Solar Energy Transformation Program Performance Report #3

1 July 2020 to 30 June 2021

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Project page: www.powerwater.com.au/SETuP

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1 Executive summary

As Australia's largest isolated off-grid solar program in remote 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 across the Northern Territory 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 not-for-profit 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 third knowledge sharing performance report for SETuP, covering the period 1 July 2020 to 30 June 2021. The report builds on previous versions of the performance report available online at **powerwater.com.au/publications**. The reader is encouraged to refer to those documents for additional explanatory material.

The SETuP performance outcomes for the period include achieving 18.2 per cent renewable contribution for the 23[1] medium contribution communities, exceeding the design target of 15 per cent. There was considerable variation between communities, with the result ranging from 8.9 per cent at Bulman to 27 per cent annual solar contribution at Nyirripi. In 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, achieving a 39.35 per cent renewable contribution for the reporting period. This below target Renewable Energy Fraction (REF) is attributed to a 13 per cent increase in community load and a significant increase in unavailability of the photovoltaic (PV) system, 15.3 per cent for the reporting period, up from 1.6 per cent in the previous period[2]. This unavailability was as a result of a number of electrical surges caused by lightning damaging communications systems and also cluster controller failures.

A300 kVA/970 kWh BESS was installed and commissioned at Titjikala (Maryvale) (with Northern Territory Government funding, outside of SETuP) in March 2021. This is in addition to the 400kW solar array installed under the SETuP program alongside the existing diesel power station. The BESS has resulted in the renewable energy contribution increasing to 60 per cent for March to June 2021, a significant improvement compared to 11-16 per cent for previous years.

Overall, for the 12 months to June 2021, SETuP generated more than 13 gigawatt-hours of electricity and in line with the previous report, contributed 17 per cent of the electricity needs of twenty eight communities and 30 homelands (outstations) for the period. This resulted in a saving of more than three million litres of diesel fuel.

PV array downtime was less than five per cent overall. A major contributor to array downtime is unreliable array cluster controllers. Power and Water has developed a replacement controller that was trialled at Gunbalanya. The results of the trial were a success and the solution is in the process of being rolled out to other communities.

[1] Previously 24, as Titjikala (Maryvale) is now a high contribution community.

[2] Excluding unavailability periods, Daly River achieved a 45 per cent REF.

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 2020 to 30 June 2021 (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 previous SETuP performance reports, which are available on the Power and Water website (**www.powerwater.com.au**), 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**[3] that explores a number of aspects of the program rollout in more detail and to the **Solar Diesel Mini-Grid handbook (2nd edition)**[4], which includes descriptions 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's 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) resulting in a total of 28 communities and 30 homelands benefiting from the program.

Figure 2 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 per cent average diesel savings (15 per cent 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 determined by obtaining suitable land for each identified community. While the program targeted 34 communities, a range of factors resulted in this being reduced to 24 medium contribution sites.

[3] https://www.powerwater.com.au/__data/assets/pdf_file/0013/32305/SETuP-Case-Study-Rollout-of-Tranche-One-Medium-Contribution-Sites-FINAL-APPROVED.pdf
[4] https://www.powerwater.com.au/__data/assets/pdf_file/0014/32306/1090241-PWC-Solar_Diesel-Mini-Grid-Handbook-web.pdf

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 per cent of solar energy use during the day with diesel engines operating at night. The Daly River project was designed to achieve a 50 per cent annual diesel saving (50 per cent REF). Daly River was operational from April 2018.

Building on the successes and learnings from Daly River, a 300 kVA / 970 kWh BESS was installed at Titjikala and commissioned in March 2021 (with Northern Territory Government funding, outside of SETuP), complimenting the existing 400 kW solar array that was installed under the SETuP program. As discussed in previous reports, the solar array was oversized relative to the community load – installation of the BESS enables it to reach its full potential, resulting in the REF increasing from 11-16 per cent historically to over 60 per cent for the four months from March to June 2021.

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.**

Figure 1 – Aerial photograph of the Gunbalanya SETuP array

Figure 2 – Remote communities served by Power and Water (IES communities in medium font bold)

Key

- Water supply
- Water supply and sewerage
- Power stations
- Connected to electricity grid
- Solar site
- <u>**Major remote town**</u>

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 electrical output. Each low voltage (LV) distribution feeder has either a Schneider Electric (SE) PM810 or PM5560 meter at the power station LV main board.

