Battery Storage and Grid Integration Program

Comparison of battery configurations and social research findings for VPP and neighbourhood battery trials

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1. Introduction

The Australian Capital Territory (ACT) Government has engaged the Battery Storage and Grid Integration Program (BSGIP) to analyse cost-effective battery storage solutions, considering the interests of the government, Distribution Network Service Providers (DNSPs), and consumers. The impetus and context for this work from the ACT Government is due to the following factors:

- Increasing household solar contributing to minimum operational demand
- ACT Government policy of electrification to transition away from gas by 2045
- The need to avoid costly network upgrades that would impact consumers
- Projections for future peak demand.

This report summarises some of the research conducted by BSGIP to investigate the economic, technical, and social benefits of two types of batteries commonly used at the distribution level: neighbourhood batteries (NBs) and household batteries (HBs), particularly when they are orchestrated as Virtual Power Plants (VPPs). This work quantifies the potential financial returns, peak demand reduction, and local solar utilization rates of these battery options and includes some key findings from energy and social science research for the ACT government to consider.

The report provides insights into the benefits of neighbourhood batteries, household batteries (uncoordinated and coordinated as VPPs) from multiple perspectives, and the challenges associated with the implementation and operation of these battery options from existing studies in BSGIP. The purpose is to provide the information required for the ACT Government to make informed decisions.

This report is based on modelling and existing technical, economic, and social research within the Battery Storage and Grid Integration Program (BSGIP) in Australia and other institutions. This report also includes informal discussions with BSGIP staff and Evoenergy, a DNSP in the Australian Capital Territory (ACT).

It is important to note that this report does not include research conducted directly with the ACT community to understand their views and perceptions on the various energy storage options available. However, some of the studies cited in this report, do include the views of the ACT community, such as those expressed in Converge and referenced in this report.

This report is structured in the following way. Section 1 provides an introduction of the scope of work as discussed with the ACT Government and background information on the ACT context from discussions with the ACT Government and Evoenergy. We have also included relevant information from Evoenergy's regulatory proposal for 2024 – 2029 in section 1.1.

Section 2 provides an overview of NBs, VPPs and uncoordinated HBs, discussing their benefits, limitations, and current activities in Australia. Section 3 presents a quantitative analysis using computer simulations and optimisation algorithms to compare the financial, technical, and solar benefits of these battery options under different operation objectives. This section also offers insights into the simulation results, discusses the advantages and disadvantages revealed by the analysis, and provides recommendations based on these findings.

Section 4 provides a summary of key findings and themes from social science research conducted by BSGIP researchers and other researchers on VPPs and neighbourhood batteries. The key considerations from social science research include knowledge and trust in technology, motivations, expectations and values, location and siting issues and equity considerations.

Section 4.5 also includes other considerations, specifically hot water as storage. This section is brief but is included as a consideration. BSGIP are conducting more work on this for the ACT. Section 5 provides a conclusion to this report integrating the techno-economic analysis and modelling with the social science research to provide suggested ways forward for the ACT Government. The report also includes an appendix and references.

1.1 ACT distribution network context

Evoenergy is the DNSP in the ACT and their recent regulatory proposal (2023) has projected that peak demand is expected to increase substantially out to 2045 due to increasing load and reliance on the electricity network for transport, heat and hot water, that was previously serviced by gas (Evoenergy, 2023, p. 25). As a result of this increased growth in demand on the electricity network, Evoenergy (2023, pp. 25-26) have stated that "due to increased load moving to our electricity network and ongoing growth in existing areas, reinforcement, or reshaping of our existing network is unavoidable." However, there is uncertainty about how the network needs to be reshaped and a recognition that there is also a risk to consumers if augmentation of the network is delayed or deferred, particularly if the uptake of electric vehicles is high (Evoenergy, 2023, pp. 26-27).

In a meeting with Evoenergy in April 2024, it was noted that they are interested in implementing battery storage on the distribution network to address issues that are occurring such as reverse power flow and overvoltage. Evoenergy are facilitating the commissioning of utility scale (10-15MW) batteries on the network, which will mostly operate on the FCAS market. Evoenergy has an obligation to determine the most cost-effective solution to network constraints according to the Australian Energy Regulator's regulatory investment test for distribution (RIT-D). The RIT-D only applies for investments over $5 million, therefore some battery storage projects would fall under this threshold and would not be subject to the RIT-D.

In the revised regulatory proposal from Evoenergy, they noted that the Australian Energy Regulator (AER) reduced their operating expenditure (opex) by 13.7 percent. As a result, Evoenergy adjusted their regulatory proposal to meet the AERs decision on reduced opex stating they excluded "expenditure associated with enabling and managing community batteries."[1] This decision indicates that Evoenergy is not looking at investment in community batteries. There is also no mention of VPPs in the revised regulatory proposal.

The ACT Government have also incentivised household solar and home battery storage through the Sustainable Household Scheme (SHS)[2], which provides no interest loans through Brighte, a finance company specialising in solar and other sustainable home improvements.[3] According to the Brighte dashboard, there were 1485 loans provided for bundled solar and battery systems and 1054 battery systems provided through the loans.[4] The Next Gen Energy Storage Program provided 5000 rebates for battery systems in Canberra homes and businesses, which was the

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[1] Evoenergy (2023) Revised regulatory proposal. Evoenergy electricity distribution determination 2024 to 2029. https://www.aer.gov.au/system/files/2023-12/Evoenergy-Revised%20regulatory%20proposal-November%202023.pdf. p.33.

[2] ACT government (2021) Sustainable Household Scheme. https://www.climatechoices.act.gov.au/policy-programs/sustainable-household-scheme

[3] Brighte (2024) Australia's leader in sustainable finance. https://brighte.com.au/

[4] Brighte dashboard. https://act-dashboard.brighte.com.au/#act-dashboard-google-map

target for the program and it has stopped accepting applications. The ACT Government confirmed that there are approximately 5500 behind the meter installed home battery systems in Canberra through both incentive programs. Some residents received both the Next Gen subsidy and the SHS loan, hence the discrepancy in total numbers of installed solar PV and home battery systems. There are likely to be more home battery systems outside of these programs.

A key consideration for the ACT Government with the implementation of VPPs is whether to offer incentives for participation, such as a battery subsidy. We understand from discussions with the ACT Government that further battery subsidies are not being considered at this time. It is noted here that some of the pilots and trials, such as Project Symphony and the Bruny Island Battery Trial, provided some form of financial incentives to participate. For Project Symphony, this included subsidised batteries, heat pump hot water systems and air conditioners and well as bill credits to mitigate the effects of orchestration (testing) (Boyle et al., 2023). For the Bruny Island Trial, there was a subsidy of up to $17,200 for the installation of PV, batteries and controller (Lovell et al., 2023). This is raised here as a consideration as the value proposition of VPPs are not always clear for people in the community, and we would caution that there may be risks for people who are still making payments on their systems through the SHS loan unless there is a clear rationale and financial benefit to participate.

2. Background

Demand-side batteries, such as neighbourhood and household batteries, can help address challenges caused by the increasing adoption of solar PV systems in distribution networks. The mismatch between peak solar generation during the day and peak electricity demand in the evenings strains existing network infrastructure. To prevent overloading the network, solar output may need to be curtailed.

There are many variables that influence which battery type is more suitable for the ACT region, and this report does not include every consideration. The following sections explain the differences between neighbourhood and household battery systems, as well as their benefits and limitations.

2.1 Neighbourhood and household batteries

Neighbourhood Batteries (NBs) are mid-scale batteries that are directly connected to the distribution network, typically ranging from 0.1 to 5MWh in capacity (Ransan-Cooper et al., 2021; Shaw, 2020). These batteries can be automatically controlled using smart computer programs, allowing for efficient management and optimisation of their operation.

Household batteries (HBs) are small-scale energy storage systems designed for residential use, installed behind the meter and often coupled with rooftop solar panels. These batteries allow homeowners to store excess solar energy generated during the day to use during periods of high energy demand or when solar production is low, such as in the evening or on cloudy days.

When multiple household batteries are coordinated through software and communications technology, they can form a VPP. A VPP is a network of decentralised energy resources, such as rooftop solar panels, battery storage systems, and controllable load devices such as heat pump hot water systems and air conditioners, which can be collectively managed to deliver services traditionally provided by conventional power plants (Wang et al., 2020).

Demand-side batteries can generally contribute to reducing energy costs, improving local solar utilisation, relieving local network constraints, providing network support for the main grid and reducing the reliance on additional generation sources from the grid. However, the way to realise these benefits and the degree of how much of these benefits can be achieved vary with different battery options.

2.1.1 Improving solar utilisation

All battery options (NBs, VPPs and uncoordinated HBs) can improve solar utilisation by storing excess solar energy during the day and discharging the energy later when demand peaks in the evening. VPPs and HBs can charge directly from rooftop solar panels located on residential homes, resulting in less solar energy needing to travel through the local network. VPPs also enable excess solar generation to be shared among households, further preventing the export of excess solar to the grid, where it may be curtailed due to network constraints. VPPs thus allow solar energy generation to be utilised locally. NBs always require the network to transport the excess solar energy from households; however, NBs are also effective at sharing energy with all households in the network.

2.1.2 Relieving local network constraints

All battery options can contribute to alleviating network constraints, but the extent of their contribution varies. The effectiveness of NBs in addressing network constraints depends on their location. If an NB is connected to the substation, it may not address network constraints for downstream households (those located further from the substation), thus limiting their capability to address network issues.

Uncoordinated HBs can respond to network issues arising during high demand or excess solar export periods when financial incentives such as time of use tariffs (TOU) are passed through from the DNSP to the retailer. However, HBs ability to match the desired output needed for the network is not guaranteed, as their operation is primarily aligned with households' interests for self-consumption.

VPPs are coordinated by an aggregator to optimise the operation of all participating household batteries and other assets, such as solar PV and heat pump air conditioners and hot water systems. VPPs can offer better capabilities for meeting the overall needs of the network, ensuring a more targeted and effective response to network constraints. The full capabilities of VPPs to address network constraints occurs with perfect orchestration, which assumes full control of household assets.

It is important to note, that the social research conducted by BSGIP across multiple VPP projects shows that householders value self-consumption, even when connected to a VPP. Therefore, full control of home batteries is unpalatable to most households. This means, finding a balance between network optimisation and household autonomy remains a key challenge in practice to maximise the benefits of VPPs for both the grid and individual consumers. The response of householders to VPPs is discussed further in section 4 of this report.

2.1.3 Reducing local energy costs

All battery options discussed in this report can reduce local energy costs, but they achieve this benefit in different ways. Uncoordinated HBs can reduce energy costs for individual households by optimising self-consumption of solar energy. They may also benefit from feed-in tariffs offered by retailers (passed through from the DNSPs) for exporting excess solar energy. Feed in tariffs are being phased out in most jurisdictions and are now substantially lower for exported solar.

NBs can reduce overall local energy costs by discharging to the local network during high demand times, thus decreasing the energy or power required from the grid to service demand. VPPs combine the benefits of both uncoordinated HBs and NBs, as they can reduce costs for individual households and optimise energy use at the local network level.

NBs and VPPs have additional capabilities to reduce local energy costs. They can generate extra revenue by participating in energy markets, such as the Frequency Control Ancillary Services (FCAS) market and for services on the wholesale electricity market. For example, they can take advantage of energy arbitrage opportunities in the wholesale electricity market by buying energy when prices are low and selling when prices are high. Uncoordinated HBs, however, do not meet the criteria for participation in the wholesale electricity market and thus cannot access these additional revenue streams.

