TECHNICAL ANALYSIS

July 2023

Community Resilience and Reliable Energy Feasibility Study for

Venus Bay and Tarwin Lower

Australian Government
This project received grant funding from the Australian Government

Contents

Background

Venus Bay and Tarwin Lower are within a priority region for bushfire risk according to the Federal Government's identification of priority locations. The report forms part of a suite of activities and investigations underway as part of the Venus Bay and Tarwin Lower community resilience and reliable energy study.

A community-centred design approach has been used to identify key elements of resilience from the perspectives of residents, business owners, holidaymakers and critical organisations, e.g., State Emergency Services. Local energy self-sufficiency and energy sustainability are community values that promote a vision of a completely decarbonised future energy system. The values that influence battery sizing are -safety, equity, self-sufficiency, sustainability, and reliability. Enough solar PV generation, feasibility of wind, amount of load flexibility and enough storage options are studied to reflect the community values regarding future energy options for the community.

Purpose of this report

This report has been developed as a reference to the technical and financial feasibility outcomes of the Venus Bay and Tarwin Lower sites.

It aims to:

- Identify solar PV sizes for clusters (i.e., households, businesses, commercials, and their combinations), and whole communities.
- Identify the feasibility of wind energy for suitable sites and the whole community.
- Identify the load flexibility options for the community.
- Identify battery sizes for different community users focusing on the community values such as - safety, equity, self-sufficiency, sustainability, and reliability.

Overview of Selected Feeders

The mapping exercise performed in Workshop #1 allowed the project team to identify a list of highly valued feeders in terms of contributing to community resilience. Out of ten feeders top four feeders – Cantor Fishermans, Jupiter Centre, Tarwin Lower 94 and Venus Bay 2 are chosen for deeper assessment in this report.

Besides, Canterbury Constance has been considered for further analysis considering wind energy is a viable option for that feeder. Since this feeder already got a Telstra-operated mobile tower, it is assumed that the community will agree to have a wind turbine in that area with a similar height. These key feeders are compared in Table 1.

Finally, the feasibility of solar PV, wind and community batteries for the Venus Bay and Tarwin Lower communities is studied, considering critical values identified by the community in Workshop #2. These values include but are not limited to safety, self-sufficiency, reliability, equity and sustainability.

Table 1 Energy demand and energy options of the shortlisted feeders and aggregated Venus Bay and Tarwin Lower community

Feeder Name	Description of Services	Transformer Capacity	Customers Total, residential	Solar PV and restrictions	Annual demand supplied by solar
Jupiter Centre	Venus Bay shops, general store, chemist, food outlets	315kVA	95, 75 homes	61 kW solar, restricted exports, 185 kVA peak demand	16%
Tarwin Lower 94	School, Recreation reserve, health centre and clubs	315kVA	55, 47 homes	109 kW solar, restricted exports, 106 kVA peak demand	42%
Cantor Fishermans	Fishing club, BBQs & public toilets	315kVA	68, 67 homes	38 kW solar, 101 kVA peak demand	26%
Venus Bay 2	CFA, IGA, Petrol station, Post office and shops. Tarwin phone tower	500kVA	18, 2 homes	81 kW solar, 112 kVA peak demand	20%
Canterbury Constance	Telstra tower, Optus service, transfer station	200kVA	59, 56 homes	54 kW solar, 75 kVA peak demand	32%
Aggregated VB and TL	-	-	-	1.9 MW solar, 2.5 MVA peak demand	33%

How much solar?

Solar PV generates energy by using sunlight available during the day. But the demand is distributed throughout the day and night. The energy generated from solar PVs can meet the demand during the day, and the unused solar will be wasted or exported to the grid at a lower price. The levelized cost of energy (LCOE) increased with the increase in solar capacity. The percentage of demand met, and LCOE for different solar capacities in selected feeders is presented in Table 2.

The Cantor Fishermans has 38 kW solar installed at present, which can meet 25% of the total demand. The LCOE reached 21c/kWh when the PV capacity increased to 420kW, ten times more than the present capacity. This solar can meet 60% of the total demand, and the rest of the demand needs to be managed by wind energy, load flexing, EV, BESS or importing from the grid.

The Jupiter Centre feeder has a solar capacity of 61kW. Solar power can be increased up to nearly 1 MW which can supply 60% of the demand with a LCOE of 18c/kWh. Likewise, 63% of the total demand can be met by using 763kW of solar at Tarwin Lower 94 feeder.

The present solar capacity of the Venus Bay 2 feeder is 81kW. With a solar capacity of 1200kW, 66% of the total demand can be met. At this capacity, the LCOE will be 20c/kWh.

At Canterbury Constance, the present solar capacity is 54kW. The LCOE reached 20c/kWh when the installed solar is 487kW. With this capacity, 60% of the total demand can be met. The site is considered a potential feeder for installed wind generation, which will be discussed in the following sections.

Venus Bay and Tarwin Lower area has nearly 2 MW solar capacity. The 32% of the total demand can be met with this capacity. The 60% of the total demand can be met by using 9 MW of solar. Further increase in solar capacity has little impact on the demand met but rather increases LCOE. The export solar capacity will also be limited by the capacity of the infrastructure and the service providers' regulations. One of the potential solutions is to use the generated solar as much as possible behind the meter or within the community.

Table 2 The percentage of demand met and LCOE for different solar capacities in selected feeders

Cantor Fishermans			**Jupiter Centre**			**Tarwin Lower 94**			**Venus Bay 2**			**Canterbury Constance**			**Aggregated VB & TL**		
PV (kW)	Demand (%)	LCOE[1]	**PV (kW)**	Demand (%)	LCOE[2]	**PV (kW)**	Demand (%)	LCOE[3]	**PV (kW)**	Demand (%)	LCOE[4]	**PV (kW)**	Demand (%)	LCOE[5]	**PV (kW)**	Demand (%)	LCOE[6]
38	25	0.05	**61**	16	0.04	**109**	39	0.05	**81**	20	0.04	**54**	31	0.05	**1923**	32	0.04
76	41	0.06	**122**	31	0.05	**218**	53	0.07	**162**	39	0.05	**108**	46	0.06	**3846**	50	0.06
114	48	0.07	**183**	41	0.05	**327**	58	0.09	**243**	50	0.05	**162**	52	0.08	**5769**	56	0.08
153	52	0.09	**244**	47	0.06	**436**	60	0.12	**324**	56	0.06	**216**	55	0.10	**7692**	58	0.10
192	55	0.10	**305**	51	0.07	**545**	61	0.15	**406**	59	0.07	**271**	56	0.12	**9615**	60	0.12
229	56	0.12	**366**	53	0.08	**654**	62	0.18	**487**	61	0.09	**325**	57	0.15	**10576**	61	0.13
267	57	0.14	**427**	55	0.09	**763**	63	0.20	**568**	62	0.10	**379**	58	0.17	**11538**	61	0.14
305	58	0.16	**488**	56	0.10	**872**	63	0.23	**649**	63	0.11	**433**	59	0.19	**12499**	61	0.15
343	59	0.18	**549**	57	0.11	**981**	63	0.26	**730**	64	0.12	**487**	59	0.21	**13461**	62	0.16
382	59	0.19	**610**	58	0.12	**1090**	64	0.28	**812**	65	0.14	**542**	60	0.24	**14422**	62	0.17
420	60	0.21	**671**	58	0.13	**1199**	64	0.31	**893**	65	0.15	**596**	60	0.26	**15384**	62	0.18
458	60	0.23	**732**	59	0.15	**1308**	64	0.34	**974**	65	0.16	**650**	60	0.28	**16345**	62	0.19
496	60	0.25	**793**	59	0.16	**1417**	64	0.37	**1055**	66	0.17	**704**	60	0.30	**17307**	63	0.20
534	60	0.27	**854**	60	0.17	**1526**	64	0.39	**1136**	66	0.18	**758**	60	0.33	**18268**	63	0.22
573	61	0.28	**915**	60	0.18	**1635**	65	0.42	**1218**	66	0.20	**813**	61	0.35	**19230**	63	0.23

[1,2,3,4,5,6] Not discounted

Wind Energy Feasibility

Wind power is the cheapest source of large-scale renewable energy. However, small-scale generating units face many technical and financial challenges in being connected to the LV distribution network. Many communities do not like wind turbines because they are bigger and compromise the land's aesthetic views. The installation requires land acquisition and a longer time.

Unlike solar energy, wind energy can be available during the day and night. A combination of solar and wind energy can be a communitys' most sustainable energy option. However, both energy sources are intermittent and highly depend on the weather.

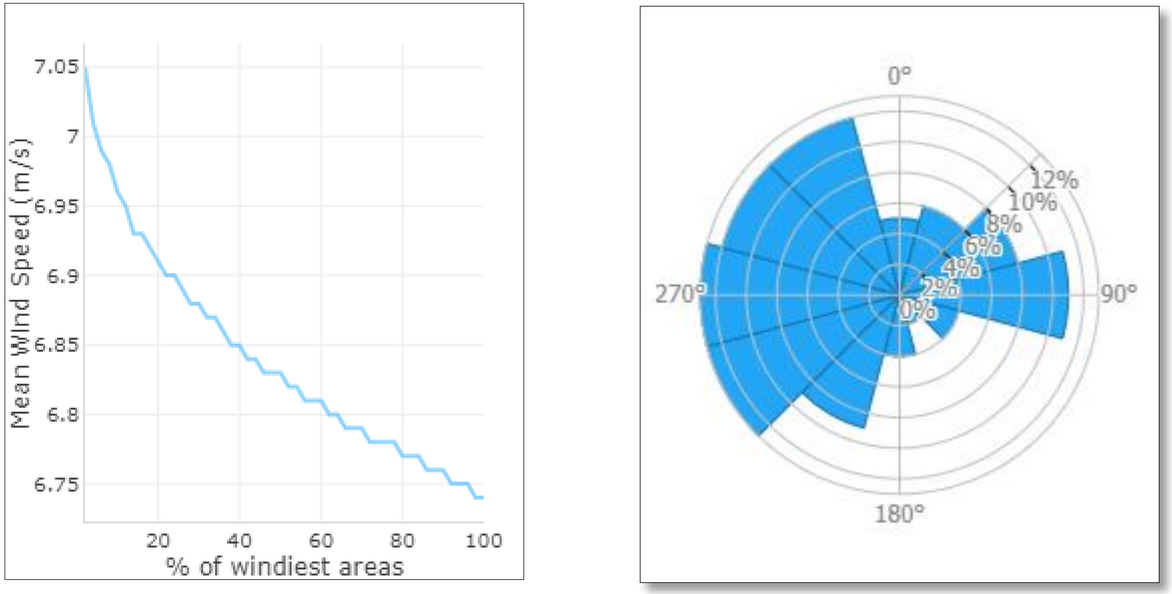

Figure 1 Wind rose diagram and wind speed at Tarwin Lower Area. Tower height = 50 meters.

Since a mobile tower is already in the Canterbury Constance area, a 100 kW wind turbine with a medium-scale wind turbine (100 kW) with a 23-meter height is proposed. 1 MW wind farm is considered for the whole Venus Bay and Tarwin Lower community. This wind farm can be built near these community areas or can be collected from already established nearby wind farms such as Bald Hills Wind Farm. The wind rose diagram of the Tarwin Lower area is presented in Figure 1.

The rose diagram in Figure 1 shows that the wind can be mainly collected from the west (the turbine should face the bay). At the 50-meter height, the mean wind speed ranges from 6.75 meters per second to approximately 7.05 meters per second. The wind speed and its distribution were generated via https://globalwindatlas.info/.

Wind Profile and Cost Analysis

The wind profile for the Canterbury Constance area is generated by using https://www.renewables.ninja/. The XANT M21 turbine is used. A lower tower height of 23m is considered. Wind data is not available beyond 2019. Therefore, the latest data from 2019 has been considered for generating energy profiles and later used in battery feasibility studies. With this model, the total wind generation in a year is 62.10 MWh, and the total spillage in the Canterbury Constance feeder is 14.7 MWh with present demand and solar capacity. However, the spillage amount might increase with increased PV installation in this area. The wind profile for the Canterbury Constance area is presented in Figure 2.

The 1 MW wind feasibility is considered for the whole Venus Bay and Tarwin Lower area either from the local generation or importing from nearby wind farms. A moderate height of 65 meters tall tower is considered for the wind generation of Venus Bay and Tarwin lower area. With this model, the total wind generation in a year is 1841 MWh, and the total spillage is 312 MWh. The wind profile for the whole Venus Bay and Tarwin lower area is presented in Figure 3. Wind farm installation requires land acquisition and other civil works to build towers and relevant auxiliaries. The capital cost may vary from country to country and for different sizes and technologies. Our study considered $4,000 as a capital cost for each kW wind capacity (https://www.windustry.org/).

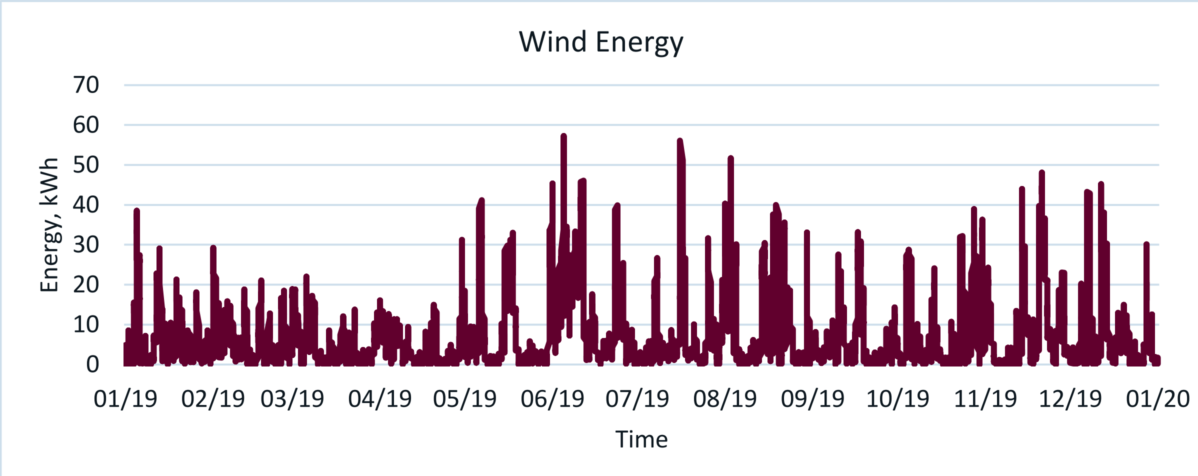

Figure 2 Wind profile for Canterbury Constance (Tower height = 23 meters)

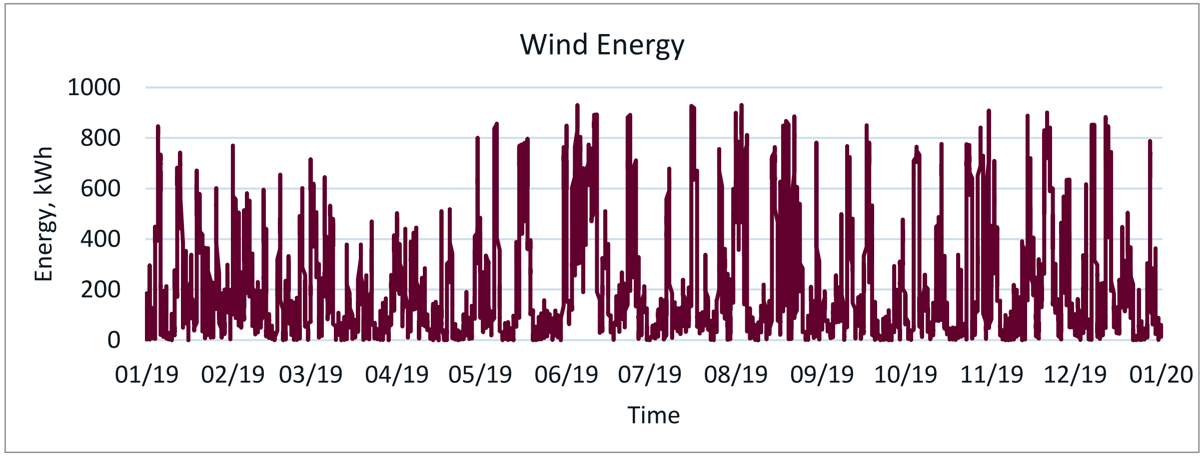

Figure 3 Wind profile for Venus Bay and Tarwin Lower Communities (Tower height = 65 meters)

Load Flexibility

Solar energy is one of the cheapest forms of renewable energy. Installing mini and micro-scale solar is relatively easy and less time consumable. Rooftop solar will continue to increase in future. However, the energy is only available to harness during the daytime and is limited by the service provider to export to the grid. One potential solution is to shift loads as much as possible from off-peak to peak solar periods. For example, 25% of the night load is considered essential loads and other 75% loads from household such as hot water and pumps are considered flexible to be shifted during solar peak hours such as from 11:00 am to 03:00 am. The overall demands, solar generation and flexible load amount of all selected feeders are presented in Table 2.