Data from various meters is collated by the power station Programmable Logic Controller (PLC) and then logged on a Human-Machine Interface (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 Supervisory control and data acquisition (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 Transmission Control Protocol/ Internet Protocol (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 3 shows the power meter within a typical Tranche 2 LV switchboard, along with the cluster controller, circuit breakers and protection.

Figure 3 – PV LV Switchboard at Maningrida array #2

3.3 Atonometrics solar monitoring

Every SETuP array includes an Atonometrics[5] 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 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.

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

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 4**) 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.

Figure 4 – Dual-input Atonometrics installation at Daly River

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:

- 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 per cent availability (i.e. no downtime) and a soiling effect of four per cent (as commonly estimated in literature).
- Maintaining 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 10 MW program capacity and 15 per cent 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 per cent 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 used. 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.

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.

Maintenance and validation of the weather data stations has proved challenging, with array functionality being prioritised. As a result, this performance report is primarily based on Atonometrics data, supported by Bureau of Meteorology (BoM) and weather station data where available.

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 therefore 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. Hence the economic focus 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 BoM (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 installed rating of 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, however 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 was summarised as the number of inverter days of unavailability and compiled to an array 'percentage unavailability'. 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 a useful estimate for the Northern Territory-delivered diesel price.

4 Performance data 2020-21

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 Daly River for July 2020 to June 2021, presented in order of commissioning. **Table 3** provides the same data for the 15 Tranche 2 communities and Titjikala, along with a program total.

Note that Maningrida received a second array as part of Tranche 2. Performance is presented separately for each array at the end of **Table 3** [7]**.**

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

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 25 kW 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 315 W modules. Daly River and Tranche 2 were constructed with 320 W rated modules.
Dual input 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).
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.
PVSYST Egrid model 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 model PV output MWh	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 0.
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.
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.
Available PV yield (Atonometrics) MWh	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.
PV actual as % of PWC model PV output	The actual yield as a percentage of the Power and Water target/modelled yield (as described above).
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.
Ideal (reference) PV yield MWh	Estimated annual potential PV yield based on historical BoM GHI data, scaled for location, array orientation and losses.

[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 2020/21

Community	kW (AC)	kW (DC)	Dual input Atonometrics	Weather station	PVSYST Egrid model MWh	PWC model PV output MWh	Diesel generation actual MWh	PV actual (yield) MWh	PV actual % of station total (REF)	Available PV yield (atonometrics) MWh	PV actual as % available yield	PV actual as % of PWC model PV output	Unavailability	Ideal (reference) PV yield MWh
Maningrida combined[9]	1,175	1,184	N	1	2,140	1,466[11]	8,245	1,626	16.5%	1,593	102.1%	110.9%	1.7%	2,540
Ramingining	500	504	N	-	886	687	3,177	636	16.7%	765	83.2%	92.6%	0.0%	1,055
Yuendumu	500	504	N	-	1,004	725[11]	4,577	537	10.5%	1,020	52.7%	74.1%	0.0%	1,076
Lajamanu	400	403	N	1	791	580[11]	2,811	663	19.1%	839	79.0%	114.3%	0.0%	868
Kaltukatjara (Docker River)	100	101	N	-	197	150	1,334	195	12.7%	199	98.0%	129.8%	0.0%	210
Kintore	225	227	N	1	392	296	1,441	347	19.4%	444	78.1%	117.2%	0.0%	481
Arlparra	450	454	N	1	928	596	3,394	777	18.6%	908	85.6%	130.4%	1.8%	1,000
Areyonga	100	101	N	-	202	127	990	118	10.7%	188	63.0%	93.1%	15.0%	211
Mt Liebig	50	50	N	-	101	93	820	93	10.2%	98	95.2%	100.2%	0.0%	107
Nyirripi	200	202	N	-	444	305	819	303	27.0%	390	77.8%	99.5%	4.7%	429
Tranche 1 subtotal	**3,700**	**3,730**	**-**	**4**	**7,084**	**5,025**	**27,607**	**5,297**	**16.1%**	**6,443**	**82.2%**	**105.4%**	**1.4%**	**7,977**
Daly River[10]	1,000	1,024	Y	1	1,820	1,676	2,039	1,323	39.3%	1,709	77.4%	78.9%	15.3%	2,106

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

[10] Losses through time shifting of the PV through the BESS are ignored for this purpose, in the same way that diesel auxiliary power requirements are ignored.

