Solar Energy Transformation Program Performance Report #1

for 1 July 2018 to 30 June 2019

OCTOBER 2020

PowerWater

Contents

Acknowledgement

This Project received funding from ARENA as part of ARENA's Regional Australia's Renewables Program. The views expressed herein are not necessarily the views of the Australian Government, and the Australian Government does not accept responsibility for any information or advice contained herein.

Document Reference: D2019/202463

1 Executive summary

As the largest isolated off-grid solar program in Aboriginal communities, the Solar Energy Transformation Program (SETuP) is a world-first.

Power and Water Corporation has been incorporating solar energy technology into our business for the past 20 years. Through the successful delivery of SETuP we have built on that experience and transformed the way we supply energy to remote communities with hybrid solar/diesel power generation becoming an integral focus.

SETuP saw the rollout of 10 megawatts (MW) of solar to benefit 25 communities serviced by our subsidiary, Indigenous Essential Services Pty Ltd. The $59 million program was co-funded by the Australian Government through ARENA and includes $27.5 million financed through the Northern Territory Government.

The arrays were completed over two years, with the first array commissioned in February 2017 and the final site completed in March 2019. This report analyses the performance of the SETuP assets for the period 1 July 2018 to 30 June 2019 with a primary focus on the medium contribution sites. The performance outcomes include achieving 14.6% renewable contribution in the first 10 completed communities, where the arrays operate alongside the existing diesel power stations with no additional supporting technologies required. This was just under the design target of 15%.

At Daly River, a 1 MW array was integrated with an 800 kW/2 MWh Battery Energy Storage System alongside the existing diesel power station, and exceeded its target with a 50.7% renewable contribution for the reporting period.

A number of influences on performance and opportunities for further improvement are described.

2 Introduction

2.1 Scope of this report

This report presents an analysis of the operational performance of the 10 (MW) of utility solar arrays installed across 25 remote Northern Territory (NT) communities under the Solar Energy Transformation Program (SETuP). The report covers performance for the period 1 July 2018 to 30 June 2019 ("Analysis Period").

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

The report presents some background information on SETuP, but for a detailed understanding the reader is directed to the additional information available on the program at www.powerwater.com.au, which includes five SETuP knowledge sharing reports. The reader is particularly directed to the *SETuP Case Study – Rollout of Tranche One Medium Contribution Sites*[1] that explores a number of aspects of the program in more detail, and to the *Solar Diesel Mini-Grid handbook (2nd edition)*[2] which includes description of the operational principles underpinning SETuP.

The analysis looks in detail of 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 modelling predictions, with exploration of the drivers and limiters of the achieved yield, and limitations of the available data. 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.

This report is focused on the performance of the SETuP arrays in "medium-contribution" operation (diesel engines always operating); for detailed analysis of the Daly River project that included battery storage and diesel-off operation, refer to our separate report *SETuP Knowledge Sharing - Daly River (Nauiyu) Lessons Learned and Performance Report - September 2019*[3].

During the Analysis Period July 2018 to June 2019, 15 arrays comprising 5.6 MW of the 10 MW SETuP total photovoltaic (PV) capacity were in the process of being constructed and commissioned, with obvious impacts on the analysis.

2.2 SETuP overview

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

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

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

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

The medium contribution arrays were rolled out in two packages or "tranches", with Tranche 1 construction completed in February 2017 and Tranche 2 completed in March 2019. Originally targeting 34 communities, a range of factors resulted in 24 existing power stations being hybridised, which serve 26 remote communities. For more information on the issues encountered during rollout, refer to the SETuP Knowledge Sharing resources at www.powerwater.com.au[4]. Community engagement is covered in a separate report[5].

---

[1] https://www.powerwater.com.au/__data/assets/pdf_file/0013/32305/SETuP-Case-Study-Rollout-of-Tranche-One-Medium-Contribution-Sites-FINAL-APPROVED.pdf
[2] https://www.powerwater.com.au/__data/assets/pdf_file/0014/32306/1090241-PWC-Solar_Diesel-Mini-Grid-Handbook-web.pdf
[3] https://www.powerwater.com.au/__data/assets/pdf_file/0018/32328/SETuP-Knowledge-Sharing-Daly-River-Nauiyu-Lessons-Learned-and-Performance-Report-September-2019-FINAL.pdf
[4] Eg https://www.powerwater.com.au/__data/assets/pdf_file/0009/32301/SETuP-Lessons-learnt-report-Rollout-Challenges-FINAL-APPROVED.pdf and https://www.powerwater.com.au/__data/assets/pdf_file/0010/32302/SETuP-Lessons-learnt-report-remoteness-challenges-FINAL-APPROVED.pdf
[5] https://www.powerwater.com.au/__data/assets/pdf_file/0011/32303/SETuP-Lessons-learnt-report-Remote-Community-Engagement_APPROVED-NEW-FORMAT.pdf

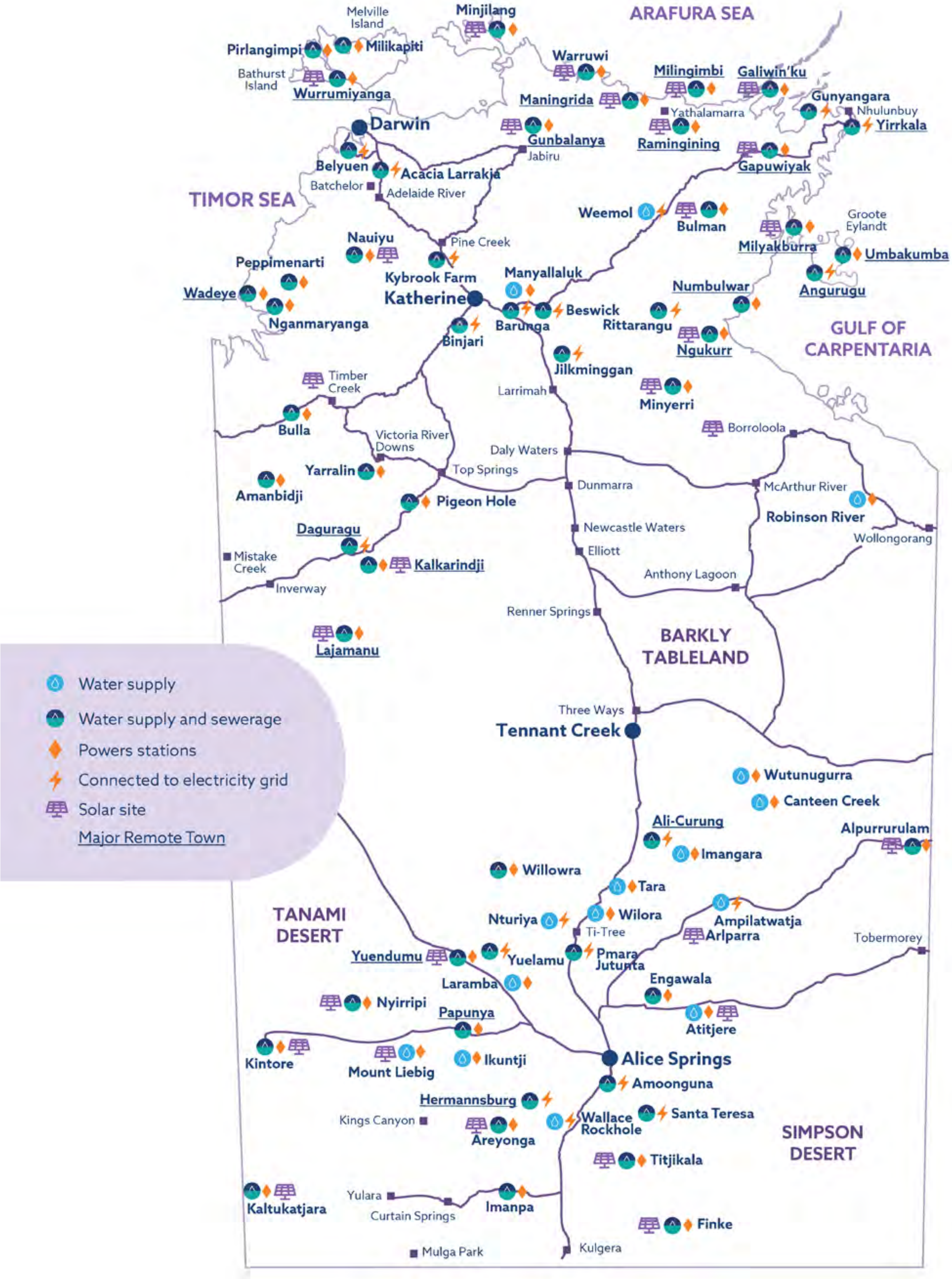

Figure 1: Remote communities served by Power and Water (IES communities in medium font bold)

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

The program rollout was dictated by obtaining suitable land for each identified community, and was delivered as two packages (Tranche 1 and Tranche 2), plus the Daly River Project as a stand-alone procurement. The first site was commissioned in February 2017 with Tranche 1 completed in July 2017. Daly River was fully commissioned in April 2018, while the Tranche 2 sites were commissioned from July 2018 with the final arrays commissioned in March 2019.