It should be noted that the revenues or savings generated by NBs can potentially be distributed to consumers in the local community through purposefully designed programs. However, it is worth highlighting that only a limited number of such initiatives have been tested or are currently undergoing trials in Australia. An example of such a trial can be found from the Alkimos Beach Energy Storage trial in Western Australia, where participants saved an average of $35.85 per billing cycle, which is bi-monthly in WA.[5]

2.1.4 Trade-offs from different battery purposes and configurations

As discussed above, batteries can provide various benefits to individual households, to the local network and for the broader electricity network. There are also trade-offs with each configuration and purpose (Figure 1). For example, allocating more capacity to improve solar utilisation and reduce local consumption decreases the capacity available for generating extra revenue from market services. Conversely, prioritising market participation reduces the capacity for providing network support, peak demand reduction, and better solar utilisation. Battery owners must carefully consider and balance these objectives based on their specific priorities and circumstances.

Figure 1 Trade-offs between different battery applications

[5] Synergy (2021) Alkimos Beach Energy Storage Trial. Final Knowledge Sharing Report. https://arena.gov.au/assets/2021/07/alkimos-beach-energy-storage-trial-report.pdf

2.2 NBs and VPPs in Australia

In Australia, grid-connected VPPs primarily focus on coordinating rooftop photovoltaic (PV) systems, battery storage, and controllable load devices by aggregating and optimising the operation of these distributed energy resources. Many VPP trials have been conducted and completed in Australia, with some of these discussed in section 4, specifically Project Symphony and Converge. These trials have demonstrated the ability of VPPs to deliver contingency Frequency Control and Ancillary Services (FCAS), respond to energy price signals, and provide local network services, sometimes delivering multiple services simultaneously (AEMO, 2021).

VPPs are often seen as an option to avoid augmentation of networks, and therefore reduce costs of upgrading the distribution or transmission network. However, research conducted with energy sector professionals and others found that the aggregation of VPPs by retailers was seen by networks as being "too uncertain to rely on for their upgrade planning requirements" (Ransan-Cooper et al., 2021, p. 7). A similar finding was noted for electric vehicles (EVs) with EVs seen as risky for DNSPs to rely on when required as stated by a DNSP noting, "It's got to be closer to 80-90% reliable before that's something that I can realistically dispatch, and trust will manage to keep the network stable" (Jones et al., 2022). Therefore, there is no guarantee that the use of VPPs will in fact reduce network spending, given reliability concerns by networks, and the level of control that is realistically palatable for householders connected to a VPP as will be discussed in this report.

Neighbourhood batteries have gained significant interest in Australia due to their potential benefits. DNSPs are largely focused on increasing the hosting capacity of the network, and to potentially defer other investment (such as transmission infrastructure), whereas citizens perceive other benefits of neighbourhood batteries, such as local storage and a greater sense of control and community engagement. Citizens also see the potential to avoid network investment and enable efficiencies through local production and consumption (Ransan-Cooper et al., 2022, p. 5). Several state and federal government-backed trials are currently underway to investigate the ability of NBs to facilitate the integration of more renewables into the grid, reduce energy costs, support decarbonization efforts, and provide local economic benefits.[6] The Australian Renewable Energy Agency (ARENA) will also publish knowledge sharing reports from their Community Batteries Funding Program[7] in the near future.

3. Modelling and simulation results

This section details the methodology and results of our simulation study. It covers the network and battery scenarios modelled, defines the battery operation objectives considered, and outlines the criteria used for evaluating battery benefits. We also describe the data sources and

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[6] BSGIP (2023) Neighbourhood battery trials and tariffs in Australia. https://bsgip.com/knowledge-hub/neighbourhood-battery-trials-programs-in-australia/

[7] ARENA (2023) Strong demand for community batteries across Australia. https://arena.gov.au/news/strong-demand-for-community-batteries-across-australia/#:~:text=As%20part%20of%20the%202022,deliver%20at%20least%20342%20batteries

software employed in our simulations. The section concludes with a presentation of simulation results and a discussion of the advantages and disadvantages of different battery scenarios.

The ACT Government wanted to understand the “optimal mix” of VPPs or NBs for the ACT, and this modelling provides an understanding of the benefits of different demand-side battery options. The different priorities or purposes under the same situation are modelled to provide a more comprehensive understanding of the benefits, and the trade-offs between different battery options.

This section provides an understanding of the advantages and disadvantages of different battery options. In summary:

1. NBs and VPPs share a similar range of benefits, but each has its own advantages and disadvantages in the realisation of those benefits.
2. HBs offer a smaller range of benefits and reduced capability in realising those benefits for their independent operations and self-interest driven behaviours, however, all batteries can provide some benefits for the network, compared to using no batteries.
3. Under the same situation, the benefits of each battery option vary with their purpose and priorities. For example, the degree of solar utilisation, cost reduction and network support will reduce or increase depending on how the services the battery provides is prioritised, such as whether there is a prioritisation of a single benefit, or a combination of several benefits.

3.1 Network and battery scenario

This study considers a simulated network section of 100 households, 70 of which have rooftop solar panels, to evaluate the financial, technical, and solar utilisation benefits of neighbourhood batteries and household batteries. Four scenarios were considered.

3.1.1 Base scenario

In this scenario, no battery is installed at any point of the distribution network.

Figure 2 No battery baseline scenario

3.1.2 Neighbourhood battery only (NB) scenario

In this scenario, only one NB is installed and connected to the distribution network. No household has a battery on-site.

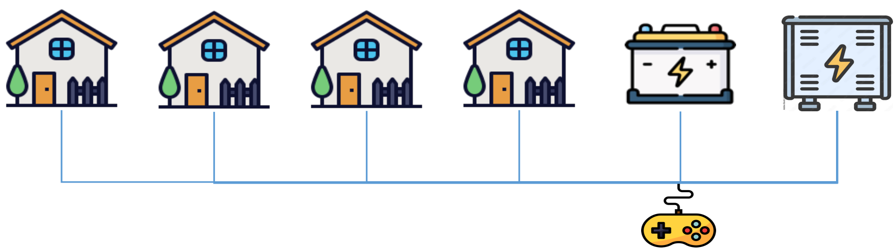

Figure 3 Neighbourhood battery only scenario

3.1.3 Uncoordinated household battery (HB) scenario

In this scenario, HBs are installed in individual homes but are not coordinated or controlled by a third-party entity. Each household independently decides when to charge or discharge without considering the actions of other households or the broader network conditions.

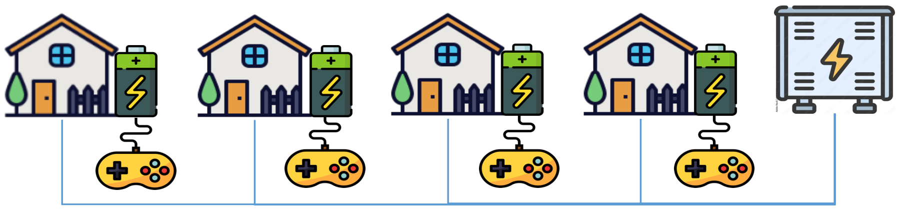

Figure 4 Uncoordinated household battery scenario

3.1.4 Virtual power plant (VPP) scenario

In this scenario, all household batteries are perfectly coordinated and controlled by a third-party entity, such as an aggregator, to function as a virtual power plant. The VPP can participate in the energy market, provide network services, and optimise the collective operation of the household batteries.

It is important to note that the term perfect orchestration of household batteries refers to the third-party entity (usually an aggregator) having direct access and full control of the battery status and its charge and discharge behaviours in real-time, and all household battery owners agree to participate in this orchestration.

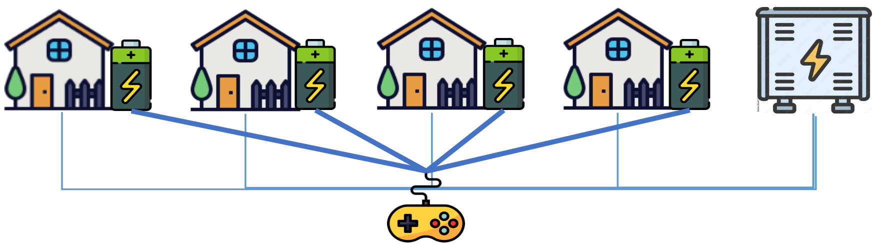

Figure 5 Virtual power plant scenario

3.2 Battery operation objectives

Given that batteries can provide various benefits based on the priorities of their operators or owners, as explained in Section 2, we define three types of battery operation objectives. These objectives reflect varying sets of priorities, therefore enabling a more comprehensive analysis and understanding of the multiple benefits offered by battery systems. Table 1 below summarises the priorities of each objective.

Table 1 Priorities of different battery operation objectives

Battery Objective	**Priority**			
	Charge from cheap times	Discharge at expensive times	Charge from solar hours	Discharge at high consumption times
Solar soaking			✓	✓

Profit maximisation	✓	✓		
Balanced	✓	✓	✓	✓

3.2.1 Solar Soaking

To achieve a solar soaking objective, solar utilisation is prioritised by minimising the power imported from the grid and the power exported from the local network, particularly solar power. It does this by charging during solar hours when local generation is high and discharging during the evening when demand is high and solar generation is low as illustrated in Figure 6 below.

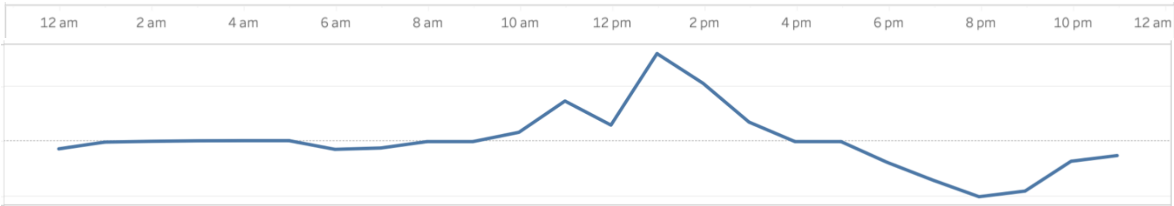

Figure 6 Example of battery operation for solar soaking

3.2.2 Cost minimisation

To achieve this objective, a battery prioritises cost reductions through minimising the costs of charging from the grid and maximising the revenues from discharging back to the grid. It does this by charging when the wholesale electricity price is low, typically from midnight, and discharging when the price is high, usually during the early evening, as shown in Figure 7.

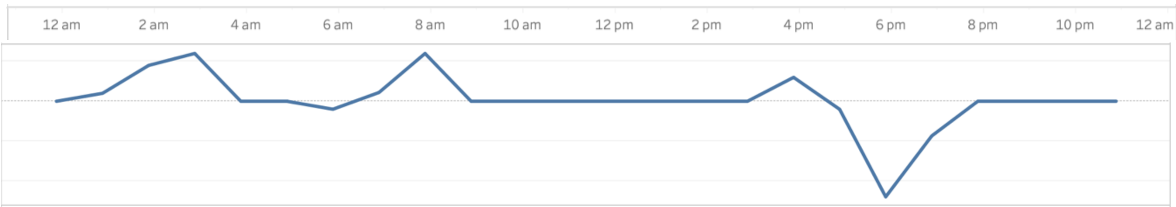

Figure 7 Example of battery operation for cost minimisation

3.2.3 Balanced

To achieve this objective, a battery seeks to find a balance between solar soaking and cost minimisation. It does this by charging during both cheap off-peak periods and solar hours when local generation is high, and discharging during expensive peak periods and night hours when demand is high and solar generation is low, as illustrated in Figure 8.

