CO-LOCATION OF LARGE SCALE WIND AND SOLAR FARMS

Learnings from Gullen Solar Farm Operation

This report was prepared by
BJCE Australia for Gullen Solar Pty Ltd

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This report has been prepared by BJCE Australia for the Australian Renewable Energy Agency (ARENA).

Selected text has been redacted for distribution to the public due to it being commercially sensitive.

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1 Definitions

- AEMO – Australian Energy Market Operator
- ARENA – Australian Renewable Energy Agency
- ASEFS – Australian Solar Energy Forecasting System
- ATV – All Terrain Vehicle
- AWEFS – Australian Wind Energy Forecasting System
- BOP – Balance of Plant
- CAPEX - Capital Expenditure
- DA - Development Application
- DBJV – Decmil Balance Joint Venture (the EPC Contractor)
- DPIE – NSW Department of Planning, Industry and Environment
- EPC – Engineer Procure Construct
- GHI – Global Horizontal Incident Irradiation
- GPS – Generator Performance Standards
- GRWF – Gullen Range Wind Farm
- GSF – Gullen Solar Farm
- HMI – Human Machine Interface
- IGBT – Insulated-gate Bipolar Transistor
- LGC – Large-scale Generation Certificate
- ULSC – Upper Lachlan Shire Council
- MLF – Marginal Loss Factor
- NER – National Electricity Rules
- NGRWF – New Gullen Range Wind Farm Pty Ltd, the owners of Gullen Range Wind Farm
- NSP – Network Service Provider
- O&M – Operations and Maintenance
- OPEX – Operational Expenditure
- PCB – Power Conversion Block, consisting simplistically of an inverter and a transformer
- PPA – Power Purchase Agreement
- SCADA - Supervisory Control and Data Acquisition System
- WF – Gullen Range Wind Farm

2 Executive Summary

Gullen Solar Farm (GSF) is a 10MW AC (13.2867 MW DC) solar farm, co-located with the Gullen Range Wind Farm (GRWF) in the Southern Highlands of NSW. It is owned by Gullen Solar Farm Pty Ltd. GSF connects to the electricity grid through the GRWF 33/330kV substation. Both GSF and GRWF are owned by Beijing Jingneng Clean Energy (Australia) Pty Ltd (BJCE Australia).

GSF was identified for a $9.9 million grant from the Australian Renewable Energy Agency (ARENA) in 2014. The grant was provided to assist in demonstrating the benefits of co-locating large scale solar generation with existing wind farms, particularly utilising existing wind farm infrastructure, connection to the electricity network and stakeholder relationships to reduce construction and operational costs.

As a requirement of Gullen Solar Farm's participation in the Advancing Renewables Program, Gullen Solar Pty Ltd is required to prepare two knowledge sharing reports. The first of these reports titled "Co-location of Large-Scale Wind and Solar Farms – Learnings from Gullen Solar Farm Development and Construction" was submitted to ARENA on 29th January 2020. This is the second report, and focuses on learnings from the operational phase of the project.

The GSF is operated and maintained by DBJV, who built the project under an EPC contract. BJCE Australia undertakes asset management outside of DBJV's responsibilities.

Learnings from the operation of GSF, relating to co-location of wind and solar, included the following:

- Integration of SCADA systems for co-located wind and solar farms should be carefully considered, including the costs vs the benefits and ensuring relevant contracts cover interfaces.
- Arrangements for high voltage switching and isolation of the co-located facility should be considered at the design stage and relevant stakeholders feedback sought.

Learnings from the operation of GSF, not related to co-location include:

- Solar panel cleaning can be problematic, particularly for hard to remove substances such as bird faeces.
- Use of sheep for grass control inside the solar farm array has been effective at reducing operational costs.

Community consultation has continued through the operational phase of the project and no operational phase complaints have been received.

Operational cost savings from co-location have been evident, including from shared use of wind farm expertise and labour, buildings, and asset management staff.

The solar farm continues to perform well, although generation during Quarter One 2020 was affected by reduced solar irradiation, likely as a result of bushfire smoke and retrofitting of GRWF substation, which occurred for reasons unrelated to GSF.

MLF has reduced slightly since the previous knowledge sharing report and merchant power prices have been reduced in February and March 2020, most likely due to the COVID-19 pandemic and associated reduced demand.

The GSF operational costs have been less than modelled, although some costs have been incurred by NGRWF that were originally modelled to be GSF's liability.

An analysis of solar farm downtime was undertaken. Faults related to the PCB's have been the main source of downtime, which is not unexpected, as they are the most complicated part of the solar farm.

Panel degradation was analysed, but it was not possible to calculate a reliable degradation percentage using SCADA data. This was due to the large variability in site derived data for irradiance, temperature and generation compared to the small magnitude of expected degradation. Solar panel cleanliness and the transient nature of cloud cover are additional uncertainties making conclusive analysis difficult.

Building on the information presented in the previous knowledge sharing report, further analysis of the effect of the GSF on the intermittency of GRWF on a diurnal basis was undertaken. Analysis supported the conclusions of the previous report, that is, on a diurnal basis, and based solely on a goal of reducing intermittency, co-location of GSF and GRWF has not been that effective. However, other significant benefits of co-location remain apparent, such as the reduction of intermittency on a seasonal basis.

3 Introduction and Background

Gullen Solar Farm (GSF) is a 10MW AC (13.2867 MW DC) solar farm, co-located with the Gullen Range Wind Farm (GRWF) in the Southern Highlands of NSW. It is owned by Gullen Solar Farm Pty Ltd.

Gullen Solar Farm (GSF) received a grant from the Australian Renewable Energy Agency (ARENA) under the Advancing Renewables Program in 2014. ARENA provided $9.9 million of grant funding to the project under this program. The grant was provided to assist in demonstrating the benefits of co-locating large scale solar generation with existing wind farms, particularly utilising existing wind farm infrastructure, connection to the electricity network and stakeholder relationships to reduce construction and operational costs. Financial Close under the Arena Funding Agreement was achieved on 15th July 2016.

As a requirement of Gullen Solar Farm's participation in the Advancing Renewables Program, Gullen Solar Pty Ltd is required to prepare two knowledge sharing reports. The first of these reports titled "Co-location of Large-Scale Wind and Solar Farms – Learnings from Gullen Solar Farm Development and Construction" was submitted to ARENA on 29th January 2020. This is the second report, and focuses on learnings from the operational phase of the project.

This report should be read in conjunction with the January 2020 report. The January 2020 report is referred to throughout this report as the previous knowledge sharing report.

GRWF is owned by New Gullen Range Wind Farm Pty Ltd (NGRWF). Beijing Jingneng Clean Energy (Australia) Holding Pty Ltd (BJCE Australia) has been the majority shareholder of NGRWF since 2014 and has owned Gullen Solar Farm Pty Ltd since 2016.

GSF is located on land owned by Gullen Solar Farm Pty Ltd. The solar farm connects to the electricity grid via the existing substation at GRWF. The solar farm has approximately 42,000 solar panels connected to four PCB's. A single underground 33kV circuit is connected to an existing set of switchgear on the wind farm's 33kV switchboard. The solar farm shares the wind farm Operations and Maintenance building. A site plan of the development was included as an attachment to the previous knowledge sharing report.

GSF was constructed and is currently operated and maintained by Decmil Balance Joint Venture (DBJV).

4 *Overview of Operation*

The project was constructed under an Engineer Procure Construct (EPC) contract by DBJV following a competitive tender process. As is standard market practice, DBJV was awarded a contract for the operations and maintenance of the plant to overlap with the EPC defects liability period, being 2 years. The operations and maintenance contract (O&M contract) was tendered at the same time and to the same parties as the EPC contract, with the successful tenderer being selected on the basis of their combined proposals.

Due to issues with registration of the plant with AEMO, it initially was commissioned at a reduced capacity of 9.17MW AC on September 1st 2017. Refer to the previous knowledge sharing report for more detail regarding AEMO registration. The AEMO issue was resolved and output at 10MW AC was achieved on August 28th 2018. Completion under the EPC Contract was subsequently awarded on 28th November 2018 and services under the O&M contract began. Between September 1st 2017 and 28th November 2018, the plant was operated under the terms of the EPC contract.