Further details on the SETuP program including case studies and lessons learnt documents are available from the Power and Water website at www.powerwater.com.au.

2.3 SETuP design principles

The approach taken to the SETuP medium contribution solar array design and deployment is provided in brief here, and is explored in detail in the Solar SETuP Case Study – Rollout of Tranche One Medium Contribution Sites[1] . For the Daly River high contribution project, refer to its respective report[3].

SETuP arrays were deployed to communities serviced under the IES program by a stand-alone diesel power station. Several of the power stations also serve nearby communities (Yuendumu to Yuelamu, Ngukurr to Rittarangu and Bulman to Weemol) as well as a total of 30 connected homelands.

The power stations typically consist of three or four diesel generators of varying power capacities, with sufficient capacity to cover the expected peak demand with the largest generator being out of service. At least four weeks of diesel fuel supply is stored on site. The power stations are operated by a local automated control system (PLC), with typically one generator placed on-line, selected to meet the current system load plus a margin of spinning reserve sufficient to meet short term load variations. In normal operation no additional capacity is kept online to cover a sudden loss of the current generator, with the remaining diesel engines usually being able to be brought online and at full load within two minutes from cold standby.

Figure 2: Areyonga Diesel Power Station and SETuP solar compound

The SETuP solar arrays are deployed as fixed tilt flat-plate PV arrays, contained in a dedicated restricted entry compound, sited adjacent to the power station or as close as practical (refer to the rollout challenges and other knowledge sharing reports for an exploration of issues relating to land acquisition). The program did not attempt to utilise existing rooftops within the communities.

The cluster controller has a dedicated high speed communications link to the local power station's PLC which issues a maximum allowable PV output set-point to the cluster controller. This setpoint is chosen dynamically to ensure the required minimum load is maintained on the diesel generator that is operating at any point in time.

Figure 3 provides a simplified view of the components of a typical IES power system after solar hybridisation.

The array detailed design and construction was issued as Engineer Procure Construct (EPC) contracts, with Power and Water retaining responsibility for site preparation, and for electrical and communications interconnection. The EPC approach allowed for some innovation on design and layout but specified the following items:

- Array build to industry standards and conventions, with focus on achieving a 25-year asset life (business case assumed industry standard PV module degradation and replacement of electronic components only within 25 year life)
- Fixed tilt flat plate PV modules from a pre-qualified Tier 1 list
- Ground-mounted array, with module orientation for maximum annual yield of fixed array: oriented within 2 degrees of north, and tilt to 15 degrees for northern communities and 20 degrees for southern locations
- 1:1 DC (solar module) to AC (inverter) power ratio (in line with industry convention and Clean Energy Council requirements prevailing in 2015 and 2016)
- Inverters standardised on the SMA STP25000TL 25kW three phase string inverter
- One SMA cluster controller coordinating the multiple inverters at each site
- maximum 2% loss in AC and DC cables combined up to the Point of Common Coupling (PCC)
- Solar resource measurement through an Atonometrics RDExxx device controlling one module in the plane of the array (and sited within the array tables, not free-standing)
- Lightning protection system, for sites in northern areas of NT only, to level PL IV (incorporating external protection system, earthing and bonding, magnetic shielding, and coordinated surge protection).

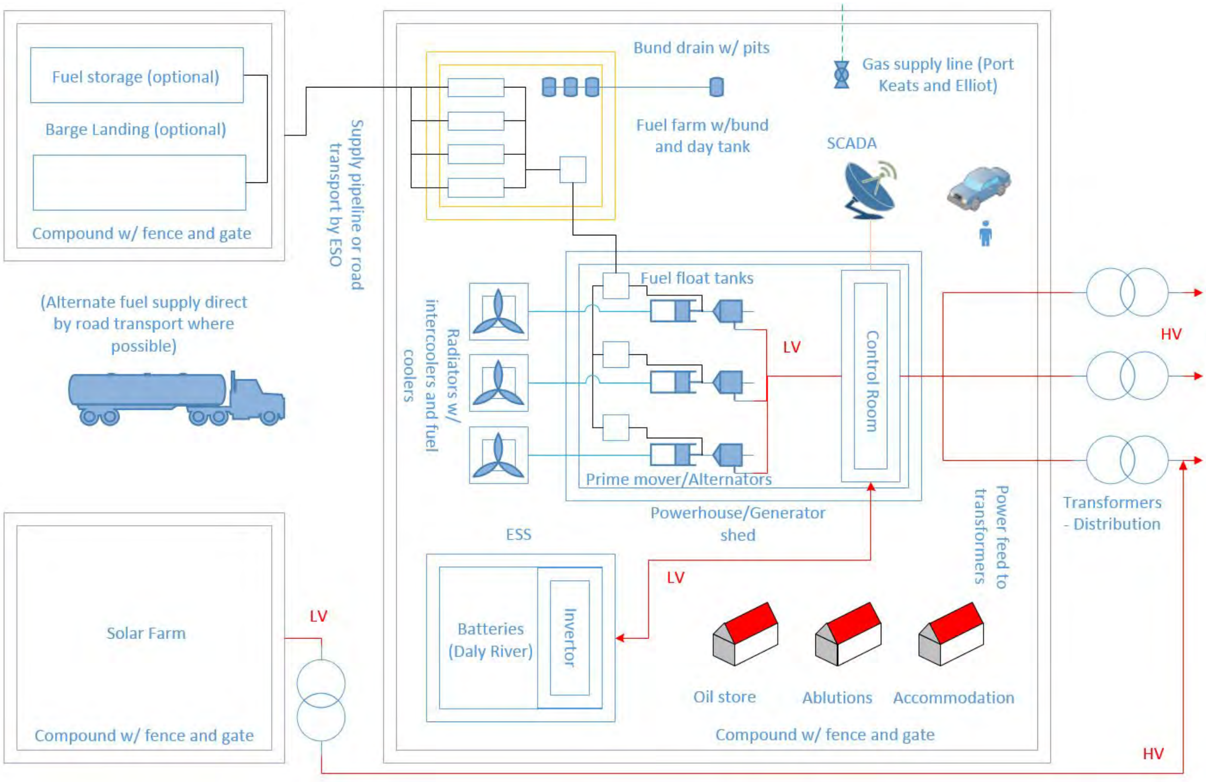

Figure 3: Typical components of Power and Water and IES remote generation systems

The solar arrays were designed and built to achieve a 25-year asset life, and to minimise maintenance needs given the high costs of mobilising to remote communities. Areas of focus including minimising corrosion (specification of aluminium and stainless steel, managing dissimilar metal junctions), minimum heights above ground level, UV protection of cables, managing heat (cabinet sun shields, selection of high temperature rated electronics).

The array size for each community was determined by techno-economic modelling of the solar hybrid power system operation using a combination of the ASIM and HOMER software modelling tools. This modelling took into account a number of technical factors including historical annual load data (2013-14), the expected PV array available energy, the existing diesel generators' minimum load set-points. Financial factors include the delivered cost of diesel, the expected diesel price growth rate, cost of capital, and PV array repair, maintenance and operational costs. It was assumed that operation would be such as to not increase or decrease any other diesel asset and operational costs other than diesel fuel savings.

The array sizes were selected to optimise the annual diesel savings, with a nominal 15% fuel saving target (REF) expected for the program as a whole and 50% targeted for Daly River. The actual REF per community was a function of the individual techno-economic outcome. Importantly, periodic significant curtailment of potential solar output was an expected and economically acceptable outcome.