Table 3 – Tranche 2 and Titjikala array details, performance data and program total for 2020/21

Community	kW (AC)	kW (DC)	Dual input Atonometrics	Weather station	PVSYST Egrid model MWh	PWC model PV output MWh	Diesel generation actual MWh	PV actual (yield) MWh	PV actual % of station total (REF)	Available PV yield (atonometrics) MWh	PV actual as % available yield	PV actual as % of PWC model PV output	Unavailability	Ideal (reference) PV yield MWh
Apatula (Finke)	100	102	N	-	199	145	832	147	15.0%	206	71.3%	73.9%	2.2%	219
Milyakburra	100	102	N	-	193	152	766	157	17.0%	174	90.5%	81.4%	0.5%	204
Minyerri	275	282	N	-	532	301	2,163	265	10.9%	547	48.5%	49.9%	3.8%	608
Atitjere (Harts Range)	225	230	N	-	452	299	705	230	24.6%	501	45.9%	50.9%	0.0%	498
Milingimbi	425	435	N	-	804	380	3,427	650	16.0%	765	85.0%	80.9%	1.4%	913
Minjilang (Croker Island)	100	102	N	-	189	138	1,234	146	10.6%	176	82.6%	77.1%	8.5%	211
Galiwinku (Elcho Island)	750	768	N	1	1,399	1,045	6,580	1,104	14.4%	1,300	85.0%	78.9%	2.2%	1,558
Warruwi (Goulburn Island)	175	179	N	-	332	293	1,744	295	14.5%	327	90.2%	88.9%	0.0%	373
Ngukurr	400	410	N	1	774	556	4,337	574	11.7%	661	86.9%	74.2%	1.6%	882
Wurrumiyanga (Bathurst Island)	1,075	1,101	N	1	1,897[11]	1,520[11]	6,082	1,424	19.0%	1,781	79.9%	75.1%	2.2%	2,159
Gapuwiyak (Lake Evella)	425	435	N	-	191	163	2,811	477	14.5%	701	68.1%	249.8%	9.6%	855
Bulman	100	102	Y	-	764	607	1,198	117	8.9%	174	67.0%	15.3%	9.3%	214
Gunbalanya (Oenpelli)	675	691	N	1	1,264	979	4,555	803	15.0%	1,242	64.6%	63.5%	13.1%	1,428
Tranche 2 subtotal	**5600**	**5733**	**-**	**4**	**9,784**	**6,124**	**36,436**	**6,390**	**14.9%**	**8,555**	**74.7%**	**71.1%**	**4.4%**	**10,122**
Titjikala (Maryvale)[10]	400	410	N	1	794	254	783	307	28.2%	868	35.3%	38.6%	4.1%	877
SETUP Total	**9925**	**10109**	**2**	**10**	**18,688**	**13,533**	**66,864**	**13,316**	**16.6%**	**17,575**	**75.8%**	**80.8%**	**4.4%**	**21,082**

[11] 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 2020/21 financial year, is provided in **Table 4**. A total of 13.3 GWh was exported from the arrays, saving 3.515 million litres of diesel and avoiding 9,527 tonnes of CO_2 equivalent emissions.

The diesel saving figures are calculated using the historical average fuel efficiency of the remote diesel fleet, being 0.264 L per kWh[12].

The yield for the previous twelve months is also listed and indicates largely consistent PV yield comparatively.

Daly River did not achieve the target REF for the reporting period, which is attributed to a significant increase in unavailability of the PV system due to a number of electrical surges caused by lightning damaging communications systems and also cluster controller failures, and a 13 per cent increase in community demand.

Titjikala yield has increased substantially primarily due to the commissioning of a 300 kVA/970 kWh BESS in March 2021. Historical REF was 11 per cent and 16 per cent for previous years, however for the four months from commissioning to end June 2021 the REF increased to over 60 per cent.

