Lady Elliot Island eco-resort's transition to 100 percent renewable energy

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Griffith Institute for Tourism Research Report No 16

January 2020

ISSN 2203-4862 (Print)

ISSN 2203-4870 (Online)

ISBN 978-1-925455-96-0

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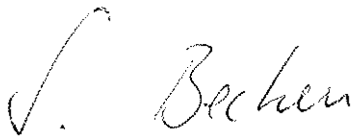
Peer Reviewer

Professor Susanne Becken, Griffith Institute for Tourism



About this report:

This report presents an industry case study of the Lady Elliot Island eco-resort's transition to 100 percent renewable energy. The transition started in 2007 and has proceeded over a period of over a decade during which the main drivers of energy demand and supply have changed significantly. The eco-resort has become steadily busier, electrical loads have changed, the island's renewable energy infrastructure has been extended and improved, and a number of energy and power management initiatives have been implemented.

The eco-resort's daily energy demand and supply characteristics are settling down and detailed power supply and demand monitoring data are available. The eco-resort is now providing a more stable platform for follow-on research into various aspects of the island's renewable energy system, but this report focuses on the story of how the eco-resort team overcame barriers to change, the problems encountered in operating renewable energy infrastructure in a remote and harsh environment, and the ways in which the eco-resort has improved its power and energy management practices to assist the transition.

This report is published as part of the GIFT Research Report Series because it provides important insights and knowledge on tourism sustainability that will be of great use to other tourism stakeholders, both researchers and practitioners.

Acknowledgements:

We thank Professor Susanne Becken for her help and guidance.

The eco-resort's transition to 100 percent renewable energy has also been assisted by funding and other support by the Great Barrier Reef Marine Park Authority; the Great Barrier Reef Foundation's Reef Islands Initiative; and the Queensland Government's Great Barrier Reef Island Resorts Rejuvenation Fund. Thanks to all.

Organisation involved:

Lady Elliot Island Eco-Resort

Lady Elliot Island is the southernmost island on the Great Barrier Reef. It is home to a small eco-resort that is served by small aircraft flying from Bundaberg, Hervey Bay and the Gold Coast. The eco-resort operates according to a strong sustainability imperative, managing the island for the benefit of future generations.

Executive Summary

The Lady Elliot Island (LEI) eco-resort in the southern Great Barrier Reef operates under a lease from the Commonwealth of Australia and is managed according to a strong sustainability ethic. In 2005, the eco-resort's lease passed to new owners who resolved to reduce its carbon footprint by breaking away from its reliance on diesel generators.

Solar power is the most attractive renewable energy option for the eco-resort. The island's wind energy potential shows it to be attractive for a small (< 20 kW) wind turbine facility but a wind turbine suitable for the island has not yet been found. Tidal and wave energy options were considered unacceptable for a variety of reasons.

LEI management took a staged approach to the transition to renewable energy, since they had no experience of operating a solar facility or battery banks. They decided to establish a Hybrid Solar Power (HSP) station that integrated solar and diesel power generation and used batteries to store energy, with a control system tailored to the eco-resort's situation. Following this first step, the transition to renewable energy would then take place over a period of years.

A 2007 audit of the electric energy usage of the eco-resort led to an ongoing energy reduction program. The kitchen accounted for two-thirds of the energy usage and electric ovens were replaced with gas units to reduce the early morning and late afternoon peak power demand which was difficult for the HSP station to handle. The eco-resort's solar power generating capacity has now grown to the point that the kitchen is about to return to using electric ovens.

Modifications to the desalination plant allowed it to meet the eco-resort's daily freshwater requirements within day time hours, and the freshwater storage capacity was doubled so the freshwater storage tanks act as additional batteries and enable the eco-resort to avoid using the desalination plant on cloudy days when solar power generation is reduced. Similarly, extra air compressors and air storage cylinders were added to the eco-resort's dive operations, allowing the power-hungry compressors to be operated mainly during periods of peak solar power generation. The extra stored compressed air reduces the need to run the compressors on cloudy days, and SCUBA air tanks can be filled more quickly than before.