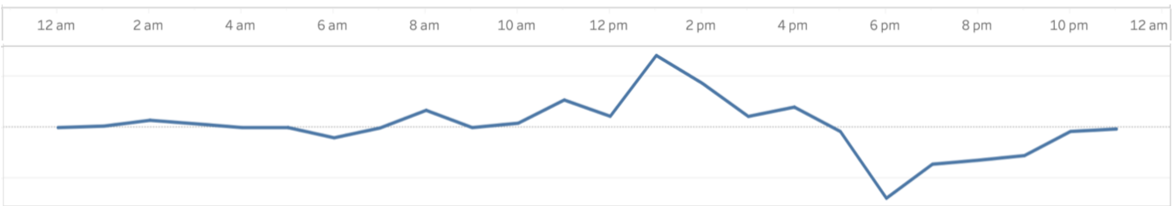

Figure 8 Example of battery operation for balancing solar soaking and cost minimisation

It is important to note that the balanced objective offers flexibility in that the relative importance of solar soaking and cost minimisation can be adjusted to meet specific needs in various situations. It should be noted that periods of low wholesale prices do not always coincide with peak solar generation hours, and high wholesale prices may not always align with periods of peak demand (Figure 9). Therefore, this balanced objective enables an adaptive approach to battery operation, considering the interplay between pricing signals, solar generation patterns, and load profiles. This approach allows for a more refined battery management strategy that can respond to varying grid conditions, energy market dynamics, and local energy needs. Consequently, it maximises the overall benefits for the local network section, including all households and the NB (if applicable).

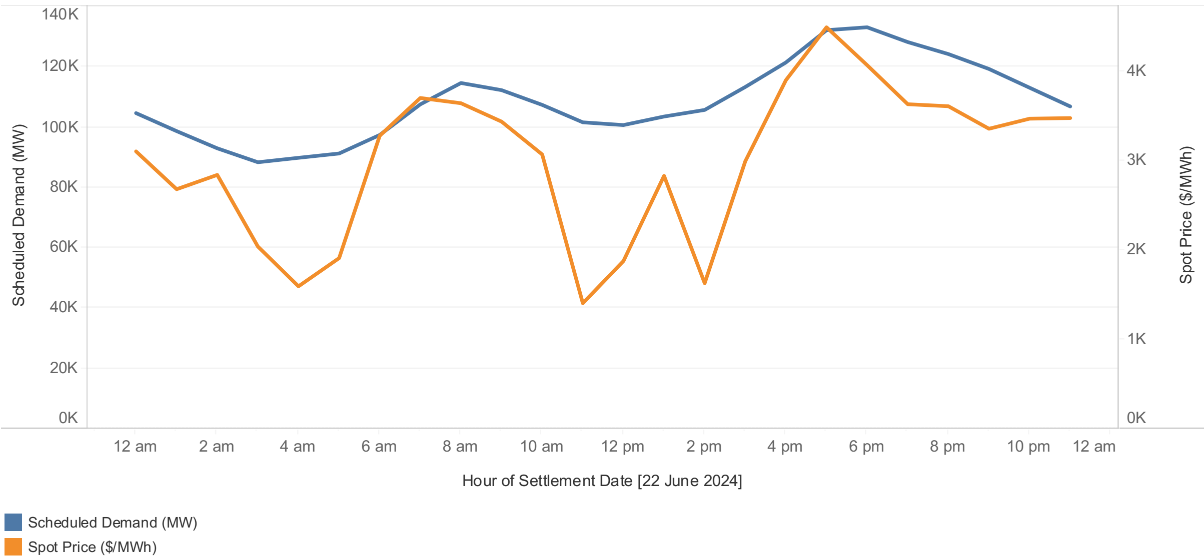

Figure 9 NEM wholesale spot prices and demand on 22 June 2024, sourced from AEMO

3.3 Evaluation criteria for battery benefits

To evaluate and compare the benefits of different battery applications, we define three sets of criteria to quantify different battery benefits.

3.3.1 Financial benefits

The financial benefits are assessed using two main components: the wholesale electricity cost and the network charge.

The wholesale electricity costs represent the expenses and revenues associated with buying and selling electricity in the wholesale electricity markets. It is calculated as the difference between the cost of purchasing electricity from the market and the revenues earned by selling excess electricity back to the market.

The network charge is the fee paid to the DNSP for delivering electricity to consumers. Some network tariffs include TOU rates, where the rate varies across off-peak, peak, or shoulder periods of a day, as defined by the DNSP in their tariff structures. Furthermore, certain TOU rates are applied to bidirectional power flows, which means consumers pay for importing electricity and receive payment for exporting to the grid. Under these conditions, a battery can be operated strategically to charge during low network charge periods or discharge when export rates are favourable, thus lowering electricity costs. An example of such network tariff structures is provided by Evoenergy[8]. Evoenergy's tariffs for residential batteries and neighbourhood batteries are used in the simulation presented in section 3.5.

Although wholesale costs and network charges are ultimately passed on to consumers through their electricity bills, this report does not analyse the financial benefits for specific entities such as consumers, DNSPs, retailers, or generators. Instead, the wholesale electricity cost and the network charge serve as overall indicators of financial benefits, as they constitute the two most significant components of consumers' electricity bills (Figure 14). By focusing on these components, the report provides a general assessment of the financial implications of different battery scenarios without delving into the specific financial outcomes for individual stakeholders.

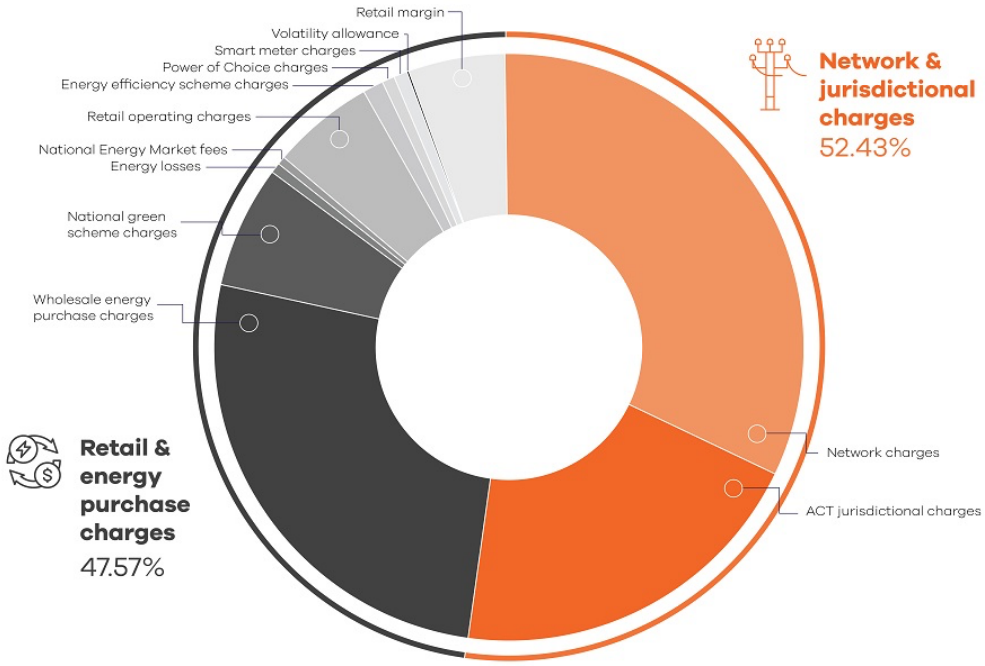

Figure 10 A breakdown of the electricity bill for consumers in ACT[9]

3.3.2 Technical benefits

We used two types of measurements: the maximum daily peak demand and the average daily peak demand over a year.

First, we are interested in comparing the maximum daily peak demand for each battery scenario under different operation objectives. The maximum daily peak demand is important as it defines the minimum capacity required for the power system. The daily peak demand is measured as the highest demand in 30-minute intervals throughout the day. The maximum daily peak demand is the highest daily peak demand over a year.

Second, we compare the average daily peak demand for each battery scenario under different battery objectives. This is because the maximum daily peak demand only occurs for a small

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[8] Evoenergy (February 2022). Sub-threshold tariff notification. https://www.aer.gov.au/system/files/2024-03/Evoenergy%20-%20Tariff%20trial%20notification%20-%202022-23.pdf. p.10

[9] Evoenergy. Electricity network prices and tariffs. https://www.evoenergy.com.au/Your-Energy/Pricing-and-tariffs/Electricity-network-pricing

period of time, typically during extreme hot or cold days. Using maximum daily peak demand alone does not indicate the peak demand on normal days in general. Therefore, we also compare the average daily peak demand to provide a more comprehensive understanding of typical daily peak demand throughout the year.

3.3.3 Solar benefits

The solar utilisation benefit is evaluated using two key metrics: the self-consumption rate and the self-sufficiency rate.

The solar self-consumption rate measures the proportion of locally generated solar energy that is consumed within the network section, rather than being exported to the grid. This metric indicates how effectively the battery scenarios optimise the use of solar energy generated by the households. A higher self-consumption rate suggests that more solar energy is being used locally, reducing the amount of excess energy exported to the grid.

The self-sufficiency rate, on the other hand, quantifies the percentage of the local energy demand that is met by the locally consumed solar generation. This metric demonstrates the extent to which the battery scenarios reduce the reliance on electricity imported from the grid by maximising the use of locally generated solar power. A higher self-sufficiency rate indicates that a greater portion of the local energy demand is being met by solar energy, thus reducing the need for electricity from the grid.

Together, these two rates provide a comprehensive understanding of how well each battery scenario improves the utilisation of solar energy and enhances the energy independence of the network section. By analysing both the self-consumption rate and the self-sufficiency rate, the report offers insights into the effectiveness of different battery scenarios in optimising the use of locally generated solar power and reducing the reliance on the grid.

3.4 Simulation approach

The full details of the simulation approach are summarised in Table 2 in the Appendix.

3.4.1 Data sources

The data used in the simulation included year-long, 5-minute interval data of the NSW wholesale prices for 2022 from AEMO, and household load and solar generation data from the NextGen trial in the ACT. Evoenergy network tariffs for NBs and households with batteries (both recently proposed trial tariffs) were also applied.

3.4.2 Simulation Software and Algorithms

The in-house software, echo was used to evaluate the benefits of different battery applications for each scenario (Figure 11). The echo takes input data, including wholesale prices, network tariffs, household load and solar profiles, and battery operation objectives, and calculates the optimal way to discharge and charge for every 5-minute interval over the year. Using the optimal battery schedules, the software then calculates the financial, technical and solar utilisation benefits. The core capability of echo is the optimisation algorithms that make optimal decisions to minimise costs or maximise benefits based on constraints given by the software users. These optimisation algorithms are based on mathematical programming which is widely used in cost-benefit analysis in commercial and industrial settings.

