Solar Energy Transformation Program Performance Report # 2

1 July 2019 to 30 June 2020

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PowerWater

Contents

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1 Executive summary

As the largest isolated off-grid solar program in Aboriginal communities, the Solar Energy Transformation Program (SETuP) is a world-first. Power and Water Corporation has been incorporating solar energy technology into our business for the past 30 years. Through the successful delivery of SETuP we have built on that experience and transformed the way we supply energy to remote communities with hybrid solar/diesel power generation becoming an integral focus.

SETuP has seen the rollout of 10 megawatts (MW) of solar to benefit 25 communities serviced by our subsidiary, Indigenous Essential Services Pty Ltd. The rollout commenced in 2016 and was completed with the final array commissioned in March 2019. The $59 million program was co-funded by the Australian Government through the Australian Renewable Energy Agency. It includes $27.5 million financed through the Northern Territory Government.

This is the second knowledge sharing performance report for SETuP, covering the period 1 July 2019 to 30 June 2020. The report builds on the first performance report for the period July 2018 to June 2019, and the reader is encouraged to refer to that document for additional explanatory material.

The SETuP performance outcomes for the period include achieving 15.1% renewable contribution for the 24 medium contribution communities, just over the design target of 15%. There was considerable variation between communities, with the result ranging from 9.9% at Bulman to 29.0% annual solar contribution for Nyirripi. For these communities the arrays operate alongside the existing diesel power station with no additional supporting technologies required.

At Daly River a 1 MW array is integrated with an 800 kVA/2 MWh Battery Energy Storage System (BESS) alongside the existing diesel power station, and it exceeded its target with a 55.5% renewable contribution for the reporting period (up from 50.7% for 2018/19).

Overall, for the 12 months to June 2020, SETuP generated over 11 Gigawatt-hours of electricity, contributing 17% of the electricity needs of twenty eight communities and 30 homelands (outstations) for the period. In doing so we saved just over three million litres of diesel fuel.

This was the first 12 months of stable operation for the entire fleet, with PV array downtime less than 4% overall. The operational reality for the SETuP arrays is the need to balance the rapid rectification of array issues against the expense of mobilisation for a single issue. A number of influences on performance and opportunities for further improvement are explored. Particular priorities include implementation of automated alarms for indicators of arrays issues, deployment of a replacement array plant controller solution at sites with ongoing issues, the in-progress BESS project for Titjikala, and the ongoing uptake of low-load capable diesel generators as part of business-as-usual generator replacement.

2 Introduction

2.1 Scope of this report

This report presents an analysis of the operational performance of the 10 Megawatts (MW) of utility solar arrays installed across 25 remote Northern Territory communities under the Solar Energy Transformation Program (SETuP). The report covers performance for the period 1 July 2019 to 30 June 20120 (the reporting period), during which all of the program's solar arrays were operational.

The SETuP program received funding from the Australian Renewable Energy Agency (ARENA), and this report is the second performance report as part of the knowledge sharing deliverables under the program's funding agreement.

It is assumed that the reader is familiar with the information and context available in the first SETuP performance report which is available at www.powerwater.com.au[1], along with a number of other SETuP knowledge sharing reports.

The reader is particularly directed to the *SETuP Case Study – Rollout of Tranche One Medium Contribution Sites*[2] that explores a number of aspects of the program rollout in more detail, and to the *Solar Diesel Mini-Grid handbook (2nd edition)*[3] which includes description of the operational principles underpinning SETuP.

The analysis looks in detail at the actual annual energy yield achieved from each array, and the associated annual Renewable Energy Fraction (REF) achieved and resulting diesel consumption savings. This is compared to program targets and yield predictions, with exploration of the drivers and limiters of the achieved yield. Financial performance is not included in any detail due to commercial sensitivities, and a financial analysis of the program against its business case is not the intent of this report.

2.2 SETuP overview

SETuP was established in July 2014 with a goal to deploy 10 MW of solar technologies integrated with remote diesel power stations at a transformative scale, as well as demonstrating technologies to enable higher solar contributions for isolated diesel mini-grids.

The $59 million program was rolled out to 25 communities serviced by Power and Water subsidiary Indigenous Essential Services Pty Ltd (IES), with financing from the Northern Territory Government and grant funding from ARENA. The participating communities provide power to nearby communities and homelands (outstations) with the result that a total of 28 communities and 30 homelands are benefiting from the program.

Figure 1 provides a map of the IES communities (along with major and minor centres).

The primary focus of SETuP was the integration of ground-mounted flat-plate photovoltaic solar arrays, working alongside the existing diesel engines at a 'medium contribution' level to achieve 15% average diesel savings (15% REF) without requiring additional supporting technologies. By deploying established solar technologies at scale in a low-risk way, solar-diesel hybrid would become part of everyday utility operations.

The medium contribution arrays were rolled out in two packages or tranches, with Tranche 1 construction completed in February 2017 and Tranche 2 completed in March 2019. The program rollout was dictated by obtaining suitable land for each identified community. While we originally targeted 34 communities, a range of factors resulted in this being reduced to 24 medium contribution sites.

The second major component was a flagship high-contribution project at Nauiyu (Daly River) combining a 1 MW solar array with a 2 MWh BESS, allowing for 100% of solar energy use during the day with diesel engines operating at night. The Daly River project was designed to achieve a 50% annual diesel saving (50% REF). Daly River was operational from April 2018.

In total, 25 existing power stations were hybridised, which collectively serve 28 remote communities and 30 nearby homelands (outstations). Further details on SETuP including case studies and lessons learnt documents are available from the Power and Water website at www.powerwater.com.au.

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[1] https://www.powerwater.com.au/about/projects/current-projects/solar-energy-transformation-program
[2] https://www.powerwater.com.au/__data/assets/pdf_file/0013/32305/SETuP-Case-Study-Rollout-of-Tranche-One-Medium-Contribution-Sites-FINAL-APPROVED.pdf
[3] https://www.powerwater.com.au/__data/assets/pdf_file/0014/32306/1090241-PWC-Solar_Diesel-Mini-Grid-Handbook-web.pdf

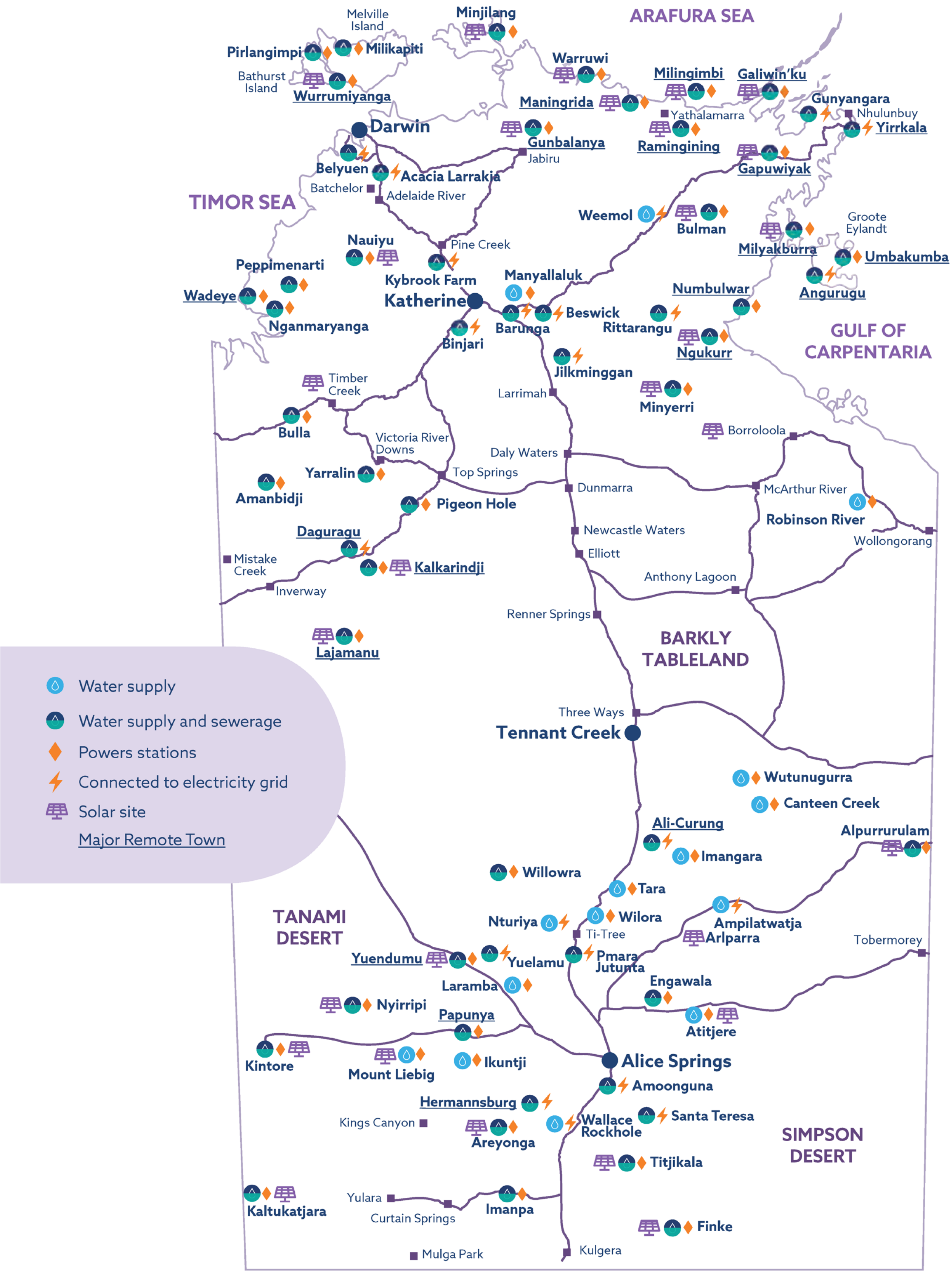


Figure 1: Remote communities served by Power and Water (IES communities in medium font bold)

3 Performance Data Sources

3.1 Diesel generation and feeder load data

Each diesel generator at Power and Water's isolated power stations has a dedicated Woodward EasyGen controller that meters output. Each low voltage (LV) distribution feeder has a Schneider Electric (SE) PM810 or PM5560 meter at the power station LV main board (before the 11 or 22 kV distribution step-up transformers).

