PowerWater

Solar Energy Transformation Program Performance Report #4

1 July 2021 to 30 June 2022

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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 fourth and final knowledge sharing performance report for SETuP, covering the period 1 July 2021 to 30 June 2022. The report builds on the previous performance reports available on the **Power and Water website**[1]. The reader is encouraged to refer to those documents for additional explanatory material.

The SETuP performance outcomes for the period include achieving a 14.9 per cent renewable contribution for the 23[2] medium contribution communities, almost achieving the design target of 15 per cent. As per previous years there was considerable variation between communities, with the result ranging from nine per cent at Bulman to 28.5 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 46.9 per cent renewable contribution for the reporting period, falling shy of the design target (50.0 per cent). The shortfall is due primarily to a 3.8 per cent increase in the total community load. The solar array energy generation increased by 23.7 per cent compared to the previous year due to improved array availability.

A 400 kW SETuP array is integrated with a 300 kVA/970 kWh BESS at Titjikala (Maryvale). The BESS, funded by the Northern Territory Government, was installed and commissioned in March 2021 and achieved a 52.9 per cent renewable contribution in the community for the reporting period.

During the 12 months from July 2021 to June 2022, the SETuP solar arrays generated more than 14 gigawatt-hours of electricity, achieving 16.85 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 3.7 million litres of diesel fuel.

For the period July 2018 until June 2022 SETuP has saved over 13.1 million litres of diesel (35,600 tons of CO_2 emissions) and the program has managed an average total yearly PV contribution of 16.4 per cent. This ongoing performance demonstrates that solar/diesel hybrid and diesel-off operation is now business as usual for Power and Water's remote community service provision.

[1] Power and Water website - https://www.powerwater.com.au/about/publications-and-forms.

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

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 2021 to 30 June 2022 (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 fourth 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**[3], 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**[4] that explores a number of aspects of the program rollout in more detail and to the **Solar Diesel Mini-Grid handbook (2nd edition)**[5], 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] Power and Water website - https://www.powerwater.com.au/about/publications-and-forms

[4] https://www.powerwater.com.au/__data/assets/pdf_file/0013/32305/SETuP-Case-Study-Rollout-of-Tranche-One-Medium-Contribution-Sites-FINAL-APPROVED.pdf

[5] 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 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), complementing 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 and installation of the BESS enabled it to reach its full potential, resulting in the REF reaching 52.9 per cent for the reporting period.

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**.

Figure 1 – Aerial photograph of the Gunbalanya SETuP array

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

Key

- Water supply
- Water supply and sewerage
- Power stations
- Connected to electricity grid
- Solar site
- Grid-forming BESS site

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 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 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[6] 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.

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.

Figure 4 – Dual-input Atonometrics installation at Daly River

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

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 per cent availability (i.e. no downtime) and a soiling effect of four per cent (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 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 of 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.

Figure 5 – The SETuP solar array at Kaltukatjara (Docker River)

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 and weather station data where available.

Figure 6 – SETuP weather station at Titjikala

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[7]. 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 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.

[7] 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 2021-22

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 2021 to June 2022, presented in order of commissioning.

Table 3 provides the same data for the 15 Tranche 2 communities and Titjikala, along with a program total.

Figure 7 – The SETuP solar array at Mt Liebig

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 3.4.
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 per cent 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 Bureau of Meteorology 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 2021/22