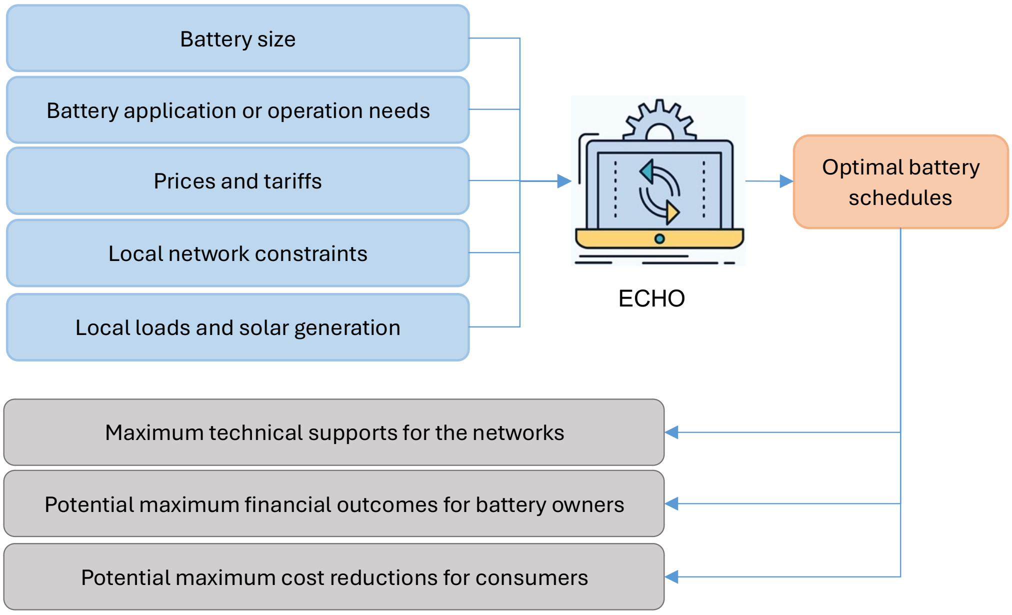

Figure 11 Application of echo in analysis

3.5 Simulation results

We demonstrated the financial, technical and solar utilisation benefits of the NB, VPP and uncoordinated HB scenarios under the solar soaking, balanced and cost minimisation operation objectives, and compared the benefits of those scenarios against the BASE scenario.

3.5.1 Financial Benefits

Figure 12 provides a comparison of the total costs for each scenario using the wholesale electricity costs and network charges as described in section 3.3.1.

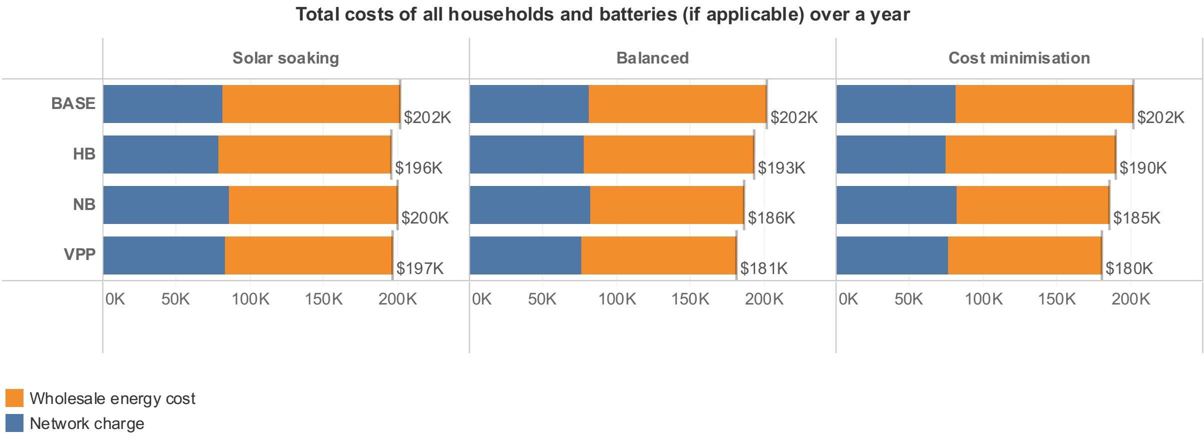

Figure 12 The total cost of all households and the batteries (if applicable)

Results of the analysis show that for total cost (wholesale cost + network charge):

- All battery scenarios reduce the total costs compared to the base scenario.

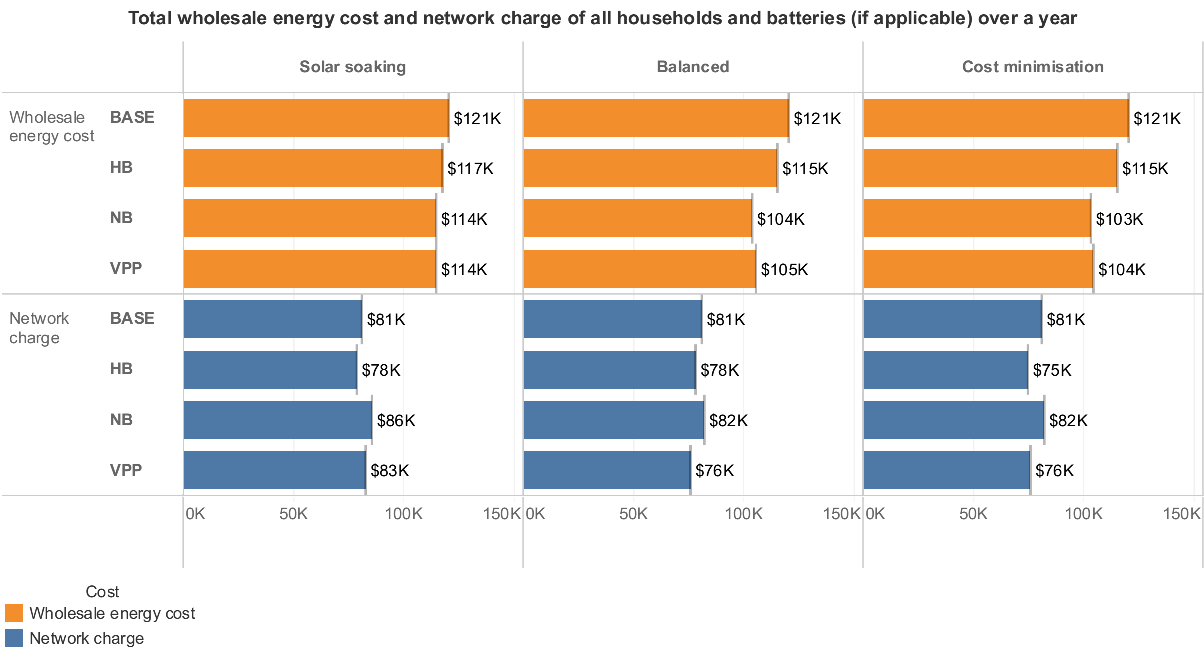

Figure 13 The total wholesale energy cost and network charge of all households and the NB (if applicable)

Further breaking down the wholesale cost and network charge provides results as shown in Figure 13 and indicates:

For the wholesale cost:

- All scenarios reduced the wholesale costs under all objectives.
- The NB and the VPP scenarios achieved the lowest and almost identical total wholesale cost under all operation objectives, followed by the uncoordinated HB scenarios.

For the network charge:

- HBs and VPPs were more effective at reducing the network charge. Installed at the household sites, HBs and VPPs can directly charge from local solar energy resources, reducing the need for using the network infrastructure to transport energy. This results in less energy flowing from the households to the network, lowering the network charges for households.
- NBs always require the network to transport energy from the rooftop solar to the battery. Consequently, all excess solar generation must travel through the network to reach the battery, resulting higher total network charges for both households and the NB owners.

In summary, all batteries reduce both network and wholesale electricity costs. NBs and VPPs are more effective at reducing the wholesale costs due to their ability to earn additional revenues from energy market participation. VPPs and HBs were more effective at reducing network charges, as they can charge directly from local solar sources without requiring the network for energy transport.

3.5.2 Technical Benefits

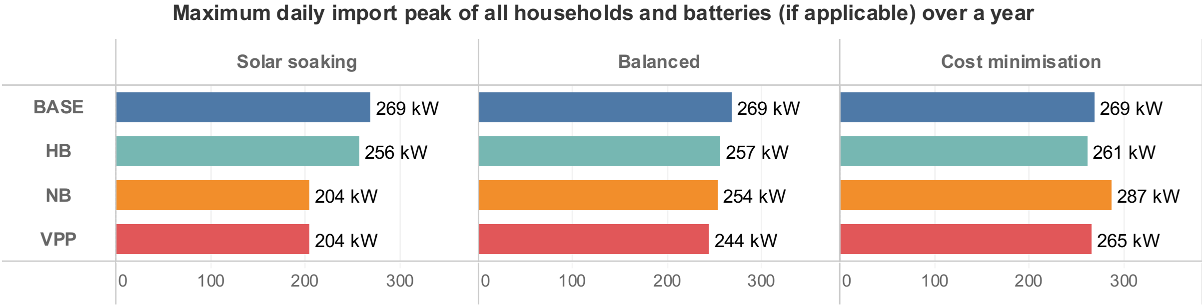

Figure 14 The maximum daily import peaks of all household and the NB (if applicable)

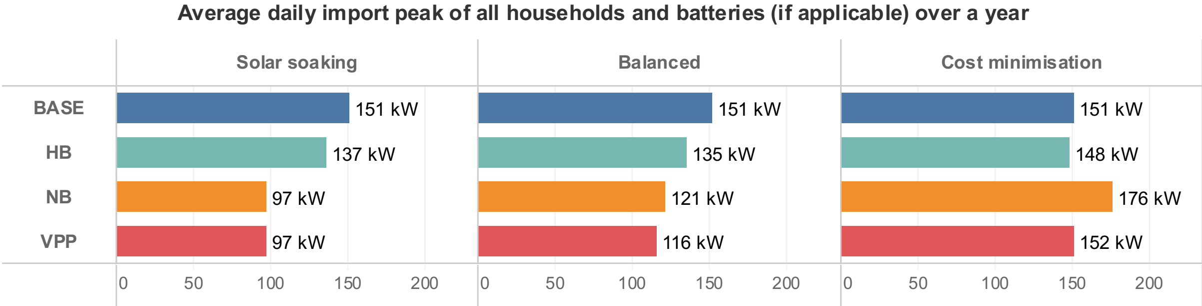

Figure 15 The average daily import peaks of all households and the NB (if applicable)

The technical benefits of each scenario, as shown in Figure 14 and Figure 15 above, reveal the following for daily import peaks:

Under the solar soaking and balanced operation objectives:

- NBs and VPPs exhibited greater efficacy in reducing both the maximum and average daily import peaks compared to uncoordinated HBs.
- This is due to their capacity to optimise operation for the collective benefit of all households, in contrast to the self-interest driven operation of uncoordinated HBs.

Under the cost minimisation objective:

- NBs and VPPs were less effective than uncoordinated HBs.
- NBs and VPPs, when optimising revenue from wholesale market participation, tend to maximise charging during periods of low wholesale prices and maximise discharging during prices of high prices. However, this strategy is not always aligned with the needs for reducing import peaks.
- Uncoordinated HBs, lacking access to the wholesale market, are limited to reducing costs through responding to financial incentives provided by the DNSP or retailers for demand reduction or charging from excess solar generation. These incentives typically present less price variations compared to those observed in the wholesale market.

Consequently, this results in moderate charging and discharging behaviours that can be more effective in reducing import peaks.