Data from various meters is collated by the power station PLC and then logged on a HMI/computer onsite (running the CITECT SCADA system).

Not all power stations have a backhaul data link with Power and Water's central systems, though these were put in place at all SETuP sites to support data collection. At SETuP sites, selected station electrical performance data trends (tags) are compressed and transferred from the HMI computer to the central corporate OSI PI data historian. Several hundred tags are transferred, including frequency, power, voltage and current readings for all meters and a number of alarms and other parameters. The set of tags is kept as consistent as possible between sites with similar control systems. The Pi link is typically configured to only send readings when the value changes outside of a specified deviation parameter, meaning that the resultant data in the historian is not on fixed intervals.

In addition to the automated interval data collection, the Essential Services Operator (ESO) conducts daily checks and fills out a weekly log sheet including a set of diesel and solar generation readings. Diesel fuel consumption data for this report is based on aggregated weekly power station readings that are manually read from fuel meters by the ESO. This fuel consumption data is verified against historical trends, manual fuel tank dips and checked for logical errors using known kWh generation data. This means that only weekly diesel volume consumption totals are available for analysis purposes, limiting finer resolution analysis of actual diesel savings.

Longer term there is an intent to migrate fuel data collection to an automated SCADA process so it may also be added to OSI PI, once a majority of sites have remotely read fuel meters and a quality backhaul link in place. In the meantime manually collated and verified measurements continue to form the basis of diesel fuel monitoring.

3.2 SETuP output measurement

The electrical performance of each SETuP array is measured with a Schneider PM5560 meter located in the main LV switchboard for each array. A range of electrical parameters are read from this meter (via Modbus over TCP/IP) and imported into the power station control system. These readings, along with a range of other system data are then captured and compressed by the OSIsoft Pi connector application and transferred to Power and Water's central Pi Historian. The analysis in this report is based largely on the compressed Pi data.

Figure 2 shows the power meter within a typical Tranche 2 LV switchboard, along with the cluster controller, circuit breakers and protection.

Figure 2: PV LV switchboard at Maningrida array #2

3.3 Atonometrics solar monitoring

Every SETuP array includes an Atonometrics[4] RDE300 series device with one of the array's modules attached as its reference source. The module is installed in the plane of the array, and for safe and tidy installation it is installed within the array tables displacing a functional module. This results in one inverter at each site having one less module on one string. The device also includes a temperature sensor affixed to the rear of the reference module.

The majority of sites have the single input RDE363 model. The Atonometrics device provides a measurement of the maximum power point of the monitored module once per minute "Pmax". It also provides an in-plane irradiance reading once per minute, calculated from the temperature-corrected short- circuit current (Isc) of the in-plane module, using its stored calibration constants. The stored constants are derived from calibration at the time of array commissioning using a field calibration kit with an OEM pre-calibrated reference cell.

No cleaning of the Atonometrics-connected reference module is undertaken (other than for its initial calibration), meaning that the Atonometrics measurements are reflective of the soiling state of the module which is assumed to be generally consistent with the entire array.

The Pmax available module power is the primary operational value of the Atonometrics device, as it provides a direct measure of the available power of one module that has orientation, tilt, temperature, wind and soiling conditions common to all modules. The Atonometrics Pmax value is scaled up to provide a near real-time estimate of the array available power and thus an estimate of real-time curtailment to support operations.

While this is an effective means of estimating "real-world" curtailment losses, it is not able to measure the degradation of the array modules themselves; for that comparison a separate source of measured irradiance is required (as per AS/NZS61274.1:2020 clause 7.2.1.4). Independent reference cells were not included at every SETuP array site, however a subset of sites have either an additional Atonometrics or weather station reference cell as described below.

Like other system measurements, the Atonometrics readings are transferred from the power station control system into the Pi historian with compression applied.

The Daly River and Bulman arrays are fitted with an RDE361 Atonometrics device (instead of RDE363) which includes an additional calibrated in-plane reference cell (as shown in Figure 3) with a self-washing function. The reference cell enables independent in-plane irradiance measurement and facilitates soiling loss measurement. However the Bulman device was not operational for much of the analysis period, and the device at Daly River had a likely calibration error after lightning damage was repaired.

[4] Atonometrics, Inc. www.atonometrics.com

Figure 3: Dual-input Atonometrics installation at Daly River[5]

3.4 SETuP original modelling outputs

During the design stage detailed modelling of each community was carried out to determine suitable array sizes. The modelling used the following data and important assumptions:

- the diesel engine capacities and their minimum load requirements that were in place in 2014/15
- historical community load data
- historical delivered diesel fuel prices
- climate data available from relevant Bureau of Meteorology stations
- fixed tilt optimally aligned solar arrays
- minimal shading, 100% availability (i.e. no downtime) and a soiling effect of 4% (as commonly estimated in literature)
- maintain Power and Water's existing engine call-up regime (call-up the closest kW capacity match to the current load, keep engine online for half hour after starting unless a larger set is required).
- nominal aggregate goal of 10MW program capacity and 15% fuel savings.

A combination of the Power and Water-developed ASIM tool and the HOMER Pro modelling package were used to produce a recommended array size taking into account the above factors and seeking the lowest levelised cost of energy. The modelling also provided an estimate of annual kWh yield for each array after curtailment.

It can be seen in comparing this value to the PVSYT model output that the SETuP arrays were designed with an expectation of a substantial amount of curtailment, around 30% for the stated analysis period.

The list of communities included in the SETuP program evolved during delivery, which saw arrays redistributed from several communities (in order to maintain the program 10 MW total), in response to a range of challenges encountered during various stages of the program, including during construction phase. Those factors are explored in the knowledge sharing reports described in the Introduction.

Where arrays were relocated or their capacity redistributed remodelling was not completed in all cases, with the previous after-curtailment yield estimate retained or another estimate utilised. These are highlighted in Table 3.

There are two implications for performance assessment: that the array size may have been selected for a different combination of load and diesel settings than now exist; and that the modelled yield presented in Section 4 is a useful metric rather than a precise reference point.

[5] At the time of photos being taken, the PV module had been cleaned for its initial calibration. The self-washing PV reference cell is mounted in the plane of the array in the foreground.

3.5 Weather stations

Ten SETuP sites had a weather station installed as part of the program, with sensors including: irradiance, rainfall, wind speed, wind direction, air temperature and humidity. The weather stations were installed to improve knowledge of local operating conditions and as a data source for improved PV output estimation.

Weather data collection into Pi Historian commenced in late 2019 with final calibration and commissioning continuing into 2020. As a result the data has proved of limited value to this performance report.

3.6 Financial performance data

The primary financial metric of SETuP is the value of the avoided diesel fuel burn. The dollar value of SETuP generation then is tied to the prevailing delivered diesel price for each community. Any reduction in financial benefit from the SETuP arrays due to low diesel prices will be more than offset by diesel cost savings for the overall IES program. The economic focus then for the IES program is to manage and minimise SETuP operating expenditure (and minimise any impact on diesel operational) while maximising array output and achieving asset longevity both for the arrays and diesel generators.

The delivered fuel prices in the IES program are subject to the confidentiality requirements of the bulk fuel supply contract and do not form part of this report's analysis[6]. More generally the financial performance of SETuP will not be presented or analysed in detail in this report.

3.7 Additional data sources

As part of the Engineer Procure Construct (EPC) contract for each tranche of SETuP array deployments, the contractor was required to provide a P50 estimate of the uncurtailed output of each array using the industry standard PVSYST modelling tool. The contractors were provided climatic data obtained from the Bureau of Meteorology (nearest relevant weather station), and in return provided a P50 monthly output estimate per array, incorporating the details of their design. Given issues with collation of the Atonometrics data discussed above, the PVSYST estimates have been used as a baseline for this report.

An important driver of SETuP performance is the minimum load set point of each diesel generator (expressed as the percentage of the maximum power parameter for the generator). Continuous logging of these parameters into the Pi Historian was implemented late in 2019. Manual records of parameter changes prior to that implementation are limited but can be inferred from engine performance analysis.

For this report, array outages were manually identified on a per-inverter basis and collated, and causes identified in consultation with operational teams. The data has been summarised as the number of inverter days of unavailability, and compiled to an array "percentage unavailability". The percentage is calculated only for the duration each Tranche 2 array was online in the financial year. The causes of unavailability are discussed further below.

