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Fitzroy North Community Battery

Year 1 Performance Report, FY22-23

— July 2023

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The Fitzroy North Community Battery was implemented with funding provided by the Victorian Government’s Department of Environment, Land, Water and Planning (DELWP; now DEECA) through the *Neighbourhood Battery Initiative* program

The project included significant contributions from a group of dedicated partners: the City of Yarra, CitiPower, the Australian National University’s (ANU) Battery Storage & Grid Integration Program (BSGIP), Pixii, Acacia Energy, Ventia, Mill Software, Polarium, the Department of Energy, Environment and Climate Action (DEECA; formerly the Department of Environment, Land, Water and Planning [DELWP]), and the Community Reference Group.

YEF have operated the battery in partnership with Acacia Energy, Mill Software, and ANU’s BSGIP. YEF expresses our sincerest gratitude to everyone involved and acknowledges the countless hours of in-kind work to support this project.

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We acknowledge Aboriginal and Torres Strait Islander people as the Traditional Owners and custodians of the land and water on which we all rely. We acknowledge the Wurrundjeri Woi Wurrung peoples as the custodians of the land on which the Yarra Energy Foundation is based.

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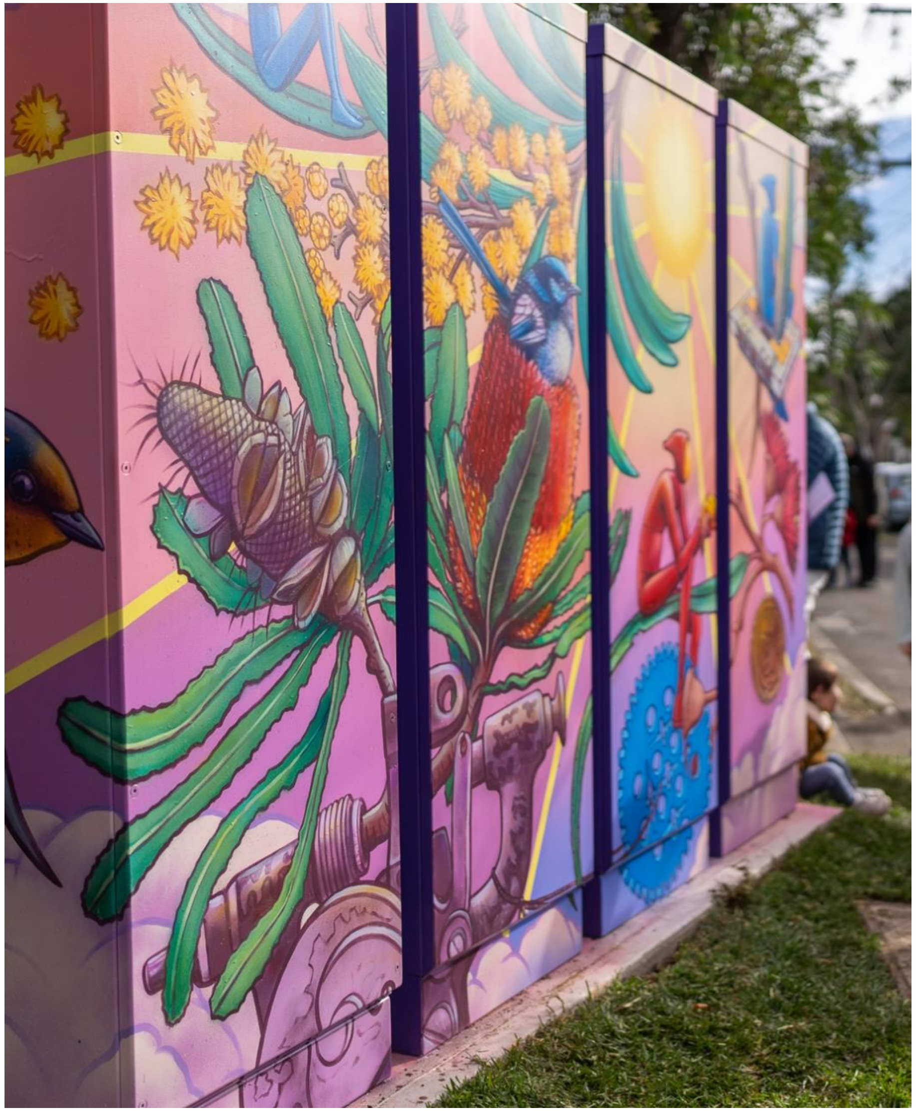
1. Executive Summary

The Hon. Lily D'Ambrosio (Minister for Climate Action, Energy and Resources, and the State Electricity Commission) launched the Fitzroy North Community Battery (FN1), a 120kW/309kWh Pixii PowerShaper, on 5th June 2022 – World Environment Day. The battery is located at 193-205 McKean St, Fitzroy North in Melbourne's inner-north suburbs. The project was funded by the Victorian Government's *Neighbourhood Battery Initiative*.

FN1 has a simple operating model of trading on the electricity market (arbitrage) through retailer/aggregator Acacia Energy, the Financially Responsible Market Participant of the system. FCAS market participation is expected to be enabled in the second half of 2023.

The software to dispatch the system was developed by ANU's Battery Storage and Grid Integration Program (BSGIP). It was integrated with the battery system and to Acacia Energy's systems by Mill Software. CitiPower introduced a trial tariff for community batteries that became effective 1st July 2022. This tariff is bi-directional and allows the battery to earn an income by charging and discharging at times that support the network.

YEF's daily dispatch rules vary slightly through the year but generally consist of charging from 11am to 4pm, discharging from 5pm to 9pm, idle overnight, and at times, a residual discharge in the morning peak.



1. Executive Summary

The year in review

In June and July 2022, FN1 was unable to carry out automatic dispatch due to issues with panel configuration, protection and control settings, and software defects.

From August 2022 to early 2023, FN1 adopted a more predictable behaviour, and the team experimented with various ways to improve performance. ANU's optimiser software was held back by the limitations of the price forecast from AEMO. Instead of an optimiser, the system uses a rules-based 'Scheduler' which operates by YEF's dispatch rules (see section 2.1).

From early 2023, FN1 became a lot more stable and the last 3 months reached a steady state of operation.

Voltage regulation: The voltage dropped by 2-3V in daytime when excess solar is exported and rose by the same amount at night during the evening peak.

Roundtrip efficiency: The average efficiency was 81.5%, with an estimated 88% for converter and storage efficiency. The difference is mainly caused by heating and cooling of the panels, i.e., parasitic loads.

Continued improvement: The YEF team continues work on reducing the state of charge variability, tuning roundtrip efficiency, enabling FCAS, and enabling ANU's Optimiser.

Revenue performance

In the first year, there were two sources of revenue: energy arbitrage and revenue from CitiPower's bidirectional community battery trial tariff.

In total, FN1 made $7,864 from energy arbitrage and $1,329 through network tariffs, for a total of **$8,417** ex-GST (after metering and market charges). It was unable to profit from the high volatility and frequent peak prices during June and July 2022.

Perfect foresight comparison: Disregarding the first two months, FN1's revenue was 50-58% of what was possible using 'perfect foresight', depending on the dispatch rules. For the full year, FN1 revenues could have been $19,361 and $22,840, respectively.

Operating expenses: Each of YEF's partners contributed significant in-kind work and offered low annual fees, not expected to be common to future systems. Section 4.3 indicates the main cost centres of a BESS.

Decarbonisation and the energy transition: FN1 supports decarbonisation in a variety of ways, although its operational emissions impact is difficult to ascertain given its scale and the way generation is dispatched within the NEM.

YEF has concluded that FN1's broader contribution to decarbonisation is more significant than its operational emissions impact, as FN1 shows a path for future systems to time shift variable renewable energy generation to peak demand periods, and as this form of generation becomes dominant in the NEM.

A critical mass of load-shifting community batteries – especially when scheduled – could hasten the exit of coal generation.

2. Background

2. Background

On June 5th, 2023, the Fitzroy North Community Battery (FN1; Fitzroy North 1) celebrated its first birthday and one year of operation. This report is both a celebration of the project's achievements and a resource for other community battery proponents.

Funded by the Victorian Government's first *Neighbourhood Battery Initiative* funding round for implementation projects, FN1 is the first inner-urban community battery in Australia not owned or operated by a distribution network service provider (DNSP). The project was delivered in partnership with CitiPower, the City of Yarra, Acacia Energy, Pixii, the Australia National University's Battery Storage and Grid Integration Program (BSGIP), Mill Software, and Ventia. In the twelve months since commissioning, YEF and project partners have continued to monitor and improve the system's performance. See also the project's final report.

FN1 is a 120kW / 309kWh Pixii PowerShaper featuring Polarium battery modules rated at 52VDC and NorthVolt Li-ion NMC (Nickel-Manganese-Cobalt) cells produced with 100% renewable energy and are 95% recyclable.

The front of FN1 faces a wall with its back to the street and painted by Hayden Dewar, a local artist selected by the project's Community Reference Group. Three panels are for converters and storage modules; the fourth is a combined meter panel / switchboard also housing a 'site controller' with 4G modem: the component that transmits signals between the cloud software and the battery panels.