The analysis work identified several relationships:

- In a diesel/PV hybrid power system (with no storage), the size of the diesel engines relative to the load is a fundamental constraint to the amount of load 'available' to be displaced by PV. Large engines (relative to load) or engines requiring a high minimum loading will effectively 'reserve' the load which reduces the potential opportunity for savings from PV generation. The program business case and funding was built on no additional investment in the diesel generation being required, thus no changes to engine sizes and no enhancements to reduce the minimum loading level.
- When the Levelised Costs of Energy (LCoE) of PV is lower than the cost of diesel fuel, it is economically beneficial to have a PV array large enough that it 'spills' (is curtailed) for some time. The degree of accepted (designed in) spill is a function of this LCoE difference.

In order to estimate the uncurtailed potential, each array includes an Atonometrics monitoring device that measures the maximum power point of one module within the plane of the array, experiencing similar soiling and environmental effects. This is explained in more detail in the Data Sources section below.

Further details on the operating philosophy are available from www.powerwater.com.au including in the Solar/Diesel Handbook 2019[2].

2.4 Performance context

The source of finance for SETUP were: capital grants from ARENA and loans from the Northern Territory Government to IES Pty Ltd via Power and Water Corporation. The capital program was approved by IES and Power and Water boards and by Northern Territory Government on the basis of a financial business case, which was itself based on the yield modelling described above.

The outcomes sought through the ARENA grant funding were non-financial measures encompassed in the programs' knowledge sharing and organisational transformation goals.

The SETuP assets form part of the overall generation mix for IES, and are operated in the context of the IES asset and service delivery portfolio. The potential diesel saving benefits from actions that increase solar contribution (primarily by reducing curtailment) need to be balanced against the risk of incurring additional costs for the diesel generation operations – particularly any increases to wear and tear on diesel engine assets.

In terms of the income from the SETuP assets, IES has an agreement with the Northern Territory Government funder that the volume of SETuP fuel savings will be calculated using the diesel generation recent historical fleet fuel efficiency value (litres per kWh) multiplied by the actual metered PV generated kWh. A dollar value of the savings is then calculated using the monthly delivered fuel price for each community. The focus of performance analysis of SETuP differs from the traditional focus for solar PV performance due to the inherent high levels of curtailment of SETuP solar array output. Understanding the drivers of curtailment and opportunities to cost-effectively reduce curtailment is therefore the performance analysis priority.

In focusing on achieving a system level REF target, the program did not set a formal target for the array performance ratio (such as the methodology in IEC61724), and did not have an explicit emissions reduction target.

The primary measures of performance for SETuP then are:

- kWh generated from SETuP arrays after curtailment converted to diesel volume savings using fleet fuel efficiency, and then to diesel price savings using monthly delivered diesel prices
- Annual REF achieved per community, and in aggregate for the medium contribution sites
- No increase in diesel generation operational and fixed costs
- No reduction in system reliability and no reduction in power quality
- Financial performance against the net present value described in the business case
- Delivery of knowledge sharing outputs
- Delivery of organisational transformation outcomes.

The remote locations of the SETuP arrays and the often extreme climate conditions are an important consideration for the program. Many of the arrays are in areas with high levels of dust from unsealed roads and desert conditions. Northern communities are in cyclone prone areas, requiring design to cyclonic wind loadings. Lightning storm exposure is another significant issue with the Top End experiencing some of the highest lightning exposure in Australia. Protection of sensitive electronic equipment is a priority for the SETuP assets, particularly single points of failure in the SCADA system (cluster controller, network switches, inverter SCADA linkages).

Remoteness is a significant challenge, with the arrays in some cases a 12-hour drive from the nearest major centre, or on islands necessitating the use of air travel (typically charted light aircraft given the limited regular services). The resultant high costs of mobilising skilled labour and equipment to the remote communities can significantly outweigh the relatively small short term losses from sub-optimal array performance. For example, at a hypothetical $1 per litre landed diesel price before excise and GST, the daily output of a 100 kW solar array will save around $150 per day compared to mobilisation costs of potentially $3000 to attend a remote community for unplanned maintenance. This reality results in delays in repair and rectification, creating potentially significant periods of data loss as well as partial or full array outage.

2.5 Correlation of load and solar availability

The electrical load profile of remote Northern Territory communities is highly seasonal, with households and commercial/government buildings being the predominant loads. The ratio of peak load, typically summer/wet season, to minimum loads, typically in winter, often exceeds 4:1. This means that the generation capacity required for peak summer load is underutilised in lower load times, resulting in lower capacity factors. This same is true for PV generation. An array designed to meet peak summer demand would be 'spilling' PV for the remainder of the year (assuming no energy storage). Conversely a small PV array suitable for minimum load times would be assured of 100% utilisation, however it would only result in small amounts of fuel savings[6].

This is visualised below in Figure 4 which shows the daily system load profile for Apatula (Finke) as half-hour average kW values over a 12-month period. The graph shows the high midday summer demand, and lower winter demand but with morning and evening peaks. Substantial variation day to day is evident, driven by a range of factors including the impact of weekends and daily weather variation. The high demand day in June coincides with the annual Finke desert race event.

[6] For further exploration of embracing curtailment of PV arrays, view https://www.eupvsec-proceedings.com/proceedings?paper=45795 "Visions From The Future: The Interaction Between Curtailment, Spinning Reserve Settings And Generator Limits On Australian Projects With Medium To High Renewable Energy Fractions"

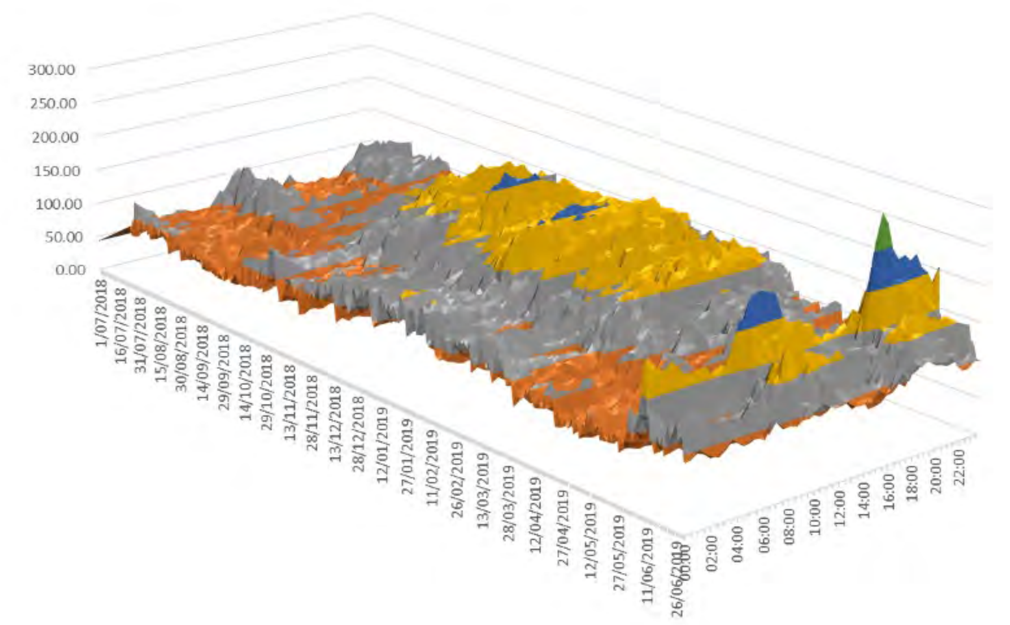

Figure 4: system load profiles for Apatula (Finke) 2018/19

In contrast, the daily availability of solar power from the Finke SETuP solar array (as estimated from the Atonometrics device) for the 2018-19 financial year is provided in Figure 5 below.

The data demonstrates the relatively predictable solar resource available from the array in a desert region, with the array oriented to north at a 20 degree tilt in order to achieve maximum annual yield[7]. Comparing this to Figure 4, it is clear that an array that is sized to be able to provide 50% or more of daytime peak demand in the summer months will be significantly curtailed during periods of lower demand, including weekends and winter daytime load.