The potential of flexible loads of commercial customers is complex to identify. Thermal loads such as heating, cooling, and hot water are suitable for energy storage and can be shifted their full/partial operation from night to day. Simply changing the temperature settings to use more energy during the day than at night can provide significant benefits.

The IGA refrigeration loads will be the most significant thermal loads on the system to be shifted. However, every commercial customer has their own priority and recommended energy setting for their appliances, which needs further investigation. The community is encouraged to use most of their solar energy behind the meter settings to achieve higher benefits from solar. There is a potential to shift 1034 MWh of flexible loads from the dead of night to the high solar peak.

Table 3 Demands, solar generation and flexible loads of all selected feeders

Feeder Name	Gross demand (MVA)	Net demand (MVA)	Net PV generation (MWh)	PV export (MWh)	Total flexible load @25% essential load (MWh)
Cantor Fishemans	216.6	159.4	57.2	8.7	35.9
Jupiter Centre	554.8	463.5	91.3	0.7	60.5
Tarwin Lower 94	390.4	227.2	163.2	28.8	48.4
Venus Bay 2	604.1	482.5	121.5	0.8	55.2
Canterbury Constance	250.6	169.5	81.1	13.1	32.9
Aggregated VB & TL	8766	5887	2879	204.9	1034

The impact of load shifting on the average daily load profile of the overall Venus Bay and Tarwin Lower community is presented in Figure 4. The net demand is low during the daytime because of the existing solar in the community. Now, the 75% of loads from 12:00 am to 04:00 am are shifted to solar peak hours from 11:00 am to 3:00 pm. When the solar generation is triple the current capacity, all additional loads can be supplied by solar energy. The export also increases due to the increase in solar generation. This extra energy can be used by converting other energy sources-operated appliances into electricity-based appliances. Over time, when the solar will be triple, loads will also be increased. Besides, the remaining export energy can be used in the neighbourhood or stored in the battery during peak tariff hours.

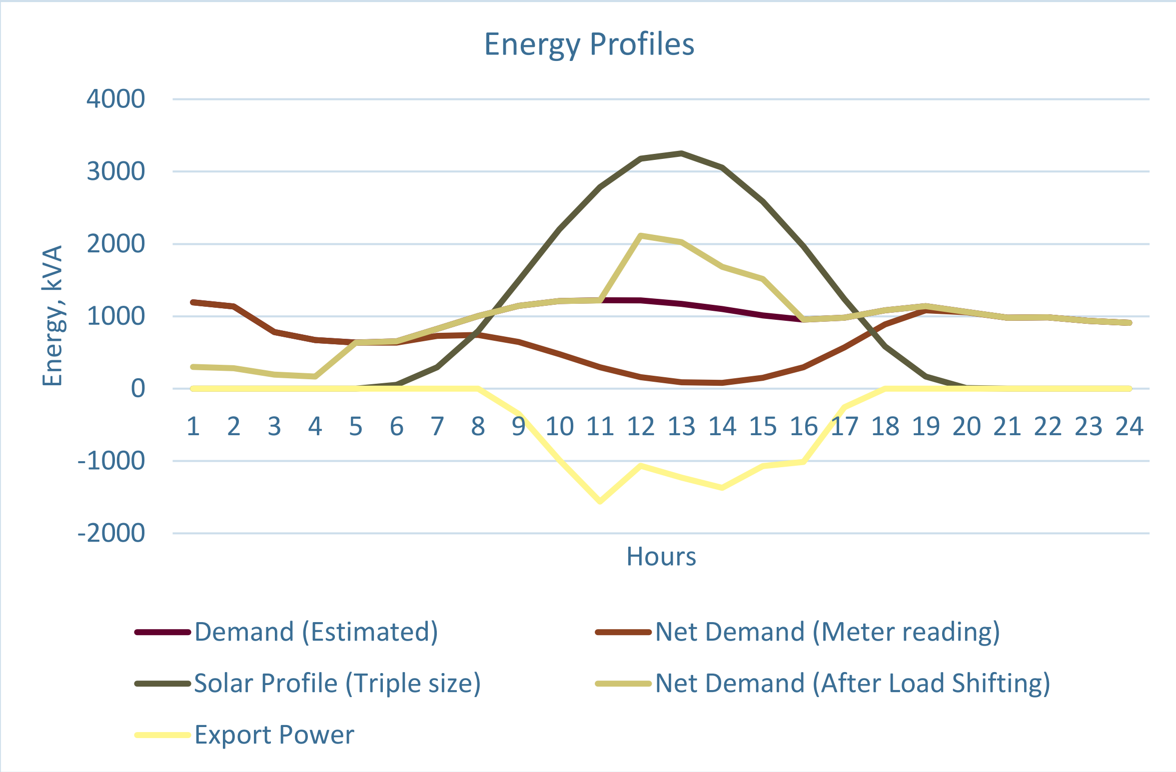

Figure 4 Impacts of load shifting on average daily demands and solar generation.

Battery Feasibility

Electricity produced by rooftop solar is the cheapest form of energy source available today. Non-essential flexible loads such as hot water can be shifted to operate during high solar generation time of the day. Despite all these efforts, about half of the demand can be met by solar because of its availability during the day and intermittent in nature. Export to the grid is not economical and restricted due to technical boundaries set by distribution network service provider (AusNet Services Pty Ltd).

Storing surplus solar energy during the day and utilising it during peak-tariff hours can reduce energy bills and promote self-sufficiency and sustainability. A larger community-scale battery will provide more reliability to the community with a considerable investment and maintenance cost. Most of the time, the battery will sit idle or underutilised and become a liability to the community.

The performance of different battery sizes with the increased solar PV capacity is analysed in this report.

Cost Analysis

The cost of batteries very from different technology and sizes. A short summary of battery price is presented in Table 3. Extra-small and small batteries are suitable for small loads like households. Small and medium sizes can be used for commercial loads. Large and Extra-large battery sizes are for community batteries. Multiple units can be aggregated to achieve desired capacity for the community. The next section presents the PV, battery and wind feasibility in various feeders.

Table 4 Battery technology sizes and costing

Battery Duration / Energy Size **Battery Capacity**	**1 hr**	**2 hr**	**4 hr**	**8 hr**
50kW	$72,000	$103,000	$165,000	$289,000
80kW	$115,000	$165,000	$264,000	$463,000
100kW	$144,000	$206,000	$330,000	$579,000
120kW	$172,000	$247,000	$396,000	$694,000
150kW	$215,000	$309,000	$495,000	$868,000
200kW	$287,000	$411,000	$660,000	$1,157,000
300kW	$430,000	$617,000	$990,000	$1,736,000

Cantor Fishermans

The Cantor Fisherman feeder supplies electricity to a fishing club and 67 households. Half of the households are holiday residents. The area is connected to a 315 kVA transformer with a peak load of 101 kVA. At present, the installed solar capacity is 38.2 kW. The gross demand of the feeder is 217 MWh, total solar generation is 57 MWh, 2.47 MWh export, and while 26% of the current demand is met by solar.

Increasing solar can meet more local demand. Shifting the flexible loads to solar peak hours will reduce the amount of surplus solar that exports to the grid or spills due to the export limitations imposed by service providers.

In this study, we considered that surplus solar will be stored in the battery and used during evening peak hours. Any energy left that will remain stored in the battery will be used to increase reliability during the nighttime. From 6:00 pm to 9:00 pm is considered as the evening peak hours. This period will be supplied by the battery because of the lack of solar production and high energy price during these hours. If the battery does not have energy stored to be supplied, the grid will supply the rest of the energy.

Three battery sizes of 25 kWh, 150 kWh and 300 kWh capacity are used to compare battery utilisation, self-sufficiency, savings and payback periods. The size mentioned in this report is the total usable amount of energy from a battery. A larger-size battery of 1000 kWh is also considered to achieve higher reliability during long blackouts (3-5 days). The

Table 5 Performance parameters for different battery and solar PV sizes installed at Cantor Fishermans feeder

Battery and Solar PV	25 kW, 75 kWh			50 kW, 150 kWh			100 kW, 300 kWh			100 kW, 1000 kWh		
	Solar PV			Solar PV			Solar PV			Solar PV		
	Present	Double	Triple	Present	Double	Triple	Present	Double	Triple	Present	Double	Triple
Energy Stored in BESS (MWh)	2.50	12.40	16.22	2.50	13.89	18.09	2.50	14.59	18.49	2.50	16.39	19.34
Battery Utilisation (Average cycles per day)	9%	45%	59%	5%	25%	33%	2%	13%	17%	1%	4%	5%
Energy Independence (% self-powered by solar/battery)	26%	47%	56%	9%	48%	62%	26%	51%	64%	10%	56%	68%
Evening Peak Demand supplied by renewables (%)	10%	46%	60%	10%	51%	67%	10%	54%	68%	11%	59%	72%
Payback period (yrs.)	-	6.69	4.04	-	12.61	7.74	-	24.52	15.30	-	60.64	39.15

performance parameters for different battery and solar PV sizes installed at the Cantor Fishermans area are presented in Table 5.

Since the energy stored in the battery depends on the surplus solar, energy stored in the battery energy storage system (BESS) is less (2.50 MWh in a year) than the energy stored with the present PV capacity. As the solar size and surplus energy increase, stored energy in the battery also increases. Most use of the battery is observed with a relatively small battery, 25 kW, 75 kWh and higher PV generation (triple the present capacity). With a larger battery size of 100 kW, 1000 kWh, the battery utilisation percentage is much less.

Self-sufficiency increases from 26% to 56% with the increased installation of solar PV for a battery size of 25kW, 75 kWh. Self-sufficiency does not increase significantly with the increase in battery capacity. The percentage of sustainable energy and grid energy for present solar PV and triple the current solar capacity are presented in Figure 5 and Figure 6.

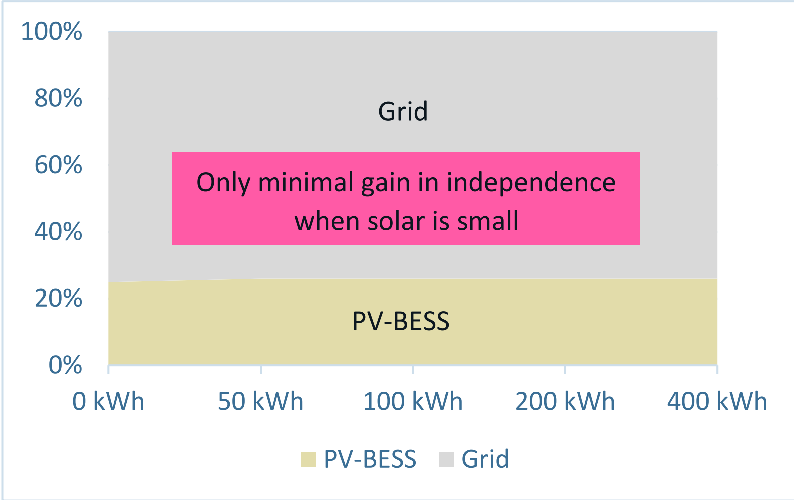

Figure 5 Percentage of self-sufficiency with present PV capacity (38 kW) of Cantor Fishermans

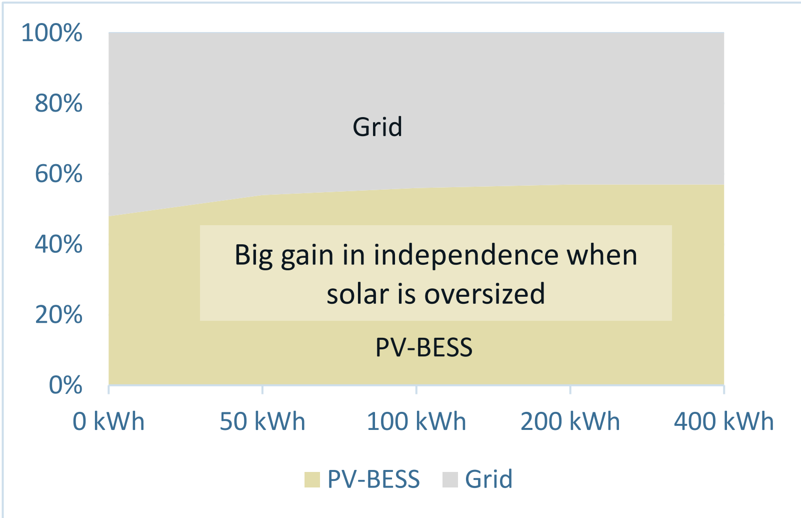

Figure 6 Percentage of self-sufficiency with triple PV generation (114 kW) of Cantor Fishermans

The percentage of battery backup for any random outage at any time of the day is calculated as a reliability parameter. The battery provides a backup if sufficient energy is stored for the next demand period. Backup durations are considered for 1 hr, 2 hrs, 4 hrs, 8 hrs, 24 hrs, 48 hrs and 72 hrs. Power backup duration for the smallest and biggest size battery used in this analysis are presented in Figure 7 and Figure 8.

With the smaller battery size, upto 1 hr backup is possible for 40% of the time during summer. However, the backup percentage is close to zero during winter (i.e., 1 hr of backup). For larger batteries, upto 72 hrs, backup is possible 100% of the time during summer. But the percentage of backup power remains very less during winter because of less solar energy generation. The reliability can be increased for any forecasted blackout or disaster by storing the battery using wind or energy from the grid during the off-peak.