The O&M contract has a broad scope. Notable responsibilities which remain with Gullen Solar Pty Ltd are settlement of generation (on a merchant basis) and LGC's, landowner and community engagement and certain compliance activities. The O&M contract scope includes:

- Scheduled maintenance
- Unscheduled maintenance
- Provision of reports and information
- Provision of a 24/7 emergency contact
- Maintenance management
- SCADA operation and management
- A market standard availability warranty

Gullen Solar Pty Ltd is responsible for managing the growth of grass under the solar panels and this is undertaken by grazing sheep. Mowing is undertaken in areas where the sheep have not been effective. The O&M contract includes the requirement to cut grass to the extent it is shading the leading edge of the solar panels, in order to avoid conflict with the O&M availability warranty.

DBJV is contracted to make efforts to ensure scheduled maintenance is conducted during low solar irradiation periods and outside of peak generation and high spot price periods. Electricity generated is traded on a merchant basis by Gullen Solar Pty Ltd.

Goldwind Australia maintains the GRWF for BJCE. DBJV utilises Goldwind Australia's staff to perform certain O&M activities. This arrangement is more efficient as it avoids mobilisation costs and takes advantage of Goldwind Australia's well-trained local staff, facilitating a lower O&M cost without a reduction in the quality of services.

5 *Complications arising from Co-location during Operation*

This report identifies complications and challenges arising from co-location during operation of the plant. It does not repeat information reported in the previous knowledge sharing report, and the two reports should be read together.

5.1.1 *Grid Compliance*

Challenges with registration of the combined wind and solar farm and their resolution were discussed in the previous knowledge sharing report. Since registration, there have been no challenges associated with grid compliance. Hold point and R2 testing results were submitted to Transgrid and AEMO and no issues were identified.

The relative size of the solar farm compared to the wind farm has made grid compliance less of a project issue than some other large-scale solar farms. For instance, the solar farm is not required to provide any reactive power in normal operation to satisfy the GPS.

The power quality metering installed as part of the GSF construction is not compatible with the proprietary software that the existing wind farm power quality meters utilise. This made R2 testing and monitoring of grid compliance more time consuming. A lesson learnt during co-location is to ensure the meters can be interrogated through the same software platform.

5.1.2 SCADA Integration and Control

As discussed in the previous knowledge sharing report, the wind farm SCADA system was modified to incorporate the solar farm, which does not have its own SCADA system. This work was managed by Goldwind Australia and their team in China, as the wind farm SCADA is a Goldwind proprietary system.

Although this arrangement did reduce construction costs, it has resulted in some frustration during operation. The modified system does not have the capability of other bespoke solar farm SCADA systems. Although all recorded data channels from the solar farm are passed across to the wind farm SCADA, some channels cannot be viewed at a convenient logging rate. Many channels can only be downloaded from the system one day at a time, which makes post processing of the data difficult. An advantage is that data from both farms is available in the one system and can be interrogated together.

Further adjustments to the system are difficult, as they need to be performed by Goldwind in China, and their focus is understandably on improving their wind offering, rather than a one-off co-located solar farm in Australia.

Some issues, such as incorrect scaling or unavailability of data, require co-operation between Goldwind and Balance Energy Solutions (one part of the DBJV joint venture), but there is no contractual link between these two parties. The bespoke nature of the arrangement makes solving issues more time consuming for everybody involved compared to an off the shelf system. New Gullen Range Wind Farm has a long-term O&M contact with Goldwind Australia for the maintenance of the wind farm, including the wind farm SCADA system, but that does not include elements relating to the solar farm, as the solar farm didn't exist when the contract was put in place and it has not been amended.

The HMI interface (the computer monitoring screens used to monitor operation) is workable, being a modified version of the wind farm HMI screens. The four PCB's are pictorially represented on the main monitoring screen with the wind turbines shown above. Key statistics are listed next to each PCB. However, convenient tools such as the PCB changing colour when it is in fault could not be implemented.

BJCE Australia is currently constructing the Biala Wind Farm, which will integrate 'behind the meter' at the Gullen Range Wind farm, alongside GSF. As part of this, BJCE Australia has taken the opportunity to upgrade the wind farm SCADA system to the latest Goldwind version, with this work performed in late March 2020. It is expected that, once fully functioning, many of the limitations described above will be overcome through this upgrade.

It is recommended that future co-located wind and solar developments consider the cost savings against the potential complications when deciding how integrated the co-located plant's SCADA systems should be with the existing plant's. The structure of new and existing contracts should be considered and detailed scopes of work prepared for all involved parties.

5.1.3 High Voltage Electrical Switching

The solar farm connects to the wind farm substation using an existing 33kV breaker in the wind farm control building. The switching of this breaker is performed by Goldwind Australia in their role as O&M contractor for the GRWF and the GRWF substation. This arrangement has worked well in operation, particularly as Goldwind has a permanent presence at the site in normal business hours. As described earlier, Goldwind wind farm technicians perform maintenance on the solar farm under contract from DBJV, which inherently assists with any wind farm interfacing issues when maintaining the solar farm.

When switching off the 33kV breaker or disconnecting power to the solar farm elsewhere in the substation, it is important to shut down the PCB's properly to avoid damage. A protocol has been established on how this should be undertaken.

There is no requirement in the wind farm O&M contract for the switching of the solar farm breaker. This work is completed as additional services.

It is important that the design of the solar farm considers the existing high voltage procedures for the wind farm, such as the procedures for isolating equipment and completing work. This should be completed at an early stage, so that procurement considers which equipment needs to be able to be 'locked out'. At Gullen Solar Farm, there was not enough involvement of the existing wind farm operations team at this early stage, which has caused some inefficiencies in the procedures for isolating the plant.

5.1.4 Electricity Metering

The previous knowledge sharing report described the arrangement for revenue metering of the solar farm. The generation output of the solar farm is metered at 33kV and a metering algorithm is applied by the Meter Data Provider to calculate output at the 330kV connection point. The algorithm caters for losses across the wind farm substation's 33/330kV transformers.

The system has worked well during operation.

5.1.5 Provision of Data to AEMO

The previous knowledge sharing report described the arrangements for passing data signals from the solar farm to AEMO. This system has worked well during operation. Fault finding is more difficult than usual, as a solar farm data signal travels from the solar farm, to the wind farm SCADA system, to the substation SCADA system and then onward to Transgrid before arriving with AEMO. A different party must be contacted to check the signal at each of those points in order to work out where an issue might be.

5.1.6 AWEFS and ASEFS

The previous knowledge sharing report discussed limitations from AEMO's AWEFS and ASEFS systems preventing the co-located wind and solar farm's receiving a combined dispatch point. A combined dispatch point would set a maximum MW output requirement from both points in the aggregate. Instead, the solar farm is sent a setpoint and the wind farm is sent a separate one. The previous report identified limitations associated with that. The arrangement of separate setpoints has not changed.

From an operational perspective, the systems put in place to cater with individual setpoints have worked appropriately.

6 Other Operational Lessons Learnt

6.1 Solar Panel Cleaning

Since the solar farm began operation, there have been some extended periods of dry weather. This resulted in the accumulation of bird faeces on some of the solar panels, which can cause localised hot spotting and solar panel damage. In conversation with other developers, this does not seem to have been a significant issue on other solar farms.

The solar panels on GSF are harder to clean than other solar farms. One of the drivers for the location of the solar farm was the north facing slope on which it is situated. However, the slope makes panel cleaning more difficult, as a person on the downhill side of the solar panel rows has to extend further to reach the top edge of the panel and their vehicle is on an angle across the slope. Across the north facing slope, there is undulation, which makes any automated system for cleaning difficult. The north facing aspect has also allowed a narrower panel spacing and therefore higher installed capacity, but it does mean the row spacing is not wide enough for a conventional utility vehicle. A small electric ATV was provided by DBJV under the EPC contract to access between the panels and that arrangement has worked well, but solutions for panel cleaning such as attachments to a farm tractor are not suitable at GSF due to the narrow width. Solar panel cleaning was considered in the design of GSF and appropriate compromises were made, but the problem of hot spotting due to bird faeces, which is quite hard to remove once it has been in the sun, was not.

Panel cleaning to date has been conducted manually, but more efficient solutions are being investigated.

6.2 Grazing in the Solar Panel Array

After an acceptable level of revegetation of disturbed ground had occurred, sheep were introduced to the solar farm array to control the height of the grass. The sheep have not caused any erosion issues and have been effective in controlling the height of the grass. Grass cutting is expensive, costing approximately $20,000 for the GSF. Tall grass can cause shading of the panels and associated generation loss, as well as being a health and safety issue, in terms of bushfire risk, prevalence of snakes and reduced visibility when accessing the solar farm array. At GSF, additional CAPEX cost was incurred to make the solar farm array suitable for sheep, such as protection of combiner boxes. The additional cost has been justified by the reduced grass cutting costs and it is recommended that this solution is investigated on future solar farms, although its suitability will be very site dependant.