The drivers of the changes in yield are explored in subsequent sections.

Table 4 – SETuP summary performance 2020/21 in comparison to 2019/20

Metric	Tranche 1[13]	Tranche 2	Daly River	Titjikala	SETuP Total
Total PV capacity MWdc	3.70	4.94	1.02	0.41	10.07
Total PV yield (MWh) 2019-20	5,441	6,232	1,654	184	13,511
Total PV yield (MWh) 2020-21	5,297	6,390	1,323	307	13,316
Total PV yield change year on year	-2.7%	2.5%	-20.0%	67.2%	-1.4%
Diesel savings (kilolitres) 2019-20	1,436	1,639	436	48	3,567
Diesel savings (kilolitres) 2020-21	1,398	1,687	349	81	3,515
Greenhouse gas savings (tonnes $CO2_e$) 2019-20	3,893	4,459	1,183	131	9,666
Greenhouse gas savings (tonnes $CO2_e$) 2020-21	3,790	4,571	946	219	9,527

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

[13] For this aggregate analysis, both Maningrida arrays have been included in Tranche 1 to avoid double counting of the Maningrida total system load. This also applies to the previous year totals.

5.2 System performance

The SETuP arrays in aggregate met or exceeded their nominal targets for renewable energy fraction (the percentage contribution from PV to the total annual system load), with the exception of Daly River as listed in **Table 5.**

This was achieved against small percentage increases in load across the Tranche 1 and 2 communities, with increases in annual diesel generation of three per cent and four per cent respectively. Daly River saw a 20 per cent decrease in PV output against an overall 13 per cent increase in total load for the isolated system[14]. This result is explored further below.

Table 5 – System performance 2020/21 in comparison to 2019/20

Metric	Tranche 1[15]	Tranche 2	Daly River	Titjikala	SETuP Total
PV annual contribution target	15.0%	15.0%	50.0%	26.67%[16]	16.6%[17]
Renewable Energy Fraction 2019/20	16.8%	15.2%	55.5%	17.6%	17.4%
Renewable Energy Fraction 2020/21	16.1%	14.9%	39.3%[18]	28.2%	16.6%
Diesel generation (MWh) 2019/20	26,883	34,888	1,325	860	63,956
Diesel generation (MWh) 2020/21	27,607	36,436	2,039	783	66,864
Diesel generation change year on year	2.7%	4.4%	53.9%	-9.0%	4.5%
Total community load 2019/20 (MWh)	32,324	41,120	2,979	1,044	77,467
Total community load 2020/21 (MWh)	32,904	42,825	3,361	1,089	80,180
Community load change year on year	1.8%	4.1%	12.8%	4.4%	3.5%

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

[15] For this aggregate analysis, both Maningrida arrays have been included in Tranche 1 to avoid double counting of the Maningrida total system load. This also applies to the previous year totals.

[16] Calculated pro-rata for the period the BESS was operational, ie. eight months at 15 per cent REF (July 2020 to February 2021) and four months at 50 per cent REF (March 2021 to June 2021).

[17] Calculated as a fraction of the 2020/21 load total.

[18] Excluding unavailability periods, Daly River achieved a 45 per cent REF.

5.3 PV array availability

Availability of the SETuP arrays decreased across the board for 2020-21 with 4.4 per cent 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.