Community	kW (AC)	kW (DC)	Dual input Atono metrics	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	Unavail ability	Ideal (reference) PV yield MWh
Maningrida combined	1,181	1190	N	1	2,140	1,466	8,712	1545	15.0%	1,675	92.2%	105.4%	11.1%	2,600
Ramingining	500	504	N	-	886	687	3,558	668	15.8%	751	88.8%	97.2%	1.1%	1,082
Yuendumu	500	504	N	-	1,004	725	4,370	795	15.3%	1,038	76.6%	109.6%	7.4%	1105
Lajamanu	400	403	N	1	791	580	3,058	546	15.1%	832	65.7%	94.2%	7.9%	879
Kaltukatjara (Docker River)	100	101	N	-	197	150	1,300	170	11.5%	201	84.5%	113.1%	1.1%	214
Kintore	225	227	N	1	392	296	1,544	327	17.4%	532	61.5%	110.6%	7.3%	495
Arlparra	450	454	N	1	928	596	3,582	662	15.2%	923	71.7%	111.0%	13.8%	993
Areyonga	100	101	N	-	202	127	879	137	13.5%	206	66.2%	107.7%	21.7%	214
Mt Liebig	50	50	N	-	101	93	808.9	89.7	10.0%	138	64.8%	96.5%	3.8%	110
Nyirripi	200	202	N	-	444	305	807	325	28.5%	415	78.3%	106.4%	1.6%	442
Tranche 1 subtotal	**3,706**	**3,736**	**-**	**4**	**7,084**	**5,025**	**28,638**	**5,265**	**15.8%**	**6,711**	**78.4%**	**104.7%**	**10.9%**	**8,134**
Daly River[9]	1,000	1,024	Y	1	1,820	1,676	1,842	1,637	46.9%	2,149	76.1%	97.6%	15.3%	2,161

[9] 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 2021/22

Community	kW (AC)	kW (DC)	Dual input Atono metrics	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	843	149	15.0%	202	73.7%	102.9%	1.4%	219
Milyakburra	100	102	N	-	193	152	757	159	17.3%	178	89.2%	104.6%	1.1%	204
Minyerri	275	282	N	-	532	301	2,175	271	11.0%	246	109.9%	90.0%	12.9%	608
Atitjere (Harts Range)	225	230	N	-	452	299	745	237	24.1%	419	56.5%	79.2%	11.0%	498
Milingimbi	425	435	N	-	804	380	3,493	624	15.1%	758	82.4%	164.3%	5.3%	913
Minjilang (Croker Island)	100	102	N	-	189	138	1,293	158	10.9%	178	89.1%	114.8%	0.0%	211
Galiwinku (Elcho Island)	750	768	N	1	1,399	1,045	7,463	1,080	12.6%	1,311	82.3%	103.3%	5.6%	1,558
Warruwi (Goulburn Island)	175	179	N	-	332	293	1,862	292	13.5%	313	93.2%	99.5%	0.0%	373
Ngukurr	400	410	N	1	774	556	4,981	592	10.6%	796	74.3%	106.4%	1.7%	882
Wurrumiyanga (Bathurst Island)	1,075	1,101	N	1	1,897	1,520	6,259	1,467	18.9%	1,816	80.8%	96.5%	0.0%	2,159
Gapuwiyak (Lake Evella)	425	435	N	-	191	163	3,127	518	14.2%	726	71.3%	317.9%	9.1%	855
Bulman	100	102	Y	-	764	607	1,232	122	9.0%	180	68.0%	20.2%	0.5%	214
Gunbalanya (Oenpelli)	675	691	N	1	1,264	979	4,843	938	16.2%	1,242	75.4%	95.8%	1.6%	1,428
Tranche 2 subtotal	**4825**	**4939**	**-**	**4**	**9,784**	**6,124**	**39,073**	**6,607**	**14.4%**	**8,367**	**79.0%**	**100.4%**	**3.8%**	**10,122**
Titjikala (Maryvale)	400	410	N	1	794	254	475	533	52.9%	1,028	51.9%	209.9%	0.0%	877
SETUP Total	**9931**	**10109**	**2**	**10**	**18,688**	**13,533**	**70,028**	**14,040**	**16.8%**	**18,255**	**76.9%**	**103.7%**	**6.0%**	**21,294**

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 2021/22 financial year and compared to the previous year, is provided in **Table 4.** A total of 14.04 GWh was exported from the arrays, saving 3.707 million litres of diesel and avoiding 10,045 tonnes of CO2 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[10].

The yield for the previous twelve months is also listed and indicates a notable improvement in yield of 5 per cent overall.

Daly River came within 3.1 per cent of the target REF for the reporting period, which is attributed to an increase in PV yield however pulled down slightly by an increase in system load.

Titjikala exceeded the target REF by 2.5 per cent.