Within two years the eco-resort estimated that it had reduced energy demand by 24 percent, which sends a clear message that energy reduction initiatives applied to a facility that hasn't paid much attention to such things can make a substantial difference in a short period of time.

Barriers to change were:

Funding. The island's renewable energy infrastructure has cost $2 million over the past decade, well beyond what the eco-resort could have afforded in 2007.

Complexity. An HSP station is much more complicated than either stand-alone generators or stand-alone solar panels.

Practical knowledge. The eco-resort realised a substantial learning curve had to be overcome. People who operate equipment in a remote location must learn how it works and service it themselves to the extent possible.

Maintenance. Equipment in a harsh environment can need specialist maintenance. Spare parts from overseas suppliers need to be available.

The eco-resort employed a number of strategies to help overcome these barriers to change, in addition to energy demand reduction initiatives.

- An initial HSP station was designed that was affordable and paid for itself quickly through reduction in diesel fuel usage. The cost of doing nothing made this an attractive proposition.
- The eco-resort took small steps, regularly adding solar panel arrays and improving power and energy management. This minimised the consequences of problems.
- The eco-resort installed a number of separate and relatively small solar panel arrays instead of a fewer number of larger arrays, to minimise the consequences in the event an array experienced a problem and had to be taken off line for some reason.
- The eco-resort shared knowledge with others, a very helpful two-way street.
- The eco-resort invested in making several of the team renewable energy specialists.
- The eco-resort team had faith in itself. A can-do attitude is essential to change.

The key components of an HSP station are solar panels, inverters, a generator, battery banks, and a control system to manage the power supply and demand. This report describes the HSP station when it was commissioned in 2008 and describes the additional renewable energy equipment installed through to late 2019. At that time the eco-resort had a solar generating capacity of 165 kW at 1,000 W/m^2 of solar radiation, plus stand-alone solar hot water units.

In October 2019, the daily solar energy production varied from 629 to 937 kWh and the average was 813 kWh. The daily eco-resort energy demand varied from 553 to 831 kWh and the average was 721 kWh. The eco-resort only ran the HSP station's generator on two days in this month, which is approaching peak tourist season.

This report also discusses the problems encountered during its transition to renewable energy. The solar panels have performed well, with few operational problems. One lesson learned was the importance of orientating some solar panels to catch the early morning and late afternoon sun, smoothing out the power production and the longer solar window meaning less reliance on batteries. The generator had some problems relating to it being used less often, an example being failure of the alternator because its wiring insulation absorbed moisture from the air.

The eco-resort encountered a number of control system problems. Some were avoidable and due to inexperience on the part of the eco-resort team, other problems required software fixes or work-arounds.

The batteries have been the worst performing component of the HSP station, with some batteries needing to be replaced much sooner than expected. Batteries not being charged properly is the single biggest issue seen by the eco-resort when liaising with operators of other renewable energy systems. The eco-resort draws down the battery banks by 30 percent each night as the best balance between battery use and life time, although drawing down batteries by more than 20 percent voids their warranty. The long-term goal is to replace lead acid batteries with batteries that perform better on the island (which is a little too hot for optimum battery performance) and which are more environmentally friendly.

As expected, several issues arose with suppliers. Some suppliers have gone out of business, others underestimated the effort needed to service equipment on a remote island. And the HSP station consists of components procured from different suppliers, so when a problem arises suppliers often blame the problem on another part of the renewable energy system.

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1. Introduction

Lady Elliot Island (LEI), is the southernmost island on the Great Barrier Reef (GBR), one of 16 cays in the Capricornia section of the GBR. In 1969/70, an eco-resort was established on the island, operating under a lease from the Commonwealth of Australia, through the Great Barrier Reef Marine Park Authority (GBRMPA). The eco-resort is served by small aircraft flying from Bundaberg, Hervey Bay and the Gold Coast.