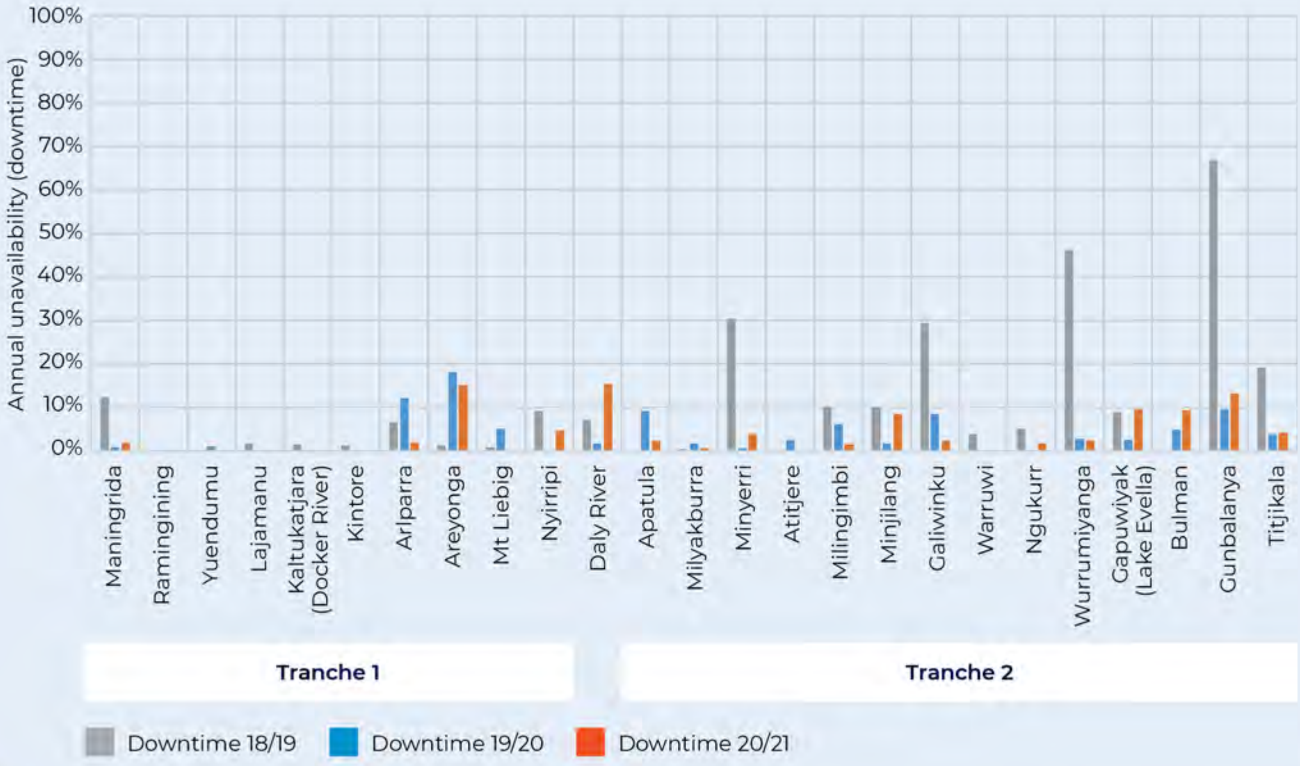
The downtime per community is shown in **Figure 5,** with a comparison to the previous year.

Eight arrays saw no downtime in 2020-21, achieving 100 per cent availability. A further eleven communities had downtime less than five per cent, with only three communities down for more than 10 per cent of the year.

Table 6 – Array availability

Metric	Tranche 1[15]	Tranche 2	Daly River	Titjikala	SETuP Total
% of time unavailable 2019/20	2.74%	2.88%	1.63%	3.83%	3.39%
% of time unavailable 2020/21	1.42%	4.39%	15.29%	4.11%	4.37%

Figure 5 – Array downtime compared year on year



[15] For this aggregate analysis, both Maningrida arrays have been included in Tranche 1 to avoid double counting of the Maningrida total system load. This also applies to the previous year totals.

The primary causes of downtime and their relative impact are summarised in **Table 7.**

Table 7 – Causes of Array downtime 2020/21

Cause	Inverter days lost	% of total
Cluster controller	2889	46%
Electrical surge	2309	36%
Communications fault	688	11%
Planned maintenance	376	6%
Failed inverter(s)	59	1%
Balance of system (BoS) failure	14	0%
Total	**5019**	**100%**

Downtime related to the cluster controller (plant controller) continues to be the largest single cause at 46 per cent of all days of inverter downtime. The majority of sites had at least one outage related to the cluster controller, with multiple occurrences at Daly River, Galiwinku, Gunbalanya, Maningrida and Wurrumiyanga.

The cause was predominantly software-related seize-ups, with 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. Power and Water has developed a replacement controller that was trialled at Gunbalanya. The results of the trial were a success and the solution is in the process of being rolled out to other communities.

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 Daly River and Minyerri.

Communications system failures were the third most-significant cause of downtime, impacting Gapuwiyak and Areyonga, caused by intermittent communications issues to inverters and radio communications system failure at the sites.