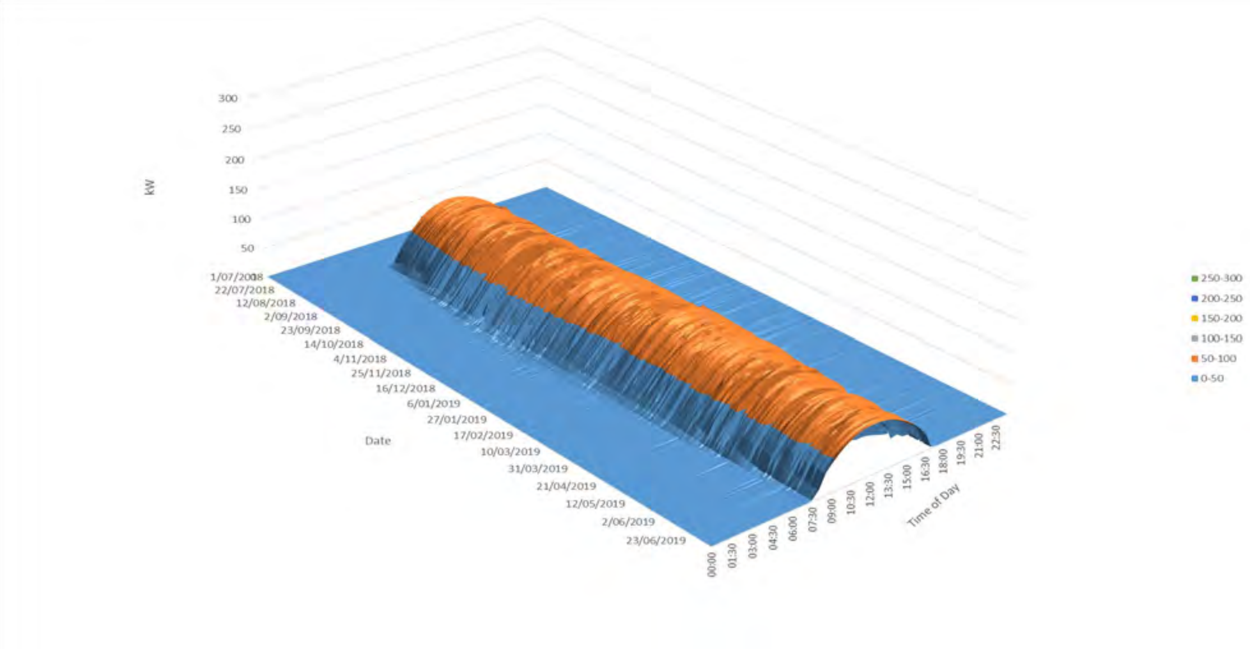

Figure 5: Half-hour averaged solar power (kW) available from Finke solar array over 12 months

[7] Note that interval data capture only commenced from late July 2018 onwards for Apatula. The slight ramping of available solar above zero during early hours is an artefact of the compression process used in the Pi system configuration during periods of no change in value.

3 Data sources

3.1 Diesel generation and feeder load data

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

Data from various meters is collated by the power station PLC and then logged on an 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, data for selected station electrical performance data trends (tags) is 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 SE 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.

3.3 Atonometrics solar monitoring

It was assumed in the SETuP design that cleaning of solar modules would not be carried out as a regular activity due to factors including:

- the relatively low anticipated losses in comparison to seasonal curtailment
- the siting in remote locations that are almost exclusively reliant on volume-limited bore water sources with a typical high mineral content
- the risks of damage from incorrect cleaning tools and methods and the difficulty in accessing skilled labour.

A measure of the available power including representative soiling was therefore considered the most valuable monitoring tool.

Every SETuP array therefore includes an Atonometrics[8] RDE363 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 RDE363 also includes a temperature sensor affixed to the rear of the reference module.

The Atonometrics device provides a measurement of the maximum power point of the module once per minute "Pmax". It also provides an in-plane irradiance reading once per minute, calculated from the temperature-corrected

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

short- circuit current (Isc) of the in-plane module, using its stored calibration constants. The stored constants are derived from calibration at the time of array commissioning using a field calibration kit with an OEM pre-calibrated reference cell.

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

It is the Pmax available module power value that is the primary focus 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.

Limitations in the data capture and data tools, including loss of data from instrument failures and other issues, meant that detailed analysis of the Atonometrics measurements was not possible for many sites for 2018/19.

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 6) 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 commissioned during the analysis period. Due to lightning storm damage at the Daly River array[9], data from this device was also lost for a large proportion of the reporting period, which has limited the ability both to measure available power and to analyse losses due to soiling.

Figure 6: Dual-input Atonometrics installation at Daly River[10]

3.4 SETuP original modelling outputs

As explored in the report introduction, 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

[9] Refer to the Daly River knowledge sharing report for details of the ongoing issues with lightning protection.
[10] At the time of photos being taken, the PV module had been cleaned for its initial calibration; the self-washing PV reference cell is mounted in the plane of the array in the foreground

- fixed tilt optimally aligned solar arrays with minimal shading, 100% availability (i.e. no downtime)
- 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% 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.

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

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

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.

However full commissioning of these stations into the Pi Historian was not completed in 2018/19, therefore weather station data does not form part of the analysis for the Analysis period. Weather data collection into Pi Historian commenced in late 2019 with final calibration and commissioning continuing into 2020.

3.6 Financial performance data

As detailed in section 2.4, the primary financial metric of SETuP is the value of the avoided diesel fuel burn. The dollar value of SETuP generation then is tied to the prevailing delivered diesel price for each community. However, any losses from low diesel prices will be more than offset by savings for the overall IES program. The economic focus then for the IES program is to manage and minimise the operating expenditure while maintaining array performance and achieving asset longevity.

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[11].

Outgoing costs for the SETuP arrays include items such as: loan interest costs, land lease costs, inspection and grounds maintenance costs through the IES ESO contracts.

Impact on diesel generation costs other than fuel were targeted to be negligible in the program design. In any case, measurement of a net impact of the SETuP hybrid operation is very difficult in practice, given the range of influences on maintenance costs of diesel operation across 25 locations with a range of engine providers, models and ages.

Any diesel savings in excess of the OPEX costs are allocated to repay loan principle, with remaining net benefit then made available for re-investment into the IES program.

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 EPC contract for each tranche of SETuP array deployments, the contractor was required to provide an estimate of the uncurtailed output of each array using the industry standard PVSYST modelling tool. The contractors were provided with climatic data obtained from the Bureau of Meteorology from the nearest relevant weather station, and provided a P50 monthly output estimate per array, incorporating the details of their design. Given issues

[11] The publicly available Darwin terminal gate prices for diesel fuel, less GST and diesel excise, are however a useful comparator for the NT.

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 percentage set point of each diesel generator (and thus also the maximum power parameter for the generator). Continuous logging of these parameters into the Pi Historian was implemented late in 2019. Manual records of parameter changes prior to that implementation are limited but can be inferred from engine performance analysis.

In terms of array component outages, a formal process for tracking the incidence of and reasons for unavailability of array components had not been implemented for the 2018-19 financial year. This need has been incorporated into a more comprehensive review of generation data collection that is currently underway.

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

4 Performance data 2018-19

4.1 SETuP array performance data

Table 2 below presents a compilation of a range of parameter and performance values for the Tranche 1 community arrays for the financial year 2018-19, presented in order of commissioning.

Table 3 provides the same data for Tranche 2 sites, but only for the period of the year that each Tranche 2 array was commissioned. The 15 Tranche 2 arrays represent 56% of total SETuP AC capacity, and the progressive rollout of those sites during the analysis period resulted in 51% of the Tranche 2 capacity being available during the analysis period (on a kW available per day basis). To compensate for that effect, the expected performance figures in Table 3 are scaled to only reflect the period of availability of each array.

The details of the performance data values are explained in Table 1.

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 315W modules. Daly River and Tranche 2 were constructed with 320w rated modules.
Atonometrics	Whether the Atonometrics irradiance and module power metering device was a single input version (1) with just one array module attached to it, or a dual input version (2), with both an array module and an OEM pre-calibrated self-cleaning in-plane-of-array reference cell attached.
Weather Station	Whether a weather station was installed at this community (1 if so).
PVSYST Egrid modelled MWh	The annual array available energy (before curtailment) expected for typical weather conditions ("P50") using the PVSYST modelling tool. This data was provided by the EPC contractor as part of the design of each array and has been scaled to the period for which Tranche 2 arrays were commissioned, using a straight-forward proportional "pro-rata" ratio of the annual total (i.e. not compensating for seasonal effects). The full year PVSYST estimate for Tranche 2 in aggregate is 11806 MWh.
Power and Water modelled PV output	The Power and Water modelled output is the expected annual solar output as derived from SETuP's original ASIM and HOMER modelling (after curtailment), where completed.