FN1 was originally procured as a 110kW / 284kWh BESS but due to panel imbalance, was upgraded in October 2022 with hardware generously donated by Pixii (indicated in orange in figure 1).

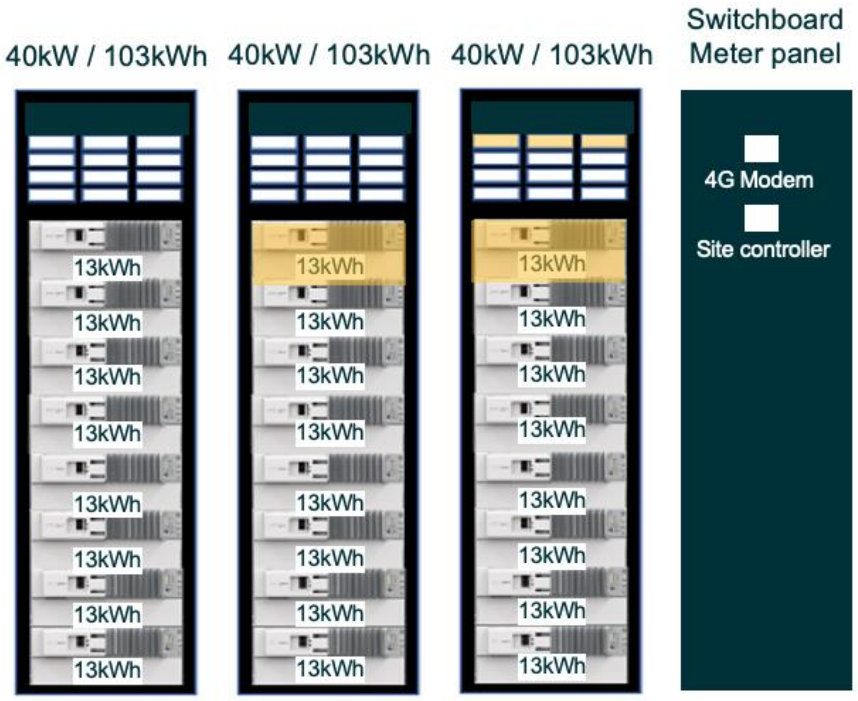


Figure 1. Battery module and converter make-up of each cabinet

2. Background

2.1. Outline of operating model

FN1’s operating model is intentionally simple, although the early intention was different (see the project’s final report). On 1 cycle/day the BESS charges at peak solar generation when prices are typically low and discharges during the evening peak demand period when prices are typically high.

YEF’s objectives for FN1 are to demonstrate that LV-connected community batteries are commercially viable, to support decarbonisation and the network, to encourage community involvement and to promote social equity.

To participate in the energy market, YEF partnered with Acacia Energy to aggregate FN1 with other assets up to 1MW. As our Financially Responsible Market Participant, Acacia Energy allows FN1 to trade on the electricity spot market.

The Battery Control System (BCS), developed by ANU and hosted and integrated by Mill Software, receives AEMO prices and forecast prices from Acacia Energy and creates the dispatch schedule for every 5 minute interval. Originally designed to be an Optimiser, it is currently a rules-based Scheduler.

The dispatch signals are sent back to Acacia Energy in the form of power commands to FN1’s site controller and FCAS bids to AEMO.

YEF is the first recipient of CitiPower’s bidirectional ‘Community Battery Trial Tariff’. Per kWh, charging from 10am to 3pm is rewarded by 1.5 cent, and discharging between 4pm and 9pm by 1 cent. However, charging from 4 to 9pm will cost 25 cents.

The resulting YEF dispatch rules are:

- Charging from 11am to 4pm at 50% power capacity to charge for a longer period. And if the price is lower than $300.
- Discharging from 5pm to 9pm at 50% power capacity, if the price is positive.
- Discharging any residual energy from 6am, if the price is positive.

These settings change slightly through the year in line with shifts in wholesale price patterns, daylight savings and the movement of the sun.

Table 1. CitiPower's community battery trial tariff

Time band	Fixed (cents/day)	Import rate (cents/kWh)	Export rate (cents/kWh)
10am – 3pm	45	-1.5	0
4pm – 9pm		25	-1.0[1]
All other times		0	0

2. Background

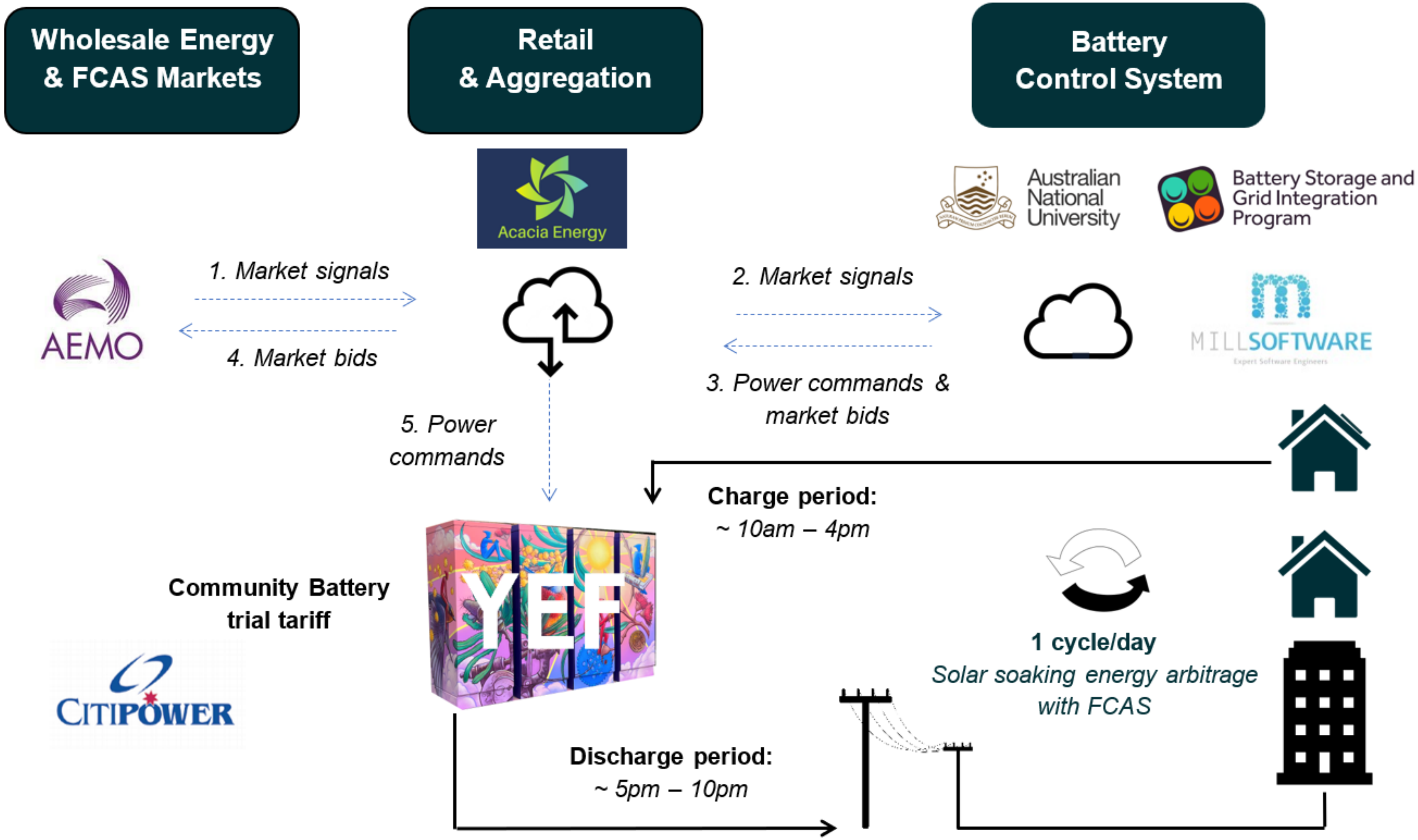


Figure 2. Fitzroy North Community Battery operating model

3. Operations and Technical Performance

3.1. Summary of year 1

The first year of operation was a steep learning curve about battery hardware, its functions, modes and settings, as well as the electricity market and how to operate a cloud-based dispatch software platform. It can be characterised by three successive phases:

Early Days (June - July 2023): After a successful launch, operation was quickly beset by complex, coupled issues that were therefore difficult to understand and isolate. This was also a time of great price volatility including a market suspension for two weeks. Unfortunately, FN1 was unable to benefit from peak prices.

Learning by Doing (August 2022 – early 2023): Having successfully managed to dispatch the BESS, unexpected behaviours surfaced leading the team to experiment with different dispatch rules and settings, while seeking to resolve an ongoing list of defects (see sections 3.2 – 3.4).

Toward Steady State (early 2023 to June 2023): As FN1's performance became increasingly stable, the team's focus shifted to fine-tuning the system by modifying parameters and working with Pixii to better understand operating modes.

Although our operating model was simple, the software stack was not so simple. Dispatch signals travel from the BCS Scheduler to the Mill integration layer to Acacia's software platform to the site controller to the Pixii Gateway, and back.

