrid is well researched, microgrid protection area has been largely neglected, as the protection system evolves with distribution systems. However, standard distribution system protection cannot be used for microgrids since it must cater for reverse power flow and the fault level changes due to plug-and-play energy resources. Directional overcurrent relays can be an option, but the converter-interfaced generators generally cannot supply sustained fault current levels. Therefore, a holistic approach will be required for microgrid protection design.

The other important issue that needs attention is the natural disaster mitigation using microgrid. When several microgrids are placed in a distribution system forming a network of microgrids, smart islanding strategies will be required in case of any natural disaster that can result in a large-scale power failure. However, a microgrid can also help in restoring the power network through black start. Therefore, both microgrid networks and disaster mitigation aspects need to be studied.

6.3 Partner Preferred Research Themes and Projects

Based on the outcomes of the partner preferences survey conducted at the second IRG meeting using Qualtrics online survey platform, the following list of themes are highlighted for incorporation into future CRC projects as a priority:

- Regulatory reforms required for the uptake of MGs, CBs and VPPs.
- Financial feasibility of MGs, CBs and VPPs.
- Revenue models and tariff reforms to encourage investments.
- Recycling battery energy storages and super capacitors.
- Cyber security for the safe and resilient operations of MGs and VPPs.
- Developing algorithms to transform existing distribution networks to a smart, self-healing, renewable energy zones to include PVs, EVs and smart meters.
- Network compensating devices in UREZ's to ensure stable operation under high renewable penetration.
- Natural disaster mitigation using microgrids.
- Network of microgrids in distribution networks.

Based on partner preferences, the following two recommended projects received the strongest interest:

- Urban Renewable Energy Zones, and
- Machine-Learning for Condition Monitoring and Forecasting of DERs.

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