The final major 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.

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 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 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.

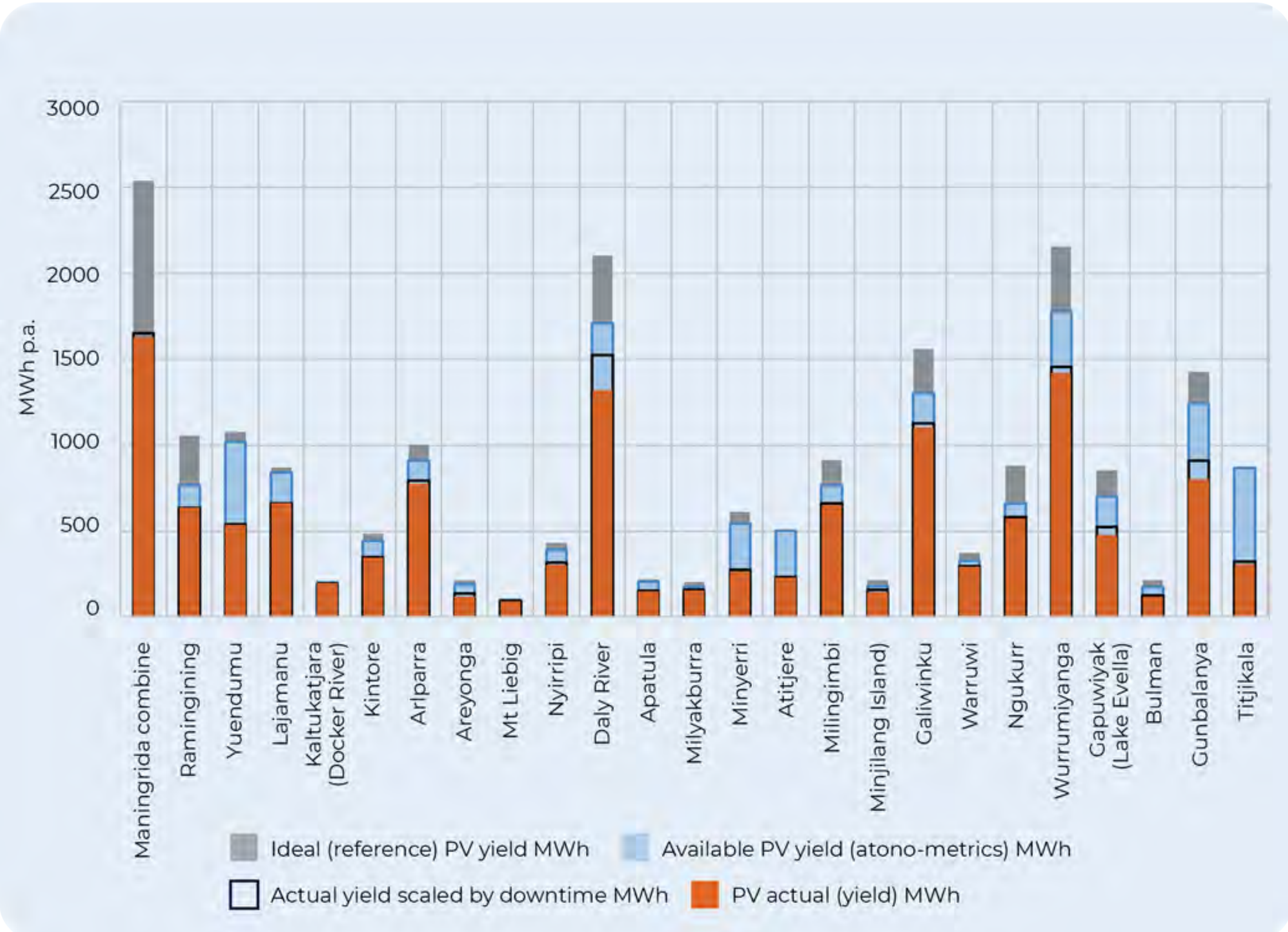
The Atonometrics device provides an estimate of the maximum power available from the reference module at one minute intervals. Scaling this estimate up by the number of modules provides an estimate of the array available power at any point in time, incorporating temperature and soiling effects.