The ANU optimiser was developed but struggled with the AEMO forecast price feed – which is a generator bid stack. Being too imprecise, we had to resort to a rules-based dispatcher.

The last 5 months were also marked by successive delays in AE's FCAS DUID registration due to administrative procedures at AEMO.

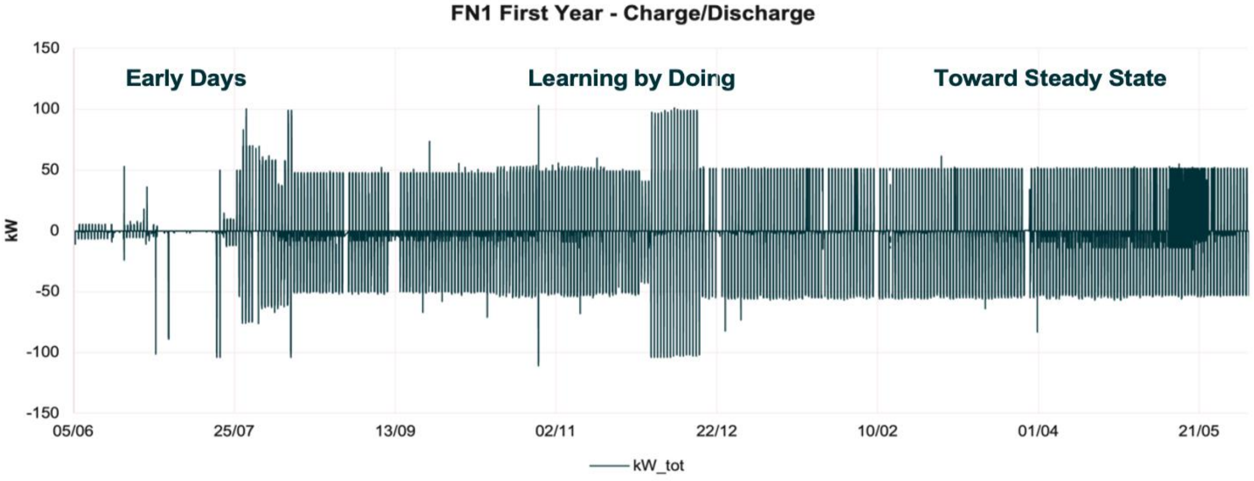


Figure 3. Overview of FN1's first year of operation – dispatch power

3.2. Early days (June-July 2022)

The early days were marred by technical challenges, the most prominent of which are reviewed below:

- **BESS panel misconfiguration**: A multi-panel Pixii PowerShaper is designed to operate with one master and several clients. The panels were not collaborating at first until a firmware upgrade resolved the problem.
- **Incorrect protection relay specification** for two reasons:
  - It had no communications capability so there was no way to know the cause of a trip without going to site.
  - It would only trip on voltage and frequency – current trips were initiated by the circuit breaker but without event logging.
- **Nuisance trips on frequency**: at one stage, the main breaker experienced “166 trips in 29 days”, shutting down the system until the frequency normalised. Having at first suspected a real grid problem, it was solved by a slight change of the relay settings.
- **Software stack not fully integrated**: corner cases led to active defect resolution from dispatcher to Modbus interface.
- **Losing charge overnight:** Due to parasitic loads such as air conditioning and heat exchange, these loads were such that the battery could not keep its charge overnight. The problem was exacerbated by a recalculation of the SOC when the current dropped below a minimum threshold, which changed the SOC and prompted a forced charge.
- **Dropped Modbus signals**: The Modbus interface between the site controller the PowerShaper Master panel lost signals at times causing the BESS to temporarily go idle. This defect was finally fixed by boosting the signal refresh rate to 1/sec.
- **Instability at low levels**: if the power command was very low, e.g., 10%, instability was observed in the AC/DC conversion and at times caused the system to switch off.
- **Optimiser delays**: “The forecast is gospel” for an optimiser, but if the forecast is imprecise, optimisation is ineffective and hence the team resorted to a simple Scheduler.
- **Firmware upgrades** could disrupt a function and cause other defects.
- **Misconfigured alarms** resulting in excessive amounts of low-level alarms and missing critical ones.
- **FCAS delays**: The service could not be enabled due to post-COVID supply chain disruption and administrative issues with AEMO.

It also took time to understand how to properly configure the rules-based Scheduler, considering time interval constraints, price thresholds and adjusting power levels to dispatch duration required to cover peak solar generation and peak demand periods.

3.3. Learning by doing (August 2022–early 2023)

The next phase benefited from a functioning system, albeit still with issues needing urgent resolution.

Jagged end of charge: balancing panels

The system initially had power and storage capacities of 110kW and 284kWh, respectively, but unevenly distributed among panels. This led to different DC voltages in the 3 panels when the current was reducing at the end of charge.

The Master panel received differing SOC signals from the other panels causing a hysteresis in panels starting and stopping– seen as a jagged dispatch power curve (see figure 4). In late October, Pixii resolved the issue by very graciously upgrading the hardware to evenly configured panels, totaling 120kW/309kWh.

Charging curtailment: preventing cell overcharging

Many BESS are operated between a nominal range of 20% and 80% SOC and sized above their rated capacity. Pixii storage is not oversized and YEF have sought to maximise the depth of discharge from 10% and 90%. This led us to discover boundary conditions such as curtailment.

The DC bus is rated at 51.2V DC with a maximum charge voltage of 57.4V at 90% SOC. Curtailment (see figure 5) is due to the DC voltage becoming constant to prevent overcharging the battery, which limits the power (i.e., the current). Originally, the system's charging power began de-rating from 75% SOC. This has now improved and there is no curtailment until 83% state of charge.

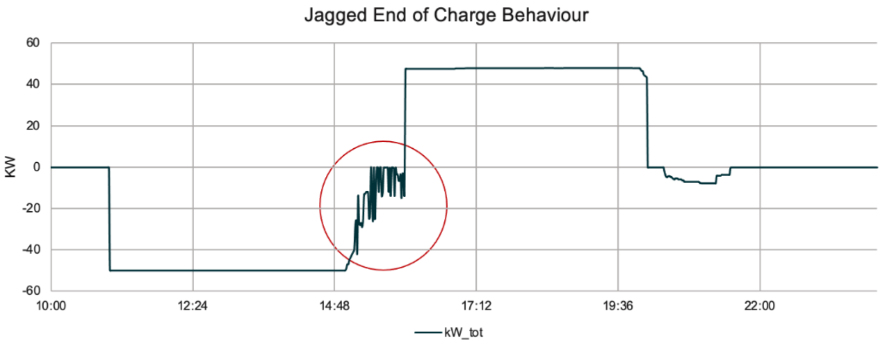


Figure 4. Fluctuating power due to unbalanced cabinets

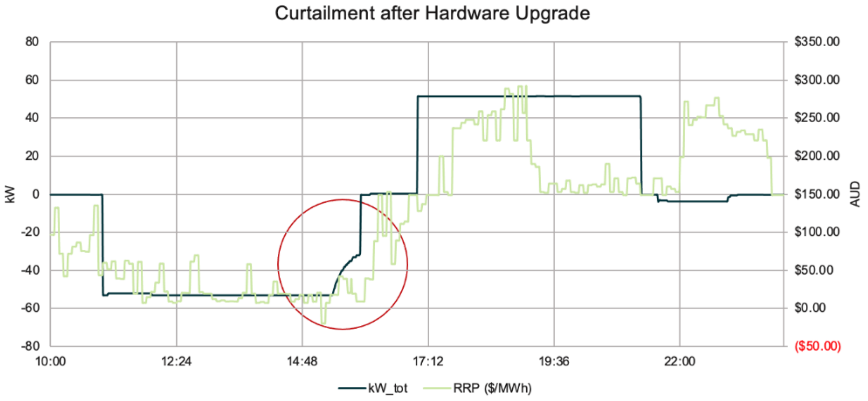


Figure 5. Smooth but curtailed power at high SOC

State of charge (SOC) recalculation

In the previous graphs (figures 4 & 5, p. 14), shortly after the end of the discharge, a very low power charge can be seen. This is a forced charge imposed by the BESS when the SOC falls below 8%. The implication for the SOC can be seen in figure 6 (right).

The cause of this behaviour is the way the Polarium batteries estimate the SOC by two different methods. At the end of discharge, as the current is very low, the Polarium BMS does a recalculation by a second method causing a SOC step change, which in turn can lead to a forced charge.

An upgrade to the firmware confirmed that the recalculation will always take place but allowed it to be much reduced. A lower recharge current further reduced the SOC variability by not triggering the BMS to use the first calculation method.

Roundtrip efficiency and parasitic loads

The charge and discharge rates per month indicate significant consumption by the BESS, resulting in total roundtrip efficiency for the year of 81.5%.

The estimated roundtrip efficiency of the converter and storage modules is 88.5%. However, this number is reduced by the air conditioning and heat exchanger, so-called parasitic loads. Expectations are that this will improve with low current auto-charging configuration overnight and tweaking the air conditioning settings to prevent over cooling.

Tuning parasitic loads remains a priority for the project. Pixii is also looking to alter future designs for enhanced efficiency.