[6] The publicly available Darwin terminal gate prices for diesel fuel, less GST and diesel excise, are however a useful estimate for the Northern Territory-delivered diesel price.

4 Performance data 2019-20

4.1 SETuP array and performance data

This section presents a compilation of a range of parameter and performance values for each of the SETuP communities, with discussion and analysis provided in the following sections of the document.

An explanation of each performance data value (table column) is provided in Table 1.

Table 2 then lists values for the 10 Tranche 1 communities and for Daly River for July 2019 to June 2020, presented in order of commissioning. Table 3 provides the same data for the fifteen Tranche 2 sites along with a program total.

Note that Maningrida appears in both tables, as it received a second array as part of Tranche 2. Performance is presented separately for each array with a combined value for Maningrida provided at the end of Table 3[7].

Table 1: Explanation of performance data columns

Column name	Description
Community	The name(s) of each community. Many communities have multiple names; more details including pronunciation guides can be found at www.bushtel.nt.gov.au
kW (AC)	The sum of the inverter AC power ratings in kW. All SETuP arrays used 25kW inverters, hence all ratings are a multiple of 25.
kW (DC)	The total rating of the installed solar modules; while SETuP specified a 1:1 DC to AC ratio (industry practice in 2014/15), the installed DC value is typically slightly higher than the AC rating in order to fill all array tables and ensure balanced inverters. All Tranche 1 sites used 315W modules. Daly River and Tranche 2 were constructed with 320w rated modules.
Atonometrics	Whether the Atonometrics irradiance and module power metering device was a single input version (1) with just one array module attached to it, or a dual input version (2), with both an array module and an OEM pre-calibrated self-cleaning in-plane-of-array reference cell attached.
Weather Station	Whether a weather station was installed at this community (1 if so).
PVSYST Egrid modelled MWh	The annual array available energy (before curtailment) expected for typical weather conditions ("P50") using the PVSYST modelling tool. This data was provided by the EPC contractor as part of the design of each array.
Power and Water modelled PV output	The Power and Water-modelled output is the expected annual solar output as derived from SETuP's original ASIM and HOMER modelling (after curtailment), where completed. This is further described in section 3.4.
Date PV array online	The date when commissioning of the array was completed by Power and Water. The table rows are sorted by this date.
Unavailability	The percentage of commissioned time that the array was unavailable to generate, calculated on a per-inverter basis as described in Data Sources above.
Diesel generation actual MWh	The energy generated by all diesel generators at the power station for the period, as metered by the EasyGen controller.
PV actual (yield) MWh	The energy exported to the grid from each solar array, as measured at the main LV switchboard power meter, in megawatt-hours. The energy imported (overnight energy consumption) for each solar power station consists only of power required for networking and protection devices, and equates to an average of 0.03% of daily exported power. It is therefore ignored for this analysis.

[7] In subsequent combined analysis both arrays are combined into Tranche 1 in order to avoid double counting of the Maningrida total station values.

Column name	Description
PV actual % of total delivered (REF)[8]	The proportion of the total energy delivered to the grid that was provided by the SETuP solar array. This column is highlighted in recognition of this being the nominal performance metric for the rollout.
PV actual as % of Power and Water model PV output	The actual yield as a percentage of the Power and Water target/modelled yield (as described above).
PV actual as % PVSYST model PV	The actual PV yield as a percentage of the PVSYST modelled P50 value. This provides an estimate of the likely yield if each array were able to operate unconstrained.
Atonometrics potential PV yield	Where data quality allowed for summarisation, the annual potential PV yield is estimated using the Atonometrics measured peak power capacity of one module scaled up to the array size.
Yield as % of potential	The actual PV yield as a percentage of the Atonometrics potential yield, where available.

[8] Note that the SETuP REF ignores any contributions by customer-owned rooftop solar, however installed levels are low in SETuP communities.

Table 2: Tranche 1 and Daly River array details and performance data for 2019/20

Community	kW (AC)	kW (DC)	Dual input Atonometrics	Weather station	Date PV array online	PVSYST Egrid model MWh	PWC model PV output PWh	Diesel generat-ion actual MWh	PV actual (yield) MWh	PV actual % of station total (REF)	Available PV yield (atono-metrics) MWh	PV actual as % available yield	PV actual as % of PWC model PV output	Unavailability	Ideal (referenc e) PV yield MWh
Maningrida combined[9]	1175	1184	N	1	3/02/2017	2139.8	1466[10]	7,182.9	1802.3	20.1%	1766.4	102%	123%	0.8%	2618.4
Ramingining	500	504	N		17/02/2017	885.6	687	2,818.5	686.5	19.6%	813.1	84%	100%	0.0%	1112.8
Yuendumu	500	504	N		30/03/2017	1004.2	725[10]	5,139.7	593.1	10.3%	1071.7	55%	82%	1.0%	1117.7
Lajamanu	400	403	N	1	21/04/2017	791.4	580[10]	3,005.9	659.4	18.0%	857.9	77%	114%	0.0%	891.9
Docker River	100	101	N		4/05/2017	197.4	150	1,466.0	168.1	10.3%	206.2	82%	112%	0.0%	218.2
Kintore	225	227	N	1	18/05/2017	391.9	296	1,484.7	393.0	20.9%	463.5	85%	133%	0.0%	498.7
Arlparra	450	454	N	1	1/06/2017	927.5	596	3,495.3	606.5	14.8%	927.5	65%	102%	12.1%	1014.2
Areyonga	100	101	N		23/06/2017	202.0	127	983.2	121.7	11.0%	193.6	63%	96%	18.0%	220.6
Mt Liebig	50	50	N		26/07/2017	100.7	93	806.4	96.1	10.6%	100.7	95%	103%	5.1%	111.4
Nyirripi	200	202	N		26/07/2017	443.5	305	769.7	314.2	29.0%	422.8	74%	103%	0.0%	443.8
Tranche 1 subtotal	**3325**	**3352**	**-**	**4**	**-**	**7083.9**	**5025**	**27,152.3**	**5440.9**	**16.7%**	**6823.4**	**80%**	**108%**	**2.7%**	**8247.7**
Daly River (PV only)	1000	1024	Y	1	17/10/2017	1820.1	1676	1,324.79	1654.3	55.5%	1916.1	86%	99%	1.6%	2198.5

[9] Values for the two distinct Maningrida arrays are included at the end of the next table.

Table 3: Array performance data for Tranche 2 communities and for program total for 2019/10

Community	kW (AC)	kW (DC)	Dual input	Weather station	Date PV array online	PVSYST Egrid model MWh	PWC model PV output MWh	Diesel generat-ion actual MWh	PV actual (yield) MWh	PV actual % of total delivered (REF)	Atono-metrics available PV yield MWh	PV Yield as % of available yield	PV actual as % of PWC model PV output	Unavailability	Ideal (reference) PV yield MWh
Apatula (Finke)	100	102	N		29/07/2018	199.3	145	836.3	121.07	12.6%	199.3	61%	83%	9.0%	225.8
Milyakburra	100	102	N		10/08/2018	193.0	152	694.5	159.53	18.7%	186.0	86%	105%	1.6%	217.1
Minyerri	275	282	N		26/09/2018	532.0	301	2,117.4	325.50	13.3%	558.7	58%	108%	0.5%	635.1
Atitjere (Harts Range)	225	230	N		12/10/2018	452.0	299	743.7	300.32	28.8%	481.4	62%	100%	2.5%	510.9
Titjikala (Maryvale)	400	410	N	1	17/10/2018	794.0	254	860.1	183.50	17.6%	862.0	21%	72%	3.8%	913.1
Milingimbi	425	435	N		25/10/2018	804.0	380	3,267.4	633.39	16.2%	813.4	78%	167%	6.0%	963.4
Minjilang (Croker Island)	100	102	N		2/11/2018	189.0	138	1,279.7	171.43	11.8%	187.1	92%	124%	1.6%	223.4
Galiwinku (Elcho Island)	750	768	N	1	9/11/2018	1399.0	1045	6,132.2	1016.87	14.2%	1351.7	75%	97%	8.5%	1650.7
Warruwi (Goulburn Island)	175	179	N		18/01/2019	332.0	293	1,585.0	316.68	16.7%	332.0	95%	108%	0.2%	394.1
Ngukurr	400	410	N	1	23/01/2019	774.0	556	4,028.0	621.75	13.4%	752.3	83%	112%	0.0%	923.5
Wurrumiyanga (Bathurst Island)	1075	1101	N	1	6/02/2019	1897.0[10]	1520[10]	5,922.1	1159.25	16.4%	1928.9	60%	76%	2.7%	2292.9
Lake Evella	425	435	N		14/02/2019	191.0	163	2,561.1	124.71	9.9%	171.6	73%	77%	2.5%	227.1
Bulman	100	102	Y		18/02/2019	764.0	607	1,138.4	592.97	18.8%	750.6	79%	98%	4.8%	900.7
Gunbalanya (Oenpelli)	675	691	N	1	7/03/2019	1264.0	979	4,400.1	689.03	13.5%	1316.8	52%	70%	9.4%	1488.8
Tranche 2 subtotal	**5600**	**5733**	**-**	**5**	**-**	9784.3	6124	35,565.9	6416.0	15.3%	9692.6	66%	105%	3.2%	11566.8
SETUP Total	**9925**	**10109**	**2**	**10**	**-**	**13,500**	**9,533**	64,043.1	13000.7	17.1%	18432	71%	101%	3.8%	44887.9
Maningrida array #1	800	806	-		3/02/2017	1447.0	960	7182.9	1204.79	13.4%	1190.7	101%	125%	0.8%	1772.2
Maningrida array #2	375	384	-		15/3/2019	692.8	506	-	597.46	6.6%	575.7	104%	118%	0.8%	846.1

[10] Value for Power and Water modelled yield based on an average ASIM yield value, modelling from before relocation, or 15% of 2016/17 load in lieu of community-specific HOMER/ASIM modelling

5 Findings and discussion

5.1 Array summary performance

The annual output from the SETuP arrays, summarised for each tranche and in aggregate for the 2019/20 financial year, is provided in Table 4. A total of 13.5 GWh was exported from the arrays, saving 3.567 million litres of diesel and avoiding 9,666 tonnes of CO2 equivalent emissions.