7 Summary of Community Consultation

Extensive community consultation was undertaken in the development phase for Gullen Solar Farm, as discussed in the previous knowledge sharing report. Consultation was undertaken to the extent that the original proposed location of the farm was changed, resulting in additional costs and program implications.

However, the high level of consultation in earlier stages has benefited the project in operation. A complaints register is maintained for the project. There have been no operational complaints submitted.

The project maintains an 1800 number, a website, an email address and a mailing address by which people can make contact. In 2019 there were 2276 visitors to the project website and a total of 5502 page views by those visitors.

BJCE Australia conducts regular engagement across all of its projects in the local area, being Gullen Range Wind Farm, Gullen Solar Farm and Biala Wind Farm. Gullen Solar Farm features in BJCE Australia's program of public tours. Six times per year, a free mini-bus tour of Gullen Range Wind Farm and Gullen Solar Farm is conducted, with members of the public able to register through the project website. The tours are run in conjunction with ULSC's tourism coordinators. BJCE Australia is also involved in the Science in Schools Program through Regional Development Australia Southern Inland Division, and regularly speaks at local schools about the co-located facility.

8 Discussion of Financial Benefits to Co-location

Section 0 of this report details the OPEX costs for the solar farm in 2018 and 2019. The previous knowledge sharing report discussed CAPEX savings resulting from co-location during the construction phase, in comparison to analysis performed by Goldwind Australia prior to award of ARENA grant funding.

The largest cost saving evident during the operational phase, is that Gullen Solar Pty Ltd does not need to pay an ongoing connection fee to Transgrid as GSF is connected 'behind the meter' to the GRWF substation. GRWF pays an annual fee for its connection, the majority of which is an annuity arrangement for the capital works performed by Transgrid when GRWF was built. The analysis in the previous knowledge sharing report and the prior analysis performed by Goldwind, considered that the substation capital works were paid for upfront. Therefore, the approximate $4,479,105 grid connection related saving reported in the previous knowledge sharing report already includes this saving.

Additional OPEX cost saving areas resulting from the co-location of GSF with GRWF include:

1. Reduced O&M costs - The use of skilled Goldwind Australia labour, already located at the adjacent wind farm, reduces the value of the O&M contract, without affecting quality of service.
2. Shared use of facilities – GSF shares the existing GRWF O&M building. This has avoided the cost of maintaining another O&M building, including ongoing costs associated with utilities and services.
3. Substation maintenance costs – Maintenance is performed annually on the GRWF 33/330kV substation that GSF connects to. Those maintenance costs have not significantly increased due to the connection of the solar farm.

4. Asset Management – The close location of the two farms, together with a large crossover in the stakeholders, means asset management of the GSF has been absorbed by the existing GRWF asset management staff.

9 Operational Phase Analysis

The previous knowledge sharing report included analysis of solar farm data up until the end of the 2019 calendar year, which included the period from September 1st 2017 to August 28th 2018 when plant output was restricted to 9.17MW AC and the subsequent period to 31st December 2019 at 10MW AC max capacity.

That analysis has been updated below to be current at the end of March 2020. Discussion below is limited to new observations arriving from the additional data, or where the additional data requires revision to the conclusions made in the previous report.

9.1 Solar Farm Performance

9.1.1 Forecast to Actual Electrical Output

Since quarter ending December 2017 until the end of March 2020, GSF has exported 51829 MWh, compared to a predicted output in the financial close model of 52368 MWh. The first quarter of 2020 was a poor one for Gullen Solar Farm. Figure 1 illustrates less than expected generation, although cumulative generation (Figure 2) is still reasonably close to as modelled. The poor Quarter One performance was due to a combination of lower than expected GHI (Figure 3 and Figure 4) and poor plant availability. The GHI result was likely due to the prevalence of bushfire smoke in January and February. Plant availability was lower mainly due to a seven-day grid connection outage at the end of March. The outage was required for major retrofits to the GRWF substation in order for the connection of BJCE Australia's nearby Biala Wind Farm which is currently under construction.