Table 4 – SETuP summary performance 2021/2022 in comparison to 2020/2021

Metric	Tranche 1	Tranche 2	Daly River	Titjikala	SETuP Total
Total PV capacity MWdc	3.74	4.94	1.02	0.41	10.10
Total PV yield (MWh) 2020-21	5,297	6,390	1,323	307	13,316
Total PV yield (MWh) 2021-22	5,264	6,607	1,637	533	14,040
Total PV yield change year on year	-0.6%	3.4%	23.7%	73.6%	5.4%
Diesel savings (kilolitres) 2020-21	1,398	1,687	349	81	3,515
Diesel savings (kilolitres) 2021-22	1,390	1,744	432	141	3,707
Greenhouse gas savings (tonnes $CO2_e$) 2020-21	3,790	4,571	946	219	9,527
Greenhouse gas savings (tonnes $CO2_e$) 2021-22	3,767	4,726	1,171	382	10,045

[10] This is the method agreed as part of the IES – Northern Territory Government funding agreement.

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).

This was achieved against small percentage increases in load across the Tranche 1 and 2 communities of three per cent and 6.6 per cent respectively. Daily River also saw a small load increase of 3.5 per cent, while Titjikala recorded a 7.4 per cent reduction in annual system load year on year.

Table 5 – System performance 2021/2022 in comparison to 2020/2021

Metric	Tranche 1	Tranche 2	Daly River	Titjikala	SETuP Total
PV annual contribution target	15.0%	15.0%	50.0%	50.0%	17.8%
Renewable Energy Fraction 2020/21	16.1%	14.9%	39.3%	28.2%	16.6%
Renewable Energy Fraction 2021/22	15.5%	14.4%	46.9%	52.9%	16.6%
Diesel generation (MWh) 2020/21	27,607	36,436	2,039	783	66,864
Diesel generation (MWh) 2021/22	28,077	39,187	1,853	481	69,599
Diesel generation change year on year	1.7%	7.0%	-10.0%	-62.8%	3.9%
Total community load 2020/21 (MWh)	32,904	42,825	3,361	1,089	80,180
Total community load 2021/22 (MWh)	33,901	45,680	3,479	1,008	84,367
Community load change year on year	3.0%	6.6%	3.5%	-7.4%	4.9%

5.3 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 per cent to three per cent. 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.