Column name	Description
	This figure has also been scaled down by the number of days that each Tranche 2 array was commissioned for the analysis period July 2018 to June 2019 inclusive. It should be noted that the modelling made no allowance for array outages, and had to evolve with the program's rollout which saw arrays redistributed from several communities at a late stage in the program, and full remodelling was not completed in all cases. These are highlighted in Table 3. It can be seen in comparing this value to the PVSYT model output that the SETuP arrays were designed with an expectation of a substantial amount of curtailment, around 30% for this ated analysis period. The drivers and economics of this design outcome are described in detail in the Introduction.
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.
PV days online	The number of days the array was commissioned between July 2018 and June 2019 – used to scale pro-rata value for Tranche 2 data
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. The value is only calculated pro-rata for Tranche 2 sites, for the period each array was commissioned. Additional data per community is available in Appendix 1 - PV array availability.
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 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)[12]	The proportion of the total energy delivered to the grid that was provided by the SETuP solar array. This column is highlighted in recognition of this being the nominal performance metric for the rollout.
PV actual as % of Power and Water model PV output	The actual yield as a percentage of the target/modelled yield.
PV actual as % PVSYST model PV	The actual PV yield as a percentage of the PVSYST modelled P50 value. This provides an estimate of the likely yield if each array were able to operate unconstrained.
Atonometrics available PV yield	Where data quality allowed for summarisation, the annual potential PV yield is estimated using the Atonometrics measured peak power capacity of one module scaled up to the array size.
Yield as % of potential	The actual PV yield as a percentage of the measured available array energy, where available.

[12] 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 2018/19

Community	kW (AC)	kW (DC)	Atonometrics	Weather station	PVSYST Egrid modelled MWh	PWC modelled PV output	Date PV array online	PV days online	Unavailability	Diesel generat-ion actual MWh	PV actual (yield) MWh	PV actual % of total delivered (REF)	PV actual as % of PWC model PV output	PV actual as % PVSYST model PV
Maningrida #1	800	806	1	1	1447.0	960	3/02/2017	365	12.3%	7,544	1016.7	11.6%	106%	70%
Ramingining	500	504	1		885.6	687	17/02/2017	365	0.0%	2,787	583.0	17.3%	85%	66%
Yuendumu	500	504	1		1004.2	725[13]	30/03/2017	365	0.0%	5,232	605.8	10.4%	84%	60%
Lajamanu	400	403	1	1	791.4	580[13]	21/04/2017	365	1.6%	2,882	712.7	19.8%	123%	90%
Docker River	100	101	1		197.4	150	4/05/2017	365	1.4%	1,466	147.9	9.2%	99%	75%
Kintore	225	227	1	1	391.9	296	18/05/2017	365	1.1%	1,550	338.5	17.9%	115%	86%
Arlparra	450	454	1	1	927.5	596	1/06/2017	365	6.4%	3,170	580.3	15.5%	97%	63%
Areyonga	100	101	1		202.0	127	23/06/2017	365	1.1%	933	141.0	13.1%	111%	70%
Mt Liebig	50	50	1		100.7	93	26/07/2017	365	0.8%	794	101.1	11.3%	108%	100%
Nyirripi	200	202	1		443.5	305	26/07/2017	365	9.0%	844	239.8	22.1%	79%	54%
Tranche 1 subtotal	**3325**	**3352**	**-**	**4**	**6391.1**	**4,519**	**-**	**365**	4.7%	**27,203**	**4,466.6**	**14.6%**	**99%**	**70%**
Daly River (PV only)	1000	1024	2	1	1820.1	1,676	17/10/2017	365	7.0%	1,545	1,587.8	50.7%	95%	87%

Table 3: Pro-rata array performance data for Tranche 2 communities and for program total for 2018/19

Community	kW (AC)	kW (DC)	Atonometrics	Weather station	PVSYST Egrid modelled MWh	PWC modelled PV output	Date PV array online	PV days online	Unavailability	Diesel generat-ion actual MWh	PV actual (yield) MWh	PV actual % of total delivered (REF)	PV actual as % of PWC model PV output	PV actual as % PVSYST model PV
Apatula (Finke)	100	102	1		184.4	133	29/07/2018	336	0.0%	760	133.3	14.9%	100%	72%
Milyakburra	100	102	1		169.9	135	10/08/2018	324	0.3%	544	92.0	14.5%	68%	54%
Minyerri	275	282	1		394.9	229	26/09/2018	277	30.3%	1,768	170.1	8.8%	74%	43%
Atitjere (Harts Range)	225	230	1		321.6	214[13]	12/10/2018	261	0.0%	677	148.2	18.0%	69%	46%
Titjikala (Maryvale)	400	410	1	1	557.6	178	17/10/2018	256	19.1%	668	85.0	11.3%	48%	15%
Milingimbi	425	435	1		516.3	258	25/10/2018	248	10.1%	2,333	399.1	14.6%	154%	77%
Minjilang (Croker Island)	100	102	1		116.1	91	2/11/2018	240	10.0%	835	97.3	10.4%	107%	84%
Galiwinku (Elcho Island)	750	768	1	1	832.9	667	9/11/2018	233	29.3%	3,935	521.3	11.7%	78%	63%
Warruwi (Goulburn Island)	175	179	1		142.7	131	18/01/2019	163	3.7%	727	116.5	13.8%	89%	82%
Ngukurr	400	410	1	1	325.4	241	23/01/2019	158	5.1%	1,775	266.2	13.0%	111%	82%
Wurrumiyanga (Bathurst Island)	1075	1101	1	1	762.9	321[13]	6/02/2019	144	46.2%	2,547	253.8	9.1%	79%	33%
Lake Evella	425	435	1		279.0	226	14/02/2019	136	8.8%	936	189.6	16.8%	84%	68%
Bulman	100	102	2		69.6	59[13]	18/02/2019	132	0.0%	366	56.9	13.5%	97%	82%
Gunbalanya (Oenpelli)	675	691	1	1	412.1	308[13]	7/03/2019	115	66.9%	1,711	61.7	3.5%	20%	15%
Maningrida #2	375	384	-		199.3	148	15/3/2019	107	0.0%	1,975	176.8	7.1%[14]	119%	87%
Tranche 2 subtotal	**5600**	**5733**	**-**	**5**	**5,285**	**3,339**	**-**	**-**	23.0%	**21,555**[15]	**2,767.8**	11.4%	83%	52%
SETUP Total (pro-rata)	**9925**	**10109**	**-**	**10**	**13,500**	**9,533**	**-**	**-**	12.3%	**48329**	**8822.2**	**15.4%**	**93%**	**65%**
Maningrida combined										*7,544*	*1,193.5*	*13.7%*	*108%*	*72%*

[13] 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

[14] Maningrida #1 contributed 326 MWh during the commissioned period of #2

[15] the diesel power station production for #2 is not included in the totals to avoid double counting

5 Findings and discussion

5.1 Overall performance

Key measures of the SETuP assets' overall performance for the 2018/19 financial year are summarised in Table 4: Overall SETuP performance 2018/19 (pro-rata for Tranche 2). The diesel saving figures are calculated using the historical average fuel efficiency of the remote diesel fleet. The REF that could potentially have been achieved with 100% array uptime (no unavailability) is also estimated by scaling up the actual yield proportional to the unavailability data.

Table 4: Overall SETuP performance 2018/19 (pro-rata for Tranche 2)

Metric	Tranche 1	Tranche 2	Daly River
% of year commissioned*	100%	51%	100%
Nominal annual contribution target	15.0%	15.0%	50%
Actual yield % contribution (*Renewable Energy Fraction - REF*)	14.6%	11.7%*	50.7%
Actual yield as % of HOMER/ASIM modelled yield	99%	83%*	95%
Actual yield as % of PVSYST estimate	69.9%	52.4%*	87%
% of time array/inverters unavailable	4.7%	23%*	7%
Diesel savings (Litres)	1,223,856	709,926	435,052
Greenhouse gas savings (tonnes $CO2_e$)	3,317	1,924	1,179
Potential REF with 100% uptime	15.2%	14.8%	52.5%

* Tranche 2 performance figures are a simple (not seasonally adjusted) pro-rata figure for the proportion of the period after commissioning was completed

The 2018/19 financial year saw the Tranche 1 and 2 sites achieve close to but under their nominal 15% target. Many sites also saw yield somewhat below the predictions from the original modellings.