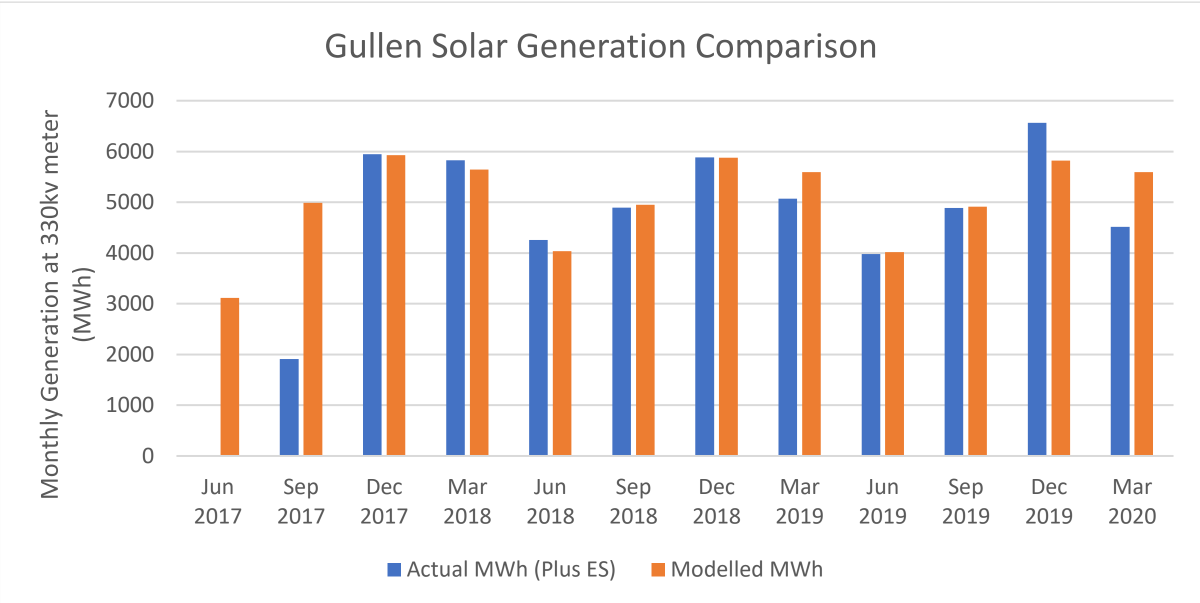

Figure 1 – Comparison of Gullen Solar Actual and Predicted Generation by Month

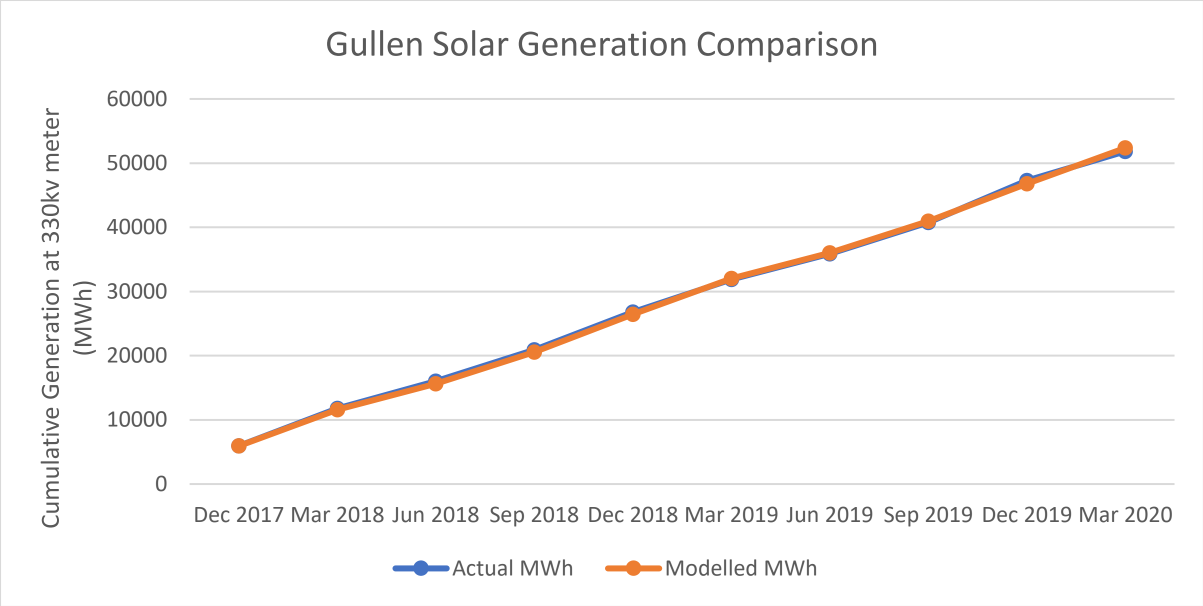

Figure 2 - Comparison of Gullen Solar Actual and Predicted Cumulative Generation

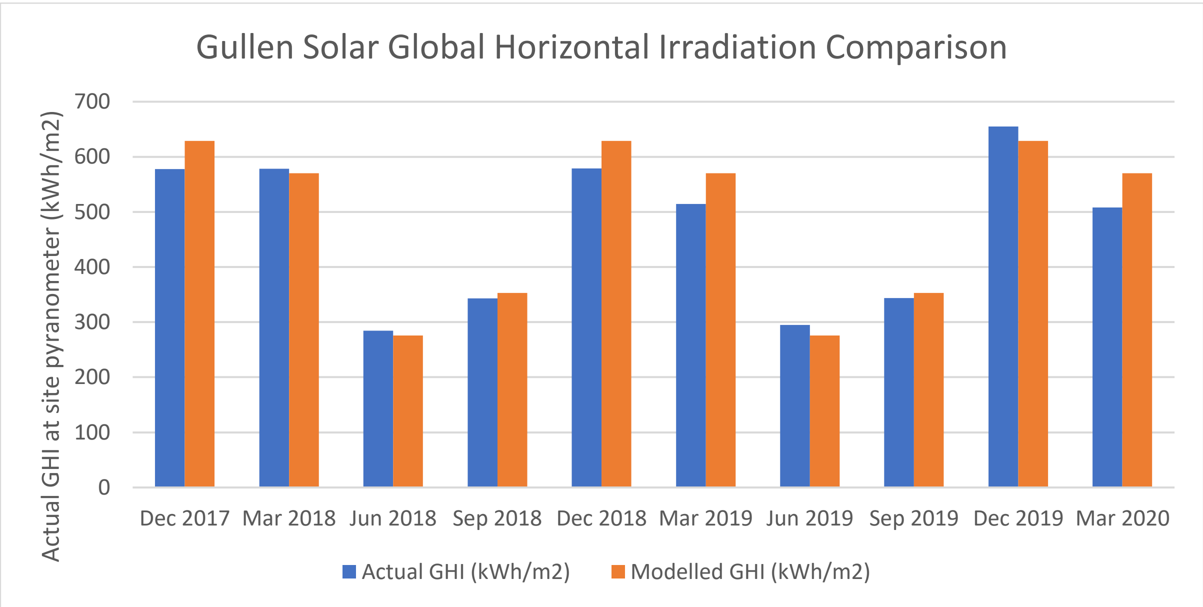

Figure 3 - Comparison of Gullen Solar Actual and Predicted GHI by Month

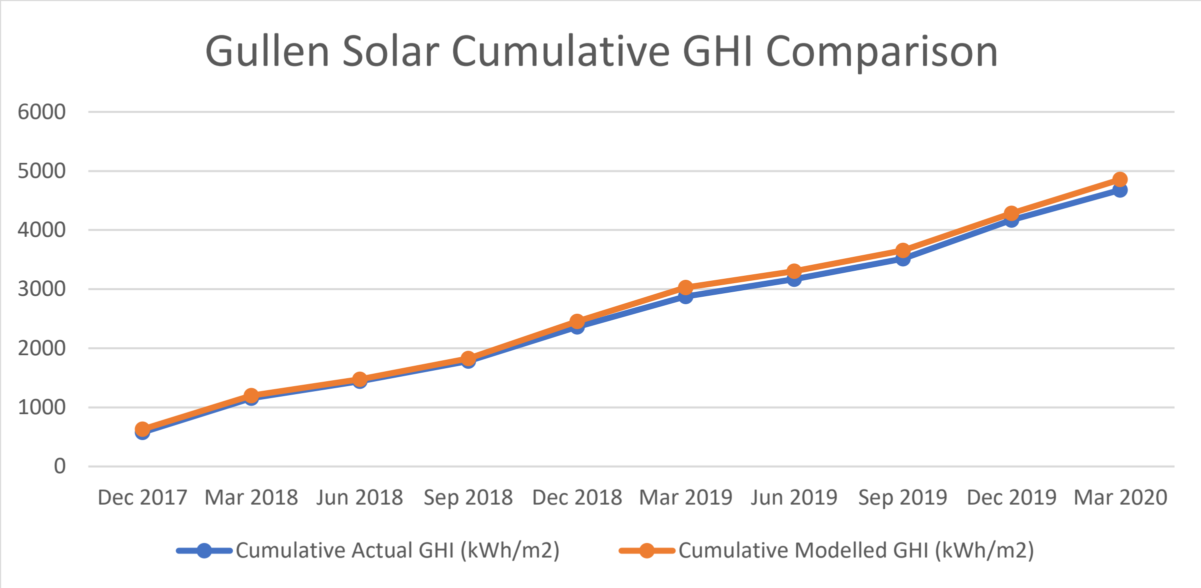

Figure 4 - Comparison of Gullen Solar Actual and Predicted Cumulative GHI

Figure 5 analyses plant availability in comparison to deviation between actual and modelled monthly electricity generation. Availability is presented as hours of PCB downtime. Gullen Solar has four PCB stations. For clarity, if all four PCB stations were unavailable for one hour, that would be presented as four hours of downtime. Figure 5 illustrates high PCB availability was a contributory factor toward the less than predicted generation in Quarter ending March 2020. As stated above and discussed further in 9.4, the major cause of this unavailability was due to an outage of the substation.

Figure 6 analyses deviation between actual and modelled GHI in comparison to deviation between actual and modelled monthly electricity generation. Figure 6 shows actual GHI being less than modelled GI was also a contributory factor toward the less than predicted generation in Quarter One. It is clear from Figure 5 and Figure 6 that GHI has been a much more influential factor on electricity generation than plant availability since December 2017.

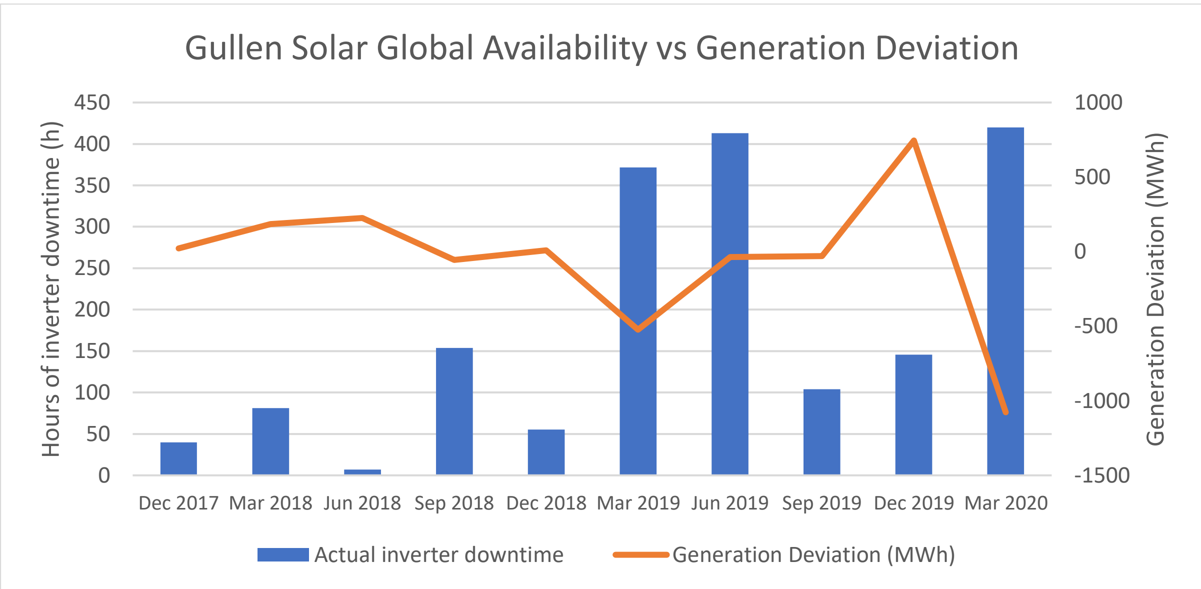

Figure 5 – Comparison of Actual and Forecast Generation Deviation to Solar Inverter Downtime