The LEI eco-resort operates according to a strong sustainability imperative, managing the island for the benefit of future generations. In 2005, the eco-resort's lease passed to new owners who resolved to reduce its carbon footprint by breaking away from its reliance on diesel generators. The potential economic benefit of switching to renewable energy was further incentive to change. Also, no amount of care in fuel handling can eliminate the risk of a fuel spill, which could have devastating consequences for the island's biodiversity.

Figure 1. Lady Elliot Island is a 40 ha coral cay that lies at the southern end of the GBR, 80 km north-east of Bundaberg. The presence of an eco-resort ensures people do not bring dogs on the island, burn or remove vegetation, fish, or disturb seabird rookeries. Visiting vessels are required to anchor at approved locations.

In 2007, the eco-resort engaged a consultant to audit the resort's energy usage, and then implemented an ongoing program of energy reduction initiatives. In 2008, despite a number of barriers to change, it commissioned a company to design and build a Hybrid Solar Power (HSP) station, consisting of solar panels, a generator, battery banks and a control system. Over the next decade, the eco-resort solved the problems of operating this equipment in a harsh and remote location and installed additional renewable energy infrastructure. In late 2019 the eco-resort operated for an entire week without using the HSP station's generator, meeting its daily 800 kWh energy needs entirely with power generated by its solar panel arrays.

GBRMPA, the Queensland State Government and other authorities have been very supportive of the eco-resort's work to transition to renewable energy. The initiative aligns with GBRMPA's Great Barrier Reef blueprint for resilience (GBRMPA, 2017) which *promotes the uptake of renewable energy and emission reduction activities among reef communities, industries and visitors, including through showcasing practical initiatives.*

The LEI eco-resort's initiative in 2007/08 was one of the first attempts by a GBR island facility to significantly reduce its carbon footprint. There are now several similar initiatives such as the University of Queensland's research station on Heron Island, which is expecting to commission a solar power facility in mid-2020 that will reduce the research station's reliance on diesel generators by about 80 percent. The University's research station and the LEI eco-resort have very similar factors motivating their transitions to renewable energy. The research station wants to end its reliance on diesel-generated power, and they also want to "demonstrate – particularly to businesses in remote and marine environments – that renewables are a cost-effective option" (Chapman, 2019).

James Cook University's research station on Orpheus Island has also transitioned to renewable energy. In March 2019 the research station commissioned a renewable energy system that is smaller but otherwise quite similar to the LEI eco-resort's HSP station.

It is not surprising that University research stations are among the first island facilities to transition to renewable energy since universities have funding and technical capacities that help to overcome barriers to change. However, the LEI eco-resort's initiative shows that island facilities other than research stations can also achieve a transition to renewable energy.

This paper tells the story of how the eco-resort did it and lessons learned on the way. It starts by explaining why the eco-resort chose this renewable energy option, describes the energy reduction initiatives that assisted the transition, and then discusses the barriers to change and the eco-resort's strategies to overcome these barriers. It describes the HSP station equipment and operation in detail, and the way the eco-resort's solar power generation capacity was gradually increased and improved, with a focus on discussing the operational problems encountered since the HSP station was commissioned in 2008.

2. Rationale for choosing a hybrid solar power system

Solar power is the most attractive renewable energy option for the eco-resort. Photovoltaic efficiency has steadily improved, the cost of solar panels has steadily reduced, and solar panel technology is simple and reliable. Bureau of Meteorology data show that the Capricornia section of the Queensland coast receives an annual average of about 18 MJ/m^2 of solar energy per day, but LEI receives a little more than this because a small offshore island tends to have less cloud cover than the coast.

LEI has a weather station, and analysis of the island's wind energy potential shows it to be attractive for a small (< 20 kW) power supply top-up wind turbine facility. The wind turbine would need to be bird-friendly, low noise, highly resistant to corrosion and compatible with the HSP station. However, the eco-resort is located on the windward (east) side of the island so the wind turbine would be well placed to take advantage of the island's strong easterly wind signature. The eco-resort has not yet found a suitable wind turbine but hopes to do so within the next few years.