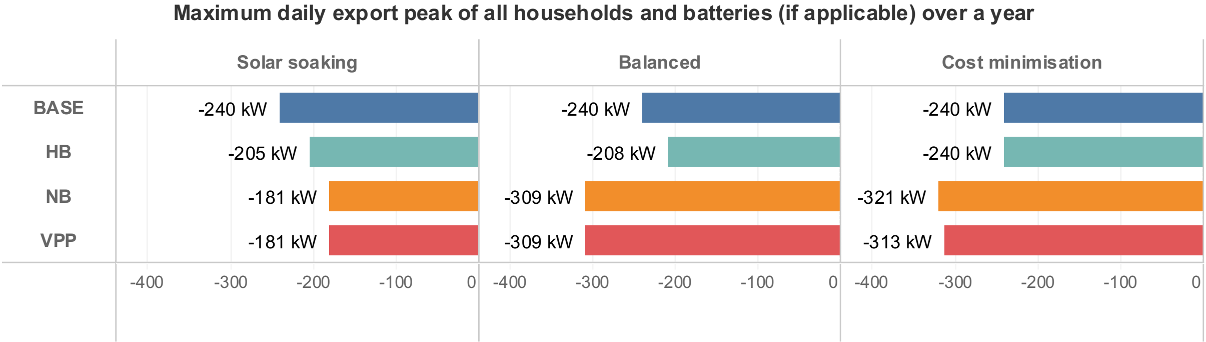

Figure 16 The maximum daily export peak of all households and the NB (if applicable)

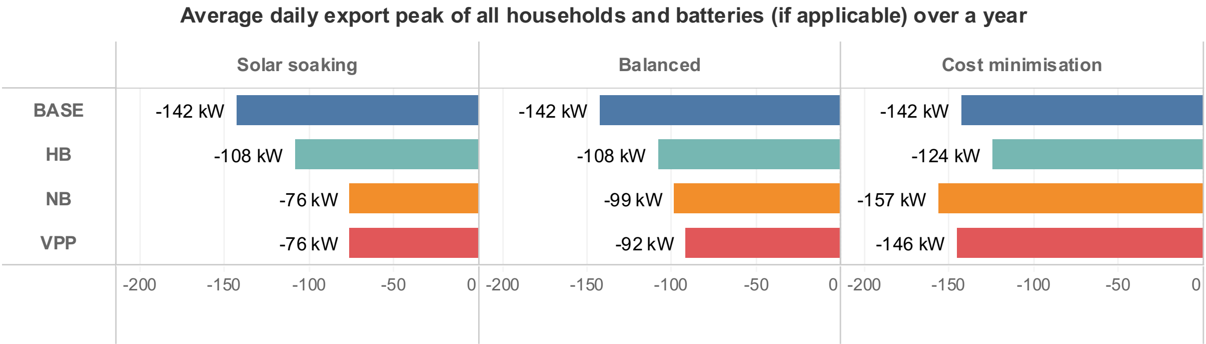

Figure 17 The average daily export peak of all households and the NB (if applicable)

For daily export peaks (Figure 16 and Figure 17):

- Uncoordinated HBs consistently reduced or maintained daily export peaks across all operation objectives. However, the reduction was limited in magnitude.
- NBs and VPPs demonstrated high effectiveness in reducing daily export peaks under the solar soaking objective, with average daily export peaks halved. Conversely, NBs and VPPs increased the maximum daily export peaks under the balanced and cost minimisation objectives.

In summary, uncoordinated HBs provided stable, albeit limited, reduction in both daily import and export peaks across all operation objectives. NBs and VPPs offered more substantial reductions in both peaks under the solar soaking objective compared to the BASE scenario. However, NBs and VPPs demonstrated the potential to increase both import and export peaks when cost reduction was prioritised (i.e., under the balanced and cost minimisation objectives). This behaviour of NBs and VPPs is attributed to the greater price variations typically observed in the wholesale market compared to the financial incentives offered to uncoordinated HBs by DNSPs or retailers. Consequently, NBs and VPPs were incentivised to increase import and export peaks to maximise revenues from the wholesale market and minimise overall costs.

These observations indicate the importance of choosing appropriate objectives and priorities to achieve the desired outcomes, as this choice can greatly influence the performance of different battery options in managing network peaks and reducing overall electricity costs.

3.5.3 Solar Utilisation Benefits

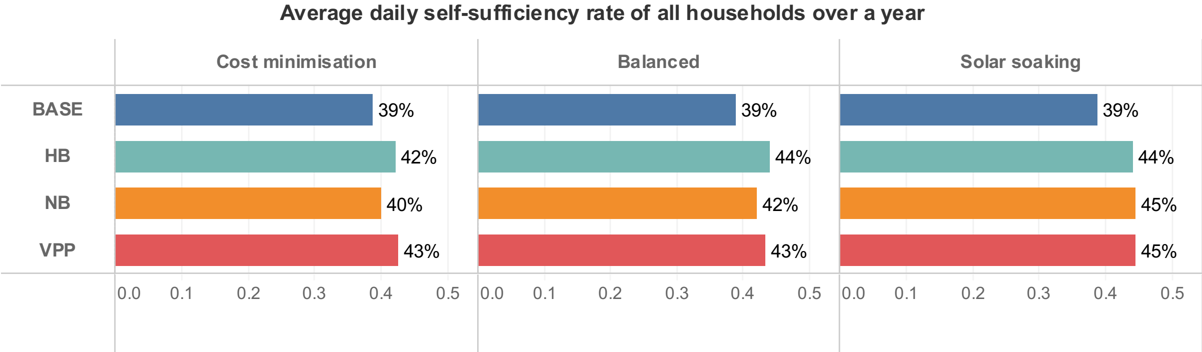

Figure 18 The average self-sufficiency rate of all households and the NB (if applicable)

Regarding the self-sufficiency rate (Figure 18):

- All battery scenarios demonstrated an increase in this rate.
- Under solar soaking objectives, all scenarios achieved nearly the same outcomes.
- Under cost minimisation and balanced objectives, the uncoordinated HB and VPP scenarios exhibited marginally better effectiveness. This slightly improved performance can be attributed to their proximity to households, enabling direct reduction of household loads.

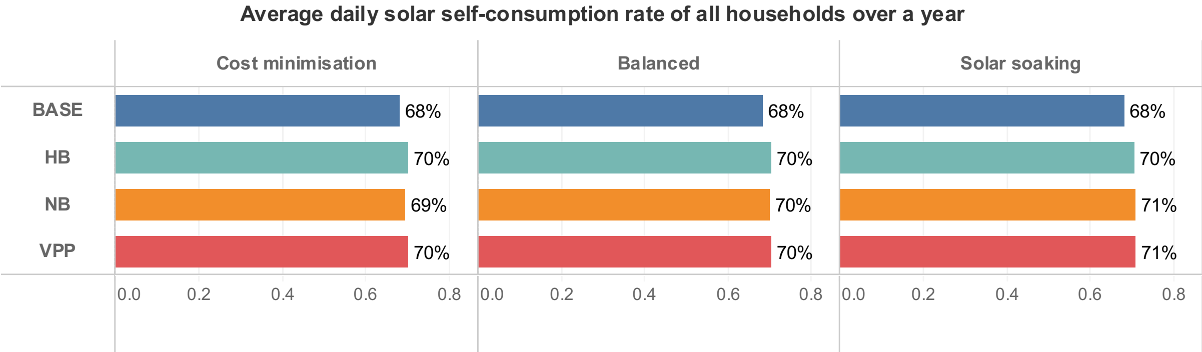

Figure 19 The average solar self-consumption rate of all households and the NB (if applicable)

Regarding the solar self-consumption rate (Figure 19):

- All battery scenarios demonstrated an increase in this rate, with nearly the same outcomes observed across all objectives.
- However, the magnitude of this increase was relatively small compared to the BASE scenario, with an improvement of less than 2%.

In summary, all battery scenarios exhibited the capacity to enhance solar utilisation. Notably, the outcomes were almost identical across all operation objectives considered in this report.

3.6 Discussion

3.6.1 Limitations

This simulation had several limitations that should be considered when interpreting the results:

1. Network tariff dependency: This simulation only used network tariffs from Evoenergy. It is important to note that the realised benefits, and consequently the differences in the benefits among various battery scenarios, will vary when network tariffs from other DNSPs are applied.
2. Fixed PV penetration and battery capacity: This simulation did not explore how benefit changes with varying percentage of PV penetration or battery capacity. As a result, this study does not capture the different interactions among the realised benefits, PV penetration and battery sizes.
3. Assumed perfect VPP orchestration: This simulation assumed perfect orchestration, as described in section 3.1.4. While this approach demonstrates the best possible benefits of a VPP, real-world benefits are likely to be lower due to challenges in achieving such perfect orchestration in practice. These challenges are further discussed in the findings from social research in section 4.
4. Perfect forecast assumption: This simulation also assumed perfect knowledge of future loads and solar generation. However, this level of accuracy in forecasts is rarely achievable in practice. The actual realised benefits of all battery scenarios are conditional on the accuracy of forecast data used to optimise their operations.
5. Absence of network power flow analysis: This simulation did not utilise any actual network topology to analyse the impacts of different battery scenarios on local network constraints. While we acknowledge the importance of such network power flow analysis, it falls outside the scope of this report.

3.6.2 Findings

Under conditions that could be considered "perfect" or "optimal", where future load and solar generation are accurately forecasted without consideration of network constraints, and all batteries within the VPP are orchestrated perfectly without interruptions or disruptions:

- All battery scenarios demonstrate the capacity to reduce costs. However, NBs and VPPs offer greater reductions in wholesale electricity costs, while VPPs and HBs provide better reductions in network charges.
- All battery scenarios show improvements in solar utilisation, achieving the almost identical outcomes across all objectives.
- HBs consistently demonstrate a stable reduction in import and export peaks, albeit with limited magnitude. In contrast, NBs and VPPs exhibit the potential for significant peak reduction or, conversely, peak increase. The direction and magnitude of NBs' and VPPs' peak management effect depend on the degree to which cost reduction is prioritised within the battery operation objectives.

3.6.3 Suggestions

Both NBs and VPPs demonstrate the capacity to enable greater financial and technical benefits compared to uncoordinated HBs. However, it is vital to determine which benefits to prioritise, as this prioritisation significantly impacts the actual outcomes.

The simulation results showed that VPPs outperform NBs in cost reduction and peak reduction by a small margin. It is important to note that a VPP involves multiple household batteries, which indicates an increased complexity in encouraging and maintaining household participation to achieve the desired benefits. As stated in this report, the VPP scenario simulated in this study relies on perfect orchestration, which we know from social research is unrealistic and not palatable for householders. In contrast, an NB involves only one battery, which exhibits less uncertainty in ensuring the desired operation. Therefore, the choice between an NB and a VPP should consider not only the differences in the achieved benefits under these perfect conditions but also the practical challenges in ensuring those benefits are realised.

The simulation results suggest that it is worthwhile to evaluate the costs, resources, and efforts required to ensure the desired outcomes are achieved in practice, against the additional benefits that can theoretically be achieved from choosing a VPP over an NB.

A study published by colleagues within BSGIP suggested that NBs may offer a preferable option as they provide similar financial and technical benefits to VPPs without the complexities of recruiting and managing households (He et al., 2023).

4. Findings from social research

The Battery Storage and Grid Integration (BSGIP) program has conducted extensive research on Virtual Power Plants and neighbourhood batteries in the ACT and across Australia. The key learnings from projects and research conducted by BSGIP researchers are discussed in this section to provide considerations for the ACT Government when deciding on an approach for increasing storage capacity in the ACT. Additional literature is included where relevant.

In April 2021, BSGIP conducted a co-design workshop that was held virtually to discuss a "Big Canberra Battery" and a report was prepared for the ACT Government. Attendees at the workshop included representatives from government, market and regulatory bodies, consumer advocates, network service providers, retailers and generators, battery suppliers and energy consultants (BSGIP, 2021, p. 13). This report noted that among the attendees, there was strong support for community batteries (i.e., distribution scale batteries) up to 20MW to assist the ACT to meet its zero emissions targets.

Participants of the Big Canberra Battery co-design workshop also discussed benefits of batteries for the ACT community noting that batteries could increase resilience of the energy system with extreme weather events, increasing the solar PV hosting capacity of the distribution network and provide potential bill savings for ACT customers (with lower network charges if this was more cost effective than upgrading network assets).