The diesel saving figures are calculated using the previous year historical average fuel efficiency of the remote diesel fleet, being 0.264 L per kWh[11].

The yield for the previous twelve months is also, listed and in all cases an increase year on year resulted. The large increase for Tranche 2 reflects the fact that those arrays were progressively commissioned during 2018-19 with the total Tranche 2 capacity commissioned for 51% of the previous year on a capacity weighted (but not seasonally adjusted) basis.

The drivers of the net increase in yield are explored in subsequent sections.

Table 4: SETuP summary performance 2019/20 in comparison to 2018/19

Metric	Tranche 1[12]	Tranche 2	Daly River	SETuP Total
Total PV capacity MWdc	3.73	5.35	1.02	10.10
Total PV yield (MWh) 2019-20	5,441	6,416	1,654	13,511
Diesel savings (kilolitres)	1,436	1,694	436	3,567
Greenhouse gas savings (tonnes $CO2_e$)	3,893	4,590	1,183	9,666
Total PV yield (MWh) 2018-19	4,643	2,591	1,588	8,822
Increase year-on-year	17%	148%	4%	53%

5.2 System performance

The SETuP arrays in aggregate exceeded their nominal targets for renewable energy fraction (the percentage contribution from PV to the total annual system load), as listed in Table 5.

This was achieved against small percentage increases in load across the Tranche 1 and 2 communities, with decreases in annual diesel generation of 1% and 9% respectively. Daly River saw a 4% increase in PV output and a 14% decrease in diesel generation, against an overall 5% decrease in total load for the isolated system[13]. This result is explored further below.

[11] This is the method agreed as part of the IES – NTG funding agreement.

[12] For this aggregate analysis, both Maningrida arrays have been included in Tranche 1 to avoid double counting of the Maningrida total system load. This is applied to the 2018/19 totals also.

[13] An analysis of the drivers of load changes year to year is outside the scope of this report.

Table 5: System performance 2019/20 in comparison to 2018/19

Metric	Tranche 1*	Tranche 2	Daly River	SETuP total
Diesel generation (MWh) 19/20	26,883	35,748	1,325	63,966
Total community load 2019/20 (MWh)	32,324	42,164	2,979	77,477
PV annual contribution target	15.0%	15.0%	50.0%	16.3%[14]
Renewable Energy Fraction 2019/20	16.8%	15.2%	55.5%	17.4%
Renewable Energy Fraction 2018/19	14.6%	6.2%	50.7%	11.5%
Diesel generation (MWH) 18/19	27,177	39,222	1,546	67,945
Diesel generation change year on year	-1.1%	-8.9%	-14.3%	-5.9%
Total community load 2018/19 (MWh)	31,820	41,813	3,134	76,767
Community load increase year on year	*2%*	*1%*	*-5%*	*1%*

5.3 PV array availability

Availability of the SETuP arrays improved across the board for 2019-20, and was below 4% downtime (unavailability) in aggregate as per Table 6. The "unavailability" figure is calculated on the basis of downtime of individual inverters so accounts for periods of partial availability of each array.

The 2019/20 result was an improvement on the previous year across the board. Post-commissioning issues and defect rectification account for the improvements for Tranche 2 and Daly River, while the Tranche 1 improvement is explored in more detail below.

Table 6: Array availability

Metric	Tranche 1*	Tranche 2	Daly River	SETuP total
% of time unavailable 2019/20	2.7%	3.2%	1.6%	3.4%
% of time unavailable 2018/19 (commissioned period only)	4.7%	23.0%	7.0%	12.3%

The downtime per community is shown in Figure 4, with a comparison to the previous year (for commissioned period only).

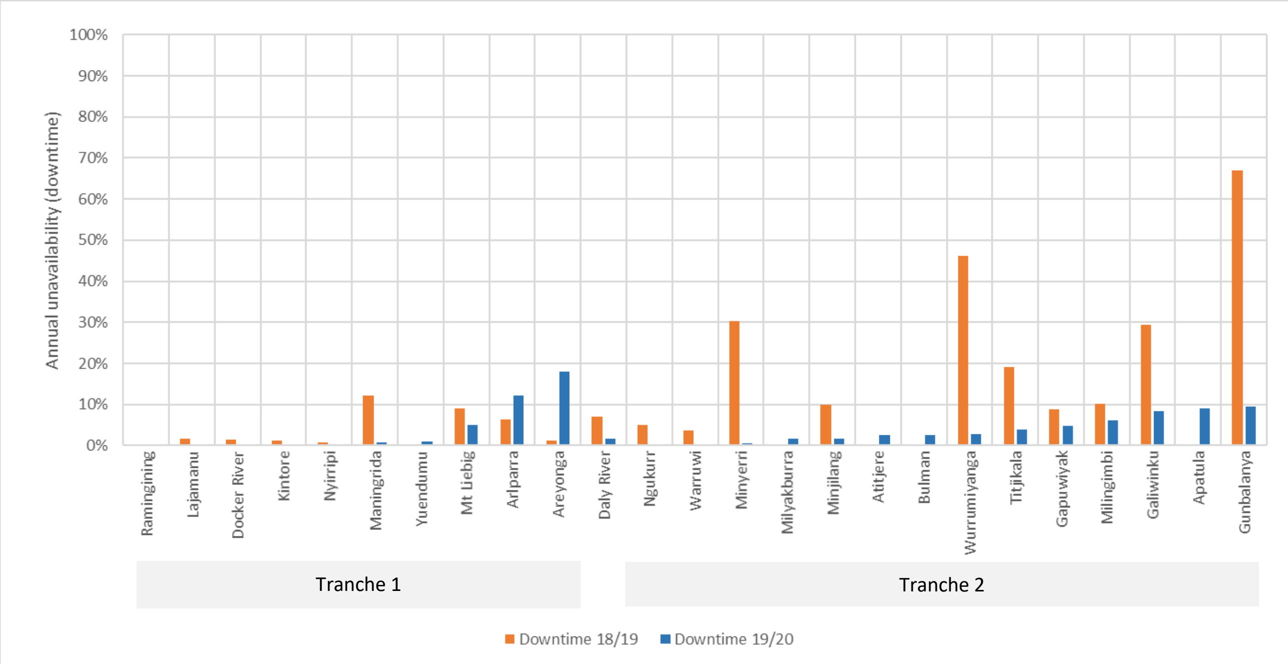
Six arrays saw no downtime in 2019-20, achieving 100% availability. A further twelve communities had downtime less than 5%, with only two communities down for more than 10% of the year.

The significant improvements for Tranche 2 sites can be clearly seen, resulting from completion of rectification works. In a similar vein, the downtime for Maningrida in 2018/19 was due to the impact of construction at that community's Tranche 2 additional array.

Tranche 1 downtime was generally very low, with the exception of Mt Liebig, Arlparra and Areyonga, with the causes for those communities explored below.

[14] Calculated as fraction of the 2019/20 load.

Figure 4: Array downtime per community 2019/20 vs 2018/19



The primary causes of downtime during 2019/20 and their relative impact are summarised in Table 7.

Table 7: Causes of Array downtime

Cause	Inverter-days lost	% of total
Cluster controller related	2409	48%
Failed inverters	971	19%
Engine maintenance	685	14%
Balance of system failure	622	12%
Array maintenance	120	2%
Other	271	5%
Total	**5019**	**100%**

Downtime related to the cluster controller (plant controller) was the largest single cause at 48% of all days of inverter downtime. The majority of sites had at least one outage related to the cluster controller, with multiple occurrences at Apatula, Galiwin'ku, Gunbalanya and Gapuwiyak.

The cause was predominantly software-related seize-ups, where a power cycle typically restoring full functionality. This is an ongoing issue from the previous report period. The cluster controller is no longer in production, and the latest available firmware has not resolved the issue. Replacement of the unit with the limited remaining spare units in hand is not guaranteed to address the problem, and the high cost of mobilising to site for one rectification is not justified against the additional fuel savings.

The nominal replacement device from SMA (www.sma-australia.com.au/) requires individual IP addressing of each inverter that is not supported by Power and Water's current SCADA network scheme for sites with larger numbers of inverters. Investigation of alternative plant control options is ongoing (with a trial of the first replacement commencing in July 2020).