The eco-resort's proximity to the ocean means tidal and wave energy options for power generation were also considered. Tidal currents around the island are sufficiently strong that they have power generation potential. However, the GBRMPA would be unlikely to approve installation of marine power generation equipment in a GBR Green Zone, and the equipment would have to cope with occasionally very rough conditions on the windward reef flat and surrounding ocean. Overall, the risk of something going wrong is unacceptably high given that power supply is an essential service, especially when a suitable alternative exists (solar power) and is readily available.

LEI management realised a staged approach to the transition to renewable energy was needed, since they had no experience of operating a solar power facility or battery banks, and they didn't understand important issues such as how much solar power could be generated during a prolonged period of bad weather. A staged approach meant the eco-resort would initially continue to use a generator to help meet its power needs and as a failsafe in the event something went wrong with the renewable energy supply. However, the eco-resort wanted to gradually reduce its use of the generator and decided the best way forward was not to operate the generator and the renewable energy infrastructure as stand-alone independent power supplies. Instead, the eco-resort decided to establish a Hybrid Solar Power (HSP) station that integrated solar and diesel power generation, used batteries to store energy, with a control system tailored to the eco-resort's situation. Following this first step, the transition to renewable energy would then take place over a period of years.

3. Energy demand reduction initiatives

The 2007 audit of the electric energy usage of the eco-resort identified 776 individual loads with a total consumption of about 870 kWh per day, or 319 MWh per year. The energy demand varied throughout the day with peaks due to the kitchen using electric ovens to prepare meals. Indeed, the kitchen accounted for two-thirds of the energy usage and the balance was mainly due to the desalination plant, lighting, air conditioners, water heaters, fans, and office equipment. The eco-resort's energy demand was met by three generators, which together used about 550 litres/day of diesel fuel, emitting 550 litres x 2.68 kg CO_2 per litre x 365 days ≈ 538 tonnes of CO_2 per year.

The eco-resort commenced an ongoing energy reduction program. Actions to date include:

- Electric water heaters were replaced with on-demand LPG units. This reduced electric power demand, and also reduced total energy demand because the water heaters were often keeping water hot when it wasn't needed. However, the LPG units were temporary measures since gas is still a fossil fuel and the eco-resort is now installing solar powered hot water units.

- Electric ovens were replaced with gas units. This reduced the early morning and late afternoon peak power demand which was difficult for the HSP station to handle, but the eco-resort's solar power generating capacity has now grown to the point the kitchen is about to return to using electric ovens.

- Conventional lights were replaced with low-power lights (initially CFLs, now LEDs).

- Insulation curtains were installed to reduce heat loss when opening refrigerators and freezers.

- Energy efficiency is considered when purchasing new equipment.

- Staff protocol is to turn off all lights and equipment when not in use. Guest arrival induction advice and signage throughout the eco-resort urges guests to be careful with power (and water) use.

- Clothes driers were replaced by clothes lines covered to protect them from bird droppings.

- Extra air compressors and air storage cylinders (from which SCUBA air tanks are filled) were added to the eco-resort's dive operations. This allows the power-hungry compressors to be operated mainly during periods of peak solar power generation, and the extra stored compressed air can be used on cloudy days (i.e. it acts as a battery). In addition, air tanks can be filled more quickly than before.

- The eco-resort monitors power use and investigates any periods of unusually high demand.

- The desalination plant's seawater pump was adjusted to operate on-demand instead of continuously.

- The desalination plant's reverse osmosis membranes were replaced with larger units, and a larger motor was installed with a variable speed drive. This enabled the desalination plant to produce water at twice the previous rate, but at approximately the same power requirement, so it only has to operate for about nine hours a day to meet the eco-resort's daily freshwater requirements and it does not need to operate outside daylight hours.

- The eco-resort's freshwater storage capacity was approximately doubled to just over 400,000 litres enabling the desalination plant to produce surplus freshwater when more solar power is being generated than the eco-resort needs, so the freshwater storage tanks act as additional batteries. Increased water storage also enables the eco-resort to avoid using the desalination plant on cloudy days when solar power generation is reduced.