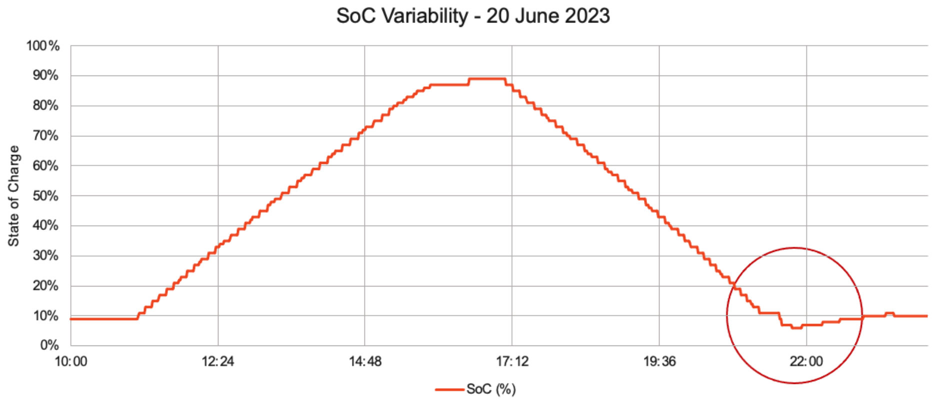


Figure 6. State of charge recalculation at end of discharge cycle

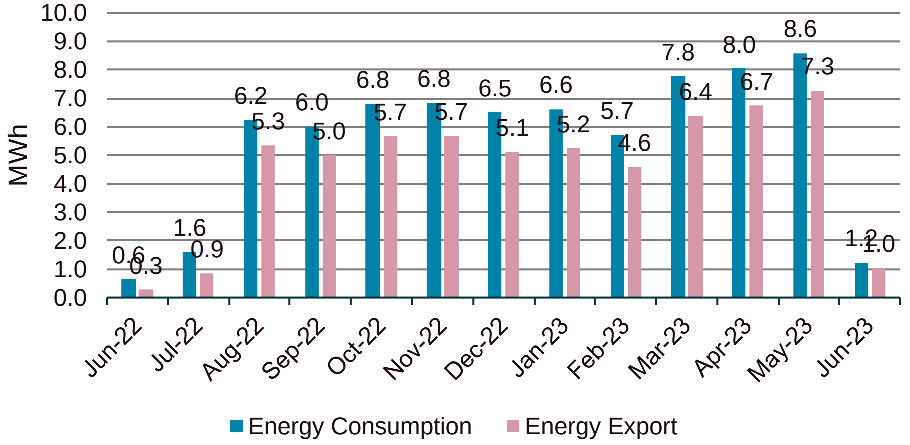


Figure 7. Total energy imported and exported each month

3.4. Towards steady-state operation

YEF remains active in resolving outstanding issues to improve dispatch performance and revenue.

Reducing state of charge variability

The state of charge variability is one of the more persistent challenges YEF is facing. The measured SOC can vary by ~5% depending on whether the system is charging or discharging.

It is of particular concern as accurate measurement of stored energy is critical to ensure there is sufficient energy overnight to respond to frequency excursions and provide FCAS.

Improving roundtrip efficiency

The roundtrip efficiency of the BESS is largely determined by the efficiency of the following energy transfers: Converting AC current to DC, storing and discharging energy, converting DC current to AC, and parasitic loads.

Continued effort is seeking to improve efficiency from currently observed 81.5% to the converter and storage theoretical limit of 88.5%.

FCAS enablement

YEF hope to begin offering FCAS soon.

Optimiser enablement

The AEMO forecast is currently limiting the implementation of the ANU-developed Optimiser. However, YEF remains committed to working with ANU through current and future projects to implement a forecasting facility that can allow for a higher performance than currently possible with the rules-based Scheduler.

The public dashboard

FN1 performance is always visible at https://yess.community/fn1/dashboard, as shown below. YESS is the acronym for Yarra Energy Storage Systems.

3.5. Evaluation of ancillary benefits

Voltage regulation

FN1 provides voltage regulation by lowering the voltage (measured at the connection point) when charging during the day and solar energy is exported, and by raising the voltage when discharging as the evening load peaks.

Figure 8 (right) shows the average daily voltage pattern over the past year.

In the catchment of FN1, the red phase shows a higher load than the other phases. FN1 begins the charge period at half capacity of 53kW, and the voltage drops by 2.5V. It rises by the same amount as FN1 begins the discharge period.

Other benefits

It is understood that FN1 reduces peak demand every day by 53kW by YEF’s dispatch rules.

Since 5/6/22, three new solar arrays were installed but may be unrelated, there was no transformer reverse flow, and no reduction in curtailment (which requires a customer request).

It can be noted that the voltage of the three phases hovers around 240V, although the nominal for Australia is 230V. The difference of 10V represents a higher consumption of electricity, energy cost and greenhouse gas emissions.

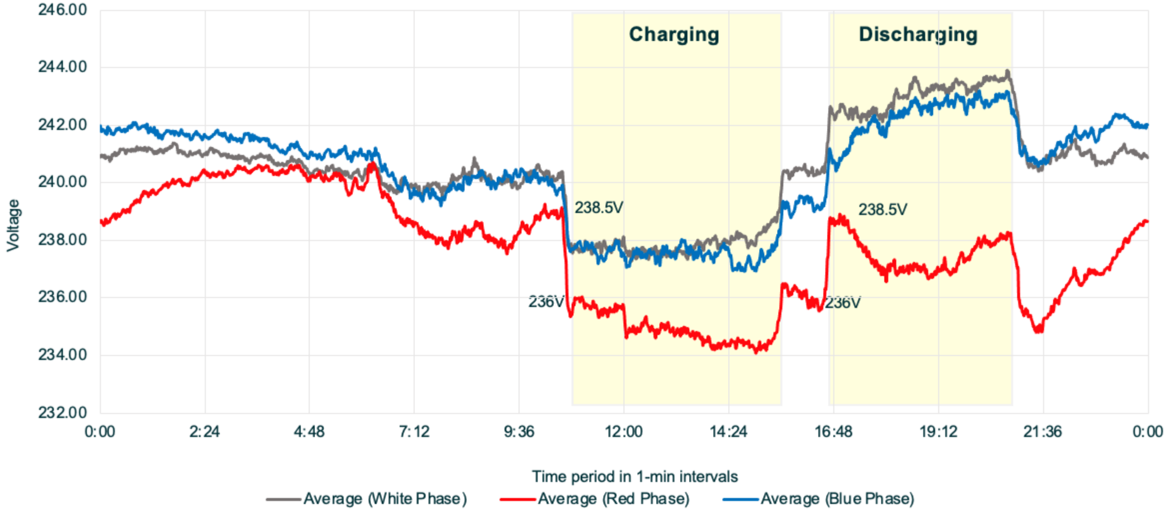


Figure 8. Voltage effects of FN1’s dispatch (average of April and May 2023)

Key learnings – operations and technical performance

1. **Conduct extensive testing on the production system prior to launch.**

The software was tested remotely on a lab system at ANU in Canberra, with a similar set up to the production system although with less power and storage capacity and with a grid simulator. This was not sufficient to qualify performance. An extended period on the actual system is necessary to validate all operating modes.

2. **Develop a clear understanding of FCAS energy required at state of charge boundaries.**

The difficulty of knowing the exact SOC at the end of charge makes it difficult to know the amount of energy available to service an FCAS event. Caution would err to a conservative high reserve that limits arbitrage opportunities. This requires ongoing fine-tuning.

3. **Seek optimal cooling and heating of the BESS for higher efficiency.**

At 81.5% roundtrip efficiency, the BESS consumes a lot more than it discharges. This leads to higher costs and lower profitability.

It is possible that the electronics and the battery chemistry do not require as tight a temperature hysteresis as currently configured. Fine-tuning will be financially rewarding.

4. Financial Performance

4.1. Annual revenue summary

The battery's first year of operation is characterised as a year of learning with complex issues (Section 3) which resulted in delays and limited the battery's opportunities to generate revenue.

Importantly, FN1 missed out on revenue in the first two months after launch during which there was high volatility and frequent peak prices in the energy market. During the following period of experimentation, we implemented changes to various aspects of battery operation to smoothen battery behaviour and maximise revenue. As the first year ended, we observed a steady state of operation and are now seeking to fine-tune dispatch for maximum revenue potential.

The two sources of revenue were:

(1) Energy arbitrage

(2) CitiPower's community battery trial tariff

Energy arbitrage involves buying energy at low prices (by charging) and selling when prices are high (by discharging).

The bi-directional community battery trial tariff provided a monetary incentive to charge during the afternoon (when there is low demand on the network) and discharge during evening peak (when there is high demand), it also penalises charging during evenings.

By following the above principles FN1 did not incur network cost except for covering parasitic loads.

In total, between 5 June 2022 to 5 June 2023, FN1 made **$7,864** from energy arbitrage and **$1,329** from network time-of-use tariff, for a total of **$8,417** ex-GST (after metering and market charges). Non-OPEX costs include metering charges of $703 and AEMO market fees of $71.