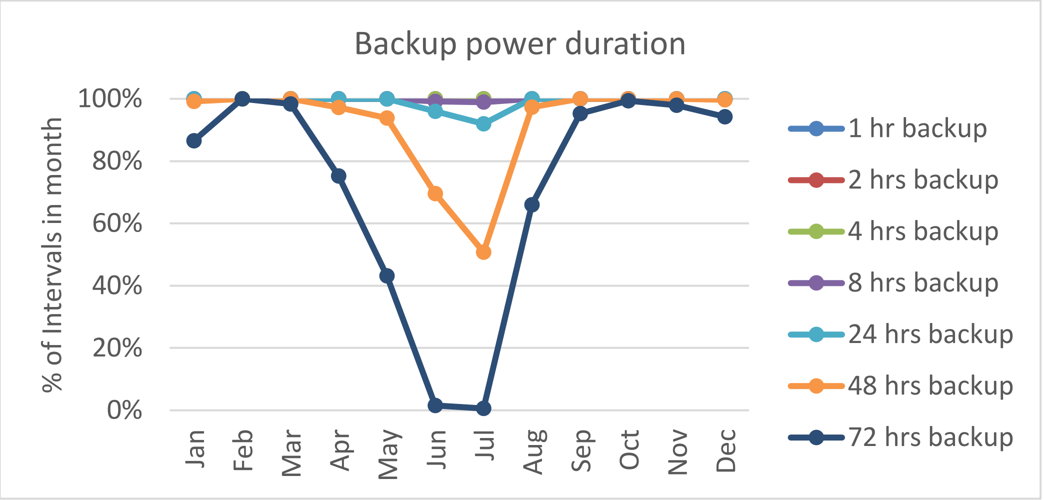

Figure 7 Percentage of power back up using 25 kW, 75 kWh battery at Cantor Fishermans feeder

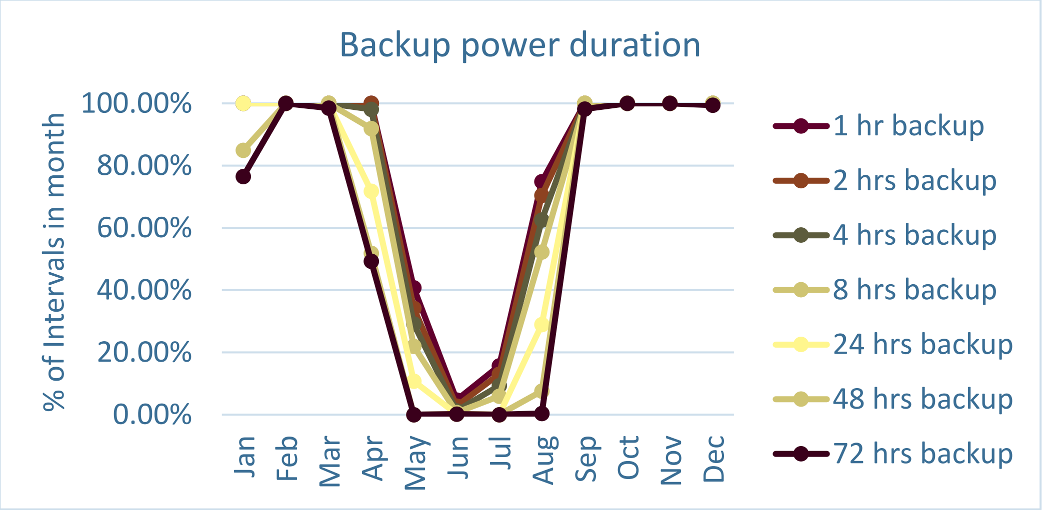

Figure 8 Percentage of power back up using 100 kW, 1000 kWh battery at Cantor Fishermans feeder

Economic Analysis

The investment cost, simple payback periods, battery cycles in a lifetime, savings and the levelized cost of energy (LCOE) are calculated for different sizes of batteries in the Cantor Fishermans feeder and presented in Table 6.

As the battery size gets bigger, the simple payback period increases. Most manufacturers provide a warranty for ten years or 2500 to 3000 cycles lifetime of a battery, whichever comes first. Small batteries need to work more which can cause early reach of their lifecycle threshold. The revenues generated by a 40c/kWh uplift in values in a year are considered savings, which does not show a significant increase in battery size.

Table 6 Economic analysis of different storage sizes for Cantor Fishermans feeder

Battery Capacity		Investment Cost ($)[1]	Payback period (yrs)[2]	Cycles per day (%)	Total cycles in 10 yrs[3]	Yearly energy discharged (MWh)[4]	Savings ($0.4/kWh)[5]	LCOE ($/kWh)
kW	**kWh**							
25	50	51,250	10	73%	2655	13.3	5,309	0.42
25	75	66,750	10	59%	2166	16.2	6,498	0.44
25	100	82,250	12	46%	1666	16.7	6,662	0.52
25	125	97,750	14	37%	1352	16.9	6,761	0.60
25	150	113,250	17	31%	1137	17.1	6,822	0.69
50	100	102,500	15	48%	1742	17.4	6,969	0.63
50	150	133,500	18	33%	1206	18.1	7,237	0.78
50	200	164,500	22	25%	918	18.4	7,347	0.94
50	250	195,500	26	20%	740	18.5	7,397	1.10
50	300	226,500	30	17%	620	18.6	7,445	1.26
100	200	205,000	28	25%	918	18.4	7,347	1.20
100	300	267,000	36	17%	620	18.6	7,445	1.52
100	400	329,000	44	13%	471	18.9	7,541	1.83
100	500	391,000	51	10%	381	19.0	7,618	2.14
100	600	453,000	59	9%	320	19.2	7,674	2.44

[1] CAPEX - $810/kW, $620/kWh, OPEX -$16/kW; [2] Simple payback - Not discounted; [3] Considering 10 yrs as warranty period; [4] Energy used from the battery; [5] 40c/kWh uplift in values in a year are considered savings; [6] Considering 10 yrs lifetime and without considering interest rate and discouts

Jupiter Centre

This area is connected to a 315 kVA transformer with a peak load of 185 kVA. Most of the Venus Bay shops are located in this area. There are 20 shops and 75 households. Total 61 kW solar is already installed in this area with restricted exports to the grid. The gross demand of this area is 555 MWh in a year, and out of it, 91 MWh demand is met by solar, which is 16% of the gross demand. The total exported solar energy to the grid is 0.07 MWh. The shops mostly operated during the day, and more flexible loads operating at night would be less. Households' hot water and other flexible loads can be shifted to operate during high solar generation time. We assumed that solar generation would increase three times the present capacity to meet the future demand.

To analyse the feasibility of batteries in this area, we considered that surplus solar energy would be stored in the battery during the daytime and utilised during evening peak hours from 06:00 pm to 09:00 pm. If the battery energy is insufficient to fulfil the demand, the required energy will be taken from the grid. If any energy remains in the battery after meeting the evening demand, that will be stored for the night and provide additional power backup.

The battery sizes considered for this area are similar to the Cantor Fisherman feeder. The performance parameters for different battery and solar PV sizes installed at the Cantor Fishermans area are presented in Table 7.

Table 7 Performance parameters for different battery and solar PV sizes installed at Jupiter Centre feeder

Battery and Solar PV	25 kW, 75 kWh			50 kW, 150 kWh			100 kW, 300 kWh			100 kW, 1000 kWh		
	Solar PV			Solar PV			Solar PV			Solar PV		
	Present	Double	Triple	Present	Double	Triple	Present	Double	Triple	Present	Double	Triple
Energy Stored in BESS (MWh)	0.07	5.56	13.92	0.07	7.5	23.54	0.07	8.23	30.09	0.07	8.30	35.86
Battery Utilisation (Average cycles per day)	0%	20%	51%	0%	14%	43%	0%	8%	28%	0%	2%	10%
Energy Independence (% self-powered by solar/battery)	16%	32%	44%	16%	33%	46%	16%	33%	47%	17%	33%	48%
Evening Peak Demand supplied by renewables (%)	1%	8%	19%	1%	11%	31%	1%	12%	39%	1%	12%	46%
Payback period (yrs.)	-	6.53	3.10	-	12.13	5.25	-	23.56	9.51	-	61.11	22.99

Since the amount of surplus solar is meagre in this area, the energy stored in the battery will be negligible and unable to provide energy during the evening peak. Increasing the solar PV up to three times the present capacity will provide up to 47% energy independency, and 39% of the evening peak demand will be met by battery energy. The 75-kWh battery will be utilised most, and the 150-kWh battery will also work nearly 43% of its duty cycle throughout the year. For smaller battery sizes, the payback period is also lower than 10 yrs which is the usual warranty period of most battery manufacturers.

Self-sufficiency increases from 16% to 44% with the increased installation of solar PV for a battery size of 25kW, 75 kWh. The self-sufficiency does not increase significantly with the increase in battery capacity. The percentage of sustainable energy and grid energy for present solar PV and triple the current solar capacity are presented in Figure 9 and Figure 10.

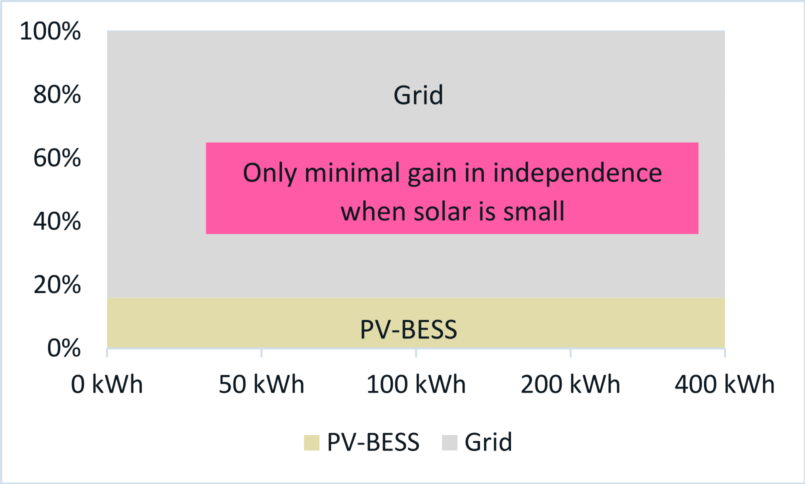

Figure 9 Percentage of self-sufficiency with present PV capacity (61 kW) of Jupiter Centre

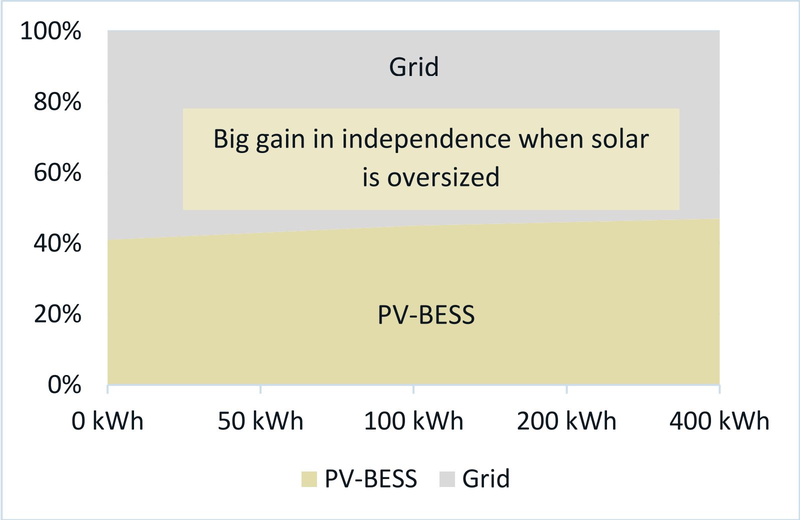

Figure 10 Percentage of self-sufficiency with triple PV generation of present capacity (183 kW) of Jupiter Centre

The battery provides a backup if sufficient energy is stored for the next demand period. Backup durations are considered for 1 hr, 2 hrs, 4 hrs, 8 hrs, 24 hrs, 48 hrs and 72 hrs. The power backup duration for the smallest and the big battery used in this analysis is presented in Figure 11 and Figure 12.

With the smaller battery size, upto 1 hr backup is possible for 30% to 40% of the time during summer. However, the backup percentage is close to zero for providing 1 hr of backup during winter. For larger batteries, nearly 100% backup is possible upto 8 hrs of outage. Upto 72 hrs, backup is possible even in the summer. During winter, most solar-generated power is utilised during the daytime, and backup is hardly possible on many days. The large battery can store energy from solar and, instead of supplying to the evening demand, keep the power for backup only.

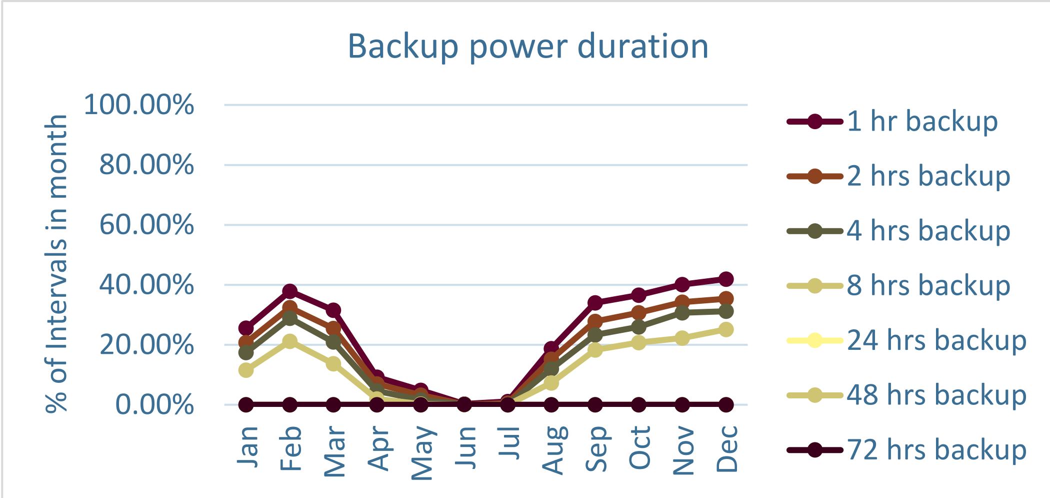

Figure 11 Percentage of power back up using 25 kW, 75 kWh battery at Jupiter Centre

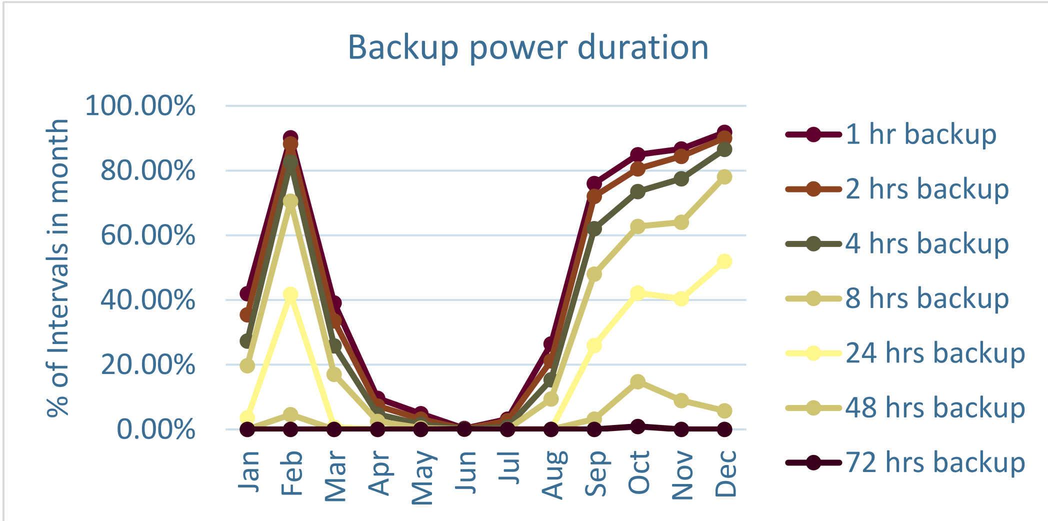

Figure 12 Percentage of power back up using 100 kW, 1000 kWh battery at Jupiter Centre

Economic Analysis

The economic analysis of different sizes of battery installation in the Jupiter Centre feeder is presented in Table 8. The LCOE is lowest for 25-kW 75-kWh battery and uses 51% cycles on average. The payback period is 12 years, closer to the ten-year warranty period.