The second largest cause of downtime was failed inverters. Electrical surge damage was the predominant suspected cause requiring replacement either of the communications module, control module or the entire inverter. This was a significant factor in the higher downtime experienced at Areyonga and Arlparra. The PV array at Daly River also experienced further outages related to surge damage to its communication modules, resulting in some array maintenance downtime to allow installation of further communications cabling surge arrestors.

The third most-significant cause of downtime was diesel engine maintenance resulting in full curtailment due to very high minimum loading requirements of the larger remaining generators, or from the PV array being disabled altogether to enable engine run-in. Some downtime of the Battery at Daly River also contributed to reduced yield from the PV array. An example of planned downtime is the battery capacity test that took four days last reporting period, Power and Water expect this can be shortened to two days or less. Another example is a recent change to the type of air filter in use. During a controlled land clearing fire the filter became blocked resulting in a temporary HVAC shutdown until the filter was cleaned and replaced.

Balance of system failures included a failed network switch at Titjikala, and a main circuit breaker requiring replacement at Wurrumiyanga.

A continuing area of focus for reducing downtime is to improve the reliability and/or rapid replacement capacity of sensitive electronic equipment that represent single points of failure for the array: the network switch, the cluster controller, and associated in-line surge arrestors. Essential spares are now being kept at regional centres to facilitate rapid deployment.

The investment required to further improve availability must be measured against the additional diesel savings that would be achieved over time. For instance, storing of a spare cluster controller on-site is not necessarily practical given the equipment shelf life and the technical knowledge needed to commission the device in place. However, storage of spare communications line surge arrestors that can be replaced by a trained ESO is a practical option.

Similarly, a low level of array downtime in response to power station and network maintenance is inevitable and will be factored into operational expectations going forward.

5.4 Soiling effects

Several analysis tools are available for assessing the yield effect of soiling in addition to manual inspection, and these are discussed below.

The Atonometrics module provides a calibrated source of irradiance data at one-minute intervals from its reference module that is in the plane of the array and experiences soiling as per the rest of the array modules. Calibrations were completed in the field and in most cases validated by the OEM.

Dual input Atonometrics devices were installed at two communities with the intent of supporting soil impact analysis, relying on a second source of irradiance measurement from a cleaned reference cell in the plane of the array. However replacement of the Atonometrics control module at Daly River is suspected to have resulted in a mis-calibration with the result that the cleaned cell irradiance is lower than that obtained from the soiled reference module. In addition, the device at Bulman requires replacement and no useful data was available for the period.

Weather stations with measurement of global horizontal irradiance were installed at ten SETuP sites. Ongoing issues with data access limited their value for the purpose of soiling analysis, and in any case do not provide coverage of all arrays.

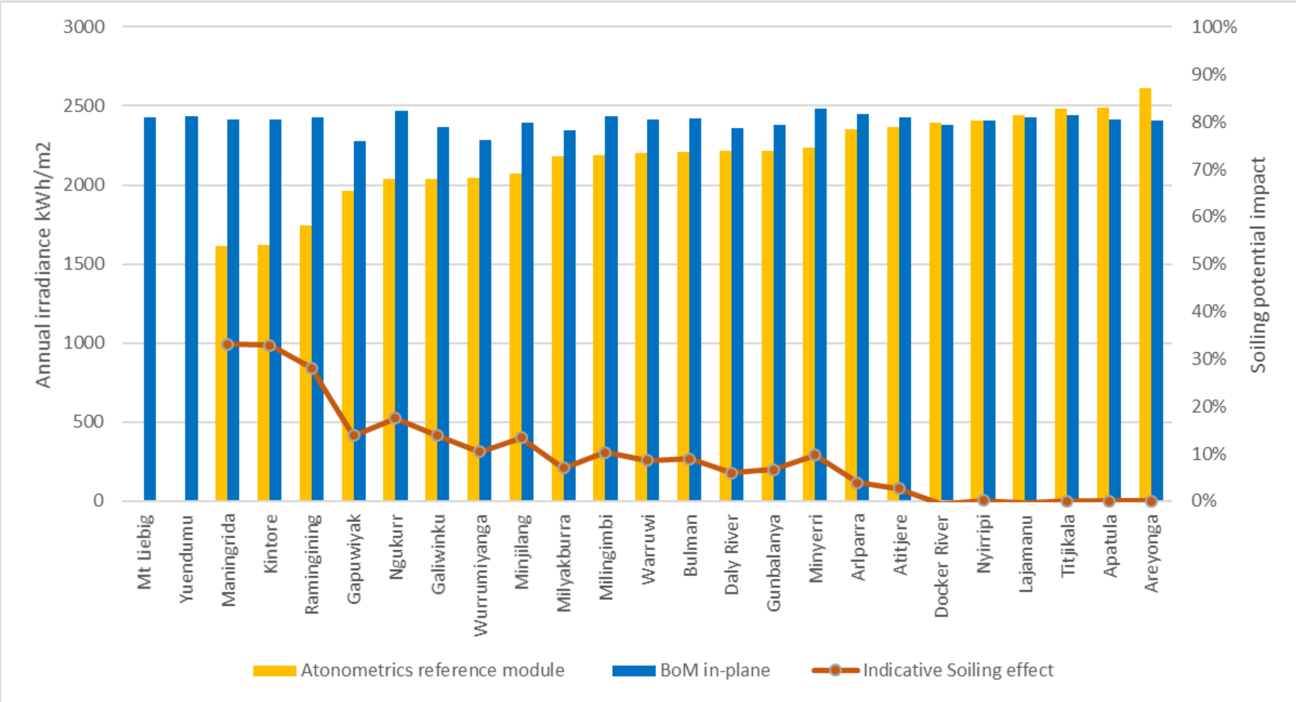
Global Horizontal Irradiance data was instead obtained from Bureau of Meteorology weather stations, with a majority of SETuP communities having a station in or very close to the community providing daily readings. Transposition into the plane of the array provides a useful measure to compare to the irradiance values obtained from the “soiled” reference module monitored by the Atonometrics device in each community.

A comparison of the annual solar irradiation measured by the reference module against transposed BoM data is provided in Figure 5, sorted by lowest to highest Atonometrics annual irradiance. Reference module irradiance was not available from Mt Liebig and Yuendumu and due to the differing configurations of their unsupported legacy control systems.

Large annual impacts are suggested for Maningrida, Kintore and Ramingining. At the other extreme Areyonga’s Atonometrics data suggests significantly more irradiance than the BoM weather station. An investigation of the correct calibration of that community’s Atonometrics module will need to be scheduled.

As expected, the soiling impact is generally estimated to be higher at northern communities where humidity encourages accumulation of dust. The current approach to array cleaning and the implications of the data in Figure 5 is discussed below.

Figure 5: Soiling impact inferred from Atonometrics vs BoM irradiation



A majority of SETuP arrays are exposed to some level of seasonal dust fall, with nearby unsealed roads a particular source. The higher humidity in northern regions is also seen to contribute to increased retention of dust on the face of the modules. A stark indication of these effects is in the comparison of Figure 6 and

Figure 7. Dust from the adjacent unsealed row has clearly accumulated on the Maningrida array in Figure 6, with a particular effect on the bottom row of cells.

The Areyonga array (

Figure 7) in contrast demonstrates minimal soiling, having being in place for a similar period to Maningrida, with a moderate amount of recent regional rain but a much lower rainfall region. Neither array was known to have received deliberate cleaning since commissioning.

Figure 6: Soiling on the front row of Maningrida's original array, June 2020

Figure 7: PV array at Areyonga, January 2020

The cost and risks associated with regular cleaning of arrays in remote communities, using local labour and local water drawn exclusively from bore sources with potentially high mineral contents, have meant that cleaning has not yet been proactively scheduled, with the cleaning effect of annual rainfall being relied on.

However, comparison of the soiling on Maningrida's original array in Figure 6 compared to Figure 8, showing the soiling of Maningrida's Tranche 2 array installed immediately behind the original but two years later, shows the potential for accumulation over time (notwithstanding two of the lowest rainfall wet seasons on record in between).

Figure 8: soiling level on Maningrida's Tranche 2 array, June 2020

Ongoing analysis of soiling effects will inform scheduled cleaning on an as-needs basis, bearing in mind the risks of permanent damage to the reflective coatings from incorrect cleaning methods and equipment, and the high cost of mobilising skilled teams to remote communities. For example, Maningrida is an eight to 10-hour drive from the nearest major centre Darwin (550 to 900 km depending on route) with a large proportion on unsealed roads and exposed to tidal rivers and wet season road closures. This adds at least two additional days of labour plus accommodation costs to a deployment. A charter flight for a day trip could add in the order of $4000 to the cost.

The other factor to consider is whether the soiling impact is coincident with seasonal curtailment, meaning that the effect of soiling on yield is reduced, and cleaning may not result in significant additional yield prior to seasonal rains providing a cleaning effect. The effect of soiling was included in the business case modelling for SETuP, with an assumed average 4% soiling impact. Seasonal curtailment is explored further below.

5.5 Inverter performance

We chose early in the SETuP design phase to standardise string inverters of a size allowing field replacement without heavy-lifting equipment, which is difficult to source in communities and expensive to mobilise. The choice of string inverters also reduces single point of failure risk for the arrays.