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, however are estimated to amount to two to three per cent. Comparing the downtime scaled actual yield to the annual total of the Atonometrics energy yield estimate provides an indication of the effect of engine curtailment, taking into account the confidence in inverter yield identified in the previous section.

Figure 6 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 in previous reports. The below figure indicates significant soiling impacts at a number of communities including Maningrida, Daly River and Waurrumiyanga.

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.



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 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.

5.5 Daly River battery system performance

The Daly River hybrid system continued its strong performance, despite only achieving a REF of 39.8 per cent against the target REF of 50 per cent. This is attributed to a 13 per cent increase in community demand and a significant increase in unavailability of the PV system, 15.3 per cent for the reporting period up from 1.6 per cent in the previous period[19]. This unavailability was as a result of a number of electrical surges caused by lightning damaging communications systems and also cluster controller failures.

The average daily stored energy was 1,129 kWh, with 412 MWh imported for the period. This represents a high daily use of the total storage capacity. It also represents 31 per cent of the total PV yield for the year, meaning a third of PV array energy was time shifted by the BESS.

The BESS primary round trip efficiency for the reporting period was 91 per cent, with gross efficiency including local light and power needs at 86 per cent.

5.6 Titjikala battery system

Building from the success of Daly River's high contribution solar plus BESS hybrid power station, Power and Water with the support of the Northern Territory Government has begun implementing BESS solutions to other remote communities. Titjikala (Maryvale) is the first community to have a BESS integrated with the existing diesel and solar after completion of the SETuP program.

Titjikala is a remote community located approximately 125 km south of Alice Springs. The existing power station consists of three diesel engines (320 kW, 270 kW and 138 kW), and a 400 kW solar array that was installed under the SETuP program.

Power and Water had previously identified Titjikala as a 'battery ready' community due to its relatively oversized PV array. The array was oversized due to redistribution of the array originally intended for Numbulwar, where the proposed location was determined to be unsuitable due to future inundation with rising sea levels and insufficient time to obtain a new lease.

Separate to the SETuP program, Power and Water procured the design, supply, installation and commissioning of a suitable 'least cost' BESS at Titjikala, with the successful tenderer implementing a 300kVA / 970 kWh BESS. The purpose of the BESS is to achieve additional fuel savings from the existing 400 kW solar array installed under SETuP, by load shifting additional available energy from the solar array and enabling diesel off operation.

Titjikala had achieved 11 per cent and 16 per cent REF in previous reporting periods, however for the four months following commissioning in March 2021 to June 2021, it achieved over 60 per cent REF demonstrating a strong success in improving the renewable penetration.

Figure 7 shows the significant improvement of solar yield vs calculated available yield from the Atonometrics device, with an average of 20 per cent yield in 19/20, to achieving almost 100 per cent yield in June 2021. Note that the power station was undertaking significant augmentation with installation of the battery system hence low output in January and February 2021.

[19] Excluding unavailability periods, Daly River achieved a 45 per cent REF.