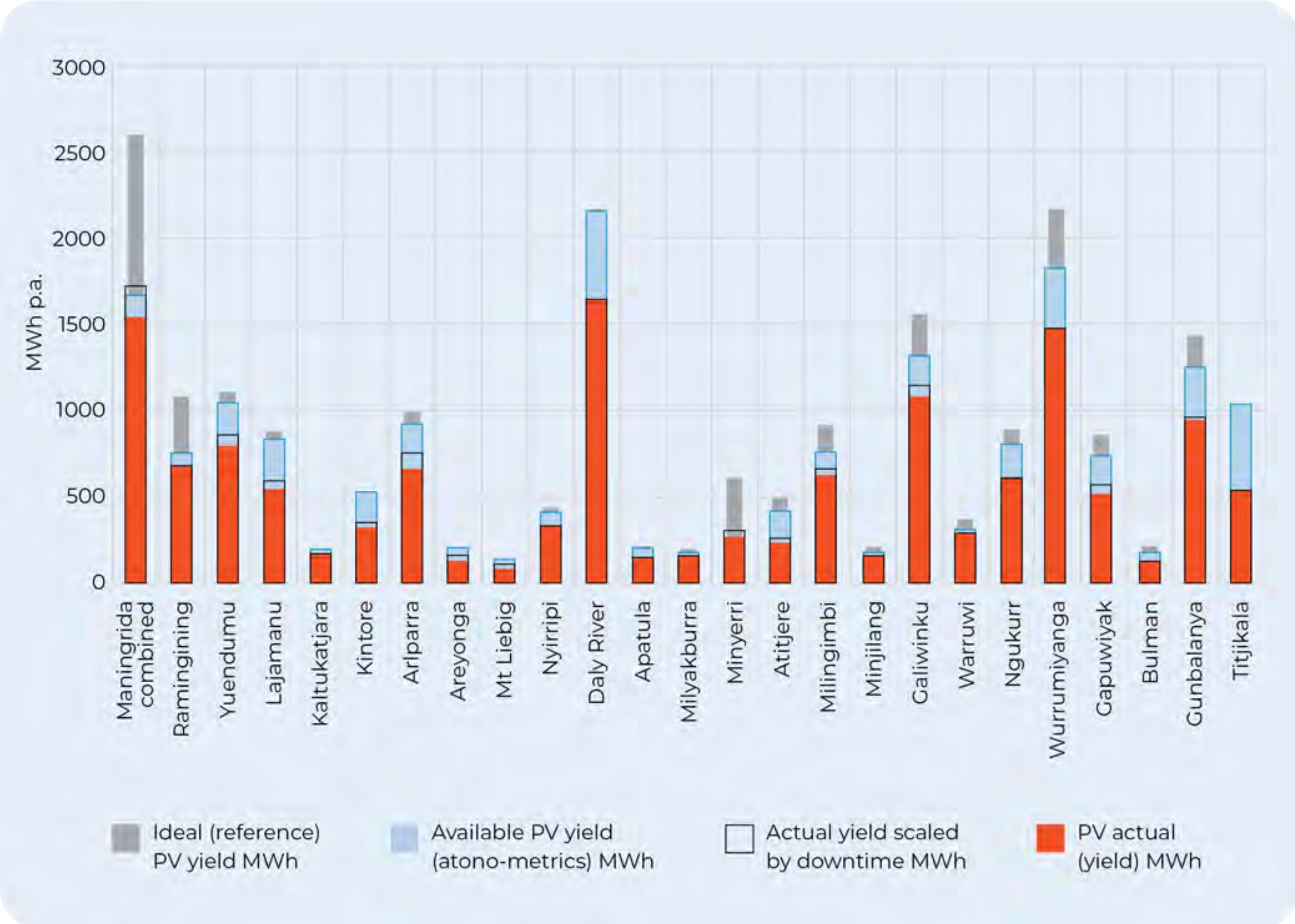
Figure 5 graphs the ideal or reference yield (Yr) calculated using Bureau of Meteorology weather station irradiance (ideal as it uses the panel conversion efficiency at standard test conditions without accounting for temperature de-rating). This is compared to the Atonometrics yield estimate, the actual 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.

Figure 8 – Installation of solar modules at Daly River

Figure 9 – Yield estimate comparisons for all communities 2021/22



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). An outage of a smaller generator can result in significant curtailment due to the higher minimum load requirements of the remaining sets.

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.

5.4 Daly River battery system performance

The Daly River hybrid system continued its strong performance, with the solar array generating 1,637 MWh for the year, a 23.7 per cent increase on the year prior. An increase in community load for the period meant that the solar contributed 46.9 per cent just below the target REF of 50 per cent.

The average daily stored energy was 1.31 MWh, with 477 MWh imported for the period. This represents a high daily use of the total storage capacity of two MWh. It also represents 30 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 87 per cent.

5.5 Titjikala battery system

The Titjikala hybrid system performance significantly improved achieving a REF of 52.9 per cent against the target REF of 50 per cent. For several months during spring and autumn a REF of over 70 per cent was recorded.

The average daily stored energy was 0.584 MWh, with 212.6 MWh imported for the period. This represents a high daily use of the total storage capacity. It also represents 50 per cent of the total PV yield for the year, meaning half of the PV array energy was time shifted by the BESS.

The BESS primary round trip efficiency for the reporting period was 90 per cent.

5.6 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.

5.7 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.

Figure 10 – Titjikala BESS at sunrise – 'Dawn of a new era'

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 2021 to June 2022.

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

The medium contribution sites achieved their 15 per cent annual REF target in aggregate, and Daly River achieved just under its 50 per cent target, a result attributable to a 3.6 per cent increase in community load.

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 addition of a BESS to complement the SETuP array at Titjikala proved successful, meeting and exceeding expectations for the full year of operation by increasing array output with load shifting, increasing the REF to over 50 per cent and achieving extended periods of diesel-off operation, including for 32 hours continuously on at least one occasion during March 2022.

The success of the Daly River project and more recently the Titjikala project, combined with the 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.

7 Glossary

Abbreviation	Definition and explanation
ARENA	Australian Renewable Energy Agency
BESS	Battery Energy Storage System
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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