As a result, the program exclusively used SMA Tripower 25kW inverters, with a total of 397 deployed across the 25 communities. Capture and transfer of per-inverter energy data into the Pi Historian was an ongoing task at the time of writing, meaning that readily accessible per-inverter data was only available for a subset of sites for a portion of the report period.

Table 8 presents an analysis of the valid per-inverter kWh yield metering data within the period January to June 2020, for 11 SETuP arrays (Maningrida's two arrays are analysed separately).

Comparison of the sum of inverter yields to the whole array export meter identifies a consistent small difference, with the inverter total reading lower than the whole array meter. SMA states the accuracy of the inverter's measurements as +/- 3%[15]. The difference between the PV meter total and the sum of inverter readings is therefore acceptable, taking in to account the estimated 1% or less losses in the AC cabling between inverter and array meter, and the consistency of the difference provides confidence that the metering and AC losses are consistent across sites.

Seven of the arrays exhibited a range between inverter yields of 5% or less, representing an expected variation within an array. For four of the arrays, differing inverter issues are identified with comments on the status provided in the table. The outcomes for Ngukurr and Maningrida warrant field inspection as part of the next scheduled specialist visit.

In terms of the overall performance analysis, the identified issues provide confidence that active curtailment is the primary cause of yield loss below Atonometrics yield estimate.

[15] Refer https://files.sma.de/dl/7418/Messgenau-UEN092520.pdf

Table 8: Inverter performance analysis 19/20

Array	No. of inver-ters	Days of Useful Data	Inverter total metered yield as % PV Meter total	Daily Average Inverter Yield (kWh)	Yield Range (% of average yield)	Comments
Apatula	4	151	98.7%	92.3	33%	Period of underperformance of 2 inverters; rectified in May 2020, after which the yield range was under 2%
Titjikala	16	151	98.6%	31.8	270%	Ten inverters disabled to remove risk of reverse powering station. The six online inverters had a yield range of 1.7%
Arlparra	18	112	99.0%	133.4	3%	-
Daly River	40	137	99.0%	107.4	5%	Inverter repairs during the period
Galiwinku	30	182	98.9%	90.4	2%	-
Gapuwiyak	17	182	99.2%	90.9	3%	-
Milingimbi	17	147	99.4%	97.7	2%	-
Ramingining	20	182	98.3%	89.9	4%	-
Ngukurr	16	182	99.3%	110.2	25%	One inverter at 3/4 output from a blown in-line DC fuse, subsequently rectified
Maningrida #1	32	97	98.5%	98.3	10%	Broader spread of yields
Maningrida #2	15	103	99.0%	103.8	3%	-

5.6 Estimating active curtailment

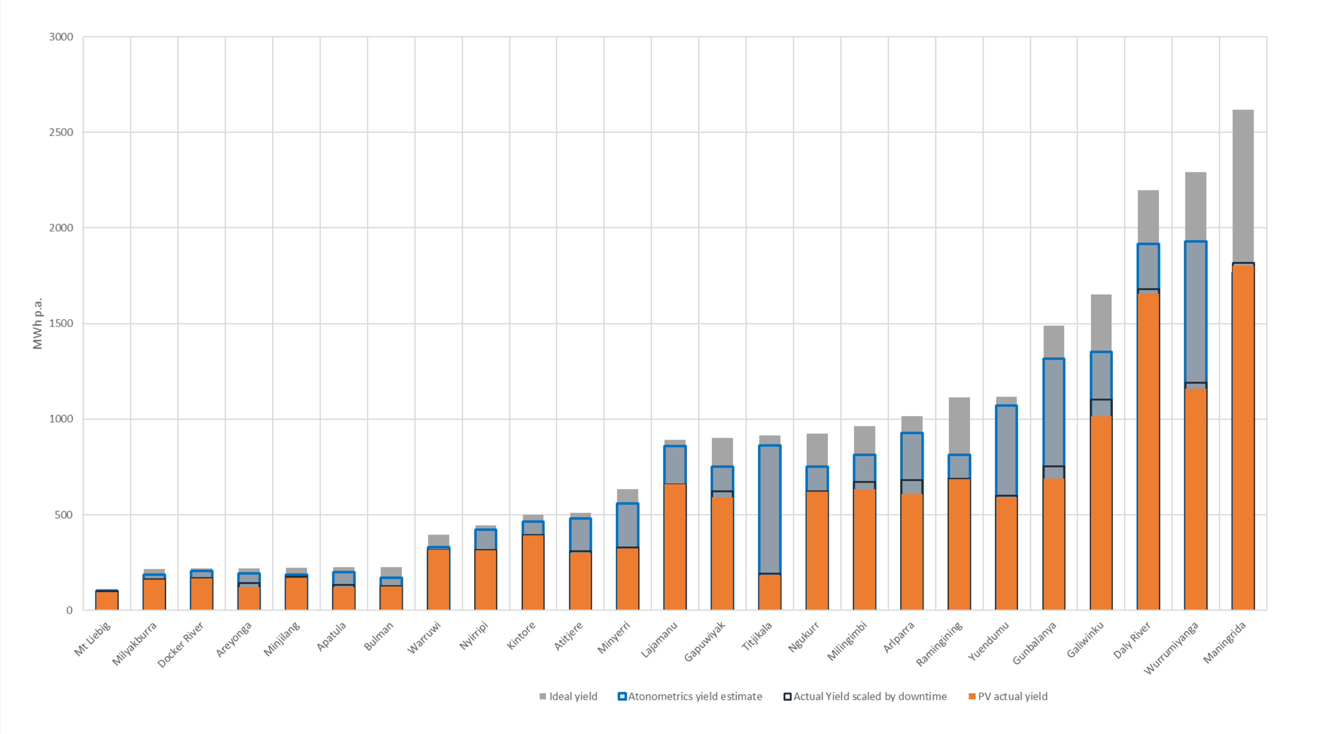
The most significant expected impact on SETuP PV yield is active curtailment by the control system in order to balance supply and demand and maintain the prioritised minimum loading levels on the diesel generators.

The Atonometrics device provides an estimate of the maximum power available from the reference module at 1 minute intervals. Scaling this estimate up by the number of modules provides an estimate of the array available power at any point in time, incorporating temperature and soiling effects.

The actual PV yield can be scaled up by the known downtime to provide an estimate of the PV yield without downtime, noting that this does not capture the small effect of inverter and cable losses up to the PV meter. Those losses are difficult to measure in the SETuP curtailed context, but are estimated to amount to 2% to 3%. Comparing the downtime scaled actual yield to the annual total of the Atonometrics energy yield estimate then provides an indication of the effect of engine curtailment, taking in to account the confidence in inverter yield identified in the previous section.

Figure 9 graphs the ideal or reference yield (Yr) calculated using BoM weather station irradiance (ideal as it uses the panel conversion efficiency at standard test conditions without accounting for temperature de-rating). This is compared to the Atonometrics yield estimate, the actual yield, and the actual yield scaled by the downtime. The difference between the ideal yield and Atonometrics estimate is a measure of the combined impact of temperature de-rating, array mismatch and soiling impact (and/or instrument calibration issues) as explored previously. The difference between Atonometrics yield estimate and downtime adjusted actual yield then reflects the curtailment due to engine minimum loads (along with the minor effect of any DC wiring and inverter efficiency issues on yield). The active curtailment is seen to vary significantly between communities.

Figure 9: Yield estimate comparisons for all communities 2019/20



The level of PV curtailment at any moment is dependent on both the available PV power and the "solar contribution window", being the difference between the total station load and the minimum load requirement of the operating diesel generator(s).

The seasonal availability of PV yield versus the seasonal load is a significant driver of curtailment. System load varies more over the course of a year than does the average available solar yield, resulting in solar arrays sized to achieve higher contribution levels in higher load (summer/hot months) experiencing significant curtailment in low load months.

Decreasing the minimum load requirements of the diesel engines is the most effective tool to reduce active curtailment. The cost of achieving this can be low if the existing engine can, with little or minor modifications, support operation at lower loads, or if the existing engine is due for replacement and can be replaced with a low load rated engine for a similar cost. Deploying a low-load rated replacement engine before end-of-life is a large outlay taking in to account mobilisation and demobilisation, labour costs, and the increasingly limited value of redeploying the removed engine. During 2019 and 2020 a number of reductions in approved minimum load settings were made along with deployment of several lower minimum load capable generators.

Table 9: Summary of per-community performance below provides a summary per community and commentary on the indicators of active curtailment. It can be seen that a significant portion of communities now have at least one engine with minimum load percentage of below 30%. Communities with a high potential yield in comparison to the annual load are highlighted, as are the higher values of curtailment.