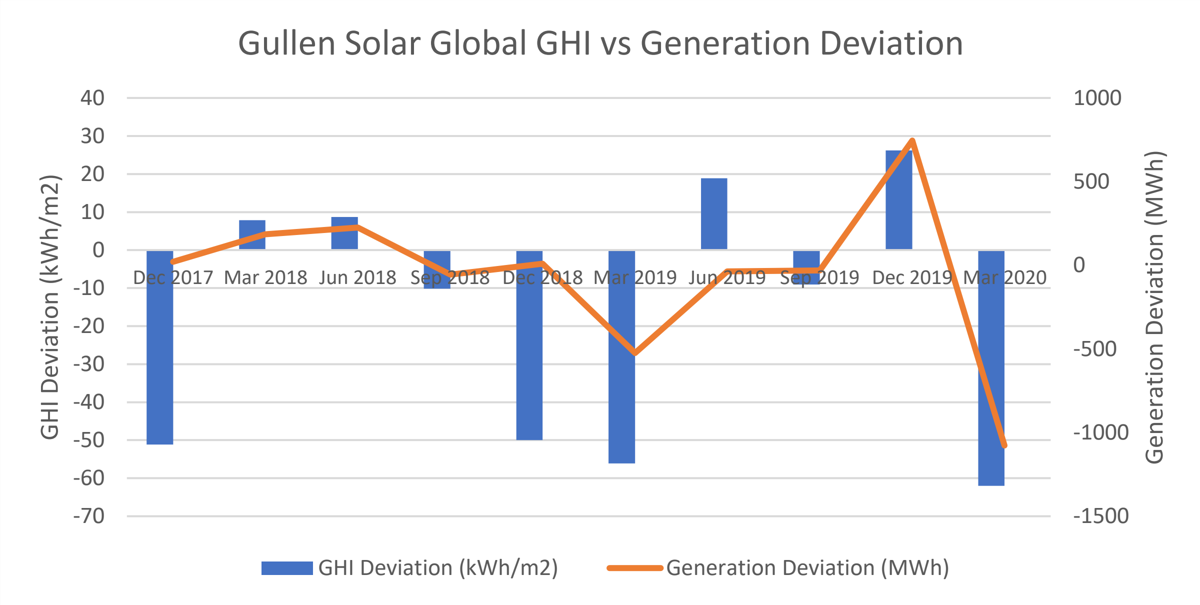

Figure 6 - Comparison of Actual and Forecast Generation and GHI Deviation

9.2 MLF and Merchant Power Price

Table 1 is an update of the corresponding table in the previous knowledge sharing report describing the Marginal Loss Factor or MLF attributable to Gullen Solar Farm. Data for quarter ending March 2020 has been added. The actual MLF fell marginally in the latest AEMO update, which was opposite to that predicted in the project financial model. However, the difference between actual and modelled MLF is not significant.

Quarter	MLF Model	Actual MLF
Jun 2017	0.9909	0.9909
Sep 2017	0.9909	1.001
Dec 2017	0.98	1.001
Mar 2018	0.98	1.001
Jun 2018	0.98	1.001
Sep 2018	0.98	0.9959
Dec 2018	0.9697	0.9959
Mar 2019	0.9697	0.9959
Jun 2019	0.9697	0.9959
Sep 2019	0.9697	0.9694
Dec 2019	0.9698	0.9694
Mar 2020	0.9698	0.9693

Table 1 – MLF Factors

Figure 7 and below are updates of the merchant price comparison in the previous knowledge sharing report. As with previous years, January saw strong prices. However, the settlement prices in February and March 2020 have declined dramatically, resulting in prices that are below the financial model's assumed price, as illustrated in Figure 7. It is perceived that the COVID-19 pandemic is a large factor in this price reduction.

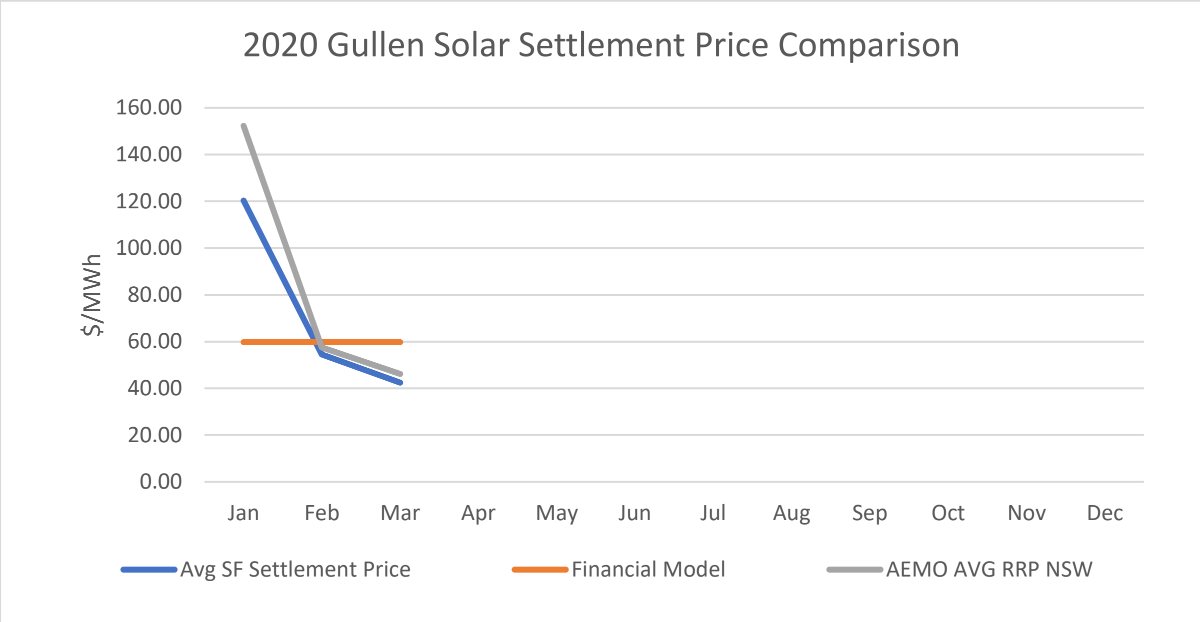

Figure 7 – Comparison of Settlement Prices from 2018 to 2020

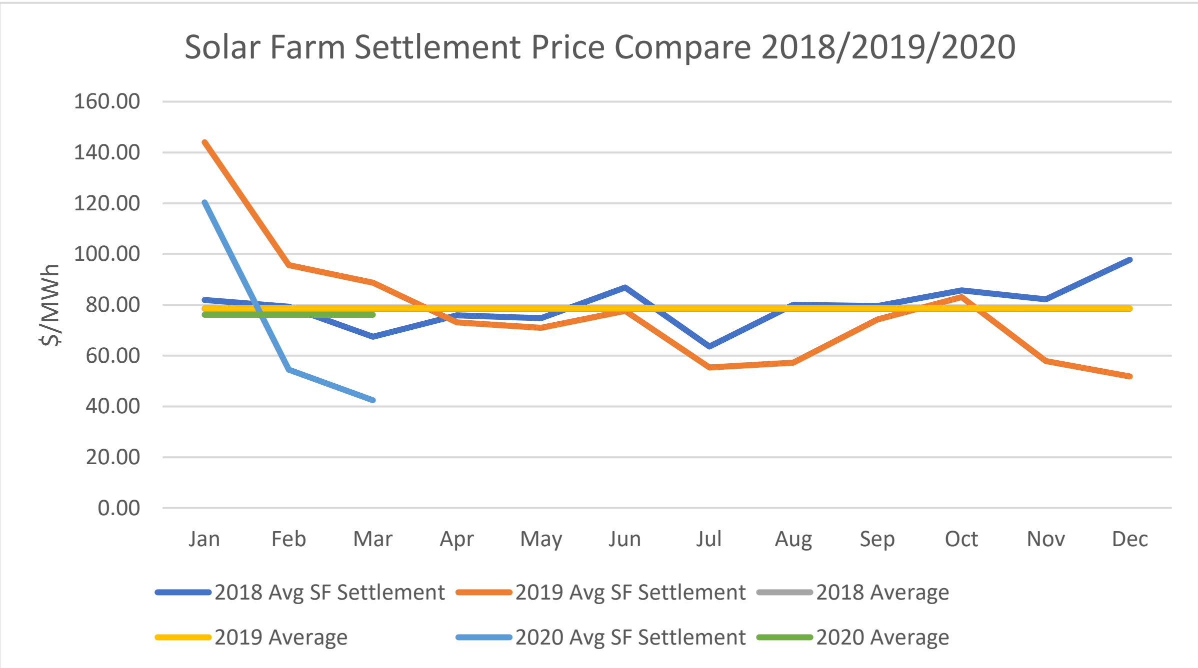

Figure 8 - Comparison of Settlement Prices from 2018 to 2020

9.3 Actual OPEX Compared to Predicted OPEX

A summary of forecast OPEX to the actual OPEX for 2018 and 2019 is included in Table 2. It can be seen from the Table that 2018 and 2019 OPEX are below the OPEX forecast at ARENA Financial Close.