Figure 7 below presents a visualisation of the key performance metrics for Tranche 1 and Daly River, being the sites with a full year of data. The wide spread in REF values can be readily seen.

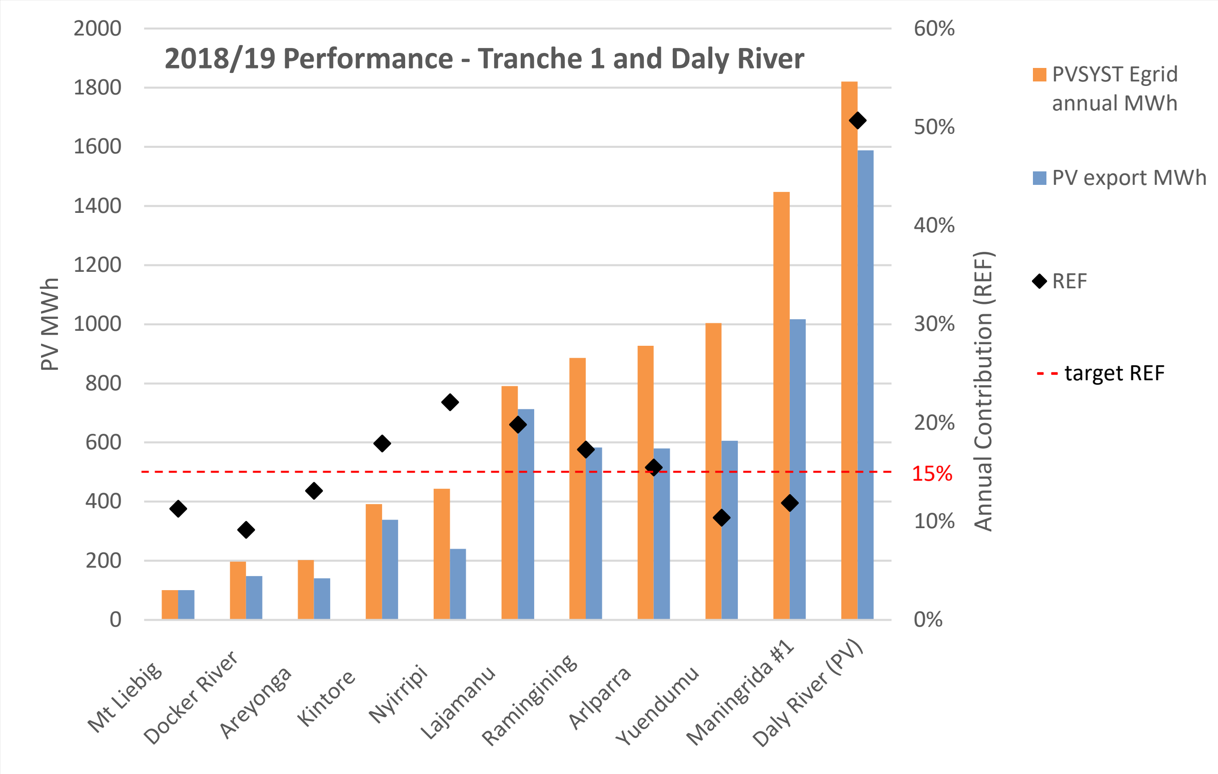

Figure 7: Actual yield, PVSYST potential and REF 2018/19

The likely causes for falling short of the target are explored below.

5.2 Array downtime

A significant factor impeding SETuP array performance for the period in question was unavailability of the arrays due to hardware and other issues. The detailed causes of downtime per community are provided in Appendix 1 - PV array availability. In summary, the primary causes of array unavailability were:

- Curtailment during investigation and rectification of an issue with the toroid arrangement used for the earth leakage detection system in the EPC switchboards deployed for the larger Tranche 2 sites. This required curtailment to 500 kW maximum output to avoid erroneous trips. All sites were subsequently rectified.
- Suspected lightning surge damage at multiple locations resulted in failure of the cluster controller, inverter communications cards, network switches and/or the “fail-open” in-line communications surge arrestors
- An issue with one firmware version of the cluster controller resulted in intermittent lockups requiring a system restart. An upgrade to the latest firmware version rectified the issue
- Maintenance and upgrade works at the power station or on the distribution feeder connecting the solar array preventing the solar array from feeding in.

It is important to note that the original modelling did not allow for any periods of planned or unplanned array outage. A simple scaling of the PV yield for a hypothetical 100% array availability results in the potential REF figures in Table 4, which are in line with the fleet overall target.

The significant downtime experienced for Daly River and Tranche 2 is not representative of likely future performance given the impact of commissioning and post-commissioning issues rectification during the period as described earlier.

The Tranche 1 result is more indicative of future performance for Tranche 2, at 4.7% downtime. Nevertheless, the per-community issues point at several opportunities for improving availability overall.

A primary area of focus is improving 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.

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

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

5.3 Array redistribution

Several changes were made to the array allocation per community during Tranche 2.

The first of these was the redistribution of the array originally intended for Numbulwar, after the proposed location was identified as prone to future inundation with rising sea levels. With insufficient time to obtain a new lease, an additional 200kW was assigned to Titjikala to make this community "battery ready", and an additional 25 kW was assigned to Milingimbi. While the Milingimbi augmentation was incremental, the Titjikala increase was anticipated to result in the high levels of curtailment that were measured at 85% of PVSYST annual estimate. The intent was for this additional diesel savings opportunity to support a separate business case for investment in a Daly River style BESS and that project is approved and in progress.

The second redistribution was the consolidation of the arrays intended for Pirlangimpi and Milikapiti to a single larger array at Wurrumiyanga, in anticipation of a proposed grid interconnection project that would bring all three communities together. At present the array is only serving Wurrumiyanga, resulting in high spill (66% of PVSYST estimate).

The third was the reallocation of the array intended for Umbakumba after asbestos contamination was discovered during site preparation at a crucial juncture in contracted project delivery. The full array capacity was relocated to Maningrida after modelling identified it as the location most able to absorb the additional generation in conjunction with a trial of low load settings on a primary diesel generator. Early results were positive with this relocated array achieving 87% of the pro-rata PVSYST estimate.

5.4 System load and diesel generator characteristics

In the absence of storage technology, the output of each medium contribution SETuP array is constrained (curtailed) to fit the window at any point in time between the instantaneous power system load and the minimum loading set point of the diesel generator that is online[16].

Curtailment or 'spill' will likely always exist in PV-diesel power systems where the load profile is seasonal, unless the PV array is very small. In the Northern Territory peak loads typically occur summer. As explored in the introduction, the optimal PV array size is an economic decision that trades off PV "levelised cost of energy" against diesel costs. When PV energy cost is lower than diesel generation, some amount of spill in the cooler load months is economical as PV supplies the higher summer load. The higher the diesel price the greater the amount of seasonal spill is economical.

In isolated power systems it is possible to optimise PV curtailment but it is difficult to completely avoid without the use of battery energy storage system or by under sizing the PV array. This is different to large grid connected systems which have until recently been largely able to operate unconstrained due to their lower contribution levels.

The SETuP arrays were largely sized based on modelling from 2013 and 2014 data. Community loads have varied in the intervening years. For example, Mt Liebig's system load grew by 46% from 2013/14 to 2018/19, which can explain the array achieving a very low spill and exceeding the modelled yield, but also achieving a low REF.

A constraining factor for SETuP array performance is non-optimal generator sizes, where the installed capacities are not well matched to the seasonal loads. This can be due to anticipated growth in load from housing programs not eventuating, and in some instances from shrinking loads due to changes in residency and/or improvements in energy efficiency. Replacement of diesel generators ahead of their end of life can be a large cost in comparison to the marginal improvements able to be achieved from reduced SETuP spill, and it is typically optimal to wait until engines are due to be replaced.

Another opportunity for improvement of solar yield is to review and optimise the minimum load settings on each generator in order to increase the amount of load that can be met from solar. Discussions with the manufacturers on this topic are ongoing. A number of initiatives were progressed during 2018/19 to reduce the minimum load settings of diesel generators at SETuP communities, both through planning for deployment of new engines with manufacturer lower load ratings, and working with manufacturers on reviewing settings for existing engines. This included deployment of a low load set to the community of Nyirripi, and a trial of low load settings at Lajamanu, both of which saw REFs well above 15%.