In discussions with Evoenergy, one of the main barriers to neighbourhood batteries they identified was the need for external funding or government grants for this to be cost effective. As part of Project Converge, Evoenergy worked on a software platform called the Real Time Regulatory Investment Test for distribution (RIT-D). The tool finds constraints in the network and assesses the most cost-effective network or non-network solutions (i.e., batteries). Evoenergy are currently in discussions with ANU to develop this software tool further.

Research findings from both VPPs and NBs has found that people value self-sufficiency, independence and autonomy and this can clash with network logics and needs (Boyle et al., 2023; Jones et al., 2024; Ransan-Cooper et al., 2022). For participants who sign up to a VPP, there is a need for the industry to be more transparent about what orchestration involves, so people can make informed decisions about their involvement. There are also fundamental consumer protections that are currently lacking with VPPs, with increasing calls to state-based Ombudsman's about VPPs in various states.

The Australian Energy Regulator (AER) recently undertook a review of consumer protections for future energy services to advise state energy ministers. The review analysed the benefits and risks of new energy services (including VPPs) and provided potential mitigants under the existing Australian Consumer Law.[10] The AER identified several risks for new energy services, including VPPs (aggregation services) that have also been found with the research discussed in this report. Some of the risks for consumers of aggregation services include handing over control of CER for operation on the energy market, locked in contracts, complexity for consumers who may not know what they are signing up for, lack of clarify for dispute resolution and data and privacy issues. The list of benefits noted in the review is shorter, and the benefits will depend on the aggregation service offered and the contract. Some benefits noted include payment for aggregation services, optimising consumption (thus reducing bills), and the potential for packages that minimise complexity.[11]

Another consideration that was raised from the Converge trial is the role of the algorithms that essentially make decisions on behalf of the consumer (for self-consumption), but also decisions for the aggregator. The allocation decisions that algorithms make are based on inputs that are usually focused on price or other quantifiable measures. These algorithms (and the decisions they make) was raised as something to be questioned from participants of the Converge trial (Jones et al., 2024, p. 50). The CONSORT (Bruny Island) trial also had a similar finding (Thiebaux et al., 2019). Ransan-Cooper et al. (2021) also discuss how the algorithms used in the energy sector are limited to considerations such as financial values that are easier to quantify.

4.1 Knowledge and trust of technology

Issues of trust and control are likely to be very significant in whether neighbourhood batteries come to be understood by the community as a better alternative to home batteries (Russell et al., 2023, p. 11).

Ransan-Cooper et al. (2022) undertook research to explore the techno-economic, social and regulatory dimensions of neighbourhood batteries as a basis to assist with policy development. As part of this research, a stakeholder analysis from 57 participants across Australia was conducted that included local and state governments, DNSPs, energy retailers, general citizens and consumer advocacy groups. The aim of this research was to understand the potential benefits and risks of neighbourhood batteries.

The findings from this research indicated that both energy sector professionals and citizens were generally positive about NBs, citing various benefits (Ransan-Cooper et al., 2022, p. 4). The benefits noted by the participants were grouped into broad themes that included supporting renewables and decarbonisation, local energy production and consumption, stability and reliability and the building of social capital. For citizens the building of social capital included strengthening of connections with neighbours and the expression of hopes and values that included, fairness, environmental benefits, inclusiveness and autonomy. For energy sector

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[10] Australian Consumer Law. https://consumer.gov.au/australian-consumer-law

[11] Australian Energy Regulator (2023) Review of consumer protections for future energy services. https://www.aer.gov.au/documents/aer-review-consumer-protections-future-energy-services-final-advice-november-2023. Pp.37-38.

professionals the potential to build trust in the energy sector was noted (Ransan-Cooper et al., 2022, pp. 5-6).

The stakeholder analysis also revealed that value was placed on local energy production, and that for citizens a sense of agency and control was important. Citizens felt that having power stored locally would assist with having that sense of agency (Ransan-Cooper et al., 2022, p. 5). However, the complexity of ownership and ongoing maintenance of a neighbourhood battery was also noted by the citizen participants, with suggestions that local governments, schools, nursing homes and research institutes could be the owners and operators of local storage (Ransan-Cooper et al., 2022, p. 7).

The success of VPPs in addressing network constraints is dependent on household uptake and acceptance of the technology solution and residential households in Australia are cautious about participating in a VPP (Patterson-Hann & Watson, 2021; Roberts et al., 2023). Recent research on household perceptions of a VPP pilot in Western Australia, Project Symphony found that the value proposition of being involved in the VPP was intangible and difficult for participants to determine (Boyle et al., 2023). Project Symphony as a VPP was a behind the meter system; however, this did not result in participants having control over their household solar PV and home battery systems due to the level of orchestration (and thus control over household assets) that occurred.

In Project Symphony, orchestration referred to four testing scenarios that were used (Figure 20) when participants solar PV, home battery systems, heat pump hot water systems and air conditioners were orchestrated (tested) as an aggregated VPP according to four scenarios that are briefly described below. These testing scenarios are further discussed in the Project Symphony Social Research Report (Boyle et al., 2023, pp. 15-16).

Figure 20 Project Symphony test scenarios (orchestration)

Source: Project Symphony Final Report[12]

The four scenarios are:

- Constrain to zero – reducing output of solar PV at the gross or net level.
- Energy services – dispatching of Consumer Energy Resources according to economic efficiency.
- Network security services – support with peak demand or local voltage issues.

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[12] Project Symphony. DER Participation: Pilot Results and Recommendations. Project Symphony Final Report. April 2024. https://arena.gov.au/assets/2024/06/Western-Power-Project-Symphony-Pilot-Results-and-Recommendations.pdf

- Essential system services (frequency control - contingency raise). Response to unplanned outages on the network.

For Project Symphony, participants did not have the ability to opt out of orchestration events and this, along with a lack of optimisation of participants CER, a lack of visibility of what was occurring with their CER and limited information in the first phase of orchestration, led to a significant power imbalance (Boyle et al., 2023, pp. 102-103). The social research from Converge found that householders who decided not to participate in the trial reported not having enough information about participation and SOEs to feel confident about participating (Jones et al., 2024, p. 40).

For Converge, a proportion of the people interviewed as part of the research were long time battery owners with existing relationships with the aggregators. There was emerging evidence from Converge that people with long term relationships with the aggregators were comfortable and relaxed about orchestration and other activities with their batteries. This has not been observed from trials with people who are relatively new to batteries and VPP agreements.[13] This suggests that there may be more acceptance with long term battery owners who have trusting relationships with their retailer or aggregator. However, it is noted here that Converge prioritised self-consumption, therefore there are still likely to be concerns from householders with full control (perfect orchestration) of household solar and HBs.

Through the Converge trial, some householders noted that they do not trust information provided by “for profit companies” and two householders noted that the protection of privacy and security of their personal energy use data would also contribute to whether an aggregator was trusted or not (Jones et al., 2024, p. 51). Trust of networks and retailers in the National Electricity Market (NEM) is generally low, as they are seen to hold profit motives and there is overall dissatisfaction with the energy system as a whole due to high energy bills, a lack of long term planning and privatisation of an essential service (Temby & Ransan-Cooper, 2021, pp. iv, 2).

For householders in WA, trust in the state-owned energy actors, Western Power and Synergy is higher than in the NEM, and this can be partially attributed to the fact they are state owned entities with lower electricity prices than what has been experienced for householders on the NEM. Some Project Symphony participants expressed gratitude that Synergy and Western Power are publicly owned (Boyle et al., 2023, p. 122). However, this trust was challenged during Project Symphony with the frequency of orchestration that occurred. Some participants also expressed concern about the monitoring that was occurring with devices installed in their homes, particularly the locked gateway device, which participants were informed to “not touch it” (Boyle et al., 2023, pp. 47, 81). The gateway device was a locked box, which contained the communication hardware needed to orchestrate householders CER. Research from Project Edge also found that it was important to give customers reassurance about the control of their devices and information (such as the amount of energy being exported) in order to build trust (AEMO, 2022, p. 4).

Findings from Project Symphony found that most participants were knowledgeable about various aspects of their energy use, such as maximising their solar, energy saving behaviour, and they became knowledgeable about the energy consumption of household devices and the testing scenarios that were used throughout the pilot over time. However, there were significant

[13] Personal communication with Dr Phillipa Watson (14 June 2024).

levels of complexity with the contracts, the apps (that were not integrated), and the language used with Project Symphony, which were largely industry insider terms. Participants also had to spend time understanding the complexity and logic of the pilot project through significant confusion, particularly in the initial stages. This complexity is rarely acknowledged within the energy industry, but it is a common finding through most of the social research discussed in this report and it can have detrimental impacts for householders (Boyle et al., 2023; Jones et al., 2023; Jones et al., 2024; Ransan-Cooper et al., 2022; Temby & Ransan-Cooper, 2021).

The initial marketing of the pilot was generic and stated that participants could get financially rewarded, receive subsidised assets and "be part of something bigger." This marketing assisted in getting people to sign up to the pilot and set an expectation of cost savings. Participants also had to sign a detailed contract to agree to be part of the pilot. Some participants interviewed found the paperwork overwhelming and difficult to understand (Boyle et al., 2023, p. 32 & 41). Recommendations on future communication were provided to the project partners of Project Symphony from the social research. This included the need for clear information to be provided at the outset, to clearly describe the purpose, the technology, what to expect when connected to the VPP, and visibility of what is occurring with orchestration, for example an interface or platform (Boyle et al., 2023, p. 129). Providing this information will allow people who are considering signing up to a VPP with the information needed to make an informed decision.

As discussed in section 4.3 below, for NBs, undertaking a site selection process will be important to enable trust and engage the community to have trust in the process. The report on evaluating and tracking impacts of neighbourhood batteries provides a list of questions to be asked when determining if the project has enabled trust and participation from the community, as well as evaluating if effective governance and accountability measures are in place (Refer to Table 2 Russell et al., 2023, pp. 13-19). The questions raised include issues around clarity and transparency of benefits, values, goals and decision making. There is also evidence to suggest that a lack of governance or community engagement can slow or stop projects (Russell et al., 2023, p. 11). For neighbourhood batteries, planning rules and access to land were also noted as barriers and there is complexity for local governments navigating this (BSGIP, 2021).

In relation to land access, difficulties arose due to having to place neighbourhood batteries in areas that made sense for the grid. Proponents of neighbourhood batteries need to determine who owns the land and whether a battery might fit with other land uses. Other considerations for siting of neighbourhood batteries include access, safety, amenity, cultural heritage and environmental issues, such as biodiversity, flood and fire risk. Victoria passed legislation for neighbourhood batteries to be exempt from planning approval. Some of these issues could potentially be avoided if neighbourhood batteries are included in the planning of new suburbs from the start.[14]

4.2 Motivations, expectations and values

One of the key considerations based on research that has been conducted on VPPs is the importance of understanding the motivations, expectations and values of people who decide to sign up to a VPP. Research conducted from Project Symphony indicated that participants were motivated to participate in the pilot project for costs savings, subsidies offered, environmental

[14] Personal communication, Dr Wendy Russell (13 June 2024).

reasons, community benefits (to help the grid), and to have energy independence and autonomy through energy arbitrage (storage for later use).[15]

The results of Project Symphony and the Bruny Island Battery Trial also showed that there was an expectation from participants to have battery back up in the event of a power outage (Boyle et al., 2023, pp. 101-102; Watson et al., 2019, p. 7). Participants of Project Symphony were not informed by Synergy at the outset of the pilot that the batteries were not configured to offer back up power and Synergy made the decision to not configure back up power on the batteries provided due to the additional costs of doing so. Research from 92 householders that took part in Victorian Ombudsman's Investigation of Consumer Experiences (VOICES), found that most householders were motivated by pro-environmental attitudes and a greater desire for self-sufficiency, resilience, community mindedness, enthusiasm for technology and comfort (Temby & Ransan-Cooper, 2021).