Predicted Annual OPEX at ARENA Financial Close	2018 Actual OPEX	2019 Actual OPEX
$747,974	$585,030	$604,800

Table 2 - Forecast OPEX against Actual OPEX in 2018 and 2019

9.4 Solar Farm Downtime and Unscheduled and Scheduled Maintenance

An analysis of solar farm downtime has been presented below. The quantity of hours referred to in the figures below is hours of individual PCB downtime. For instance, if there is a substation outage causing the entire solar farm to stop generating for eight hours, this will be recorded as 32 hours of PCB downtime, as there will be four PCB's on the site that are not working for eight hours.

Figure 9 examines the causes of downtime affecting the solar farm. Downtime outside of the solar farm has all been associated with the substation. The 'Other Owner Downtime' in 2020 is the result of retrofitting to the GRWF 33/330kV substation for the 'behind the meter' connection of Biala Wind Farm at the end of March. Substation scheduled maintenance has not yet occurred in 2020, but is an annual event. In 2019 a failure in the GRWF 33/330kV substation resulted in a number of days of downtime for the entire solar farm.

Inside of the solar farm, all unscheduled plant downtime has been associated with the PCB units. This is not unexpected, as the PCB's are the most complicated component of the solar farm. There has also been downtime in 2019 for scheduled maintenance of the PCB's.

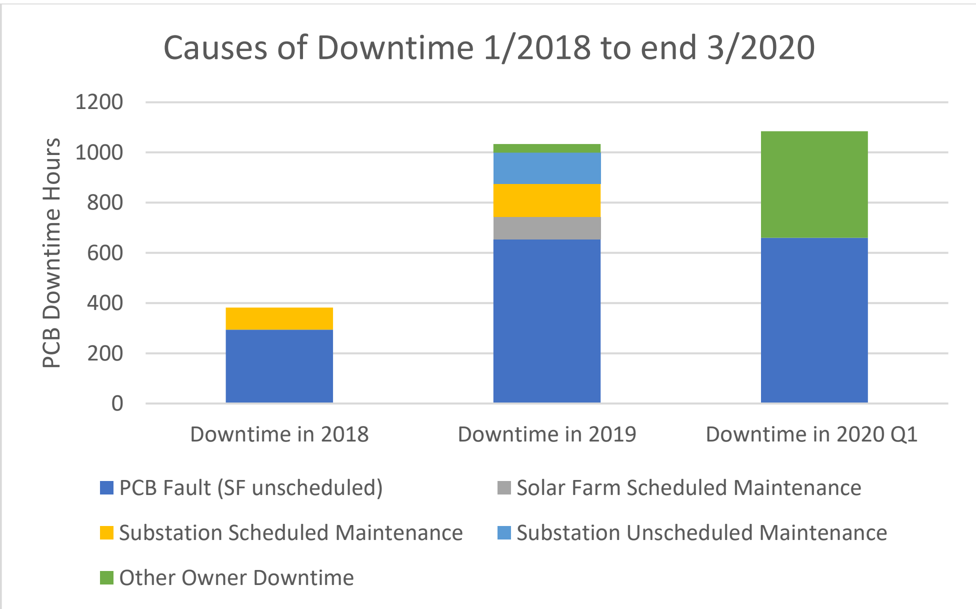

Figure 9 – Causes of Solar Farm Downtime

Figure 10 illustrates the cause of PCB failures during 2019 and Quarter 1 2020. Most of the downtime has been associated with failures inside the inverter part of the PCB. Replacement of these components requires a specialist PCB technician and sometimes parts have to be ordered. Although the on-site repair time is short, the lead time to the repair can cause a comparatively long outage.

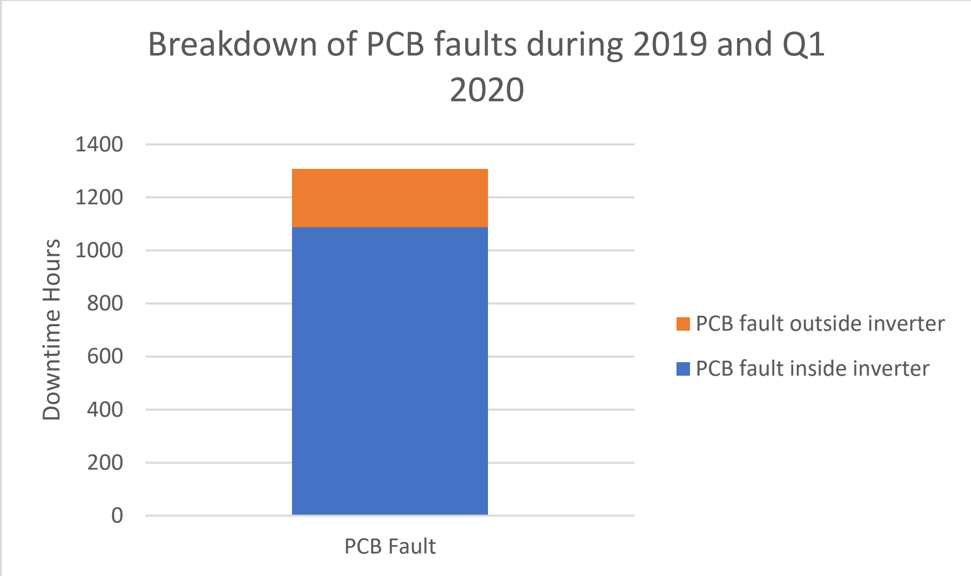

Figure 10 – Analysis of downtime due to PCB Faults

Figure 11 below shows that unscheduled maintenance is the dominant cause of solar farm downtime and that the dominant cause of downtime is due to faults inside the solar farm, rather than with GRWF substation. On this co-located facility, where the substation was part of the existing GRWF when GSF was constructed, the substation downtime can be considered downtime arising due to co-location, although it should be noted that if the solar farm had its own substation, there would be downtime related with that substation.

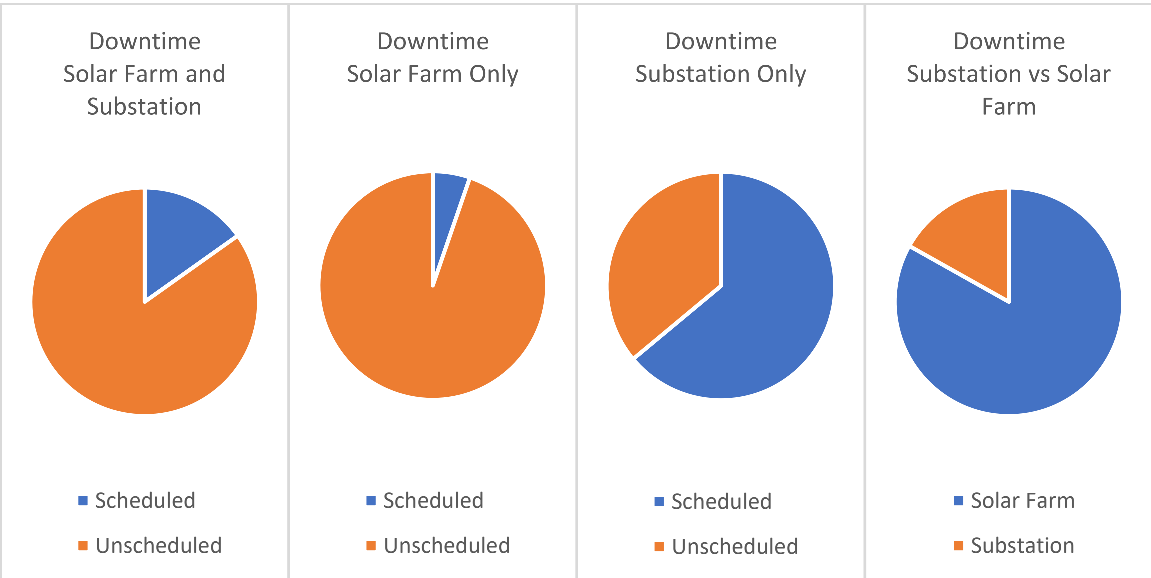

Figure 11 – Unscheduled vs Scheduled Downtime and Solar Farm vs Substation Downtime