A bigger battery will provide more reliability in exchange for investment and maintenance costs.

Table 8 Economic analysis of different storage sizes for Jupiter Centre Feeder

Battery Capacity		Investment Cost ($)	Payback period (yrs)	Cycles per day (%)	Total cycles in 10 yrs	Yearly energy discharged (MWh)	Savings ($0.4/kWh)	LCOE ($/kWh)
kW	kWh							
25	50	51,250	13	55%	2005	10.0	4,009	0.55
25	75	66,750	12	51%	1860	14.0	5,581	0.51
25	100	82,250	14	41%	1487	14.9	5,946	0.58
25	125	97,750	16	34%	1244	15.5	6,219	0.65
25	150	113,250	18	29%	1073	16.1	6,437	0.73
50	100	102,500	14	49%	1782	17.8	7,129	0.62
50	150	133,500	14	43%	1573	23.6	9,439	0.60
50	200	164,500	16	35%	1266	25.3	10,128	0.68
50	250	195,500	18	29%	1060	26.5	10,599	0.77
50	300	226,500	21	25%	910	27.3	10,922	0.86
100	200	205,000	19	37%	1354	27.1	10,830	0.82
100	300	267,000	22	28%	1007	30.2	12,084	0.94
100	400	329,000	26	22%	802	32.1	12,835	1.08
100	500	391,000	29	18%	668	33.4	13,360	1.22
100	600	453,000	33	16%	570	34.2	13,684	1.37

Tarwin Lower 94

This area is connected to a 315 kVA transformer with a peak load of 106 kVA. A recreation reserve, a club, a primary school and a health care centre and 47 households are located in this area. A total of 109 kW solar is installed with restricted grid exports. The gross demand of this area is 390 MWh in a year, whilst 163 MWh demand is met by solar, which is 42% of the gross demand. The total exported solar energy to the grid is 11.40 MWh. Most flexible loads can be shifted to operate during the high solar generation time. An assumption is made to increase solar upto three times the present capacity to maximise the utilisation of sustainable solar energy.

It is considered that surplus solar energy would be stored in the battery during the daytime and utilised during evening peak hours from 06:00 pm to 09:00 pm. Additional energy to meet the evening peak demand will be taken from the grid, and excess energy will remain in the battery for additional backup during the night.

The battery sizes considered for this area are similar to the Cantor Fisherman feeder. The performance parameters for different battery and solar PV sizes installed at the Cantor Fishermans area are presented in Table 9.

Table 9 Performance parameters for different battery and solar PV sizes installed at Tarwin Lower 94 feeder

Battery and Solar PV	25 kW, 75 kWh			50 kW, 150 kWh			100 kW, 300 kWh			100 kW, 1000 kWh		
	Solar PV			Solar PV			Solar PV			Solar PV		
	Present	Double	Triple	Present	Double	Triple	Present	Double	Triple	Present	Double	Triple
Energy Stored in BESS (MWh)	8.40	19.92	23.34	10.39	29.02	35.91	11.4	31.56	40.11	11.40	32.82	41.66
Battery Utilisation (Average cycles per day)	31%	73%	85%	19%	53%	66%	10%	29%	37%	3%	9%	12%
Energy Independence (% self-powered by solar/battery)	41%	58%	64%	42%	61%	67%	42%	61%	68%	42%	62%	69%
Evening Peak Demand supplied by renewables (%)	18%	42%	51%	22%	60%	75%	23%	65%	83%	25%	68%	87%
Payback period (yrs.)	-	3.00	1.76	-	5.16	3.11	-	9.91	5.98	-	25.43	15.45

With the present PV capacity, surplus solar energy is either exported to the grid with a cheap feed-in tariff or spilled because of the export limit exposed by AusNet Services Pty Ltd. This surplus energy can be stored during the day. The surplus energy can be used during the the evening peak (peak electricity price period)#.

When the solar increases upto three times the present capacity, i.e., 327 kW, energy independence reaches upto 68%, battery utilisation 37%, and evening peak demand meets 83%. A battery larger than this does not add much value regarding self-sufficiency and savings but increases the capital and maintenance costs.

Self-sufficiency increases from 41% to 65% with the increase in installation of solar PV for a battery size of 25kW, 75 kWh. The percentage of sustainable energy and grid energy for present solar PV and triple the current solar capacity are presented in Figure 13 and Figure 14.

#Australian Energy Regulator (aer.gov.au)

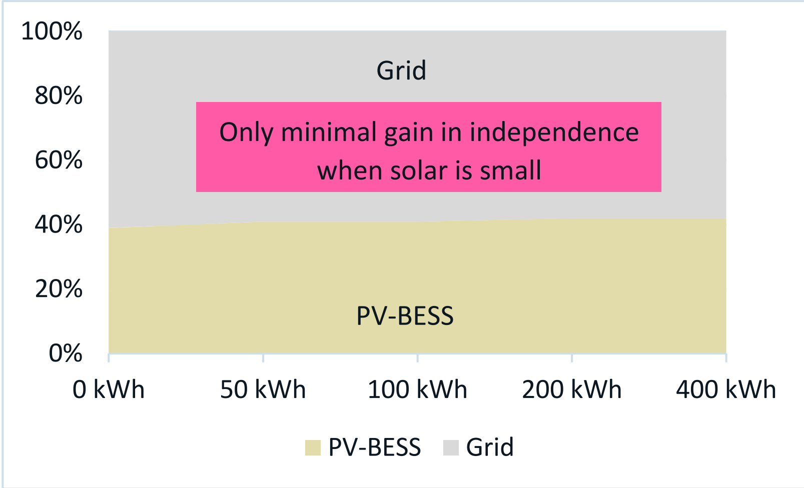

Figure 13 Percentage of self-sufficiency with present PV capacity (109 kW) of Tarwin Lower 94 feeder

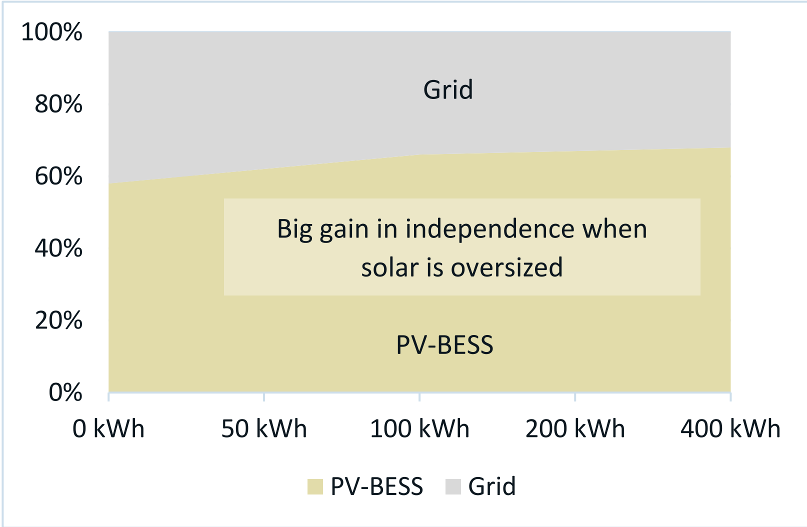

Figure 14 Percentage of self-sufficiency with triple PV generation of present capacity (327 kW) of Tarwin Lower 94 feeder

The battery provides a backup if sufficient energy is stored for the next demand period. Similar to previous site, backup durations are considered for 1 hr, 2 hrs, 4 hrs, 8 hrs, 24 hrs, 48 hrs and 72 hrs. The power backup duration for the smallest and the big battery used in this analysis are presented in Figure 15 and Figure 16.

With the smaller battery size, upto 8 hr backup is possible for 50% to 70% of the time during the summer. However, the backup percentage is zero for 24 hrs, 48 hrs and 72 hrs of backup during the winter.

For larger batteries, nearly 100% backup is possible upto 72 hrs outage during the summer. During winter, most solar-generated power is utilised during the daytime, and backup is almost impossible on many days. The large battery can store energy from solar and, instead of supplying to the evening demand, can be utilised as a backup only.

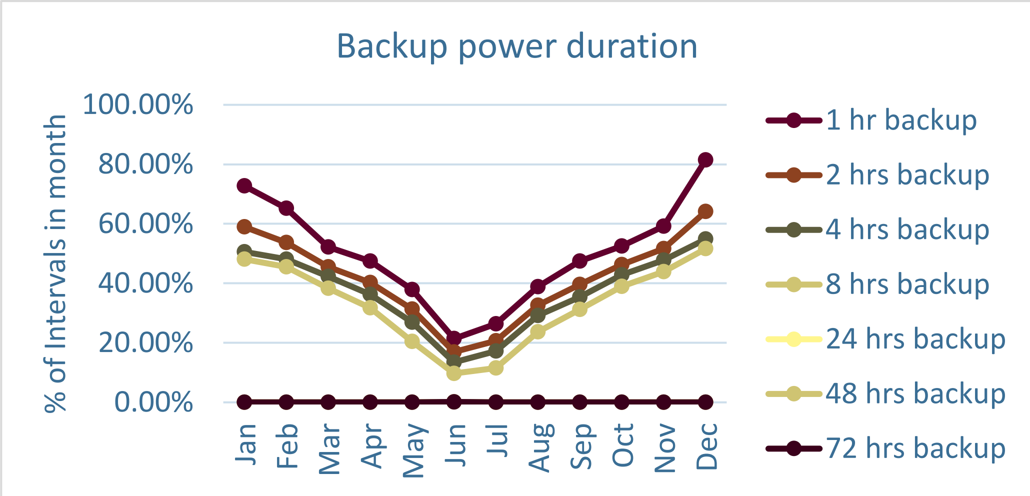

Figure 15 Percentage of power back up using 25 kW, 75 kWh battery at Tarwin Lower 94 feeder

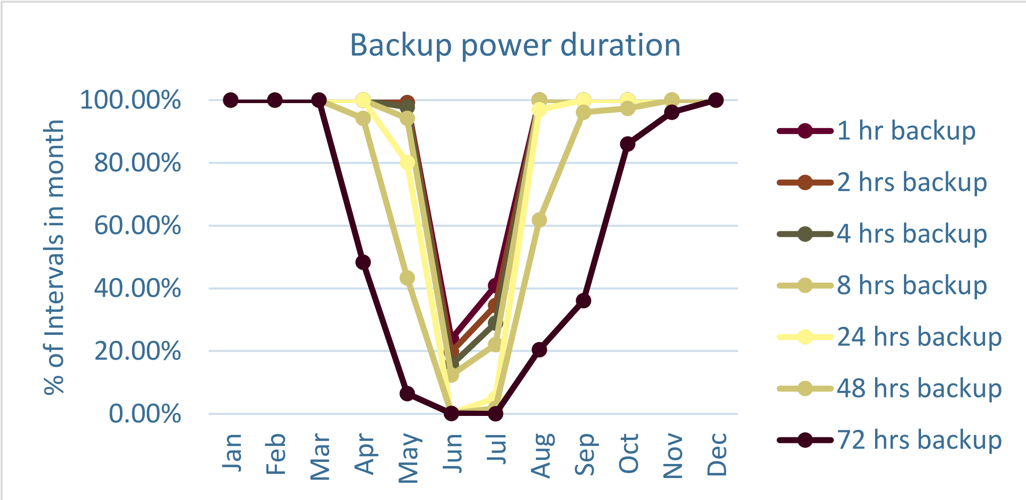

Figure 16 Percentage of power back up using 100 kW, 1000 kWh battery at Tarwin Lower 94 feeder

Economic Analysis

An economic analysis of using different battery sizes with triple solar PV capacity is performed, and the results are presented in Table 10. Smaller LCOE is observed for small battery. However, the battery must work harder than the duty cycle specified in warranty to meet the requirements of the customers. Bigger batteries are required for the community's higher reliability and energy independence, resulting in extra invetsment.

Table 10 Economic analysis of different storage sizes for Tarwin Lower 94 Feeder

Battery Capacity		Investment Cost ($)	Payback period (yrs)	Cycles per day (%)	Total cycles in 10 yrs	Yearly energy discharged (MWh)	Savings ($0.4/kWh)	LCOE ($/kWh)
kW	kWh							
25	50	51,250	8	93%	3382	16.9	6,765	0.33
25	75	66,750	7	85%	3115	23.4	9,346	0.30
25	100	82,250	9	66%	2394	23.9	9,576	0.36
25	125	97,750	10	53%	1941	24.3	9,705	0.42
25	150	113,250	12	45%	1630	24.5	9,782	0.48
50	100	102,500	9	82%	3004	30.0	12,017	0.37
50	150	133,500	9	66%	2398	36.0	14,388	0.39
50	200	164,500	11	51%	1852	37.0	14,817	0.47
50	250	195,500	13	41%	1507	37.7	15,070	0.54
50	300	226,500	15	35%	1266	38.0	15,194	0.62
100	200	205,000	13	53%	1932	38.6	15,460	0.57
100	300	267,000	17	37%	1341	40.2	16,091	0.70
100	400	329,000	20	28%	1022	40.9	16,350	0.84
100	500	391,000	24	23%	825	41.3	16,505	0.99
100	600	453,000	27	19%	692	41.5	16,599	1.13

Venus Bay 2

This feeder has the largest transformer in the community, mainly supplying to the shops, community buildings and only two households (only two hours). Therefore, most of the demand occurs during the day and the evening peak. The area is connected to a 500 kVA transformer with a peak load of 112 kVA. A total of 81 kW solar is already in operation in this area. The gross load is 604 MWh, 122 MWh demand is met by solar energy. The total surplus solar energy is 0.21 MWh in a year, reveals that most of the generated solar is utilised during the day. If the solar PV is increased three times more, the surplus energy becomes 61.55 MWh. This excess energy can be stored in a battery and utilised during evening peak hours (i.e., when the tariff is high).

Several community values have been evaluated for different battery and PV sizes. The performance parameters for different battery and solar PV sizes installed at the Venus Bay 2 area are presented in Table 11.