---

[16] For further exploration of the operating principles, refer to the "Solar Diesel Mini-Grid Handbook (2nd edition)", www.powerwater.com.au/SETuP

Another example is the trial of a 10% minimum load setting on generator #4 at Maningrida. Figure 8 below provides a visualisation of the material impact of differing minimum load settings at Maningrida. The graph shows the variation in community load in kW over the majority of one day, with the kW load being met by diesel generators also graphed. The solar array is not shown, but can be inferred as it is meeting the “window” between the diesel loading and the system load.

The impact of clouding events can be clearly seen with large spikes in diesel engine loading. The clouding events actually take place over a period of minutes, well within the engine’s capability to ramp up output. A larger consideration is ensuring that the engine and charge-air temperatures are maintained during the low load periods, while the cooling system is still able to ramp up in step with the engine output. Variable speed fan drives and other modifications are required to meet this need.

A benefit of the fluctuations caused by clouds is that the occasional high loading on the engine assists with meeting recommended periods of high loading each day; this is typically achieved through the evening peak in any case, and can be programmed into engine dispatch to ensure engine health.

The details of the impact of the minimum load set points per engine per site will form the basis of future SETuP data analysis.

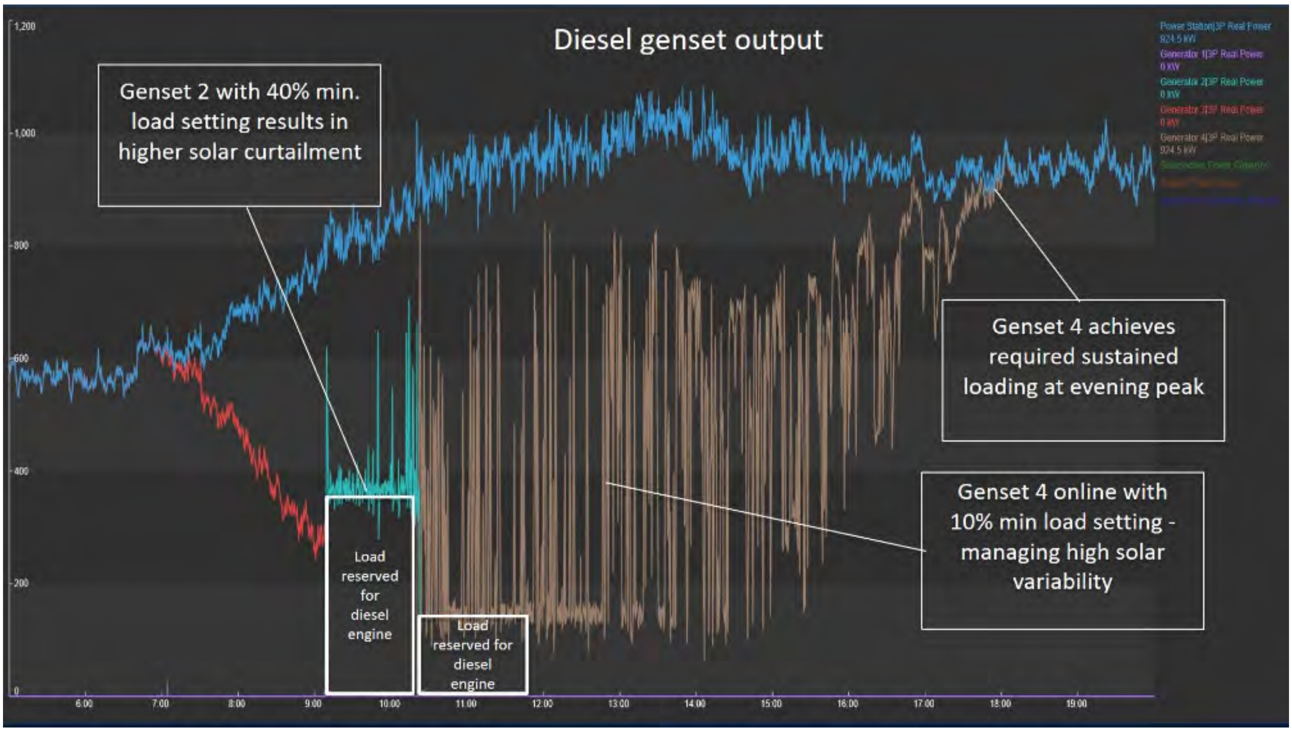

Figure 8: benefits of diesel low load settings at Maningrida

5.5 Human factors

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

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

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

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

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

5.6 Control system performance

SETuP saw the deployment of upgrades to 25 existing control systems of two pre-existing types:

- the legacy Powercorp SACS controller, communicating with a HMI computer and a separate Pi gateway device.
- the new standard deployment of Power and Water's custom UNITY code running on a Schneider PLC communicating with a Windows HMI touchscreen industrial PC running CITECT SCADA.

The SETuP approach to control system enhancement for the program was to retain the in-house control system, and to make the minimum required changes to the existing control systems, both in terms of the PLC code base, and to the look and feel of the HMI. This served the dual purpose of minimising retraining and in ensuring buy in from staff during the transition.

The solar-diesel hybrid control philosophy was the same for each code base. Incremental improvements and bug fixes were made during deployment as lessons were learnt at subsequent commissioning, primarily to the Unity system.

The fundamental operating principles of medium contribution performance remain unchanged, as described in the solar diesel mini-grid handbook. The primary approach of running the most appropriately sized engine to match the prevailing load plus a site-specific spinning reserve margin (and not providing spinning reserve to cover the sudden loss of a generator) remains. The philosophy of providing 100% spinning reserve coverage of PV output also remains in place, however this is in lieu of the no-PV spinning reserve allowance.

At the end of the reporting period, the process of retrofitting the latest code version to earlier sites was ongoing, with the result that some performance data capture issues remained to be resolved at all sites. Similarly, managing issues with data capture at the legacy control sites was on hold waiting for scheduling of upgrade of the controls for those power stations.

5.7 Daly River battery system performance

A separate analysis of the performance of the Daly River high contribution system has been published in the *SETuP Knowledge Sharing - Daly River (Nauiyu) Lessons Learned and Performance Report* available from www.powerwater.com.au.

Statistics from that report for the 2018/19 financial year included the following:

- Diesel savings achieved: 435,052 L
- Renewable Energy Fraction achieved (REF): 50.7%
- Actual yield as % of HOMER/ASIM modelled yield: 95%
- Actual yield as % of PVSYST estimate: 87%
- BESS Round trip Efficiency: 88%
- BESS system efficiency including the local light and power (primarily HVAC): 85%
- BESS average HVAC (cooling) load: 4.8kW.

The system achieved above its target REF, with no BESS faults and system reliability maintained. Solar array yield was slightly below the business case modelled yield, which can be attributed primarily to the 7% array downtime required to rectify defects and lightning surge damage to the inverters via their communications ports – a factor that was not allowed for in the project modelling.

A BESS full-cycle capacity test was conducted in June 2018, which demonstrated a minimal loss of battery storage capacity below its nominal 1.98MWh.

Refer to the Daly River report for more discussion, including consideration of capital costs.

5.8 Cloud forecasting trial

SETuP included a trial of cloud forecasting or Cloud Prediction Technology (CPT). It was anticipated that cloud forecasting if proven effective could enable more flexible scheduling of diesel generators. If clear skies are forecast, then spinning reserve sufficient to cover a large sudden drop in PV output would not be required. This would allow a smaller generator with a smaller minimum load requirement to be called up, which in turn would allow for a higher PV contribution than the business as usual case.[17]

If the forecast was inaccurate, the online generator may not be able to manage the sudden increase in load from a clouding event and load shedding or a blackout could result. Due to this risk, and the immaturity of the cloud forecasting market at the time, SETuP started with a trial of multiple vendors' equipment running alongside a diesel power station without integrating into the control system initially.

A range of technical issues, time pressures and project delivery priorities meant that the trial was not successful in capturing useful data until mid to late 2019. Engineering firm Ekistica was commissioned to develop an analysis methodology and analyse the trial data, the results of which are available in a separate report *Final Evaluation Report for SETuP Skycamera Trial* available from www.powerwater.com.au.