OPEX costs of FN1, such as retailer fees, BESS maintenance and IT support, are not covered in this report as all project partners gave YEF preferential offers that would be unlikely to be available to owners of future systems.

The table below summarises FN1's first year revenue (ex-GST):

Revenue / cost	Value
Metering	-$704
Market charges	-$71
Network income	$1,329
Arbitrage	$7,864
Total:	**$8,417**

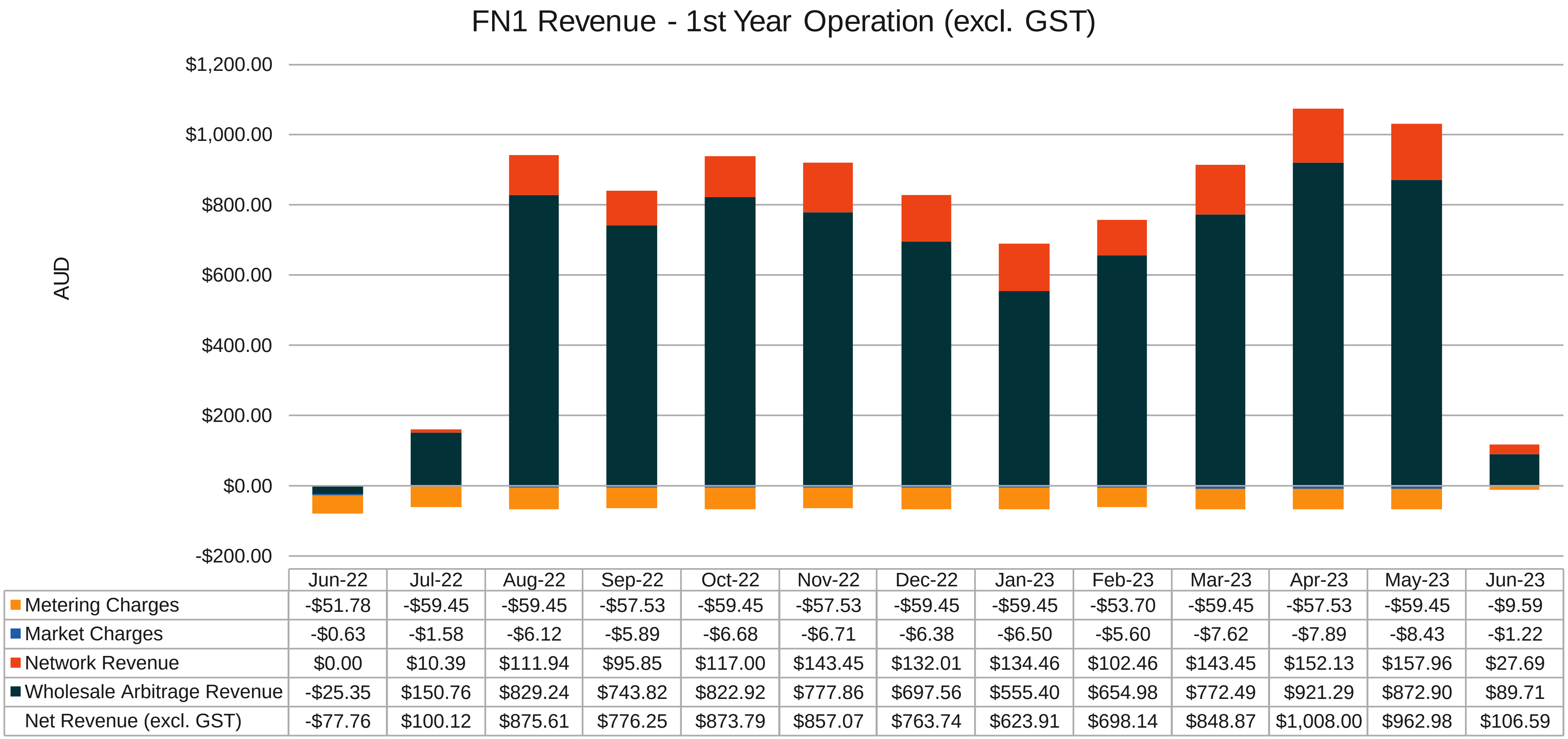
Revenue is calculated as follows:

- Energy: kWh x Reference Price x DLF
- Network: kWh x Trial Tariff x DLF

The Distribution Loss Factor (DLF) represents the electrical losses in wires in the low-voltage network (1.0467 in CitiPower's network).

4. Financial Performance

On a month-to-month basis, the revenue varied from low $600 to over $1,000 (excluding June and July 2022).



	Jun-22	Jul-22	Aug-22	Sep-22	Oct-22	Nov-22	Dec-22	Jan-23	Feb-23	Mar-23	Apr-23	May-23	Jun-23
🟧 Metering Charges	-$51.78	-$59.45	-$59.45	-$57.53	-$59.45	-$57.53	-$59.45	-$59.45	-$53.70	-$59.45	-$57.53	-$59.45	-$9.59
🟦 Market Charges	-$0.63	-$1.58	-$6.12	-$5.89	-$6.68	-$6.71	-$6.38	-$6.50	-$5.60	-$7.62	-$7.89	-$8.43	-$1.22
🟥 Network Revenue	$0.00	$10.39	$111.94	$95.85	$117.00	$143.45	$132.01	$134.46	$102.46	$143.45	$152.13	$157.96	$27.69
⬛ Wholesale Arbitrage Revenue	-$25.35	$150.76	$829.24	$743.82	$822.92	$777.86	$697.56	$555.40	$654.98	$772.49	$921.29	$872.90	$89.71
Net Revenue (excl. GST)	-$77.76	$100.12	$875.61	$776.25	$873.79	$857.07	$763.74	$623.91	$698.14	$848.87	$1,008.00	$962.98	$106.59

Figure 9. Summary of year 1 revenue

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4.2. Revenue streams and costs

Network tariffs

The CitiPower community battery trial tariff is a foundational aspect of FN1's commercial operation without which the business case for the battery would become unviable. The trial tariff rewards network supportive behaviour; this suited YEF's battery operation objectives which sought benefits the environment and the local network (i.e., time shifting solar generation to evening consumption).

Tariff revenue remained relatively consistent each month ranging from $95 to $157, averaging **$120/month** (excluding June-July 2022 when the battery was essentially non-operational).

Energy arbitrage

Wholesale arbitrage was the main source of revenue for FN1. Varying month-to-month from $555 in January to $921 in April 2023, it made an average $786, excluding the first two months.

Market charges

These are the fees paid to AEMO as ancillary and market fees, they are charged per kWh of consumption and are relatively small costs.

In addition, the Metering Service Provider charges **$700** per annum.

Table 2. Revenue from CitiPower's community battery trial tariff

Tariff time band	CB tariff (c/kWh)	kWh	Network revenue
10am – 3pm (import)	-1.5	66,786	$1,048
4pm – 9pm (import)	25	667	-$175
All other times (import)	0	4,486	$0
10am – 3pm (export)	0	202	$0
4pm – 9pm (export)	-1	58,082	$607
All other times (export)	0	602	$0
Fixed charge	45 c/day		-$153

Table 3. Revenue from energy arbitrage

Flow	kWh	Wholesale revenue
Energy export	59,166	$9,632
Energy import	72,585	-$1,769
Total:		$7,864

Table 4. Costs from market fees

Fee	Price (c/kWh)	kWh	Cost
AEMO ancillary fee	0.057	72,585.21	-$43.31
AEMO market fee	0.037	72,585.21	-$27.96
Total:			-$71.27

4.3. Quarterly revenue summaries

5–31 June 2022

The tribulations of the early days meant that FN1 lost money in the first month of operation and incurred a charge of $25.

23Q1: Jul – Sep 2022

In the second month, we saw a positive cashflow where the battery generated $150, it is important to note that in July issues were still on-going and battery only commenced proper operation on 25 July 2022. On average, the battery made $583.99 per month in this quarter, the month of August saw the most revenue at $829, and September saw comparatively low revenue of $743.

23Q2: Oct – Dec 2022

As we further optimised the battery charge and dispatch behaviour, the second quarter saw good consistent revenue. During these months the battery was paying less to charge and in December, overall, the battery was paid to charge. The revenue during discharge decreased with less volatility but charging benefitted from frequent negative prices in the afternoon, which seems to be an indication of energy patterns in summer.

The average revenue was $831.53 per month, and October the highest at $873.

23Q3: Jan – Mar 2023

Revenues in the third quarter dropped from the second quarter. FN1 made money charging for all three months on negative prices. The months of January and February saw low discharge revenue, which implies low energy prices during the evening peak. The month of March saw an improvement from the first two months.

The average revenue was $723 per month, and March the highest at $848.

23Q4: Apr – Jun 2023

The last quarter saw a significant increase in discharge revenue when compared to the third quarter. Negative charging prices ended in April. The battery operations were significantly improved by this quarter. On average, the battery made $870 per month during this quarter (note: this figure extrapolates June 2023 revenue until the end of the month).

The month of April was the most profitable in FN1’s operational lifetime when the battery made $1,008 of revenue.