With the present PV capacity, the battery will charge minimal surplus solar energy. The use of batteries will be beneficial only if the present solar is increased. When the solar is increased from 81 kW to 243 kW, the self-sufficiency increased from 20% to 56%. With a 300 kWh battery, 52% of the evening peak demand can be met. With a 150 kWh battery, upto 42% of the peak evening demand can be met. With an increased solar PV, the payback period is below 10 yrs which also falls within the usual warranty periods.

Table 11 Performance parameters for different battery and solar PV sizes installed at Venus bay 2 feeder

Battery and Solar PV	25 kW, 75 kWh			50 kW, 150 kWh			100 kW, 300 kWh			100 kW, 1000 kWh		
	Solar PV			Solar PV			Solar PV			Solar PV		
	Present	Double	Triple	Present	Double	Triple	Present	Double	Triple	Present	Double	Triple
Energy Stored in BESS (MWh)	0.21	5.23	15.38	0.21	7.50	27.40	0.21	8.78	34.79	0.21	9.27	38.59
Battery Utilisation (Average cycles per day)	1%	19%	56%	0%	14%	50%	0%	8%	32%	0%	3%	11%
Energy Independence (% self-powered by solar/battery)	20%	40%	53%	20%	40%	55%	20%	40%	56%	20%	40%	57%
Evening Peak Demand supplied by renewables (%)	2%	10%	25%	2%	13%	42%	2%	15%	52%	2%	13%	58%
Payback period (yrs.)	-	5.24	2.43	-	9.77	4.14	-	18.87	7.59	-	48.86	19.09

With the present PV capacity, the surplus solar energy is very small. The self-sufficiency is nearly 20%, mainly from the present solar capacity.

When the solar increases upto three times the present capacity, energy independence reaches upto 53% with a battery utilisation of 56% and 42% evening peak demand met. A battery larger than this does not add much value regarding self-sufficiency and savings but increases the capital and maintenance costs.

Self-sufficiency increases from 20% to 53% with the increased installation of solar PV for a battery size of 25kW, 75 kWh. The percentage of sustainable energy and grid energy for present solar PV and triple the current solar capacity are presented in Figure 17 and Figure 18.

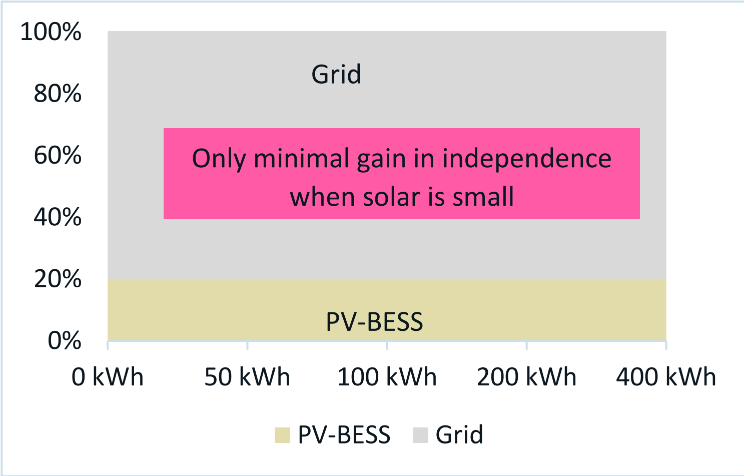

Figure 17 Percentage of self-sufficiency with present PV capacity (81 kW) of Venus Bay 2

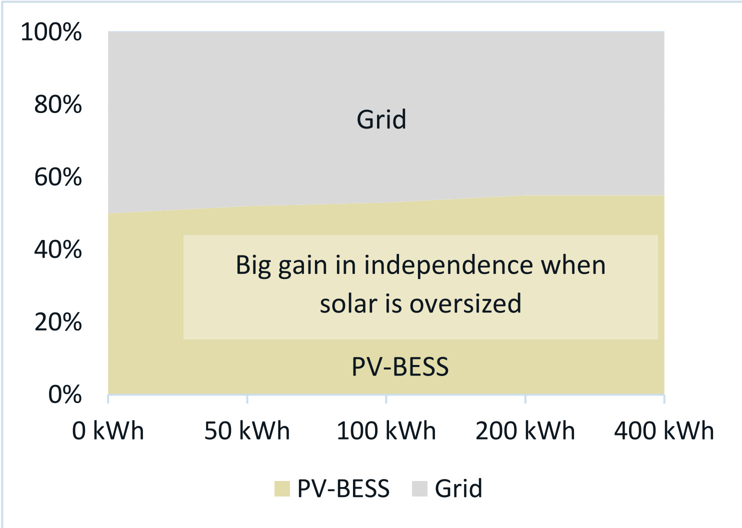

Figure 18 Percentage of self-sufficiency with triple capacity (243 kW) of Venus bay 2

The battery provides a backup if sufficient energy is stored for the next demand period. Backup durations are considered for 1 hr, 2 hrs, 4 hrs, 8 hrs, 24 hrs, 48 hrs and 72 hrs. The power backup duration for the smallest and the big battery used in this analysis are presented in Figure 19 and Figure 20.

With the smaller battery size, upto 8 hr backup is possible for 20% - 30% of the time during the summer. However, the backup percentage is zero for providing 24 hrs, 48 hrs and 72 hrs of backup during both summer and winter.

For larger batteries, nearly 100% backup is possible upto 8 hrs of outage during the summer. During winter, most solar-generated power is utilised during the daytime, and backup is almost impossible on many days. The large battery can store energy directly from solar and, instead of supplying to the evening demand, can be utilised as a backup only.

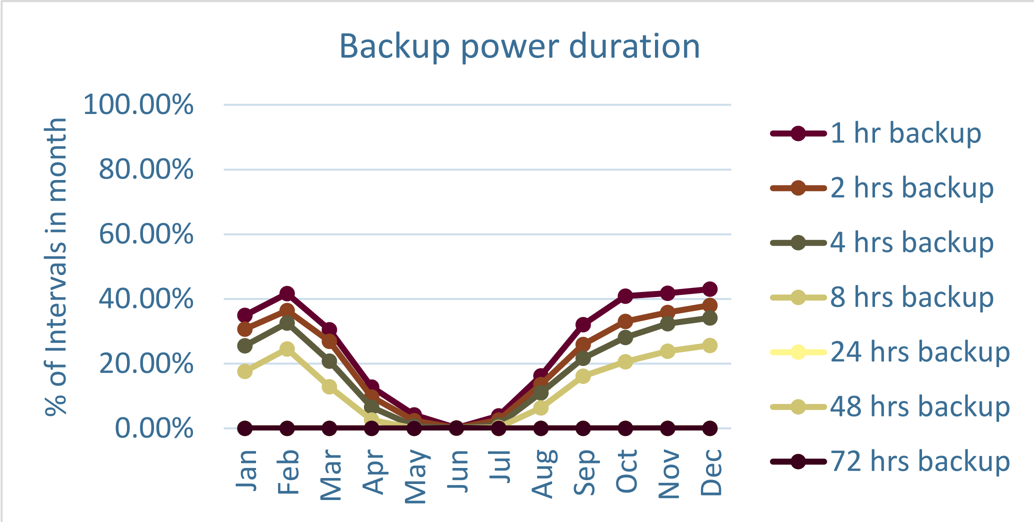

Figure 19 Percentage of power back up using 25 kW, 75 kWh battery at Venus Bay 2 feeder

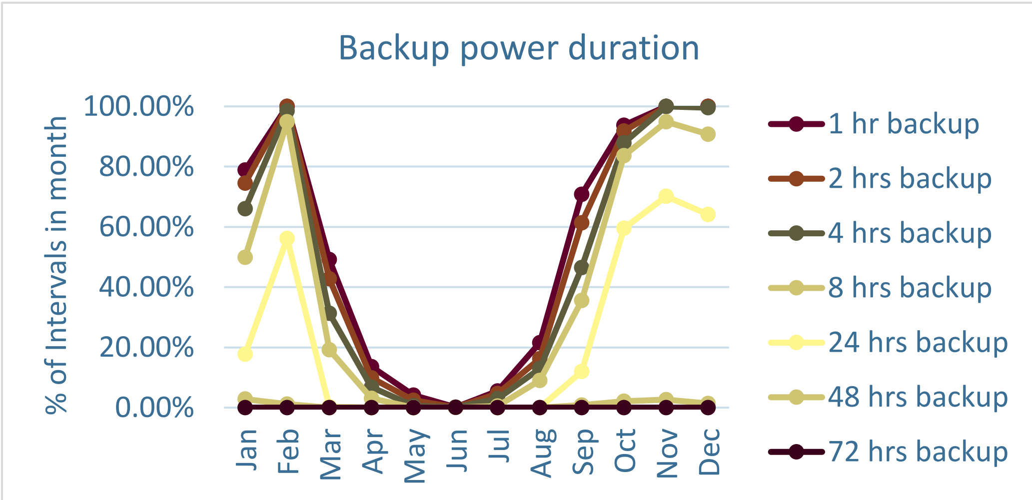

Figure 20 Percentage of power back up using 100 kW, 1000 kWh battery at Venus Bay 2 feeder

Economic Analysis

The economic analysis of the Venus Bay 2 feeder for different battery sizes is presented in Table 11. The lowest payback period is obtained for 25 kW, 75 kWh battery. The total cycles in 10 years are 2051 (lower than the warranty document). We have used the similar assumptions presented in Page 15.

Table 11 Economic analysis of different storage sizes for Venus Bay 2 Feeder

Battery Capacity		Investment Cost ($)	Payback period (yrs)	Cycles per day (%)	Total cycles in 10 yrs	Yearly energy discharged (MWh)	Savings ($0.4/kWh)	LCOE ($/kWh)
kW	**kWh**							
25	50	51,250	12	59%	2169	10.8	4,338	0.51
25	75	66,750	11	56%	2051	15.4	6,154	0.46
25	100	82,250	13	45%	1625	16.2	6,498	0.53
25	125	97,750	14	37%	1352	16.9	6,759	0.60
25	150	113,250	16	32%	1159	17.4	6,954	0.67
50	100	102,500	13	55%	1996	20.0	7,985	0.55
50	150	133,500	12	50%	1826	27.4	10,958	0.52
50	200	164,500	14	40%	1466	29.3	11,729	0.59
50	250	195,500	16	33%	1221	30.5	12,207	0.67
50	300	226,500	18	29%	1042	31.2	12,498	0.75
100	200	205,000	16	44%	1598	32.0	12,784	0.69
100	300	267,000	19	32%	1160	34.8	13,915	0.81
100	400	329,000	23	24%	893	35.7	14,285	0.97
100	500	391,000	27	20%	725	36.3	14,501	1.12
100	600	453,000	31	17%	613	36.8	14,717	1.27

Canterbury Constance

This feeder is connected to a 200 kVA transformer with 80 kVA peak demand. There are 56 households, one Optus service, one transfer station (waste management) and a Telstra Tower. A total 54 kW of solar PV has already been installed in this area and operating. The gross demand in this area is 251 MWh. Out of this demand, 81 MWh is supplied by the current solar, which is 32% of the total demand. With the existing solar, a total of 3.87 MWh surplus energy is exported to the grid on current feed-in-tariif rate.

A wind turbine of 23 m in height is considered feasible as this area. The Telstra tower is installd at the similar height. The maximum generation capacity of the turbine is 100 kW. Total generation is assumed as the historical generation data from the year 2019 because of the availability of that year's wind data. The wind generation will vary yearly based on the weather and wind profile. Total wind generation is 62 MWh, and total exports or spillage wind energy is 14.7 MWh.

We have considered three ways to charge the battery and utilise the stored energy during morning and evening peak hours. In case 1, the battery is charged using surplus renewables only. The battery is mainly charged during the high solar peak and depends only on wind energy at night. In case 2, the battery is charged using surplus energy during the day and available wind at night. This provides sufficient energy to charge the battery at night and supply more power during morning peak hours. In case 3, the grid

Table 12 Performance parameters for different battery and solar PV sizes installed at Canterbury Constance (Case 1)

Battery and Solar PV	25 kW, 75 kWh			50 kW, 150 kWh			100 kW, 300 kWh			100 kW, 1000 kWh		
	Solar PV			Solar PV			Solar PV			Solar PV		
	Present	Double	Triple	Present	Double	Triple	Present	Double	Triple	Present	Double	Triple
Energy Stored in BESS (MWh)	9.77	17.98	20.57	12.43	22.52	25.97	14.74	25.10	27.88	18.57	28.60	30.97
Battery Utilisation (Average cycles per day)	36%	66%	75%	23%	41%	48%	14%	23%	26%	5%	8%	9%
Energy Independence (% self-powered by solar/battery)	54%	69%	74%	55%	70%	76%	56%	71%	77%	57%	73%	78%
Morning Peak Demand supplied by renewables (%)	57%	72%	78%	61%	80%	88%	64%	84%	92%	68%	89%	97%
Evening Peak Demand supplied by renewables (%)	46%	72%	82%	50%	78%	89%	54%	82%	91%	58%	88%	97%
Payback period (yrs.)	17.02	4.67	2.97	26.72	8.28	5.42	44.92	15.54	10.51	100.16	37.48	26.21

electricity is used to fully charged the battery from 12:00 am to 04:00 am and use it during peak hours. The battery will charge by using surplus renewables for the rest of the time.

Case 1

Community values are evaluated, and results are presented in Table 12 for case 1 for different battery and PV sizes. The energy stored in the battery increases when the PV is doubled, but the increment rate is less when the PV is tripled. The battery cycle is utilised most (75%) when the battery size is small as 25-kW 75-kWh. A 74% energy independence is achieved with this battery size. With a 50-kW 150-kWh battery, 88% morning peak demand and 89% evening peak demand can be met by only renewable sources such as solar PV, wind and battery.

Using the 25-kW 75-kWh size battery alongside the solar PV and wind, upto 8 hrs power backup is possible for 50% instances of the year. In several summer days, upto 24 hrs of back-up is possible. Using the 100-kW 1000-kWh battery, 72 hrs backup is possible for most summer days. Total backup hours are highly reduced in July because of less solar generation. The power backup duration for the smallest and the big battery are presented in Figure 22 and Figure 23.