Ensuring that sufficient information is provided to VPP participants is crucial for understanding and to set expectations. The participants of Project Symphony had a conventional understanding and expectation that savings would accrue from having a home battery system, with excess solar generation being stored in the battery, and utilised by the household in the evening. This conventional understanding and expectation was also reinforced by the installer (Boyle et al., 2023, p. 55). However, Project Symphony orchestrated participants CER according to four scenarios (Figure 20) of the Wholesale Electricity Market (WEM) in WA. Participants were informed that their CER would be "orchestrated." A set of frequently asked questions included the testing scenarios described in Figure 1. Although this information was provided, due to the technical nature of this information and the lack of context for people about what the pilot was trying to achieve from an energy market perspective, the use of the term of orchestration did not describe what actually occurred, when it would occur, and what this meant for participants.

One of the testing scenarios, constrain to zero, restricted solar generation and export to the grid during the day. This occurred at the net level, so participants could continue to use their solar generation for household use. At times, constrain to zero also occurred at the gross level, leading to the importation of electricity from the grid on sunny days, which participants paid the flat rate A1 tariff of approximately 30ckWh[16]. This testing scenario did not match with participants expectations to reduce costs, or their expectations to participate in a project that was of benefit for the environment when they were importing grid electricity, instead of solar generation (Boyle et al., 2023).

Another testing scenario, termed energy services was utilising participants DER in response to wholesale electricity market prices. This meant that the aggregator was buying electricity when the wholesale price was low and selling when the price was high. From this testing scenario, participants noticed their batteries being charged from the grid, or exported to the grid at unexpected times, such as the middle of night or early morning. These occurrences were unexpected, and did not match with the expectations of participants to be able to utilise energy stored in their battery (Boyle et al., 2023, p. 50).

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[15] Energy arbitrage refers to purchasing (or storing) electricity at lower prices (or free) to store and use at a later time when prices on the network may be higher. For example, using stored solar energy from household PV in the evening.

[16] Synergy (2024) Synergy Home Plan (A1) tariff. https://www.synergy.net.au/Your-home/Energy-plans/Home-Plan-A1

This clash of expectations occurred as there was limited detail for participants of what they were signing up for with the VPP. Had participants understood that the aggregator would be utilising their household solar PV and batteries to buy and sell electricity on the market, according to pricing on intangible energy markets, they may not have signed up to participate. All participants of Project Symphony had existing solar PV and subsidies for home battery systems, and heat pump hot water systems were offered to some participants. Not all participants had batteries, some only had their existing solar PV signed up to the pilot.

Project Converge was a trial conducted in the ACT and included two streams: a technical demonstration of shaped operating envelopes (SOEs), and social research to understand participants experiences and expectations of SOEs. Dynamic operating envelopes (DOE) enable the allocation of network capacity for customers and aggregators. Offering DOEs assists with ensuring there is the ability to host increasing amounts of distributed energy, such as solar PV on the network (Scott et al., 2023). For Converge, participants were offered financial incentives to participate, but they were all existing battery owners and customers of the two aggregators, Reposit and Evergen. One aggregator offered a flat $200 incentive to participate, whereas the other aggregator offered a payment per kilowatt hour (kWh) for charge and discharge of the batteries (Jones et al., 2024, p. 40).

SOEs build on DOEs, but the intention is to include aggregators as agents for customer and essentially enables a more flexible approach to the capacity allocation approach of DOEs, based on the electricity needs of the household. For Converge, the algorithms directing the SOEs were optimised and prioritised for self-consumption (Jones et al., 2024). This contrasted with Project Symphony, where the self-consumption needs of participants was not prioritised, evidenced by the fact that when solar was being constrained at the gross level, participants were turning off appliances in their homes to avoid having to pay for the imported electricity.

In relation to values, findings from Converge found that some participants supported the ability of SOEs to include their perspectives to "reduce solar wastage" through maximising solar generation that could be "shared back to the grid" (Jones et al., 2024, p. 34). Project Symphony participants also maximised their solar usage during the day by using appliances such as washing machines and dishwashers when the sun was shining. The constrain to zero testing scenario inverted this relationship and some participants reported needing to shut down appliances they were running, to prevent importing electricity from the grid and paying for this.

4.3 Location and siting

The issue of location and siting of neighbourhood batteries is likely to be a key consideration for the broader ACT community. Chalaye et al. (2023) developed a site selection method for grid tied microgrids and this site selection method could also be extended (and adapted) for neighbourhood batteries, or indeed for VPPs. Chalaye et al. (2023, p. 9) note that if the site selection method is to be adapted, that consideration is given to specific technical risks and opportunities, as well as the local context.

The site selection method from Chalaye et al. (2023) involves the following four steps and the types of questions to be asked with site selection:

1. **Identifying objectives**

This step asks what the need is for the microgrid, or in this case, the need for a neighbourhood battery or VPP. This step also asks who are the key users?

2. **Establishing a process for site section**
   This step asks who is involved with determining site selection and what data is needed? At this stage, Chalaye et al. (2023, p. 5) include a set of criteria to asses vulnerability (elderly, low income, disabilities, etc), feasibility (i.e., penetration of solar PV) and socio-technical diversity (population size, non-English speaking households, etc.).

3. **Developing an output**
   This step is the development of a matrix combining the criteria identified in step two to assess vulnerability, feasibility and socio-technical diversity.

4. **Delivering an outcome for site selection**
   The final step is actual site selection and combines all former steps to determine the most appropriate site for the infrastructure (Chalaye et al., 2023, pp. 4-6).

There are potential benefits for the ACT Government to adopt a similar site selection method. For example, the first step to identify the objectives will also assist in understanding who the key users will be. If the objective is to avoid network spending, then a VPP may not be the optimal approach as discussed, as DNSPs are unlikely to rely on VPPs to avoid network spending. The fundamental starting point is for the ACT Government to identify what the objective of having neighbourhood batteries or VPPs is and to determine the needs of the community or the network and who will be the key users or beneficiary of these system. Using the site selection method also has a higher likelihood of identifying equity issues and has the potential to reduce the likelihood of exacerbating or entrenching inequality and disadvantage (Sovacool, 2021; Sovacool et al., 2019).

Location and siting of batteries was a key theme that emerged from the Big Canberra Battery workshop with participants discussing how batteries could be located in areas with high electricity demand, such as the light rail line, data centres, hospitals or schools (BSGIP, 2021). Opportunities for vehicle to grid (V2G) services was also raised at this workshop. V2G is defined as the discharging of an electric vehicle (EV) battery to serve a secondary purpose, such as managing energy within a household, a building (with multiple customers) or by discharging to the electricity network (Jones et al., 2021).

Location and site selection are also critical for community acceptance, particularly for neighbourhood batteries as they are located where people live, therefore having social impacts that can be positive or negative (Russell et al., 2023, p. 7). Local government participants in Victoria also indicated that there needed to be a focus on identifying what a battery is trying to deliver for the community.[17] This goes back to identifying the objectives and key users to any neighbourhood or VPP project.

For VPPs homes need to be retrofitted with home battery systems, inverters, gateway devices and high-speed data recorders. It was observed with Project Symphony that there was an extensive amount of equipment installed in residential garages. Bollards were also installed in

[17] Interviews conducted as part of as part of research funded by the Victorian Government's Neighbourhood Battery Initiative in 2022.

residential garages for Project Symphony as a safety measure. There are also physical space limitations with the amount of equipment that is required, and smaller housing is likely to be unsuitable for VPPs, thus hindering some people from being involved.[18] Project Symphony provided recommendations that housing quality, type, tenure and space needs to be understood as a critical factor for social equity when considering future VPP projects (Boyle et al., 2023, p. 147).

4.4 Equity

Issues of equity and justice in energy transitions are a significant concern for the energy humanities, broader community and social welfare advocacy groups, with scholarship on energy justice and equity increasing (Bouzarovski et al., 2017; Fell et al., 2020; Golubchikov & O'Sullivan, 2020; Roberts et al., 2023; Sovacool et al., 2019). Sovacool (2021) provides a political ecology framework for describing power relations and vulnerabilities with climate change mitigation using the concepts of exclusion, enclosure, encroachment and entrenchment that operate on the political, economic, ecological and social dimensions respectively. The focus in this section is the issue of entrenchment that operates on the social level, with the potential for energy transitions to worsen inequality and entrench disadvantage.

The use of solar and battery systems is an example of entrenchment where this technology is not accessible to all groups in society and has the potential to worsen inequality. This is also exacerbated where government funded incentives are offered, but in reality, these incentives and subsidies are most often only accessible to those who are homeowners, and for people who have the financial means to invest in household solar, home battery systems and energy efficiency retrofits (Willand et al., 2020).

For this report, we do not have income or home ownership data for people who received subsidies through the NextGen Energy Storage Program and the SHS loan program, however, it is likely that the majority of the recipients would be homeowners and are more likely to be on higher incomes. All participants of Project Symphony, Converge and the Bruny Island trial were homeowners, with existing solar PV systems and over half of the participants had an annual income of over $150,000. A smaller percentage (6%) of participants had income levels less than $50,000 (Boyle et al., 2023, p. 5). The majority of participants were also male (68%). In addition, several participants were in credit on their electricity bill due to previous high feed in tariffs for their solar PV and the generous $400 credit provided on electricity bills for all residents of WA over two years. The majority of participants were also not at all concerned about paying their electricity bill (Boyle et al., 2023, pp. 98-99).

For people in the ACT who are not home-owners, who may be renters or on low incomes, the ability to reduce their electricity bill through the use of solar PV and batteries is very limited. This is an issue of access, and it also has the potential to further entrench disadvantage over time if subsidies continue to be offered for home battery systems, essentially excluding non-homeowners or those who cannot afford it. In discussions with Evoenergy in preparation of this report, they noted that the Ginninderry project in the ACT did not go ahead, as most of the homes were tenanted, and not owner-occupied. The owners of the homes were offered a

[18] Personal communication with Dr Phillipa Watson (7 June 2024)

battery system for a $2000 upfront cost, yet this was rejected by the owners, as they would not benefit from the investment.

For the Converge trial based in the ACT, participants expressed values relating to "equity, justice and collective care" wanting to ensure that "no one is left behind in the energy transition" (Jones et al., 2024, p. 54). There was also a desire from DER owners to be able to share their excess generation with their community. This finding is also consistent with other research that has found the public is interested in community batteries, due to perceptions that it enables energy sharing and local benefits (Ransan-Cooper et al., 2022; Russell et al., 2023, p. 7).

Householders that participated in Converge also questioned the individual approach of promoting distributed energy systems and considered the full lifecycle of batteries, and the rare earth minerals needed to produce them (Jones et al., 2024, p. 58). This desire is not entirely unique to the ACT with many participants of Project Symphony also wanting to contribute to the greater good and questioning the resource intensiveness of critical minerals needed for batteries (Boyle et al., 2023, p. 80).

It appears there is therefore a clear desire among the ACT community to ensure that the energy system is equitable and of benefit to the environment. We understand the ACT Government does not have a strong desire to offer further home battery subsidies and we would agree with this approach, given the equity considerations noted above. As also noted, we would recommend caution for residents who may wish to sign up to a VPP with existing solar PV and home battery systems under the SHS loan, due to the general lack of clarity around financial benefits from participating in VPPs, which are likely to be exacerbated when payments are still being made on these systems. However, some recipients of the NextGen rebate and the SHS did participate in Project Converge (Jones et al., 2024, p. 56), so it may be useful to further understand any specific equity dimensions of participants who received the SHS loan and who signed up to Project Converge if the ACT Government wishes to pursue VPPs, without offering further subsidies.