4.4. FN1 performance vs 'perfect foresight'

FN1's financial performance can only be properly assessed when compared to the ideal performance of a perfectly optimised dispatcher (i.e., 'perfect foresight'). Our industry colleague, Diamond Energy, offered to run our meter data through their in-house algorithm that can analyse battery meter data to show wholesale revenue that is theoretically possible for the battery when optimised to maximise for revenue.

We analysed FN1's performance against two perfect foresight (PF) scenarios:

1. Within YEF's operational rules of specific charge/discharge time bands, operating at 1 cycle per day, and
2. Without time band constraints but operating at 1 cycle per day.

The revenue figures (Table 5) show the results, but do not consider impact from distribution loss factor. As can be seen in Figure 10, the battery missed out on significant revenue opportunities in June and July 2022.

Overall, the battery could have made $19,361 if it was optimised to maximise for revenue and operated within YEF's rules, including the high volatility months of June and July 2022. Without time-based constraints at 1 cycle per day, the theoretical maximum was $22,840.

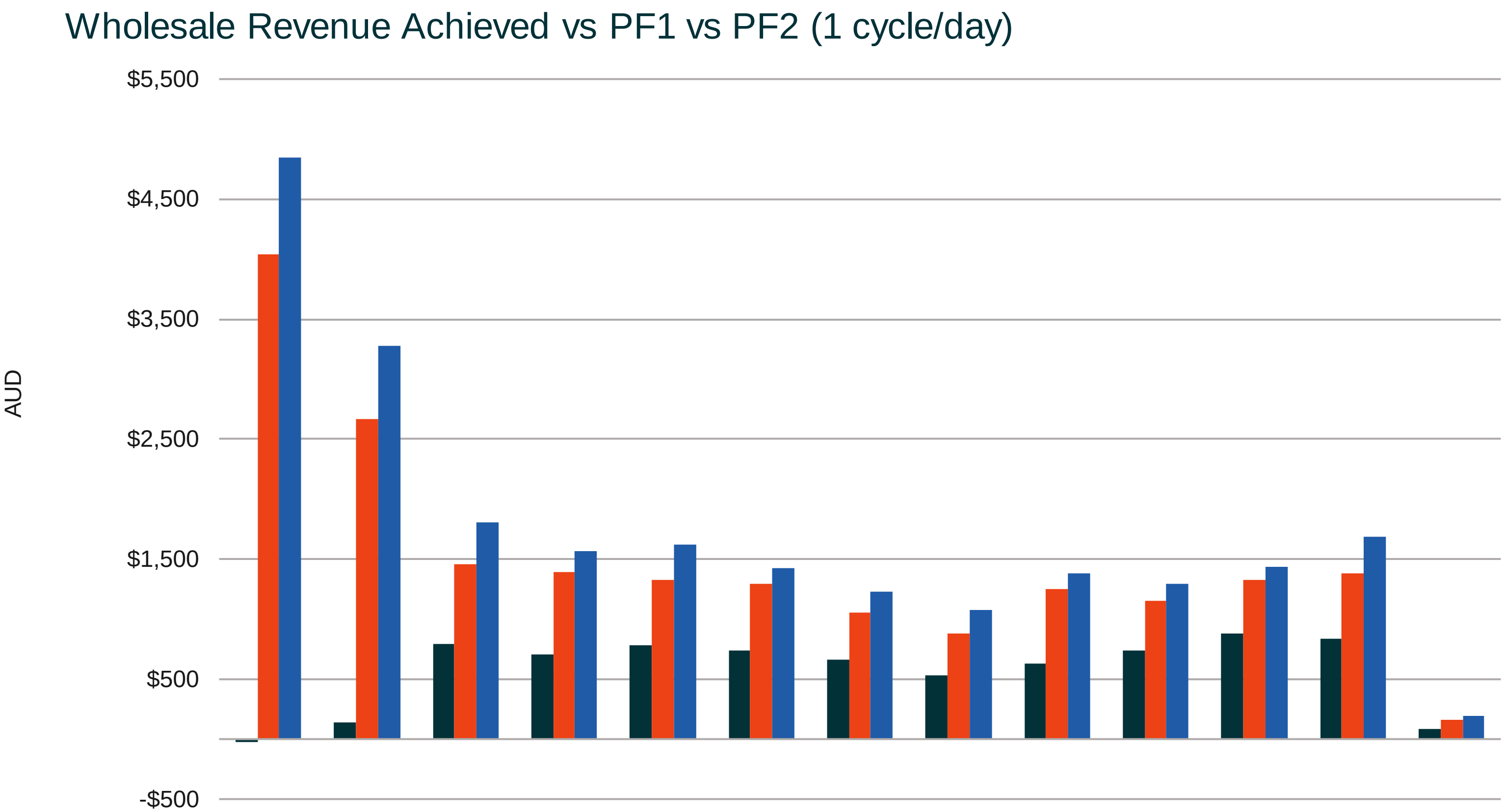
On a 10-month basis, disregarding the first two months, based on these scenarios, FN1 could have made $12,657 and $14,723, respectively.

Considering 10 months of operation FN1's performance was 58% against perfect foresight within YEF constraints, and 50% against perfect foresight if only constrained to 1 cycle/day.

Table 5. Comparison of actual revenue to perfect foresight scenarios

Month	Actual	PF 1	Actual as % of PF1	PF 2	Actual as % of PF2
Aug-22	$792	$1,456	54%	$1,805	44%
Sep-22	$711	$1,393	51%	$1,565	45%
Oct-22	$786	$1,326	59%	$1,624	48%
Nov-22	$743	$1,292	58%	$1,429	52%
Dec-22	$666	$1,050	64%	$1,230	54%
Jan-23	$531	$880	60%	$1,078	49%
Feb-23	$626	$1,247	50%	$1,381	45%
Mar-23	$738	$1,151	64%	$1,299	57%
Apr-23	$880	$1,326	66%	$1,434	61%
May-23	$834	$1,378	61%	$1,688	49%
Jun-23	$86	$157	55%	$189	45%
10-mo total	**$7,393**	**$12,657**	**58%**	**$14,723**	**50%**

4. Financial Performance



	Jun-22	Jul-22	Aug-22	Sep-22	Oct-22	Nov-22	Dec-22	Jan-23	Feb-23	Mar-23	Apr-23	May-23	Jun-23
■ Actual Revenue Achieved	-$24	$144	$792	$711	$786	$743	$666	$531	$626	$738	$880	$834	$86
🟧 YEF operational rules, revenue possible at 1 cycle per day	$4,037	$2,667	$1,456	$1,393	$1,326	$1,292	$1,050	$880	$1,247	$1,151	$1,326	$1,378	$157
🟦 Max revenue theoretically possible at 1 cycle per day	$4,844	$3,273	$1,805	$1,565	$1,624	$1,429	$1,230	$1,078	$1,381	$1,299	$1,434	$1,688	$189

Figure 10. Comparison of actual revenue to two ‘perfect foresight’ scenarios

4.5. Operational expenses (OPEX)

The innovative nature of FN1 and the strength of YEF's partnership with ANU, Mill Software, Acacia Energy and Pixii meant that the cost structure of the system is very favourable to YEF, including significant in-kind work and low annual fees. Those arrangements are not shared in this report. However, the experience of operating FN1 and from other projects have given insights into the main cost centres, as follows.

Administration, dispatch control & performance monitoring

The steep learning curve meant that YEF spent an estimated 600 hours or 2 ½ months equivalent in administering FN1 and understanding how to resolve issues arising and to best dispatch the system. A new project that implements a stable architecture with a proven operational profile should not require more than an hour a week at $50/hr or $2,600 a year.

Retail/Aggregation Fees

Depending on the chosen retailer/ aggregator, the fee can vary widely. It may be a portion of revenue, e.g., a percentage of FCAS, or a fixed fee. Typically, it would include:

- Transaction processing for both arbitrage and FCAS,
- IT Support and defect resolution if the dispatch is carried out by the retailer.
- Account administration and customer service

A well-planned tender will provide the best insight into retail offers and their variety.

IT Support

If not included in your retail fees, IT support includes hosting the software on a server, updating the software on a regular basis, and resolving minor defects. The cost may range from $1,000 to $5,000 a year.

New software functionality may attract additional cost in development, deployment and defect resolution.

Insurance

This cost centre can be seen as the 'Achilles heel' of innovative technology. Insurers would typically avoid new asset categories for which there is a lack of data and risk assessment. Even though a neighbourhood battery is built in a similar way to Electric Vehicles, albeit with larger storage, the parallel cannot be drawn by insurers.

The fire at the Victorian Big Battery in 2021 triggered a wave of caution across the insurance industry, even though the cause of the fire was not battery overheating but a leak in to cooling system leading to the power electronics catching fire.

The result is great difficulty in 2023 to source policies if the organisation does not already have a significant pool of assets as would a DNSP or council, for which adding an innovative asset is a lower risk.

The cost for 'property damage' and 'public and property liability' covers for FN1 was $4,000 ex-GST for the first year.

BESS Maintenance

Annual costs can range from a low of $500 to nearly $3,000 depending on the vendor. It is wise to include this cost as main item in a procurement tender.

Site Maintenance

Depending on the location, the main cost may be graffiti removal and mowing for a few hundred dollars a year.

Other costs

These may include land lease fees and software licenses depending on your project.