Figure 7 – Titjikala actual solar yield vs Atonometrics available yield

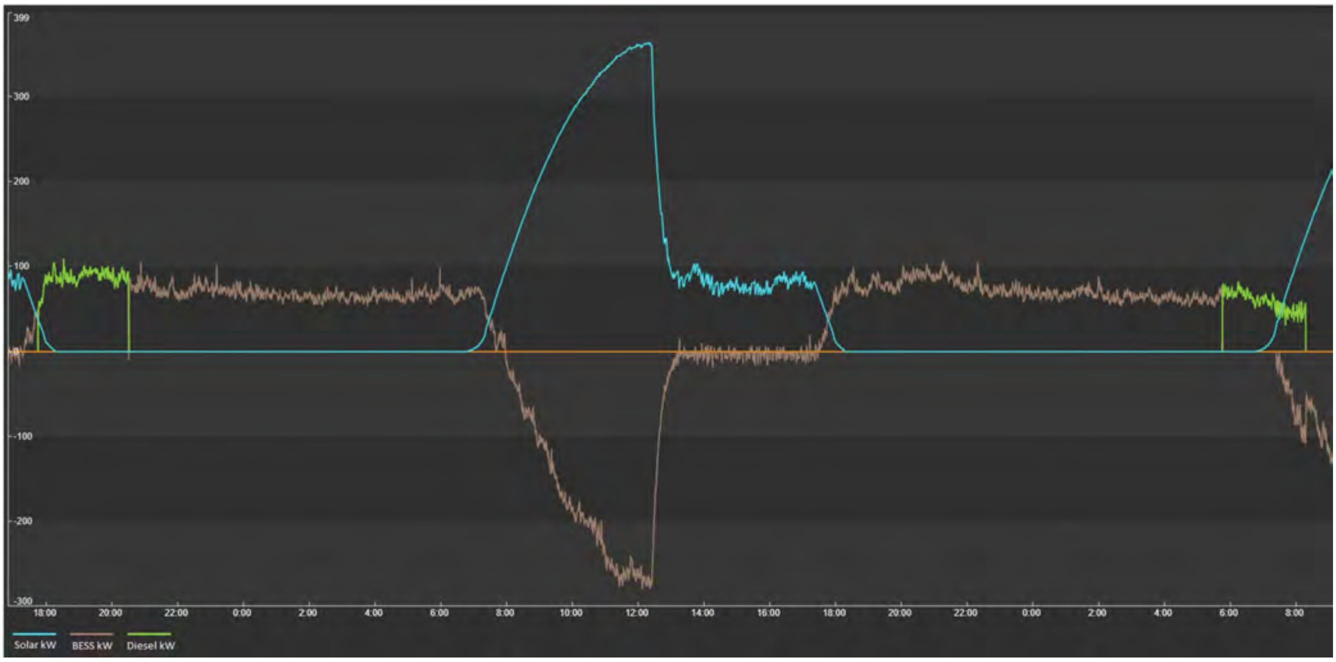
This additional yield has largely been possible due to the BESS providing load shift capability, with 40 per cent of the generated solar energy (March 2021 to June 2021) being stored and used outside of sunlight hours.

Figure 8 – Titjikala BESS at sunrise – 'Dawn of a new era'

The BESS exceeded expectations with its ability to run the community 'diesel-off' for over 24 hours on several occasions during the reporting period, including for 33 hours on two separate occasions in April 2021.

Figure 9 illustrates the operation of the power station where it operated solely from the BESS and solar array from 8:30pm on 16 April 2021 to 5:45am on 18 April 2021.

Figure 9 – Titjikala power station output 16-18 April 2021



This figure also illustrates the operation of the BESS, which with good solar conditions, is fully charged just after midday then operates to manage the instantaneous variations in solar output and load while the community is supplied 100 per cent from the solar array. It is also noted that as the battery capacity became depleted, the diesel ran only for a few hours in the early morning while the solar ramped up, before going back to diesel-off mode for the remainder of the day – in this example the diesel came on at 5:45am on 18 April 2021 and went off again at 8:15am.

5.7 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.

5.8 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 2020 to June 2021.

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 per cent annual REF target in aggregate and Daly River achieved just under 40 per cent against its 50 per cent target. This below target REF is attributed to a 13 per cent increase in community load and a significant increase in unavailability of the PV system, 15.3 per cent for the reporting period up from 1.6 per cent in the previous period[20]. This unavailability was a result of a number of electrical surges caused by lightning damaging communications systems and also cluster controller failures.

A significant factor impacting the solar yield was array downtime and there are 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 reports explore 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 system 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.

The recent addition of a BESS to complement the SETuP array at Titjikala proved successful, meeting and exceeding expectations by increasing array output with load shifting and achieving extended periods of diesel off, increasing the REF from 11-16 per cent to over 60 per cent and achieving diesel-off for 24 hours on several occasions, including to occasions of 33 hours in April 2021.

The success of the Daly River project and more recently the Titjikala project, combined with Northern Territory Government renewables target means that additional investment in the diesel generation fleet for incremental improvements to PV yield from existing arrays 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 other existing SETuP arrays without requiring any changes to the diesel fleet. Other storage technologies may also become cost effective over time.

[20] Excluding unavailability periods, Daly River achieved a 45 per cent REF.

7 Glossary

Abbreviation	Definition and explanation
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 Energy Transformation Program

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