Table 9: Summary of per-community performance and curtailment

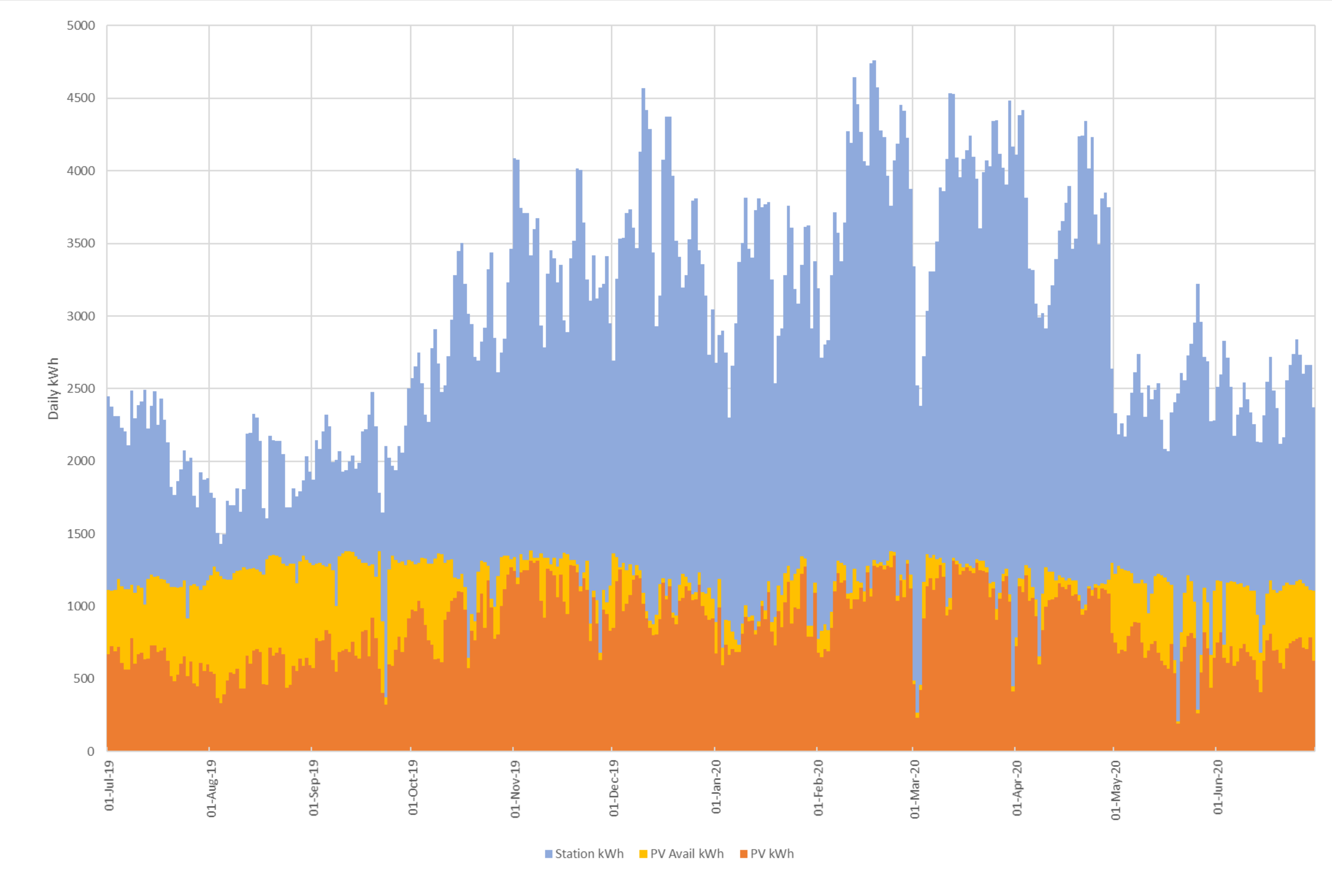
Community	Tranche	kW (AC)	REF 19/20	Downtime 19/20	Curtail-ment estimate %	PVSYST yield % of annual load	lowest min load value %	Comments
Maningrida	1	1175	20.1%	0.8%	-2%	24%	10%	Optimal sizing with benefit of low load engine; Atonometrics calibration/dust issue
Ramingining	1	500	19.6%	0.0%	16%	25%	10%	Optimal size with benefit of low load engine
Yuendumu	1	500	10.3%	1.0%	45%	18%	40%	Undersized for 15% REF, but high engine min. load curtailment
Lajamanu	1	400	18.0%	0.0%	23%	22%	10%	Optimal
Docker River	1	100	10.3%	0.0%	18%	12%	10%	Undersized for community load
Kintore	1	225	20.9%	0.0%	15%	21%	10%	Optimal
Arlparra	1	450	14.8%	12.1%	35%	23%	20%	Inverter issues, still on target
Areyonga	1	100	11.0%	18.0%	37%	18%	10%	High engine curtailment
Mt Liebig	1	50	10.6%	5.1%	5%	11%		undersized for community load
Nyirripi	1	200	29.0%	0.0%	26%	41%	10%	Oversized; low load resulting in high contribution and moderate curtailment
Daly River	DR	1000	55.5%	1.6%	14%	61%	40%	Battery means engine min load not a significant factor, seasonal spill doesn't justify additional cost of larger battery capacity
Apatula	2	100	12.6%	9.0%	39%	21%	30%	Inverter issues resulted in underperformance.
Milyakburra	2	100	18.7%	1.6%	14%	23%	10%	Optimal now that low load engine in place
Minyerri	2	275	13.3%	0.5%	42%	22%	30%	High engine curtailment
Atitjere	2	225	28.8%	2.5%	38%	43%	10%	Oversized but low load benefit
Titjikala	2	400	17.6%	3.8%	79%	76%	10%	Oversized; 10 inverters disabled; waiting on battery project
Milingimbi	2	425	16.2%	6.0%	22%	21%	40%	Good balance of REF and spill despite high minimum engine loading requirements
Minjilang	2	100	11.8%	1.6%	8%	13%	10%	Undersized for community load
Galiwinku	2	750	14.2%	8.5%	25%	20%	30%	Good size, outage issues
Warruwi	2	175	16.7%	0.2%	5%	17%	10%	
Ngukurr	2	400	13.4%	0.0%	17%	17%	30%	Undersized for community load
Wurrumiyanga	2	1075	16.4%	2.7%	40%	27%	50% (10%)	Larger array due to Tranche 2 redeployments; low load engine deployed but low runtime
Bulman	2	100	9.9%	2.5%	27%	7%	20%	Undersized array but engine issues; primary daytime load engine now 50% min load
Gapuwiyak	2	425	18.8%	4.8%	21%	44%	10%	Large array but good yield from low load settings
Gunbalanya	2	675	13.5%	9.4%	48%	25%	40%	High engine curtailment

5.7 Nyirripi high REF

The central Australian community of Nyirripi is situated 450 kilometres west of Alice Springs, half of which is on unsealed roads. The community's power system achieved a REF of just under 30% from the 200 kW SETUP solar array, without requiring a battery system or other storage. It did benefit from the installation of a high pressure common rail diesel generator capable of sustained operation at 10% minimum loading. In order to achieve a high REF with a fixed-tilt array it saw curtailment during the cooler months of around 50% of potential yield.

This is demonstrated in Figure 10 where the total daily energy supplied to the Nyirripi is contrasted with the SETuP PV array potential yield and actual PV yield. The system load can be seen to be highly variable, both over the course of a week, and seasonally with the peak demand day in February three times the August minimum. This reflects the reality for the diesel generators, which similarly experience significant variation in utilisation during the year.

Figure 10: Daily total energy and PV kWh for Nyirripi 2019/20



The engines in place at Nyirripi are:

- Set 1: 270 kW, 30% (90 kW) minimum load
- Set 2: 248 kW, 10% (24 kW) minimum load
- Set 3: 138kW, 20% (27kW) minimum load

The curtailment of a typical winter day is provided in Figure 11, where the 200kWac solar array is curtailed to below 60kW for most of the day, with genset 3 held at its ~ 27kW minimum load rating. The REF achieved on that day was 28%. It should be noted that the diesel generator continues to provide the full reactive power needs of the grid, resulting in a very low power factor. While not an anticipated operating mode it is considered well within the alternator capacity so long as it is serving a predominantly lagging reactive load.

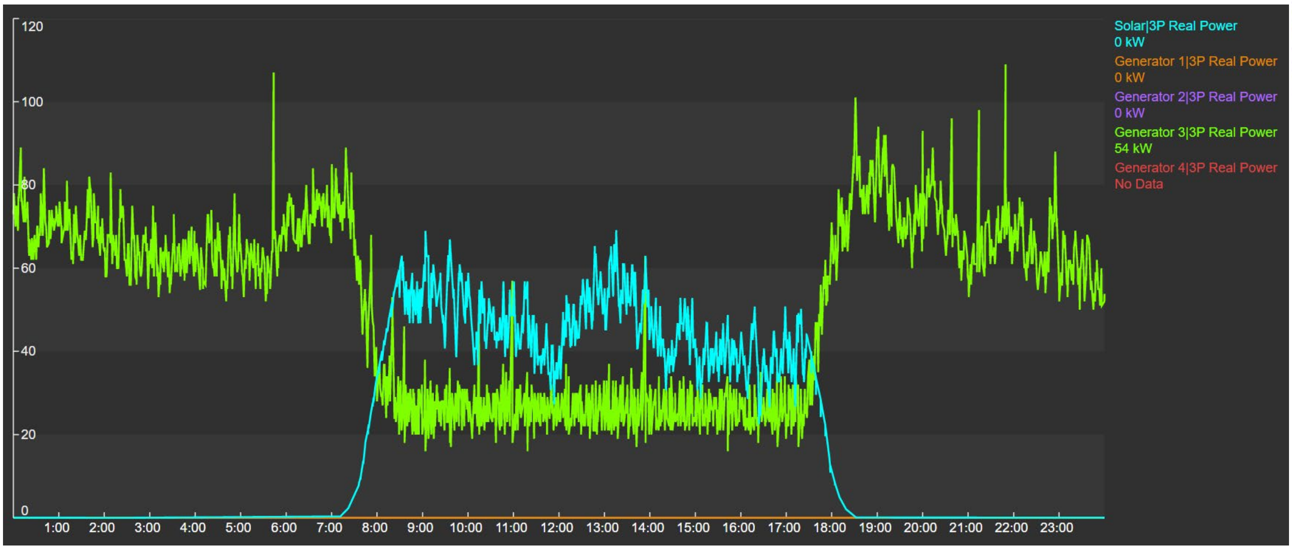


Figure 11: Nyirripi generation curves for 18 August 2019

The next figure presents in contrast a summer (higher demand) day, with the solar operating uncurtailed against set 2 with 10% (24 kW) minimum load requirement, and achieving a daily REF of 32%.