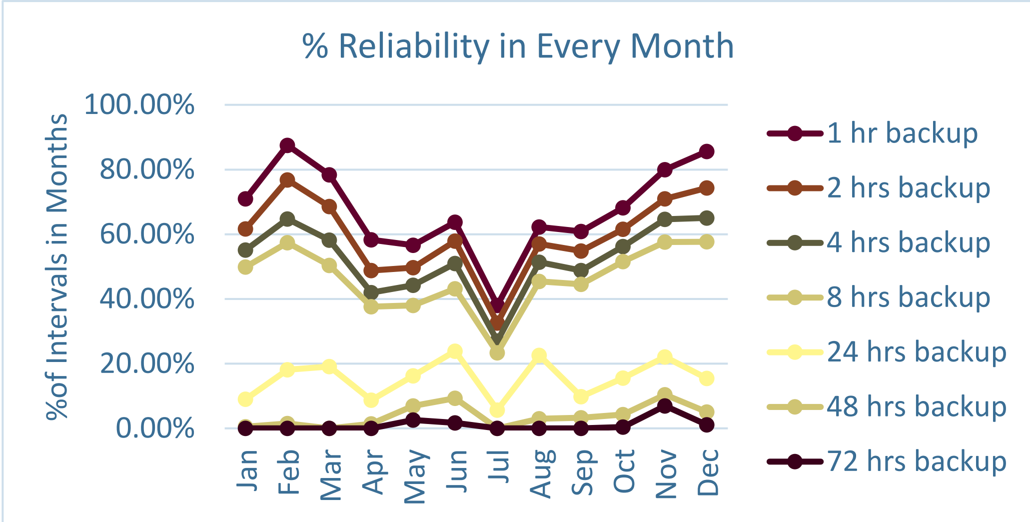

Figure 22 Percentage of power back up using 25 kW, 75 kWh battery at Canterbury Constance (Case 1)

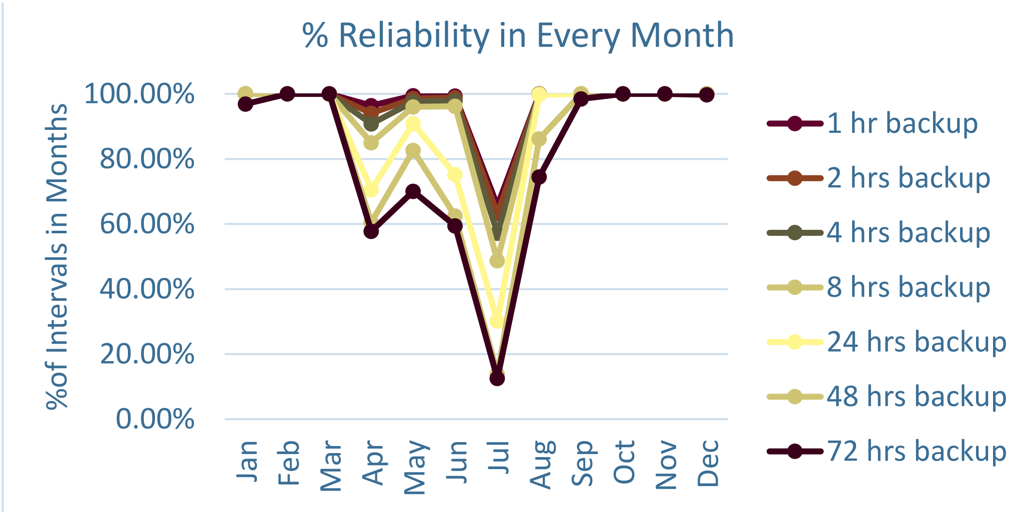

Figure 23 Percentage of power back up using 100 kW, 1000 kWh battery at Canterbury Constance (Case 1)

Economic Analysis

The economic analysis of the Canterbury Constance feeder for different battery sizes is presented in Table 13. From the table, it is evident that the lowest payback period could be obtained for 25 kW, 50 kWh and 75 kWh storage. However, the total cycles in 10 years are beyond the warranty cycle. The similar assumptions given in Page 15 are used for this analysis.

Table 13 Economic analysis of different storage sizes for Canterbury Constance Feeder

Battery Capacity		Investment Cost ($)	Payback period (yrs)	Cycles per day (%)	Total cycles in 10 yrs	Yearly energy discharged (MWh)	Savings ($0.4/kWh)	LCOE ($/kWh)
kW	**kWh**							
25	50	51,250	8	87%	3166	15.8	6,332	0.35
25	75	66,750	8	75%	2747	20.6	8,242	0.34
25	100	82,250	9	63%	2307	23.1	9,229	0.37
25	125	97,750	10	53%	1924	24.0	9,618	0.42
25	150	113,250	12	45%	1637	24.6	9,824	0.48
50	100	102,500	11	65%	2365	23.6	9,459	0.47
50	150	133,500	13	48%	1735	26.0	10,411	0.54
50	200	164,500	15	37%	1347	26.9	10,777	0.64
50	250	195,500	18	30%	1101	27.5	11,005	0.74
50	300	226,500	20	26%	931	27.9	11,177	0.84
100	200	205,000	19	37%	1350	27.0	10,800	0.82
100	300	267,000	24	26%	933	28.0	11,200	1.01
100	400	329,000	29	20%	719	28.8	11,511	1.20
100	500	391,000	33	16%	587	29.3	11,732	1.39
100	600	453,000	38	14%	498	29.9	11,948	1.57

Case 2

In case 2, the battery is charged using wind energy at night to capture sustainable energy most and use that energy during morning peak hours when solar energy is unavailable or partially available. Community values such as sustainability, self-sufficiency and reliability are evaluated for the Canterbury Constance area, and results are presented in Table 14. In this case, more energy can be stored in the battery and utilised when needed. With a 25 kW 75 kWh battery size, 79% of a daily cycle is used. However, increasing solar does not increase the stored energy much because of the SOC limitations. A larger battery can provide more capacity to store more energy. More than 70% energy independence can be achieved by using solar PV, wind and battery combination. Battery energy supply to the evening peak demand increases significantly with the increase of solar PV. The energy supplied to the morning demand also increases with the rise of solar PV and battery size. The payback period less than 10 years could be observed for 25 kW and 50 kW battery, below the manufacturer's general warranty period. The larger battery provides reliability and sustainability with a high investment and maintenance cost.

Table 14 Performance parameters for different battery and solar PV sizes installed at Canterbury Constance (Case 2)

Battery and Solar PV	25 kW, 75 kWh			50 kW, 150 kWh			100 kW, 300 kWh			100 kW, 1000 kWh		
	Solar PV			Solar PV			Solar PV			Solar PV		
	Present	Double	Triple	Present	Double	Triple	Present	Double	Triple	Present	Double	Triple
Energy Stored in BESS (MWh)	11.66	19.20	21.73	14.33	23.43	26.52	18.57	25.81	28.35	19.06	29.28	31.39
Battery Utilisation (Average cycles per day)	43%	71%	79%	26%	43%	49%	15%	24%	26%	5%	8%	9%
Energy Independence (% self-powered by solar/battery)	54%	69%	74%	55%	71%	76%	56%	72%	77%	57%	73%	78%
Morning Peak Demand supplied by renewables (%)	62%	76%	82%	66%	83%	90%	69%	86%	93%	73%	91%	98%
Evening Peak Demand supplied by renewables (%)	46%	72%	82%	51%	78%	89%	55%	82%	92%	60%	89%	97%
Payback period (yrs.)	14.28	4.49	2.91	23.20	8.09	5.38	39.77	15.28	10.43	90.08	38.95	26.10

Random outages are considered at any time of the day, and the percentage of instances that provide backup is calculated for the smallest and the largest battery. The backup power duration curve is presented in Figure 24 and Figure 25.

From Figure 24, we observe that 1 hr backup is possible for 50% to 90% of summer and winter days. Upto 24 hrs backup is also possible with this battery size 10% to 20% of the day. From Figure 25, 1 hr backup power supply is likely for 100% during summer and 80% during winter. Batteries are not charged enough to provide 1 hr backup on some very cloudy days. Upto 72 hrs, backup is possible during summer. However, in winter, Only 10% of the time instances 72 hrs backup is possible. This larger battery can be charged with solar only and discharged only the events related to reliability.

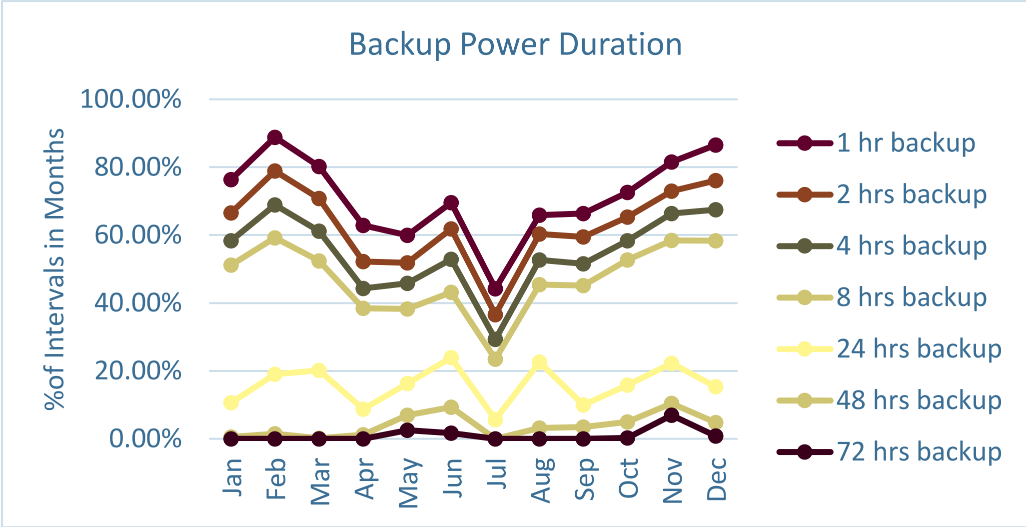

Figure 24 Percentage of power back up using 25 kW, 75 kWh battery at Canterbury Constance (Case 2)

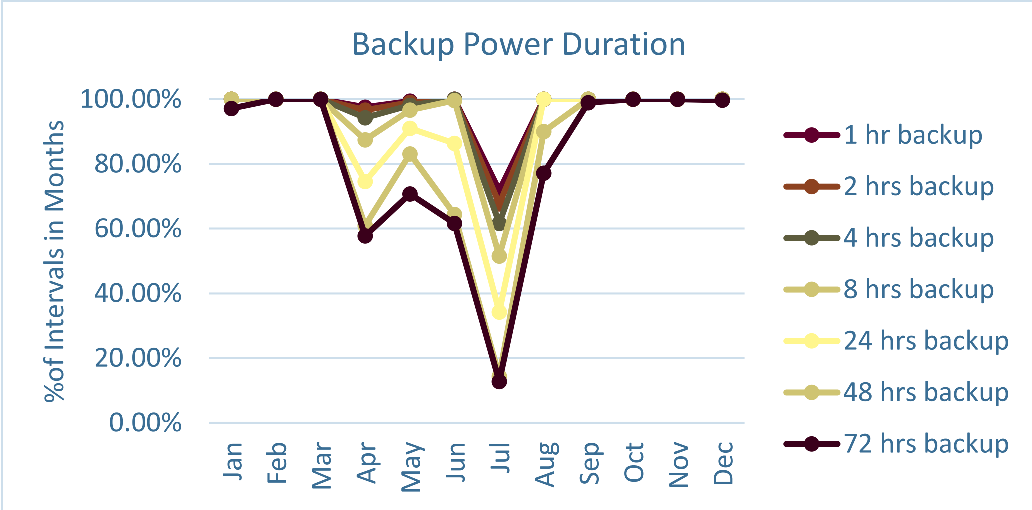

Figure 25 Percentage of power back up using 100 kW, 1000 kWh battery at Canterbury Constance (Case 2)

Case 3

Case 3 is modelled to provide more energy during the morning peak hours to reduce electricity bills. Performance parameters calculated using different battery and PV sizes are presented in Table 15. The battery uses surplus solar and wind energy during the day to charge the battery. Most of its charges are used during the evening peak demand. Again, the battery is charged from 12:00 am to 4:00 am using the off-peak grid electricity. The stored energy is then used to supply the morning peak demand. In this case, the battery is highly used to achieve more gain, sometimes costing more battery cycles and deteriorating its performance before the warranty period. The smaller battery is used up more than one cycle a day.

More energy is stored in the battery with upto 79% energy independence. Since the battery is fully charged at night. The morning demands are almost fully met. The evening peak demand is also fully supplied for the larger batteries because of the excess energy after meeting the morning demand.

Table 15 Performance parameters for different battery and solar PV sizes installed at Canterbury Constance (Case 3)

Battery and Solar PV	25 kW, 75 kWh			50 kW, 150 kWh			100 kW, 300 kWh			100 kW, 1000 kWh		
	Solar PV			Solar PV			Solar PV			Solar PV		
	Present	Double	Triple	Present	Double	Triple	Present	Double	Triple	Present	Double	Triple
Energy Stored in BESS (MWh)	26.47	27.91	27.82	38.37	34.69	32.62	41.73	36.45	33.71	42.15	36.87	34.13
Battery Utilisation (Average cycles per day)	97%	102%	102%	70%	63%	59%	38%	33%	31%	11%	10%	9%
Energy Independence (% self-powered by solar/battery)	60%	73%	77%	65%	75%	78%	66%	76%	79%	67%	76%	79%
Morning Peak Demand supplied by renewables (%)	97%	98%	99%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Evening Peak Demand supplied by renewables (%)	58%	76%	84%	91%	95%	97%	100%	100%	100%	100%	100%	100%
Payback period (yrs.)	6.30	3.65	2.64	8.69	6.36	4.90	16.04	12.35	9.67	42.12	32.41	25.39

Since the battery is fully charged at night, more backup is expected from this study case. Besides, less solar and wind surplus energy is required to charge the battery. Backup durations are considered for performance analysis for 1 hr, 2 hrs, 4 hrs, 8 hrs, 24 hrs, 48 hrs and 72 hrs. The power backup duration for the smallest and the big battery used in this analysis are presented in Figure 25 and Figure 26.

With the smaller battery size, upto 8 hr backup is possible for 50% to 85% of the time, both summer and winter. However, the backup percentage is below 30% for 24 and 48 hours-outage cases.

For larger batteries, 100% backup is possible for 24 hrs outage throughout the year. During summer, 100% backup is possible for 48 hrs and 72 hrs outage cases.