Figure 2. The desalination plant is housed in the shed with the white roof. The freshwater storage tanks in the foreground hold more than twice the eco-resort's daily needs and can supply the eco-resort on cloudy days instead of operating the desalination plant. Note the electric golf buggies used by staff for getting around the island.

By 2009, the eco-resort estimated that it had reduced energy demand by 24 percent, which sends a clear message that energy reduction initiatives applied to a facility that hasn't paid much attention to such things can make a substantial difference in a short period of time.

The energy saving efforts continued and in July 2012 (winter), the eco-resort's energy usage had decreased to about 525 kWh per day, rising to 625 kWh per day in January 2013 (summer). The total energy usage had therefore been reduced by about 35 percent, from 319 MWh per year in 2007 to 210 MWh per year in 2013.

After 2013, the eco-resort's energy demand began to increase because the eco-resort was steadily becoming busier. When the lease changed hands in 2005 the eco-resort often operated at less than 50 percent capacity and now (2019) it is operating above 90 percent capacity throughout the year (the number of people on the island is limited to a maximum of 50 staff, 100 day guests, and 150 overnight guests).

In addition, new equipment has changed the eco-resort's power requirements, for example an on-site electric-powered composting system, a new wastewater treatment plant and a new reef education centre. The eco-resort's average daily power demand is currently about 700 kWh per day, ranging from 600 kWh per day in winter to over 800 kWh per day in summer.

4. Barriers to change

There are sound reasons to change from fossil fuel to renewable energy power systems but there are also barriers to change. However, some barriers are more important at a national level than in the context of the LEI eco-resort. For example, Byrnes et al. (2013) note that Australian barriers to change include government support for fossil fuel usage and lack of action regarding setting a carbon tax or significant renewable energy targets. However, such considerations are not sufficient to negate the economic benefit of LEI's transition to renewable energy. Similarly, the not-in-my-backyard (NIMBY) syndrome is often a barrier to establishing wind farms (e.g. Seetharaman et al. 2019) but is not relevant to LEI.

This industry case study is set on a GBR island, and islands on the GBR and across the South Pacific generally share a number of barriers to changing to renewable energy infrastructure. Few islands are connected to a national electricity grid, so an island-based power supply is an essential service and diesel generators are reliable and well understood; islands have small populations and lack the financial and technical resources needed to change to renewable energy; and island are remote from suppliers (Weir, 2018).

However, islands also share strong economic, political and environmental incentives to switch from imported fossil fuels to renewable energy technologies (Betzold, 2016). Diesel fuel is expensive and has associated environmental risks; the concerns held by Pacific island nations regarding climate change are well documented; and islands often have good solar and wind energy resources. Many Pacific island nations have set ambitious renewable energy targets and donors of financial aid are very supportive of these goals (Betzold, 2016).

The LEI eco-resort team identified four principal barriers to making the transition to renewable energy that many resorts and similar facilities located on other islands on the GBR and across the South Pacific share.

i) Funding

Renewable energy infrastructure has cost the eco-resort about $2 million over the past decade. As an upfront capital expenditure this was beyond what the eco-resort could have afforded in 2007, especially since there were many other budget demands. The problem was overcome by designing an HSP station that was small enough to be affordable and able to pay for itself in 2 to 3 years through reduction in diesel fuel usage. However, the $600,000 (2008) cost was still a substantial up-front expense. Funding support of $200,000 from the Federal Government's Renewable Remote Power Generation Program helped. This program closed in 2009 but seeking funding support is certainly one way to help overcome this barrier to change.

Another helpful factor was setting the cost of the investment in renewable energy infrastructure against the cost of the do-nothing option. The eco-resort knew the HSP station alone would not be sufficient to complete the transition to renewable energy, but nevertheless estimated it could achieve significant savings in diesel fuel and freight costs. It would also reduce the cost of improving its fuel handling systems and reduce the risk of fuel spill, a major concern for an eco-resort located in a GBR Green Zone.

ii) Complexity

In 2007, the LEI team received advice from two separate consultants that the eco-resort should continue to rely on its generators, because an HSP station is substantially more complicated than either stand-alone generators or stand-alone solar panels.