Key learnings – financial performance

- A Scheduler with dispatch at half power and time bands for charging and discharging can realise 50% of a fully optimised system with perfect foresight at 1 cycle/day.
- With improvements in round trip efficiency and new value streams, imports in kWh would slightly reduce, exports would stay the same. As a result, revenue from tariff should change little and reduce in percentage.
- Operating expenses are highly dependent on the choice of BESS, of the retailer/aggregator, and of the insurance offers.
- Insurance may not be available or at a high price to an organisation with few insured assets. A large asset owner may add a BESS at a marginal cost.

4.6. Commercial viability

Cost structure assessment

With time and deployment at scale, the cost structure of BESS' would benefit from economies of scale in administration and IT support. Competitive offerings may bring down retail fees and system maintenance costs.

On a per annum basis, setting an OPEX target of $5,000-$10,000 for a 120kW/309kWh BESS may provide sufficient earning capacity as new revenue streams are made available.

Future revenue streams

YEF anticipates that Contingency FCAS will become effective later this year (2023) and add an expected revenue stream in excess of $5,000.

The second priority for FN1 is to optimise dispatch with an improved forecast so that ANU's Optimiser software be enabled.

In the medium term, several services are planned to become available to BESS as the electricity market adopts this technology. The main electricity market opportunities are:

- Capacity mechanisms: A fixed amount based on how much capacity can be supplied.
- Demand response: A contractual offering to help manage periods of high loads in the Victorian market.
- Fast Frequency Response: like contingency FCAS but requiring a faster response.
- Inertia market: to maintain system stability - advanced inverters can send 'synthetic inertia' signals.
- Operating reserve: 'Fast-start' capacity paid to be available by AEMO.

Network support services can be offered in areas of peak demand constraints or excess solar exports, at certain times of the day.

Peak demand reduction could be offered to businesses were an innovative tariff to be approved. It would deliver cost savings for business and defer network augmentation.

EV charging supply: An EV charger can be directly connected to a BESS that would manage its charge requests without overloading the network. It could be a very lucrative value stream for the battery.

Commercial viability

In simple terms, the average annual earnings* of a $300,000 BESS would need to exceed $30,000 after 10 years, or $20,000 after 15 years, to break-even.

To put this into perspective, the CAPEX of a 1MVA diesel genset may cost the same as a 120kW / 309kWh BESS, but at over 8 times the power capacity.

Halving BESS CAPEX and adding new value streams would even the deal for BESS and attract investors.

*Earnings = Revenue less OPEX

5. Decarbonising the Energy System

5.1. Supporting a transforming energy system

Energy storage is a critical requirement as we transition to an energy system predominated by variable renewable energy. The challenge of building the magnitude of storage required is enormous[1], and community batteries can make an important contribution.

In order to ensure sufficient dispatchable capacity as coal generation exits the grid, the Victorian Government has announced a storage target of 2.6 GW by 2030, and 6.3 GW by 2035. By firming distributed and variable renewable energy, community batteries can foreseeably help to meet this demand.

In addition to the essential role of firming, community batteries provide many other functions supportive of a renewable energy system. Some of these functions are directly associated with the reduction of operational GHG emissions, while others have effects at a broader temporal or geographic scale.

The latter include various functions frequently referred to as 'network support', but it should be noted that these are essential services without which the transition to renewable energy would be impossible. While these functions may have no direct, measurable emissions impact, by solving challenges associated with the transformation of the energy system, they could arguably be far more important.

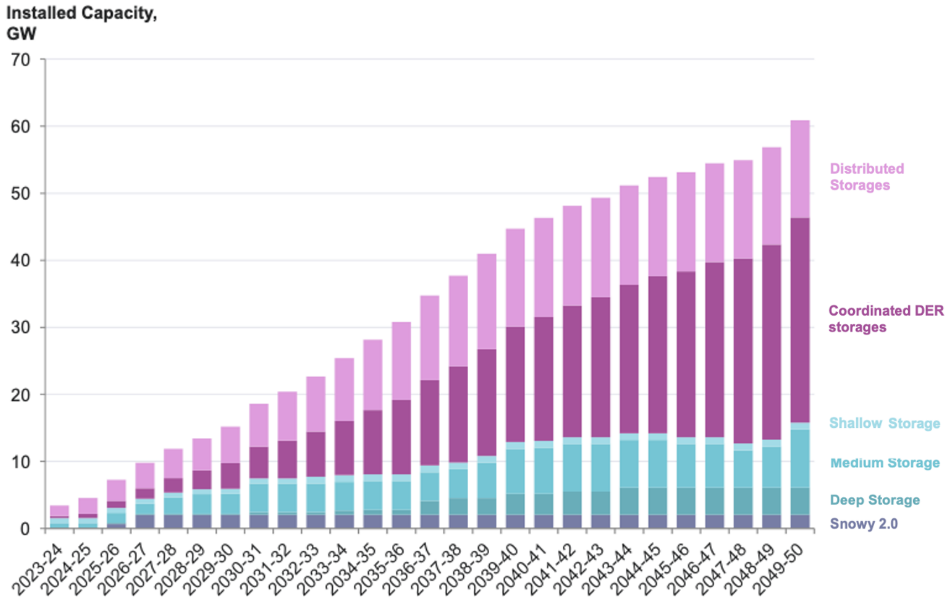


Figure 11. Forecasted storage requirements for *Step Change* scenario, ISP 2022 (AEMO)

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[1] AEMO's 2022 Integrated System Plan (ISP) projects that under the *Step Change* scenario, the NEM will require 15 GW / 399 GWh of storage in 2030, growing to 61 GW / 669 GWh in 2050. The Victorian Government has announced a storage target of 2.6 GW of dispatchable capacity by 2030, and 6.3 GW by 2035. Currently, the entire NEM boasts only 1.5 GW of dispatchable energy storage. See: https://aemo.com.au/energy-systems/major-publications/integrated-system-plan-isp/2022-integrated-system-plan-isp

5. Decarbonising the Energy System

FN1 establishes a model by which communities can work with the energy sector to implement solutions that address climate change and manage some of myriad issues that arise as we transform our energy system.

Listed in order from local scale to system scale, community batteries can support the clean energy transition in the following ways:

1. **Enabling further solar installations and exports** by increasing the solar hosting capacity of the LV network, thereby reducing 'solar waste' due to export limiting or inverters tripping due to high daytime voltages
2. **Regulating high daytime voltages on the LV network** and thereby reducing consumption (on the LV network); and potentially enabling DNSPs to modify voltage settings across the network (when deployed at scale).
3. **Supporting electrification** by providing power 'downstream' of the distribution transformer during peak demand, deferring or avoiding the need for network augmentation.
4. **Reducing widespread solar curtailment** (through use of an 'emergency backstop mechanism') by shifting demand from evening to daytime, supporting system strength at times of minimum load (when deployed at scale).
5. **Firming variable and distributed renewable energy** by charging when variable renewable energy is abundant and time shifting supply to periods of high demand, flattening the 'duck curve' in demand and wholesale energy prices.

5.2. Reducing operational greenhouse gas emissions

Reducing operational GHG emissions of energy generation using battery storage is achieved by storing clean energy and discharging to displace fossil fuel generation. We call this 'time-shifting' the supply of clean energy. In practise, this is very challenging both to accomplish, and to measure.

Achieving a net emissions reduction by time-shifting energy depends on having a sufficient difference in emissions intensity between the energy being stored and the generation being displaced.

As shown in figure 12, over the course of the past year the emissions intensity of the Victorian grid was, on average, relatively flat through the day. Figure 12 also shows the estimated emissions intensity if including rooftop PV generation, which is not included in the original NEMED dataset.

We have considered the emissions impact of FN1 charging only from the grid, not local solar, and it is therefore a worst-case scenario. With minimal difference in emissions intensity across the day, it is difficult to achieve a net emissions reduction by time-shifting grid-supplied energy, due to roundtrip losses incurred through storage.

YEF considered several approaches to calculating the emissions impact of FN1's time-shifting, based on different emissions measurements: the average of the grid, of the marginal generator, and of large generator frequency adjustments. None of these approaches present a definitive picture of FN1's emissions impact, as each makes a firm assumption about how battery's operation affects the energy market.