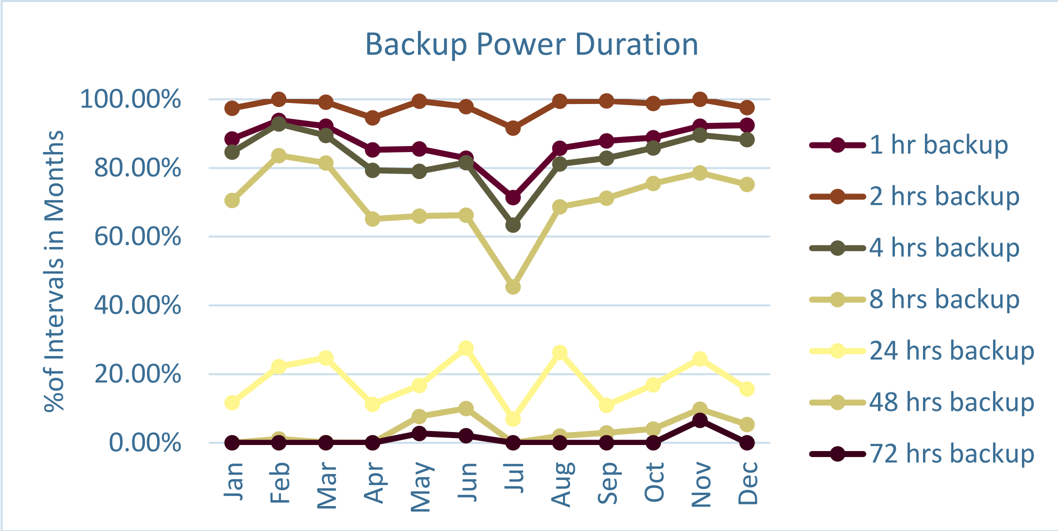

Figure 25 Percentage of power back up using 25 kW, 75 kWh battery at Canterbury Constance (Case 3)

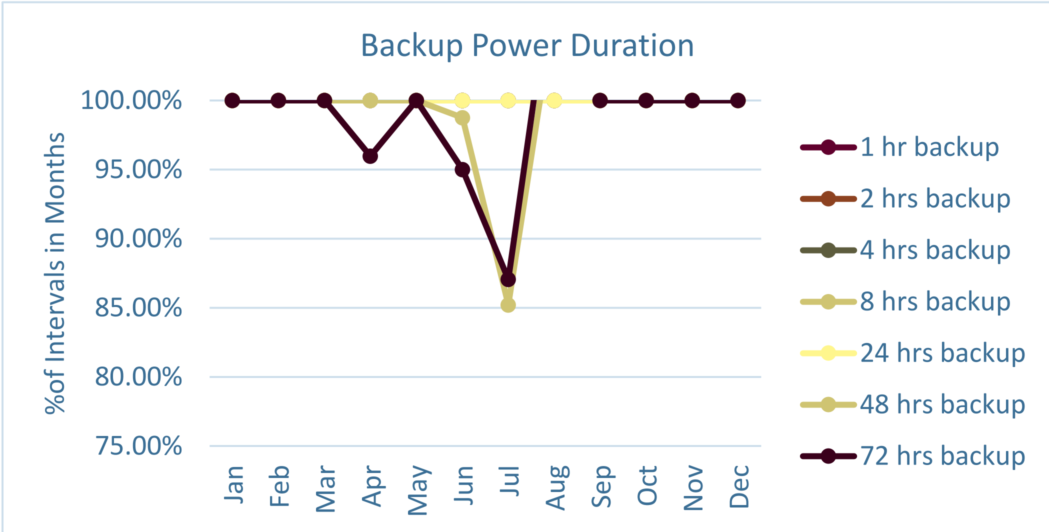

Figure 26 Percentage of power back up using 100 kW, 1000 kWh battery at Canterbury Constance (Case3)

Aggregated Venus Bay and Tarwin Lower

In this analysis, the loads of the whole Venus Bay and Tarwin Lower area are considered a single aggregated community load. This analysis considered solar and battery capacity combines all customers' aggregated solar PV and batteries. The community might agree to establish a large community battery to fulfil the battery capacity and achieve certain reliability. A 1 MW wind is also considered that could either be constructed within the community or an existing neighbouring wind farm such as Bald Hills Wind Farm. Maximum demand is 2496 kVA, and total installed solar is 1923 kW. Aggregated gross demand is 8.77 GVA, and net demand after using solar is 5.88 GVA. The entire solar generation is 2.87 GW, and the export is 204 MW. Three cases are considered for the performance evaluation of different battery and PV sizes.

Case 1

The battery is charged by the surplus renewables only. The energy stored in the battery during the day provides evening peak demand from 06:00 pm to 09:00 pm. The battery is also charged by the surplus wind during the night and discharged during the morning peak. Four battery sizes are considered for three PV capacities. The obtained results based on the community values are presented in Table 16. Stored energy in batteries significantly increases when the solar PV capacity is doubled. The 500 kW 1500 KWh battery is used upto 90% of its cycles, while the solar PV is three times the present capacity.

Table 16 Performance parameters for different battery and solar PV sizes installed at Venus Bay and Tarwin Lower (Case 1)

Battery and Solar PV	500 kW, 1500 kWh			1000 kW, 3000 kWh			1000 kW, 6000 kWh			2000 kW, 10000 kWh		
	Solar PV			Solar PV			Solar PV			Solar PV		
	Present	Double	Triple	Present	Double	Triple	Present	Double	Triple	Present	Double	Triple
Energy Stored in BESS (MWh)	218	430	494	270	647	759	315	731	850	357	787	902
Battery Utilisation (Average cycles per day)	40%	79%	90%	25%	59%	70%	14%	34%	39%	9%	22%	25%
Energy Independence (% self-powered by solar/battery)	52%	68%	73%	53%	71%	76%	53%	72%	77%	54%	72%	78%
Morning Peak Demand supplied by renewables (%)	56%	71%	77%	58%	76%	81%	59%	81%	88%	60%	82%	89%
Evening Peak Demand supplied by renewables (%)	33%	55%	63%	36%	68%	81%	39%	72%	83%	39%	75%	87%
Payback period (yrs.)	15.21	2.64	1.65	24.67	4.51	2.92	35.94	7.24	4.76	58.93	12.05	8.03

The supply to both morning and evening peak demands increases with the increase of batteries and solar PV. The battery needs to work harder to charge the battery during the night using wind energy. Energy independence is achieved upto 77% with the smaller batter. The larger battery does not include much in energy independence.

The reliability parameter is measured by the percentage of backup power for any random outage. The results concerning reliability using the smaller and the larger battery are presented in Figure 27 and Figure 28. With the smaller battery, 8 hrs backup for 20% of the instances is visible during winter, and the reliability instances increase to 50% during summer. The larger battery can supply 8 hrs backup for almost 100% of instances during summer and 30% in July. In summer, the large battery can provide backup for upto 72 hrs. The reliability of the community can be increased by keeping the battery charged 24/7 and discharging only in an emergency.

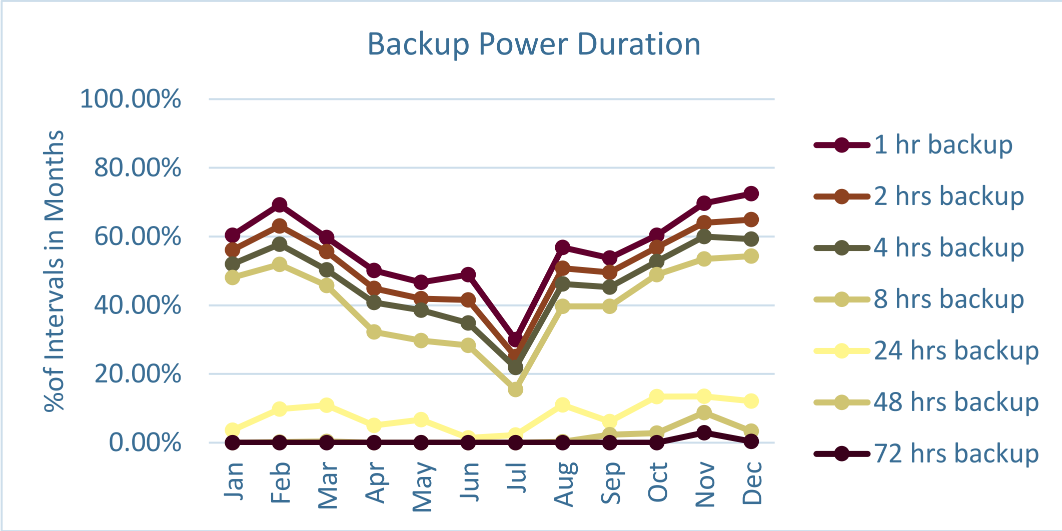

Figure 27 Percentage of power back up using 500 kW, 1500 kWh battery at aggregated VB and TL (Case 1

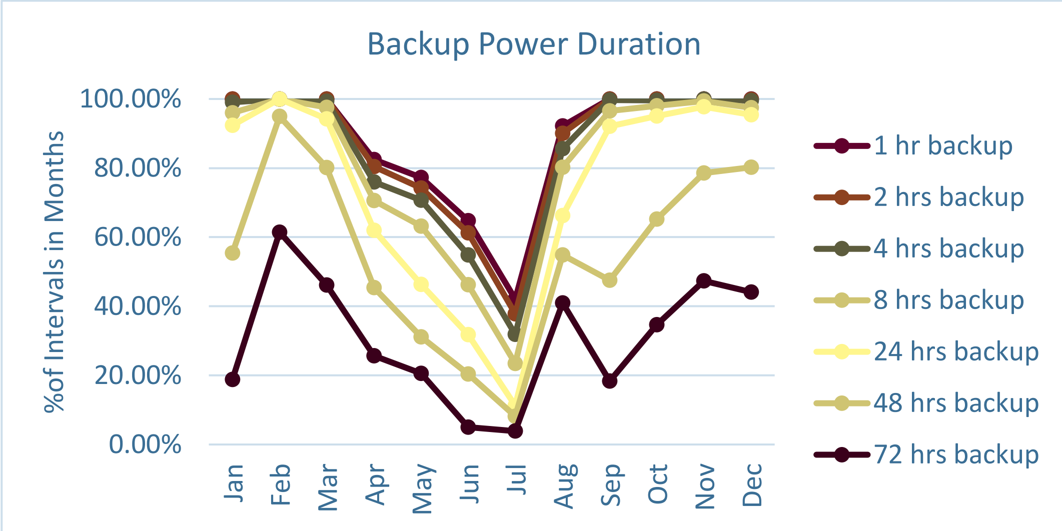

Figure 28 Percentage of power back up using 2000 kW, 10000 kWh battery at aggregated VB and TL (Case 1)

Economic Analysis

The economic analysis of the Venus Bay 2 feeder for different battery sizes is presented in Table 17. The lowest payback period is achieved for 50 kW, 1000 kWh battery with duty cycle beyond the warranty. The similar assumptions used in page 15 are used for this study.

Table 17 Economic analysis of different storage sizes for aggregated loads of VB and TL communities

Battery Capacity		Investment Cost ($)	Payback period (yrs)	Cycles per day (%)	Total cycles in 10 yrs	Yearly energy discharged (MWh)	Savings ($0.4/kWh)	LCOE ($/kWh)
kW	kWh							
500	1000	1,025,000	7	99%	3616	361.6	144,628	0.31
500	1500	1,335,000	7	90%	3297	494.6	197,841	0.29
500	2000	1,645,000	7	77%	2812	562.4	224,955	0.31
500	2500	1,955,000	8	65%	2371	592.8	237,120	0.34
500	3000	2,265,000	9	55%	2021	606.2	242,492	0.39
1000	1000	1,430,000	10	99%	3621	362.1	144,851	0.44
1000	2000	2,050,000	8	85%	3105	621.0	248,418	0.36
1000	3000	2,670,000	9	70%	2537	761.2	304,462	0.37
1000	4000	3,290,000	10	56%	2037	814.7	325,888	0.42
1000	5000	3,910,000	12	46%	1674	837.0	334,797	0.49
2000	2000	2,860,000	12	85%	3105	621.1	248,423	0.51
2000	3000	3,480,000	11	70%	2545	763.6	305,428	0.50
2000	4000	4,100,000	12	57%	2066	826.3	330,527	0.53
2000	5000	4,720,000	14	47%	1710	854.9	341,971	0.59
2000	6000	5,340,000	15	40%	1455	873.2	349,265	0.65

Case 2

In case 2, the battery is charged using surplus solar and wind energy during the day, but at night, the battery is charged with wind energy. Four batter sizes are used for performance evaluation, and the results are presented in Table 18. The stored energy in the battery becomes nearly doubled when the solar capacity is also doubled. The excess solar is stored in the battery and later utilised during morning and evening peak hours. Energy independence reaches upto 78% with triple solar and 2000 kW 10000 kWh battery. Near 75% energy independence is possible with a relatively smaller battery size. Therefore, a bigger battery size does not contribute more to energy independence. On the other hand, a bigger battery can store more surplus solar and wind energy during the day and wind energy during the night, which provides more energy during morning and evening peak hours. The payback period is below ten years for smaller to larger batteries when enough solar is installed in the community.

Table 18 Performance parameters for different battery and solar PV sizes installed at Venus Bay and Tarwin Lower (Case 2)

Battery and Solar PV	500 kW, 1500 kWh			1000 kW, 3000 kWh			1000 kW, 6000 kWh			2000 kW, 10000 kWh		
	Solar PV			Solar PV			Solar PV			Solar PV		
	Present	Double	Triple	Present	Double	Triple	Present	Double	Triple	Present	Double	Triple
Energy Stored in BESS (MWh)	278	482	536	329	686	790	375	761	869	394	816	924
Battery Utilisation (Average cycles per day)	51%	88%	98%	30%	63%	72%	17%	35%	40%	11%	22%	25%
Energy Independence (% self-powered by solar/battery)	53%	69%	74%	54%	71%	77%	54%	72%	78%	54%	72%	78%
Morning Peak Demand supplied by renewables (%)	62%	75%	81%	63%	80%	84%	64%	83%	89%	65%	84%	90%
Evening Peak Demand supplied by renewables (%)	33%	55%	63%	36%	68%	81%	39%	72%	83%	40%	75%	87%
Payback period (yrs.)	11.95	2.54	1.62	20.19	4.40	2.88	30.18	7.11	4.72	49.60	11.87	7.97

In this case study, The battery is only charged by wind at night, but surplus solar is used during the day. So, the results of the reliability parameter are identical to the reliability results obtained in case 1. The battery provides a backup if sufficient energy is stored during the blackout periods. Backup durations are considered for 1 hr, 2 hrs, 4 hrs, 8 hrs, 24 hrs, 48 hrs and 72 hrs. The power backup duration for the smaller to bigger batteries is presented in Figure 29 and Figure 30.

With the smaller battery size, upto 8 hr backup is possible for 50% to 70% of the time during summer and winter. However, the backup percentage is nearly zero for providing 24 hrs, 48 hrs and 72 hrs of backup during summer and winter.

For larger batteries, nearly 100% backup is possible upto 72 hrs blackouts during summer. Solar generation is less during winter, and backup is almost impossible on many days. However, in this case, wind energy continues the renewable energy supply days and nights, providing extra reliability to the community. The large battery can store energy from solar and wind and, instead of supplying to the evening and morning demands, can be utilised as a backup only to obtain long backup power.