South Australia implemented VPPs for public housing and this has some beneficial outcomes for public housing tenants in achieving lower bills. The public housing tenants in SA are still required to pay for every kWh of electricity they use, but they have a guaranteed lower tariff and reduced daily supply charges, hence lowering their overall bill.[19] We are not aware of any significant social research that was conducted or publicly available on how the VPP is perceived by public housing tenants. From previous discussions with the SA Government however, there were lessons learnt from the implementation of the VPP in public housing, particularly with the complexity of the information and contracts provided and the ability of public housing tenants to sign up to the VPP due to this complexity.[20]

Recent work from BSGIP researchers on the evaluation of impacts of neighbourhood batteries also found that "impact assessments are best done if they emphasise enhancing the lives of vulnerable and disadvantaged people" (Russell et al., 2023). There may be opportunities for neighbourhood batteries to contribute to equitable outcomes, however they may not be easily

[19] Energy Locals (2021) SA Virtual Power Plant FAQs. https://supportcentre.energylocals.com.au/hc/en-au/articles/4410261559961-SA-Virtual-Power-Plant-FAQs

[20] Personal communication with the Department for Energy and Mining SA.

quantified. The ACT community may however value these equitable outcomes more than the revenue that can be gained from neighbourhood batteries (Russell et al., 2023, p. 7).

For neighbourhood batteries, there is an opportunity to apply and adapt the site selection method (Chalaye et al., 2023) when deciding on an approach for the ACT. Using this method will assist in identifying the objectives of storage for the ACT, understand what the needs are, and who the beneficiaries are. This approach is likely to assist the ACT Government to give full consideration to the various options or models and there may be opportunities to address issues of equity using the site selection method.

4.5 Hot water as storage

The use of household gas in the ACT for cooking, heating and hot water is showing moderate decline as gas appliances are being converted to electricity and gas connections are limited in new dwellings.[21] Electrification of residential hot water requires technology, such as a load control devices to enable flexible demand. Many electric hot water systems in the NEM already include off peak controlled load, but the off-peak controls are set at night, when traditionally there was less demand. Several technology options exist to enable flexible demand for hot water and are discussed further in Roche et al. (2023, pp. 26-27). With the shift in off peak to the middle of the day in the ACT and across Australia, enabling flexible demand for electric hot water is an opportunity to address issues such as minimum demand, by utilising excess solar generation for water heating in the middle of the day.

Recent modelling was undertaken by BSGIP researchers to determine the feasibility of a community battery in the Victorian town of Yea. The modelling found that Yea remained on an off-peak tariff from 11pm to 7am for hot water, similar to many regional towns in Australia that are not on the reticulated gas network.[22] This off-peak tariff, resulted in peak electricity demand from 11pm to early morning, rather than the usual evening peak that occurs in metropolitan cities. The modelling found that if hot water was shifted to the middle of the day under ideal conditions, the need for battery storage was greatly reduced. The modelling also found that under off-peak tariffs for solar generation, households were mostly better off financially if they shifted their hot water heating to the middle of the day.[23] BSGIP researchers are also currently modelling the impact of heat pump hot water systems, with storage to understand the optimal mix for the ACT network.

5. Conclusions and considerations for the ACT Government

This report has provided considerations for the ACT Government to inform their approach for storage in the ACT. The report started with the understanding from discussions with the ACT

[21] Point Advisory (2023) ACT Greenhouse Gas Inventory for 2022-23. https://www.climatechoices.act.gov.au/__data/assets/pdf_file/0003/2329824/ACT-Greenhouse-Gas-Inventory-Report-2022-23.pdf. p.8

[22] Shaw, M., Ertler, W., Bardell, L. (2023) Solar hours heating redefining regional battery storage requirements. https://bsgip.com/news-events/news/solar-hours-heating-redefining-regional-battery-storage-requirements/

[23] Ibid.

Government that storage options are being considered due to the policy of electrification and the transition away from gas by 2045. The ACT Government also recognise the role of increasing household solar and its contribution to minimum demand, with a desire to avoid costly network upgrades for the ACT community.

The modelling conducted as part of this report provides a comprehensive simulation of various scenarios that included a baseline scenario of no batteries, neighbourhood batteries, VPPs and uncoordinated household batteries. The simulation has been done based on three different purposes or priorities for the different configurations (NBs, HBs and VPPs) noted above. The priorities modelled include:

- Financial benefits - lower wholesale electricity costs and network charges
- technical benefits - reducing daily import and export peaks
- solar utilisation benefits – improving solar self-consumption at the local network level (thus reducing solar export to the grid) and the self-sufficiency rate, which is the amount of solar generation that is self-consumed by the household.

The modelling shows that all battery scenarios can reduce wholesale electricity and network costs, but neighbourhood batteries and VPPs provide the most cost reductions in comparison to uncoordinated household batteries. All batteries can also improve solar utilisation and they all achieved similar outcomes for this. In relation to technical benefits (through the stabilisation of import and export peaks), neighbourhood batteries and VPPs can reduce or increase these peaks depending on whether they are optimised to increase revenue from wholesale market participation or not. Optimising for market participation tends to maximise charging during low wholesale prices and maximise discharging during high wholesale prices. Optimising in this way does not necessarily reduce import peaks.

The modelling also shows that VPPs perform better than neighbourhood batteries on reducing costs and peak demand by a small margin (Figure 14 -- Figure 16). However, it is noted here that the modelling is based on “perfect orchestration”, which assumes full control of householders solar PV and battery systems. Perfect orchestration is imperfect and impractical when factoring in household needs, and motivations for participating in a VPP. As described in section 4, Project Symphony relied on full control of householder solar PV, batteries and for some participants their heat pump hot water system and air conditioners. There were fewer participants who had heat pump hot water systems and air conditioners connected and the majority of participants who expressed negative sentiment in the pilot towards orchestration, were those who had battery systems installed.

The complexities of achieving perfect orchestration for VPPs has been discussed in this report, as it relies on householders agreeing to their solar PV and HBs to be externally controlled by an aggregator. This was challenging for participants of Project Symphony, largely due to it being unexpected, not visible and not communicated well. Perfect orchestration also clashed with participants expectations for self-consumption and storage of excess solar for their own use in the evening. Participants household assets were operated on the wholesale electricity market, but this was not visible for people, and therefore the actions were not logical, particularly when participants solar PV was completely constrained, requiring the importation of grid electricity.

Like Project Symphony, Converge also found that households value self-consumption of their solar PV, and there is an expectation with HBs to be able to store excess solar generation to utilise in the evening, thus saving household electricity costs.

Other challenges discussed in this report relating to VPPs is the amount of equipment that needs to be installed in residential homes. This is discussed in further detail in section 10 of the Project Symphony social research report.[24] Installing the devices that were required for VPP participation in homes was incredibly expensive for the WA Government and our research found that 40 percent of participants wanted the orchestration devices removed at the end of the pilot (Boyle et al., 2023, p. 91).

There are also considerable social equity considerations when deciding on an approach for the ACT. As noted in section 4.4 of this report all participants of Project Symphony, Converge and the Bruny Island Trial were homeowners. For Project Symphony the majority of participants were also high-income earners. It may be possible to achieve equity outcomes with VPPs, and the South Australian VPP installed on Housing SA properties at no cost to tenants may be a good example of this. However, this particular program is unique, and social research on this program has not been conducted, so we are unable to evaluate the benefits of this for tenants.

The results of the modelling and simulation in this report shows an ability for both VPPs and NBs to reduce wholesale electricity costs and network charges. However, the difference in reductions for network charges between VPPs and NBs is very small (Figure 13), and the cost to implement a wider VPP program, should be balanced against the potential gains for bill reductions for the wider ACT community. As also noted in section 2.2, DNSPs are unlikely to rely on VPPs to reduce their network spending, as VPPs are seen as being unreliable for network stability.

As NBs also reduce network charges, wholesale electricity costs and improve solar utilisation, we would recommend that the ACT Government consider neighbourhood batteries over further subsidising home battery systems, either uncoordinated or as part of a VPP. Neighbourhood batteries may also provide opportunities to address equity, whereas subsidising further home battery systems may have the opposite effect of entrenching further inequality. The results from Converge discussed in this report also indicate that the ACT community want an equitable energy system that is of benefit for the environment. The ACT community also questioned an individualised approach to distributed energy and expressed concern about the lifecycle of batteries, particularly the use of rare earth minerals, which was also a concern for participants of Project Symphony.

It is therefore recommended that as part of the next steps for the ACT Government, that the site selection method (Chalaye et al., 2023) as discussed in section 4.3 is undertaken, starting with identifying the objectives, needs and key users. The site selection method can be adapted for neighbourhood batteries and potentially for VPPs. Community research can also be conducted as part of this site selection process to understand community needs, perceptions, vulnerabilities and diversity to assist in determining the optimal approach for storage in the ACT. The site selection method will assist the ACT Government to clarify the objectives for storage, assess equity, and determine the most appropriate site and configurations for battery infrastructure in the ACT.

[24] Refer to Boyle, M., Watson, P., Soh, J., Lovell, H., & Jones, L. (2023). *Project Symphony social research report. Work Package 3.3* [Report]. https://arena.gov.au/assets/2024/03/Western-Power-Project-Symphony-Social-Research-Report.pdf. pp.74-96.

Appendix

Table 2 Full details of simulation methodology

1. Battery specs	Neighbourhood battery: capacity = 200 kWh, power = 100 kW, Household battery: capacity = 10 kWh, power = 5 kW Common specifications: round-trip efficiency = 0.85, depth of discharge = 90%, maximum daily cycle = 1 Note: the power is the maximum charge/discharge rate for both battery types.
2. Battery scheduler	Gurobi solver and our in-house battery optimisation software echo.
3. Battery operation mode	Given the wholesale spot prices and the network tariffs, the batteries were optimally charged and discharged to achieve the following objectives: 1) Solar soaking: Charge during solar hours and discharge during the evening peak demand periods, to minimise the import and export power of the local network (including all households and the NB) for each day. 2) Cost minimisation: Charge at times with low wholesale prices and discharge at times with high prices, to minimise the costs of all households and the NB. 3) Balanced: Seek the best balance between the needs for solar soaking and cost minimisation.
4. Load and PV data	The simulation utilized a cleaned subset of the 2018 NextGen dataset for Canberra (Shaw et al., 2019), containing historical load and solar output measurements. Following a positive load, negative loads, positive solar PV data, and days with sparse or discontinuous data were excluded (Shaw, Sturmberg et al. 2019). Load profiles and PV outputs at 5-minute intervals were then assigned to each household in the network.
5. Energy prices	Historical NSW spot prices from 2022 were used.
6. Network tariffs	Trial network tariffs, proposed by Evoenergy for community batteries and residential households with batteries, were utilized in the simulation.
7. Analyse results based on evaluation criteria	The design criteria for evaluating the financial, technical and solar benefits of different battery scenarios: 1) Technical benefit: The maximum and average daily import and export peaks of the local network (encompassing all households and the neighbourhood battery). 2) Solar benefits: a) Solar self-consumption (SSC): The proportion of local solar generation consumed within the local network (by households and the battery) rather than exported to the grid. b) Self-sufficiency (SS): The proportion of local demand satisfied by local generation within the LV network, as opposed to imported energy from the grid. 3) Financial benefits: The total cost incurred by all households and the neighbourhood battery, comprising wholesale energy costs and network charges.
8. Simulation time horizon	The optimisation of battery operation was performed for each individual day until all days in 2022 had been simulated. The optimisation assumed perfect forecasting. Realistically, imperfect forecasts will result in diminished battery performance outcomes.

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