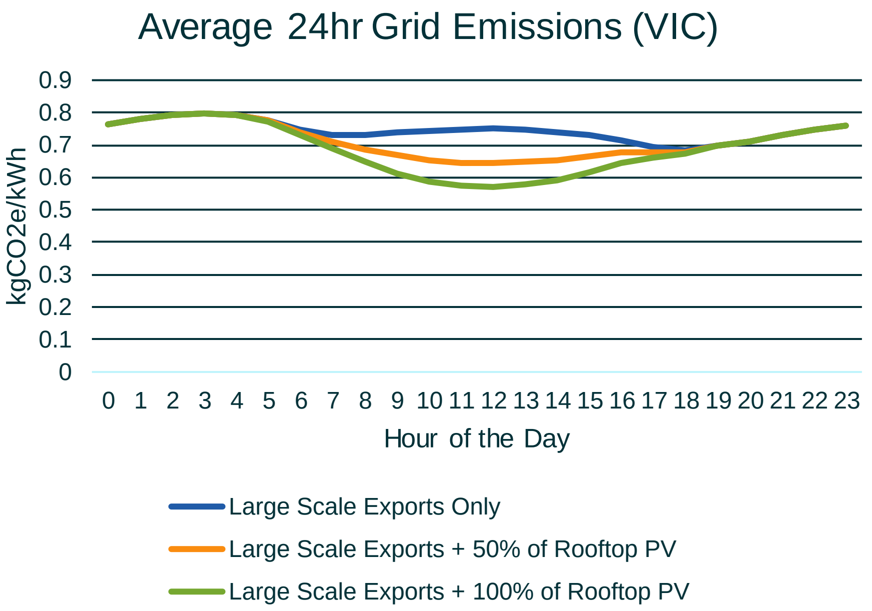

Figure 12. Average emissions intensity of the grid (VIC) over 24 hrs

We believe the relationship is more complex, and there is no 'final answer'. Even in a renewable-dominant energy system, battery storage may not achieve emissions reductions directly; and both household and large-scale batteries face the same challenge – the only difference is the scale of their impact.

5.3. Supporting local and system-scale decarbonisation

Although a community battery can support the decarbonisation of the energy system when placed in a variety of locations, a neighbourhood with high solar penetration remains the preferred location for siting a community battery for several reasons:

- The battery can charge from local solar, supporting *that neighbourhood* to reduce emissions (even if the impact may be calculated differently at the system scale).
- These areas are most likely to experience constraints associated with ‘excess’ rooftop solar, and possibly electrification, now and in the future.
- These communities are more likely to be engaged and supportive of a project.

In this situation, the battery should charge when the sun is shining, and households exporting. At other times, it should aim to charge when there is a lot of variable renewable energy (VRE) in the grid, to ‘firm’ at times when there is not.

The graph shows that the middle of the day can be the time of lowest emissions intensity generation or the highest. At 14:00 this happens almost as often. Only an emissions-focused Optimiser would produce direct emissions reduction.

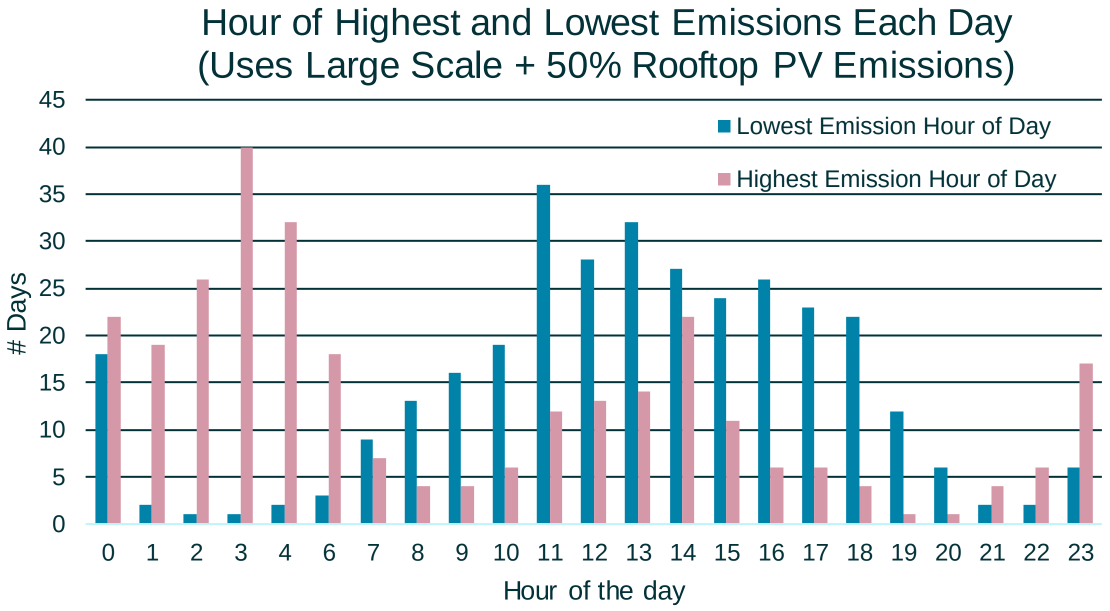

Figure 13. Highest and lowest emissions intensity hour of the day (no. of instances)

In conclusion

A community battery can be dispatched to support the local community to decarbonise, while also establishing a pattern that supports the transition to 100% renewable energy.

While these functions do not always yield direct emissions reductions, they serve a longer-term goal of decarbonising the energy system.

6. Advice for Future Systems

6. Advice for Future Systems

Strategy: Before initiating a BESS project, develop your deployment strategy for the next 5 years. It will help make decisions about your choice of BESS manufacturer(s) and retailer/aggregator. If building a BESS network is your intention, it is easier to replicate one system that works than running multiple pilots.

BESS Procurement: Enquire about boundary conditions at high and low states of charge and seek to understand roundtrip efficiency including parasitic loads. It will allow you to better anticipate how the BESS will operate.

Specify the cost of BESS maintenance as part of your tender. That cost can be a significant portion of your annual expenses if gone unchecked.

Retailer Procurement: If the retailer's dispatch software is to be used, enquire about their forecasting and optimisation performance. A Scheduler instead of an Optimiser is not a problem, but the retail cost should be aligned with revenue expectations. Enquire if the retailer/aggregator has a license to operate FCAS in your region, as needing to arrange this could lead to long delays in enabling FCAS.

Installation: Consider shading the BESS to reduce cooling power and improve efficiency.

Launch: Allow for at least a month of testing on your production system before making a public launch. This is particularly true for the first in a series of deployments.

Dispatch: Define the principles of your dispatch mode by your intention for the BESS. These principles would translate to specific settings such as time bands to charge or discharge, price thresholds, and possibly dynamic inputs. These settings should be revised monthly to ensure that the BESS operations match the market prices patterns as they change.

Operations: Monitor daily and minimise changes for a stable and predictable behaviour.

Appendices

Appendix 1. DEECA Data & Knowledge Sharing Plan

Name of data	Description (including metrics)	Data for reporting period (month-month year)
Number of customers	# of premises using the battery; either via direct connection to the feeder, subscription to the battery or on battery retail tariff.	198
Value streams	List value streams accessed during past quarter (e.g., FCAS, arbitrage). % contribution of each value stream to battery income in quarter	Arbitrage 84.2% Tariff 15.8%
Retail tariff(s)	Customer retail tariff(s) # of customers of each tariff during past quarter	90% on flat tariff C1R 10% on TOU tariff CRTOU
Network tariff(s)	Battery network tariff	Community battery trial tariff CNDB
Solar export limit	Solar export limit (kw) for houses within battery catchment # of customers with an export limit before battery commissioned # of customers with an export limit after battery commissioned	Since 5/6/2022: • 3 solar installs, • No solar curtailments/export limits removed, • No incidence of reverse flow
Battery operation modes	Which event-driven and/or non-event-driven modes were used during past quarter? Total duration of each mode during quarter	No event-driven modes were used during past quarter
Battery performance	Charge and discharge performance dynamics	72.5MWh imported 59.1MWh exported, 81.5% roundtrip efficiency
System down time	Times when battery is unavailable and reason	Down time is measured in days when the system was exporting from 4pm to 9pm at less than 40kW:

	(total of time, avg duration, date(s) of occurrence)	- From 5/6/22 to 5/6/23: 64 days, 18% downtime - From 25/7/22 to 5/6/23: 14 days, 4.4% down time Dates of export periods at less than 40kW since 25/7/22, and main cause, if known: 30/07/22 – 31/7/22: 2 periods, unclear cause. 28/08/22: 1 period, communication driver failure. 11/09/22 - 13/9/22: 3 periods, incorrect price feed due to site controller algorithm defect. 13/10/22: 1 period, DC link overvoltage, settings issue. 20/11/22: 1 period, converter alarm, unclear cause. 18/12/22: 1 period, data drop out, lost endpoints in API. 21/12/2 – 22/12/22: 2 periods, site controller firmware update causing lost API endpoints. 24/01/23: 1 period, API notification not received. 27/03/23 – 28/03/23: 2 periods, meter historical endpoint returning stale data, due to driver defect in cloud communications with site controller.

Appendix 2. Glossary of Abbreviations

Acronym	Meaning
AEMO	Australian Energy Market Operator
ANU	Australian National University
BESS	Battery Energy Storage System
BSGIP	Battery Storage and Grid Integration Program
CAPEX	Capital expense
DEECA	Department of Energy, Environment and Climate Action (Victorian Government)
DLF	Distribution Loss Factor
DNSP	Distribution Network Service Provider
EV	Electric vehicle
FCAS	Frequency Control Ancillary Services
FN1	Fitzroy North 1; the Fitzroy North Community Battery
GW	Gigawatt
kW	Kilowatt
kWh	Kilowatt-hour
LV	Low voltage
MVA	Megavolt-ampere
NEM	National Electricity Market
OPEX	Operating expenses
PF	Perfect foresight
PFR	Primary Frequency Response
SOC	State of charge
VPP	Virtual Power Plant
VRE	Variable renewable energy
YEF	Yarra Energy Foundation

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