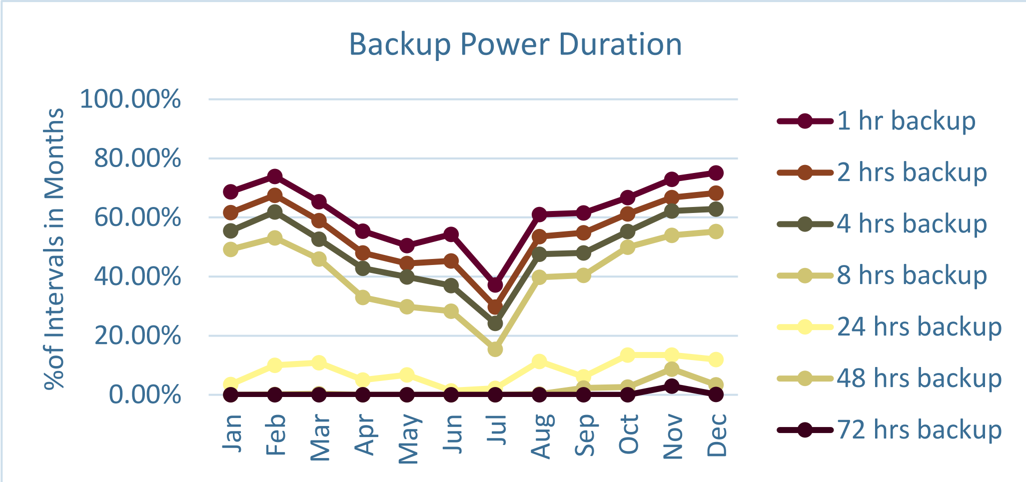

Figure 29 Percentage of power back up using 500 kW, 1500 kWh battery at aggregated VB and TL (Case 2)

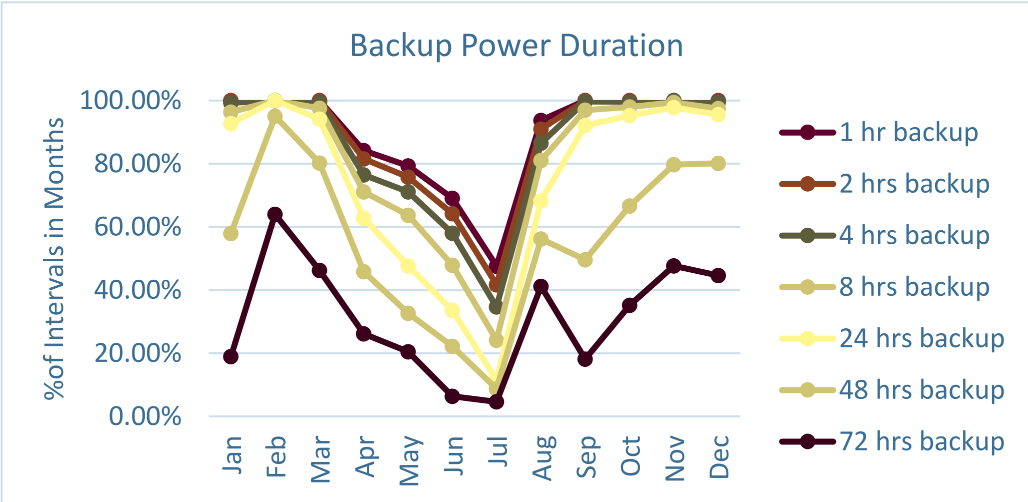

Figure 30 Percentage of power back up using 2000 kW, 10000 kWh battery at aggregated VB and TL (Case 2)

Case 3

In case 3, the batteries will be charged using surplus solar and wind energy during the daytime, and the batteries will be charged using their full capacity from the grid energy. In this way, the battery will work harder, and more energy will be stored in the battery for backup purposes. The stored energy will be used two times – morning peak hours from 06:00 am to 09:00 am and evening peak hours from 06:00 pm to 09:00 pm. The community values are evaluated using smaller to bigger sizes batteries and different solar capacities. Results obtained from the analysis are presented in Table 19. For smaller-size batteries, for example, a 500 kW 1500 kWh battery needs to operate more than one cycle per day to maintain the charging and discharging of the battery. Since energy is taken from the grid at night, 100% energy independence is impossible. A bigger battery can supply 100% morning and evening peak demands from BESS and renewables. Simple payback periods show that the batteries can be paid off before ten years of warranty periods. However, many costs associated with investment and maintenance may vary significantly – over the time.

Table 19 Performance parameters for different battery and solar PV sizes installed at Venus Bay and Tarwin Lower (Case 3)

Battery and Solar PV	**500 kW, 1500 kWh**			**1000 kW, 3000 kWh**			**1000 kW, 6000 kWh**			**2000 kW, 10000 kWh**		
	Solar PV			Solar PV			Solar PV			Solar PV		
	Present	Double	Triple	Present	Double	Triple	Present	Double	Triple	Present	Double	Triple
Energy Stored in BESS (MWh)	566	664	675	938	985	999	1137	1084	1068	1432	1249	1170
Battery Utilisation (Average cycles per day)	103%	121%	123%	86%	90%	91%	52%	50%	49%	39%	34%	32%
Energy Independence (% self-powered by solar/battery)	56%	71%	75%	60%	74%	79%	63%	76%	80%	66%	77%	81%
Morning Peak Demand supplied by renewables (%)	86%	91%	93%	97%	99%	99%	98%	99%	99%	100%	100%	100%
Evening Peak Demand supplied by renewables (%)	35%	55%	63%	57%	76%	85%	73%	85%	91%	97%	98%	99%
Payback period (yrs.)	5.89	2.23	1.51	7.11	3.67	2.64	9.96	5.91	4.36	13.65	9.40	7.24

The backup power duration significantly improves in this (case 3). The battery works more at night to store energy from the grid and supply it during morning peak hours. The power backup duration for different battery sizes is presented in Figure 31 and Figure 32. The PV capacity is considered three times the current capacity.

With the smaller battery size, i.e., 500kW 1500 kWh, upto 8 hrs backup is possible for 30% to 70% of the time during winter and summer. However, the backup percentage is below 10% for providing 24 hrs, 48 hrs and 72 hrs of backup during winter.

For larger batteries, nearly 100% backup is possible upto 8 hrs blackouts during winter and summer. More extended backup periods, such as 48 and 72 hrs, are achieved during summer. The percentage of backup instances is less in July, followed by other winter months.

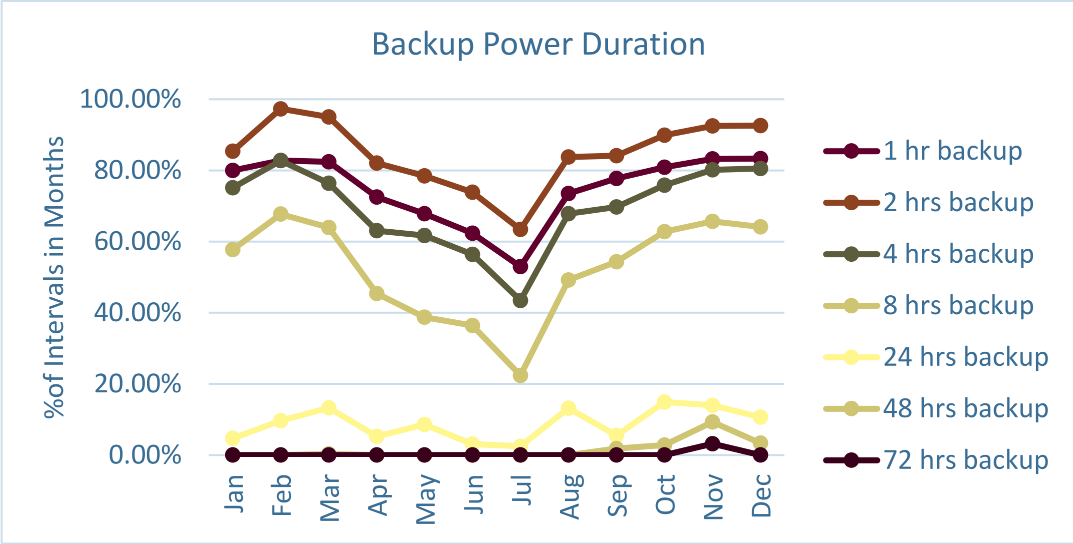

Figure 31 Percentage of power back up using 500 kW, 1500 kWh battery at aggregated VB and TL (Case 3)

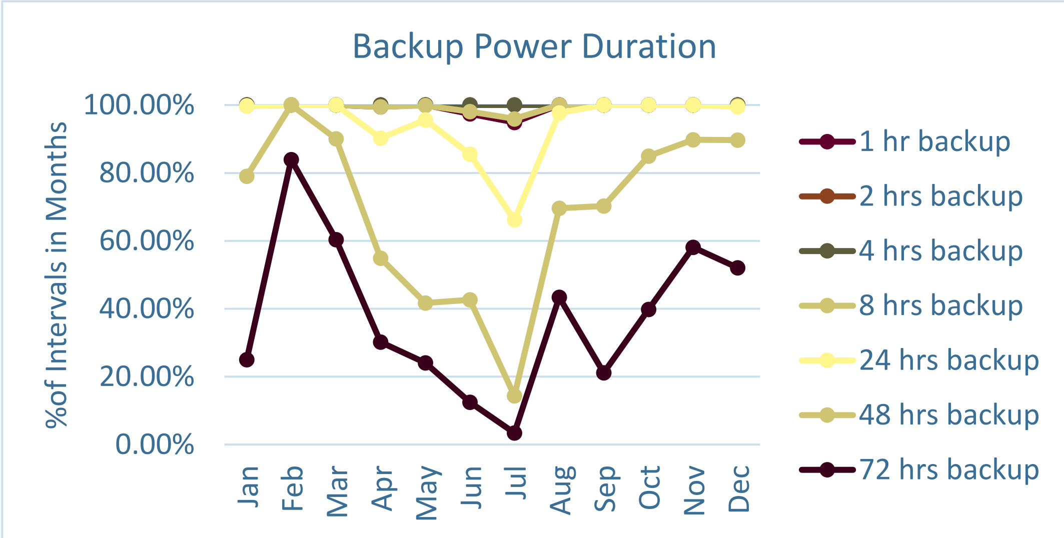

Figure 32 Percentage of power back up using 2000 kW, 10000 kWh battery at aggregated VB and TL (Case 3)

Technical Constraints

Impact of DER in the distribution system:

Figure 33 shows a conventional LV feeder. As presented in Figure 34, the voltage drop along the line's length in this form of distribution feeder gradually rises towards the endpoint. Consequently, the customer farthest from the source might encounter a voltage drop.

When solar-PVs are installed in the LV feeder (See Figure 35), the powerflow direction and amount are determined by the solar-PV generation and the load. This can cause the voltage to either increase or decrease along the feeder.

At times when the solar-PV generation is greater than the load, the voltage would increase (Figure 36). This rise would be highest in the minimum loading condition. When the solar-PV generation is less than the load, the voltage will decrease.

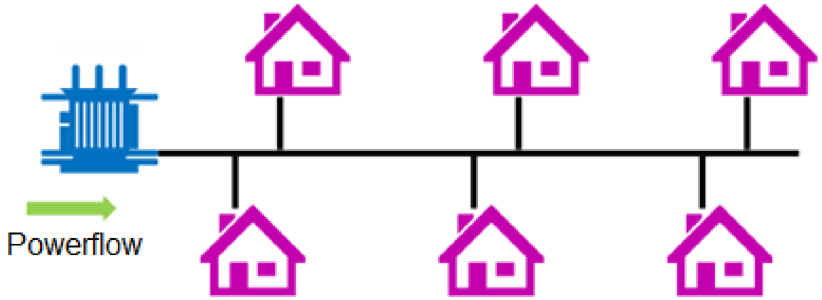

Figure 33 Traditional Distribution Feeder

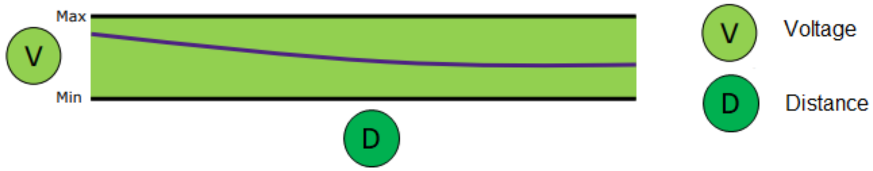

Figure 34 Voltage Profile vs Distance

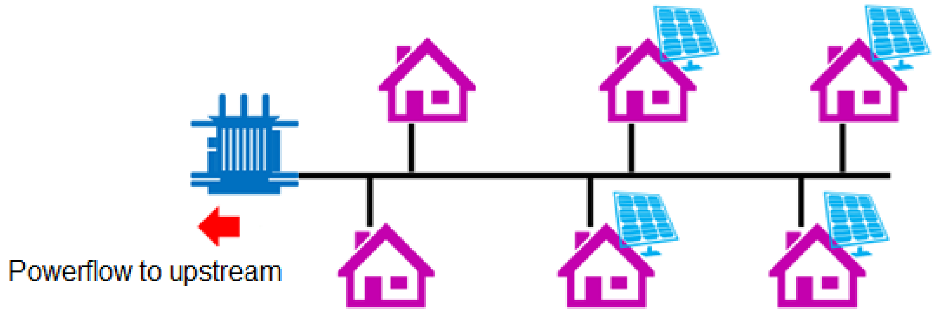

Figure 35 Distribution Feeder with solar PV

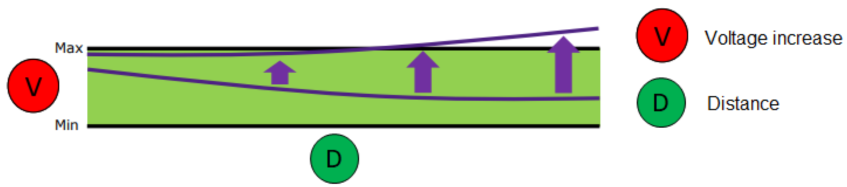

Figure 36 Voltage Profile vs Distance with solar PV

In this study, we explore the practicality of different DERs and certain technologies' potential, limitations, and restrictions Venus Bay and Tarwin Lower. It's important to note that the level of DER penetration is heavily influenced by the structure and type of network, which would require additional connection analysis and approval from DNSP.

Even with fixed power limits+, if DER integration is not properly managed, the combined exports or imports in a feeder can exceed voltage and current limits in the distribution network. Many feeders and transformers in Venus Bay and Tarwin Lower have strict export limits. This will prevent the further integration of DERs, as mentioned in this report.

Generally, DERs are connected to the system via the distribution network. These are the customers' first connection points with the wider power system. In the distribution network, asset congestion usually becomes problematic towards the head of the network due to the cumulative reverse powerflow from the high penetration of DERs. Voltage violations and asset congestion can be observed during peak daylight hours when houses are empty and at light loads, which is common in several feeders in Venus Bay. This is because the reverse powerflow and congestion are at their highest during these times. Short to medium-term network planning is required to mitigate these issues.

These are:

1. Continue enabling volt-watt and volt-var settings in inverters. Explore the opportunities for dynamic operating limits instead of fixed limits.
2. DNSP should adjust the off-load tap changer position of the distribution transformer in feeders with lower customer density.
3. Implement intelligent voltage control at the medium voltage transformer. #
4. Implement network-friendly batteries at the distribution network. ##

Intelligent voltage control can estimate the PV generation downstream (or its effects on customer voltages) and adjust the transformer tap position to target the voltage issue in the low-voltage lines.

##DNSP should exploit the flexibility of residential batteries by mandating network-friendly connection requirements. The network-friendly control strategies such as ‘network smart’ proposed in ‘ARENA’ project “Advanced Planning of PV rich Distribution Networks” can be investigated.

+ The fixed limits are typically defined by the connection agreement (with the DNSP), local regulations, and/or fuse rating (at the premise).

DNSP: Distribution Network Service Provider. The company manages the poles and wires.

DER: Distributed energy resources such as rooftop solar, batteries, small wind turbines, and others.

Fixed power limits: Fixed power import limits (and export limits in the presence of DER) are defined by the connection agreement between the customer (residential, commercial, or industrial) with local DNSP and/or the electricity distribution code at the time of connection to the distribution network. The existing fixed power limits can also be overly conservative/prohibitive in a certain part of the network, which limits the potential volume of services (otherwise could be possible with the existing resources and infrastructure).

Hosting Capacity: Maximum capacity of DER that a given section of a distribution network can host without negatively affecting normal operation (i.e., voltage limits, line, and transformer loading).

Capturing value

The high penetration of renewables is a path towards a sustainable, reliable local energy system for the community. However, capturing the value from the community energy systems depends on the complex ownership and investment model. There are different models for the ownership and operation of the community energy system. These are covered in more detail in the economic report.


VENUS BAY
COMMUNITY CENTRE
Federation
University
CHANGING WEATHER
Transforming Energy
Mycelia
Ethical
Fields