9.5 Panel Degradation Rates

Several different methodologies have been investigated to estimate the degradation of the solar photovoltaic panels installed at GSF. The electricity generated from a solar panel degrades with time. The expected maximum degradation for the Yingli panels installed at GSF is as described in Table 3 and Figure 12:

Period in years since installation	Expected degradation in output (%)
0	100
1	97.5
2	96.8
3	96.1
4	95.4
5	94.7

Table 3 – Expected Panel Degradation

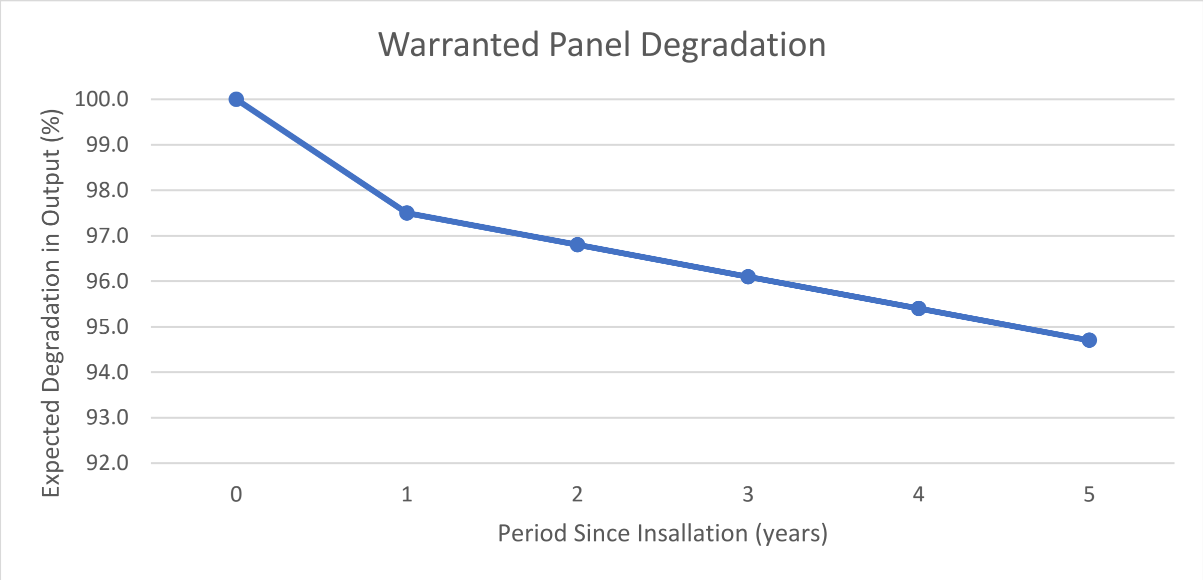

Figure 12 – Expected Panel Degradation

Installation of solar panels at GSF began in early March 2017, with the plant first generating in early September 2017. Assuming the median date for the panel installation was half way between these dates, a reasonable start date for the degradation of the panels could be June 1st 2017. The panels begin degrading as soon as they are installed, even if the plant is not grid connected, which is an important consideration during solar farm construction.

Analysis of data for this report uses data from the 2018 and 2019 calendar years, which in terms of Figure 12 is from Year 0.5 to Year 2.5. Interpolation of the expected degradation curve results in the following expected degradation, as described in Table 4.

Degradation Period	Expected Degradation
1/1/2018 to 31/12/2018	98.75 to 97.15
1/1/2019 to 31/12/2019	97.15 to 96.45

Table 4 – Interpolated Panel Degradation

Resetting to a baseline of 1/1/2018, results in the following expected degradation, as described in Table 5.

Degradation Period	Degradation from 1/1/2018
By end of 2018	98.4%
By end of 2019	97.7%

Table 5 – Interpolated Panel Degradation with 1/1/2018 Baseline

A robust method for testing panel degradation, is to test a representative sample of panels in a laboratory before installation and retest after they have been in service. This might occur where the performance ratio of the plant is deficient or to claim on the degradation warranty from the panel supplier. At GSF, a sample of panels was tested prior to installation, but no testing has been deemed necessary after a period in service.

Several methods of in-situ analysis were attempted in order to measure the degradation using available SCADA data. However, there are many factors affecting the output of a solar panel. Three of particular note are incident irradiation, panel temperature and panel cleanliness. The quantum of expected degradation is quite small in comparison to these variables. There are two met stations on the site, measuring irradiation and temperature, but transient cloud cover, as is common in the Southern Tablelands adds further uncertainties.

Some of the methods of analysis included:

1. Comparing peak AC output of the panels against peak irradiation, which was not valid, as AC output is clipped at 10MW for large portions of sunny days and this 'hides' any effects of solar panel degradation.
2. Plotting 12 months of AC output (excluding data points clipped at 10MW) against irradiation, plotting a line of best fit and comparing the comparative gradient. This assumes relatively comparable temperature across the two years of data. However, the distribution in the point cloud was too broad to draw a conclusion. Some data showed a lag between changes in incident irradiation and AC generation, and it could not be concluded whether this lag was real. The inconsistent lag contributed to the variability in the point cloud.
3. Comparing the overall generation in 2018 against that in 2019, presuming reasonably constant temperature and irradiation across such a large dataset. However, temperature and irradiation are too variable across the two periods to be able to reach a reliable conclusion.
4. Finding two similar months in terms of average temperature and irradiation, one year apart and comparing the generation between the two. May 2018 and May 2019 were selected, with a 1.45% reduction in energy across the 12-month period.

Analysis was complicated by issues with the logging of the module temperature in the first half of 2018, and incorrect logging of rainfall (used as an indicator of panel soiling). As discussed in 5.1.2, complications due to the solar farm not having its own SCADA system have affected the quality of data collected, making an analysis such as this one difficult.

Based on the analysis conducted, the actual degradation of the solar panels could not be reliably calculated. A result of 1.45% between Mat 2018 and May 2019 was obtained, but it should be treated with caution. That result is comparable but a small amount larger than the expected degradation.

9.6 Benefits from Co-location to Generation Intermittency

The previous knowledge sharing report discussed the benefits in reducing intermittency of GRWF through the co-location of the GSF. On a seasonal basis, it was shown that the solar farm's highest output months corresponded with those of reduced wind farm output, which was beneficial to reducing intermittency.

An analysis was also undertaken on a day by day basis, looking at the average diurnal output of the two plant's over a two-year period. Figure 13 below is taken from the previous report. On an average day, the wind farm by itself has relatively constant output over the 24-hour period. Introduction of the solar farm actually marginally increases the deviation between the average output of the facility and the maximum output of the facility, in comparison to the wind farm on its own.