The key findings of that report were that the forecasting was a trade-off between effectiveness (reliable cloud prediction) and efficiency (minimising false positive cloud prediction). One vendor provided a highly sensitive prediction that achieved effectively 100% clouding event prediction at an efficiency of around 30%.

Further economic analysis and trials in other climatic conditions (particularly desert communities with large numbers of clear sky days) are required to determine whether the technology will be a useful addition to the IES generation control system. The implementation of BESS technology displacing diesel generation as the primary daytime generation source reduces the originally envisaged need for forecasting for isolated grids, however there may still be situations where an effectively priced and reliable CPT would be a useful addition to isolated grids.

[17] This is explored in more detail in the *Power and Water Solar/Diesel Minigrid Handbook* available at www.powerwater.com.au

6 Conclusion

The Solar Energy Transformation Program 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 2018 to June 2019, during which over half of the PV capacity was in the process of being built and commissioned.

The energy contributed to the 25 isolated grids is found to have largely met the program's expectations, balancing the maximisation of PV contribution with avoiding increases in diesel generation repair and maintenance costs, and recognising the ongoing commissioning during the period. Financial performance for the period was satisfactory, with the diesel savings covering operational and finance costs.

The Tranche 1 sites that were operational for the full twelve months achieved 14.6% REF against a nominal target of 15%, and Daly River achieved 50.7% against 50%. The Tranche 2 sites achieved 11.7% of 15% for the period the arrays were online.

A shortfall below the nominal 15% target for the medium contribution sites is explained by a number of factors.

The shortfall is in part attributable to the original modelling and sizing not having allowed for periods of array downtime. The array unavailability for Tranche 1 sites was 4.7%, while for the Daly River array it was 7% and for the Tranche 2 sites it was 23% post-commissioning.

A range of causes of that downtime have been explored. Some of the causes were post-commissioning and fleet teething issues that have since been rectified. Others are economically unavoidable, such as outages required by broader power system maintenance and upgrade works, and the need to fully load newly commissioned diesel engines.

There are however opportunities for improvement that Power and Water has been pursuing around improving surge protection and rapid replacement of sensitive electronic equipment (network switches, cluster controller, Atonometrics irradiance system, and surge arrestors) that should result in improvements to medium-term availability above the 95% figure seen for the established Tranche 1 sites. Investigation of improved communications systems to alert coordinators to potential issues in short order is ongoing.

Another factor for the more recent installations was that a number of redistributions of array capacity occurred during the Tranche 2 rollout in response to site issues (where the program time frames did not allow for obtaining a replacement lease at an alternative location), and in response to anticipated grid connections[18]. This included oversizing of arrays at several sites, resulting in additional curtailment in the short term.

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

An exploration of the seasonal effects of curtailment alongside engine capacities and minimum load parameters was not incorporated in this report due to a lack of quality data for the period and the need to develop new corporate tools to facilitate the analysis more broadly. A number of data systems have been improved during 2019/20, including centralised logging of key diesel engine parameters and per-inverter performance data, and commissioning of weather stations at selected sites. These will support a more detailed analysis in future performance reports.

[18] Refer to published SETuP knowledge sharing documents including SETuP-Lessons-learnt-report-Rollout-Challenges-FINAL-APPROVED.pdf

The impact of actions taken by the operators and coordinators for each power systems is another important factor in SETuP PV performance. With ongoing training, experience and familiarity, and consideration of PV outcomes alongside other tasks, additional improvements in PV yield should be seen in future.

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. Some sites have achieved annual REFs well above 15%, and analysis of 2019/20 data is likely to show even higher levels being achieved as a result of significant changes to the diesel assets and operations.

It is acknowledged that the SETuP arrays were largely designed in the context of 2014/15 and earlier, both in terms of system loads and diesel fleet, but also PV technology pricing and design approaches. With ongoing falls in prices and experienced gained, a number of different design choices could be made for future projects.

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

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

7 Glossary

ARENA	Australian Renewable Energy Agency
BESS	Battery energy storage system
ESO	Essential Services Officer
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
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 modelling software package -https://www.pvsyst.com/
REF	Renewable Energy Fraction, the proportion of energy delivered over a specified period that was sourced from a renewable source (being solar power for the SETuP program)
SETuP Solar SETuP	Solar Energy Transformation Program

Appendix 1 - PV array availability

Table 5 below presents the array unavailability per community, calculated on a per-inverter basis as described in Data Sources above. As per Table 3, the value is only calculated pro-rata for the period each array was online. The table includes a brief discussion on the causes of outages at each community.

Table 5: Array unavailability per community

Community	Array non-availability	Discussion
Maningrida #1	8.4%	The array output was reduced in order to avoid an earth leakage trip within the main AC circuit breaker. The cause was identified as a parallel earth neutral connection in the cables installed in the ground. The array was isolated for safety and integration reasons during construction of the Tranche 2 array.
Ramingining	0.0%	-
Yuendumu	0.0%	-
Lajamanu	1.6%	Network switch failure in the PCC cabinet
Docker River	1.4%	The smallest generator was taken out of commission for an extended period; this resulted in the system load being at or below the minimum load requirement of the remaining generators, with full curtailment of the SETuP array
Kintore	1.1%	The array was disabled for the duration of replacement of the power station switchboard and control system.
Arlparra	6.4%	Cluster controller firmware issues resulted in outages. Ongoing issues with the availability of the small generator resulted in it being de-rated from 650 to 550; the solar window was reduced as a result, with set point at zero.
Areyonga	1.1%	Issues relating to the smallest diesel generator
Mt Liebig	0.8%	Cluster controller firmware issue
Nyirripi	9.0%	The array curtailment was high due to engine-load mismatch, with the array locked out for a period in September/October 2018. A smaller and low load capable generator was installed in October and PV generation resumed. The array was locked out for the duration of upgrade of the power station main switchboard and control system. The array was not reclosed after a system black event in January 2019; identified and rectified during weekly checks.
Tranche 1 subtotal	**3.8%**	
Apatula (Finke)	0.0%	-
Milyakburra	0.3%	Cluster controller firmware issue resulted in one outage.
Minyerri (Hodgson Downs)	30.3%	Cluster controller firmware issue resulted in an outage. A suspected lightning surge subsequently resulted in failure of the Cluster controller and one surge diverter, with access to rectify delayed by commissioning of other Tranche 2 sites.
Atitjere (Harts Range)	0.0%	-
Titjikala (Maryvale)	19.1%	PV main circuit breaker intermittently tripped, resulting in multiple outages. Cluster controller firmware issues Network switch in the PCC failed
Milingimbi	10.1%	Cluster controller firmware issues
Minjilang (Croker Island)	10.0%	A suspected lightning surge resulted in a replacement of the Cluster controller (timing meant that rectification was delayed due to commissioning of other sites)

Galiwinku (Elcho Island)	29.3%	Output was constrained for an extended period due to a busbar earth leakage detection fault Multiple outages due to Cluster controller firmware issues
Warruwi (Goulburn Island)	3.7%	Array outage due to a network switch failure
Ngukurr	5.1%	Multiple PV array outages due Cluster controller firmware issue Multiple outages for power line incidents and maintenance on the PV feeder
Wurrumiyanga (Bathurst Island)	46.2%	Output limited due to the PV main switchboard busbar earth leakage detection fault Output curtailed to avoid issues with localised voltage rise Outage due to a blown surge arrestor on the inverter communications network (one port of cluster controller also damaged)
Gapuwiyak (Lake Evella)	8.8%	Cluster controller firmware issues Current limiting fuses in the PCC failed after a lightning storm.
Bulman	0.0%	-
Gunbalanya (Oenpelli)	66.9%	The site was operated with reduced output pending completion of the site communication link installation (access hampered during wet season flooding) Output was limited due to PV main switchboard busbar earth leakage detection fault. Cluster controller firmware issues
Maningrida #2	0.0%	-
Tranche 2 subtotal	**23.9%**	
Daly River (PV only)	**7.0%**	The array was powered down for the duration of EPC rectification works in late 2018, including improvements to lighting protection. Further damage was incurred during three subsequent surge events, affecting a subset of inverter communication cards. The array was powered down for further improvements in June 2019. The array was also disabled during annual capacity testing of the BESS in June 2019[19]

[19] For further discussion on Daly River, refer to *SETuP Knowledge Sharing - Daly River (Nauiyu) Lessons Learned and Performance Report*, www.powerwater.com.au