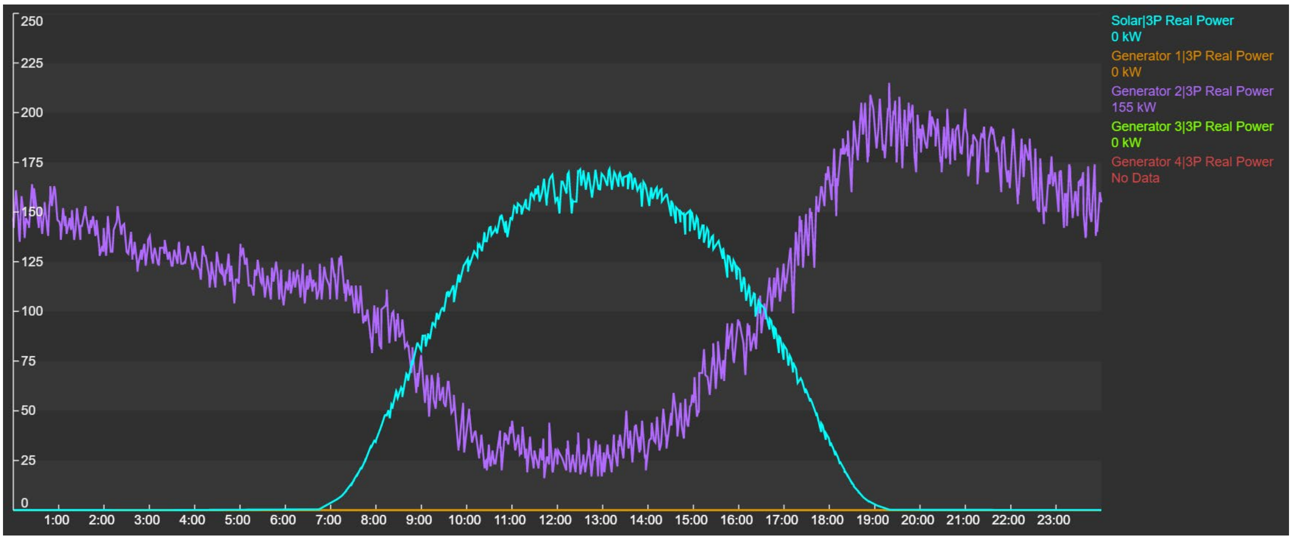


Figure 12: Nyirri generation curves for 22 Feb 2020

5.8 Human factors

The Essential Services Operator (ESO) is Power and Water's eyes and ears on the ground in each community, who monitors power system (and water system) operation, maintains compounds, and performs a range of other tasks. The availability of the array is in the first instance subject to the ability of the ESO to recognise that the solar has failed, with Power and Water's centralised technical coordinators typically only contacted when issues are identified.

Because the solar array is not essential to power system operation, it is possible for its unavailability to be overlooked by the ESO and by busy coordinators until picked up by daily and weekly checks.

Automated identification and notification of solar array non-communication is the obvious solution, and is being investigated as part of a broader review of generation asset management systems.

Another human factor was the initial tendency to isolate the solar array whenever engine or grid instability issues were identified by coordinators. This can also then lead to longer than intended array outages.

In the case of generators requiring sustained loading, the coordinators are now encouraged to adjust the minimum load of individual engines to a higher level instead of just isolating the solar at any hint of an engine/grid instability.

5.9 Daly River battery system performance

The Daly River hybrid continued its strong performance, with a REF of 55% achieved, and PV output increasing year on year by 4%, annual curtailment of PV potential yield was 14%.

The BESS was operational all year apart from an outage caused by air filter blockage during a period of local controlled burns. The inspection and cleaning regime for the filters has been increased as a result.

The average daily stored energy was 1667 kWh, with 610 MWh imported for the period. This represents a high daily utilisation of the total storage capacity. It also represents 38% of the total PV yield for the year, meaning over a third of PV array energy was time shifted by the BESS in order to achieve a 55% annual REF.

The BESS primary round trip efficiency was 88%, with gross efficiency including local light and power needs at 85%.

5.10 Effect on diesel generation costs

No significant issues were encountered with results from regular oil sample tests from the SETuP community diesel generators, nor from increases in diesel maintenance costs or unexpected engine failures.

5.11 Financial performance

Operating costs for SETuP assets and compounds were overall within modelling expectations for the period.

Having achieved target PV contribution, the financial value of displaced diesel was sufficient to cover all operating and maintenance costs including land lease and finance costs, despite depressed diesel prices.

6 Conclusion

SETuP was established with a goal to integrate solar technologies with remote diesel power stations at a transformative scale, as well as to demonstrate technologies to enable higher solar contributions for isolated diesel mini-grids.

The arrays were designed in the context of minimising impacts on the existing diesel engine fleet and avoiding the need for investment in supporting technologies. Periodic curtailment of the arrays was an expected and intrinsic part of the technical and economic design process, reflecting the highly variable nature of remote community grids and the value of displacing the high cost of diesel fuel.

More generally, assessing the performance of the SETuP investment particularly at medium contribution sites is inextricably linked to understanding the performance and limitations imposed by the diesel generation fleet that facilitate the grid-following PV contribution.

The program commissioned its first array in February 2017 and the final array in March 2019, with 10 MW integrated at 25 power stations. This report has examined the performance of the solar arrays for the period July 2019 to June 2020.

The energy contributed to the 25 isolated grids is found to have exceeded the program's expectations, balancing the maximisation of PV contribution while avoiding increases in diesel generation repair and maintenance costs, and recognising the ongoing commissioning during the period.

The medium contribution sites exceeded their 15% annual REF target in aggregate, and Daly River achieved over 55% against its 50% target. This was a significant improvement on the previous year.

One contributing factor was that array downtime was reduced year on year for the majority of sites. There are however opportunities for improvement that Power and Water will continue to pursue, particularly around reliability and rapid replacement of single-point-of-failure electronics. Investigation of improved communications systems to alert coordinators to potential issues is also ongoing.

As expected, the actual yield of the medium contribution arrays was considerably below the uncurtailed potential yield as modelled by the array designers with the PVSYST package. The report explores the major drivers of the curtailment including: the high daily, inter-week and seasonal variation in community power needs, the limited flexibility of the fixed diesel fleet with its associated minimum loading requirements, soiling loss, and other losses.

The impact of actions taken by the operators and coordinators for each power systems is another important factor in SETuP PV performance. The initiatives taken by service delivery teams have made a significant contribution to improving yield, including proactive trials of lower minimum load settings on existing diesel assets, and priority deployments of low load capable replacement engines at a number of sites contributing to improved yield.

An important outcome of SETuP has been the success of the Daly River high contribution project, which has demonstrated that a grid powered solely by solar and batteries with no fossil fuel generation for 50% of the time is reliable and effective.

The success of the Daly River project combined with Northern Territory Government renewables target means that additional investment in the diesel generation fleet for incremental improvements to PV yield must be balanced against the likelihood and potential timing of investment in battery technology and additional PV. Installing a BESS that allows for diesel-off operation will significantly improve yield from the existing SETuP arrays without requiring any changes to the diesel fleet. Other storage technologies may also become cost effective over time.

7 Glossary

ARENA	Australian Renewable Energy Agency
BESS	Battery Energy Storage System
BoM	Bureau of Meteorology
ESO	Essential Services Officer
HMI	Human-Machine Interface
HVAC	Heating Ventilation and Air Conditioning
IES	Indigenous Essential Services Pty Ltd, a wholly owned not-for-profit subsidiary of the Power and Water Corporation established for the delivery of essential services to 72 remote communities and 79 outstations in the Northern Territory under a service level agreement with the Northern Territory Government.
kWh	Kilowatt-hour (industry standard measure of electrical energy generated or delivered)
LCoE	Levelised Cost of Energy
LV	Low Voltage (nominally 230 volts phase to neutral)
MW	Megawatt (a measure of power, the rate of flow of energy)
MWh	Megawatt-hour (equal to 1000 kWh)
OEM	Original Equipment Manufacturer
PLC	Programmable Logic Controller
PV	Photovoltaic, typically used in reference to solar PV modules or panels that capture solar energy through the photovoltaic effect to produce electricity
PVSYST	A popular PV system modelling program, refer www.pvsyst.com
REF	Renewable Energy Fraction, the proportion of energy delivered over a specified period that was sourced from a renewable source (being solar power for the SETuP program)
SETuP Solar SETuP	Solar Energy Transformation Program