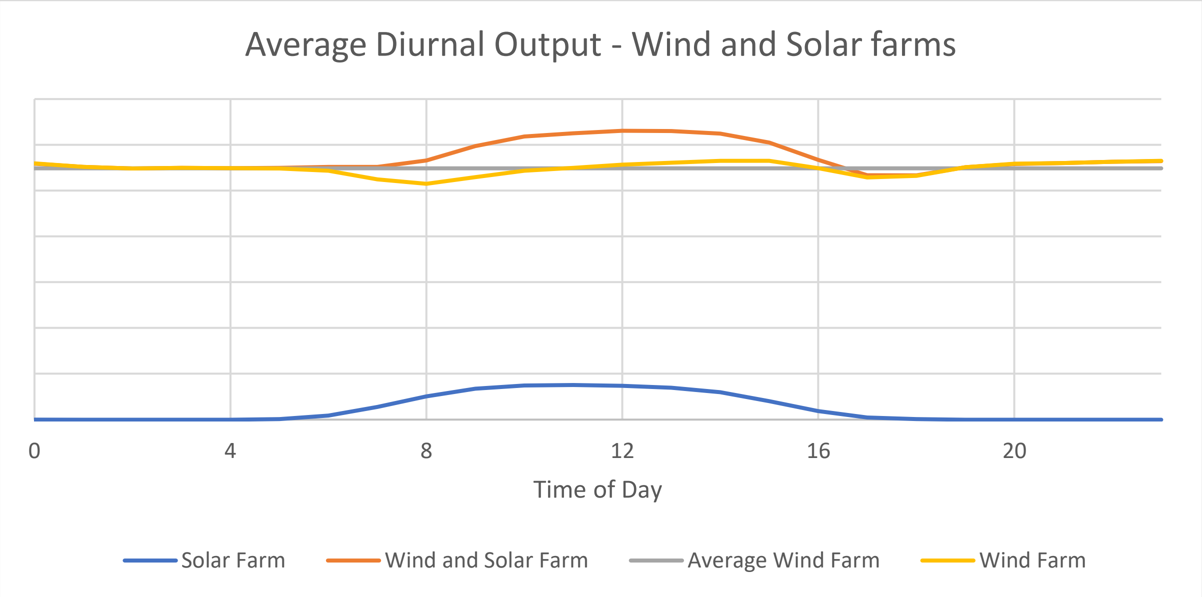

Figure 13 – Average Diurnal Output of GSF and GRWF

However, it was noted that averaging of the diurnal profile over a two-year period may not be indicative of how the solar farm affects intermittency on a day by day basis. For instance, how many low wind days does the solar farm perform well?

A further analysis was undertaken for this report, using operational data from 2018 and 2019.

Wind farm and solar farm data was filtered to only include generation during daylight hours, when it is feasible that the solar farm could assist with reducing wind farm intermittency.

The mean daily output for each month was calculated, as per Table 6.

Month	Sunrise Hour	Sunset Hour	Mean Daily Output in Daylight Hours (MWh/day)	
			WF	SF
Jan	5	19	577	65
Feb	6	18	561	56
Mar	6	18	671	59
Apr	7	17	369	49
May	7	17	622	49
Jun	7	17	479	39
Jul	7	17	838	46
Aug	7	17	814	52
Sep	6	17	703	64
Oct	6	18	667	65
Nov	5	18	963	69
Dec	5	18	707	70

Table 6 – Mean Daylight Hour Output by Month for Wind Farm and Solar Farm

A calculation was made examining how many days the wind farm produced less than its monthly average output, and of those days, how many days the solar farm produced more than its average output, as shown in Table 7 below.

Month	Sunrise Hour	Sunset Hour	Number of days in 2018/2019 where daylight hour WF daily generation is less than the WF daily mean	Of those WF days, number of SF days where the SF generation is more than the SF daily mean
Jan	5	19	37	65
Feb	6	18	26	56
Mar	6	18	41	59
Apr	7	17	40	49
May	7	17	39	49
Jun	7	17	41	39
Jul	7	17	32	46
Aug	7	17	33	52
Sep	6	17	33	64
Oct	6	18	39	65
Nov	5	18	30	69
Dec	5	18	42	70
			Total of 433 days in 2-year period	Total of 286 days in 2-year period

Table 7 – Wind Farm Days Above Average Output and Solar Farm Days Below Average Output

The ratio of SF days in Table 7 to WF days is 66%. That is, on 66% of the days that the wind farm is producing less than its average output, the SF is producing more than its average output. If the only goal of co-location was solely to minimise diurnal intermittency, in a perfect situation, this number would be closer to 100%.

A calculation was made examining how many days the wind farm produced more than its monthly average output, and of those days, how many days the solar farm produced less than its average output, as shown in Table 8 below. This is the opposite situation to that described in Table 7 above.

Month	Sunrise Hour	Sunset Hour	Number of days in 2018/2019 where daylight hour WF daily generation is more than the WF daily mean	Of those WF days, number of SF days where the SF generation is less than the SF daily mean
Jan	5	19	25	15
Feb	6	18	22	4
Mar	6	18	21	11
Apr	7	17	15	2
May	7	17	23	17
Jun	7	17	19	14
Jul	7	17	30	14
Aug	7	17	29	18
Sep	6	17	27	14
Oct	6	18	22	11
Nov	5	18	30	15
Dec	5	18	20	9
			Total of 283 days in 2-year period	Total of 144 days in 2-year period

Table 8 - Wind Farm Days Below Average Output and Solar Farm Days Above Average Output

The ratio of SF days in Table 8 to WF days is 51%. That is, on 51% of the days that the wind farm is producing more than its daily average output, the SF is producing less than its daily average output. If the only goal of co-location was solely to minimise diurnal intermittency, in a perfect situation, this number would be closer to zero.

The analysis in Table 7 was extended to more extreme cases, such as calculating how many days the wind farm produced less than (X * WF daily average output), and of those days, how many days the solar farm produced more than its average daily output. The value of 'X' was varied between 0.2 and one and the % of SF days above the daily mean as a proportion of WF days below (X * WF daily average output) was plotted, as shown in Figure 14. 'X' is referred to as the Wind Farm Mean Multiplier. This process was repeated with a multiplier on the solar farm average as well and two additional series added to the Figure, that is calculating the % of SF days above (Y * SF daily average output) as a proportion of WF days below (X * WF daily output). In the Figure, moving further left on the x-axis is toward wind farm lower daily output compared to its mean. In a perfect co-location scenario, these plots would slope downward from left to right, which would indicate that as the wind farm progressively produced less energy compared to its daily mean, the number of days the solar farm produced more energy compared to its daily mean was increased. The plots do slope marginally in that direction.

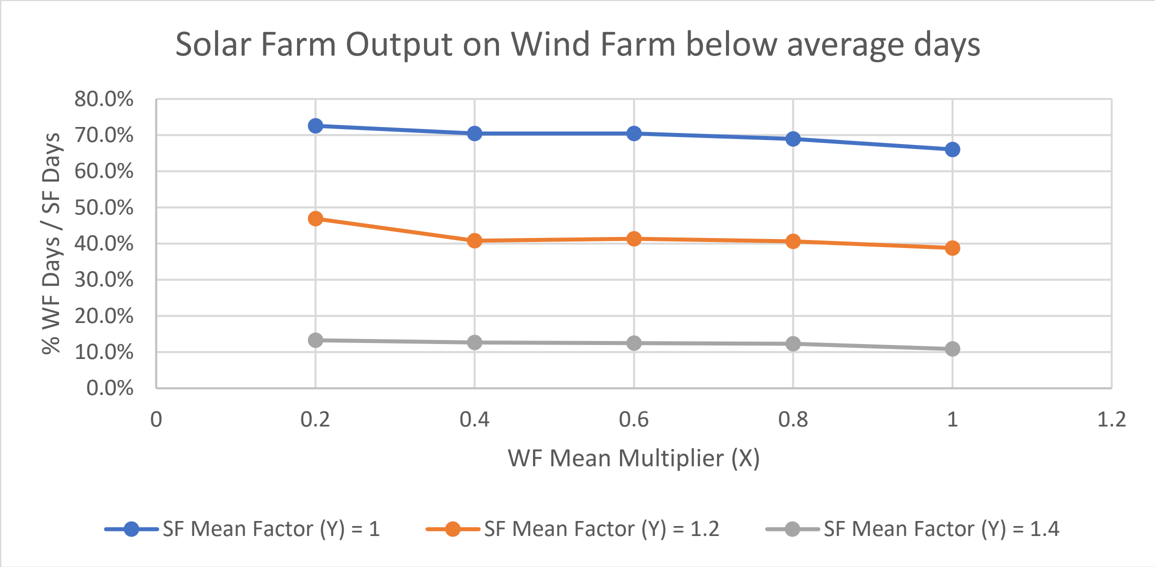

Figure 14 – Analysis of Solar Farm Above Average days on Wind Farm Below Average Days

Comparison of data from other co-located sites would be useful with this type of analysis. However, the similarity in the results of 66% and 51% is supportive of the conclusion from the previous knowledge sharing report that, on a diurnal basis, and based solely on a goal of reducing intermittency, co-location of GSF and GRWF has not been that effective.

However, there are other significant co-location strengths at Gullen Range. The previous knowledge sharing report demonstrated a reduction in intermittency on a seasonal basis. Gullen Range is unlike many other potential co-location sites, in that its connection the electricity grid had some headroom, and both the solar farm and the wind farm can run at full capacity at the same time, reducing the cost of energy for the co-located solar farm.