Power is an essential service, so the concern that the LEI team would have difficulty operating the HSP station was a significant barrier to change which resurfaced soon after the HSP station was commissioned because a mistake in operating the station led to two of the eco-resort's three generators being damaged beyond repair. Only one generator was needed to help the solar panels meet the power needs of the eco-resort, but the eco-resort had suddenly lost the ability to close down the solar panels and return to operating generators alone.

iii) Practical knowledge

An issue related to the complexity of an HSP station was lack of practical knowledge about its operation on the part of both the LEI team and suppliers. The LEI team realised they would need to overcome a learning curve before they could operate the new station with confidence. It was also clear that some people promoting the benefits of an HSP station did not have much experience of operating equipment in the harsh environmental conditions of a remote coral cay.

It is important that people who operate equipment in a remote location learn how the equipment works at a hands-on level and be able to service the equipment themselves to the extent possible, thereby avoiding unnecessary reliance on specialist suppliers. The LEI team had learned this lesson in other areas, including operation of a new wastewater treatment plant that took a lot of effort before it achieved ongoing good performance. This experience helped the team to overcome the concern that they would find themselves out of their depth. They set out on the learning curve having faith in themselves, believing they would succeed in gaining the practical knowledge necessary to ensure a transition to renewable energy. Believing something is possible improves the chance of success. A can-do attitude is essential to changing to a new way of doing things.

iv) Specialist support

Equipment operating on a barrier reef island often needs significant maintenance, due to corrosion by the salty marine air, problems caused by high air temperature and humidity, extreme weather events (including cyclones), and damage from bird faeces since the island is home to thousands of birds. Inevitably some issues require support from off-island specialists. In addition, spare parts need to be readily available, a potential problem given that many components of the HSP station would be provided by overseas suppliers.

These concerns were barriers to change, rather than outcomes of a learning experience, because they were recognised issues when the eco-resort was considering making the transition to renewable energy, since they also apply to other equipment operated by the eco-resort, such as its wastewater treatment and desalination plants. The eco-resort's experience is that some suppliers have difficulty accepting that their equipment isn't performing according to expectations because they don't appreciate the harsh environmental conditions associated with a coral cay. It is also common for suppliers to underestimate the cost of providing follow-up support for equipment operating on a remote island.

The eco-resort employed a number of strategies to help overcome these barriers to change, in addition to the measures outlined above.

- The energy demand reduction initiatives are described in Section 3. Perhaps one of the most important initiatives was the recognition that surplus freshwater and compressed air (for SCUBA tanks) produced during periods of peak solar power generation could act as additional batteries. Notton (2015) also recognised the importance of energy storage in the context of renewable energy systems for islands.

- The eco-resort took small steps. Its transition to renewable energy has taken 11 years to date, with new solar panel arrays added on a regular basis. This step-by-step strategy has minimised the consequences of problems and has facilitated a series of initiatives to improve the HSP station's performance.

- The eco-resort installed a number of separate and relatively small solar panel arrays instead of a fewer number of larger arrays, to minimise the consequences in the event an array experienced a problem and had to be taken off line for some reason.

- Knowledge sharing with others is very helpful and a two-way street. LEI management reached out to others to discuss the eco-resort's efforts to transition to renewable energy and has been contacted by others seeking to learn from the eco-resort. Indeed, this paper is deliberately written in a way that the authors hope will make it readable to operators of other facilities in remote locations.

- The LEI team invested in making several of their people responsible for leading the transition. Their goals were to know the suppliers, understand how to install and operate solar panel arrays, battery banks and the control system, seek ways to improve operation of the HSP station, and plan the installation of new infrastructure. These people were also in charge of the ongoing energy demand reduction work.

5. Renewable energy infrastructure

Figure 3 shows the key components of a hybrid solar power station, including the multi-cluster control box that integrates the components into a cohesive system.

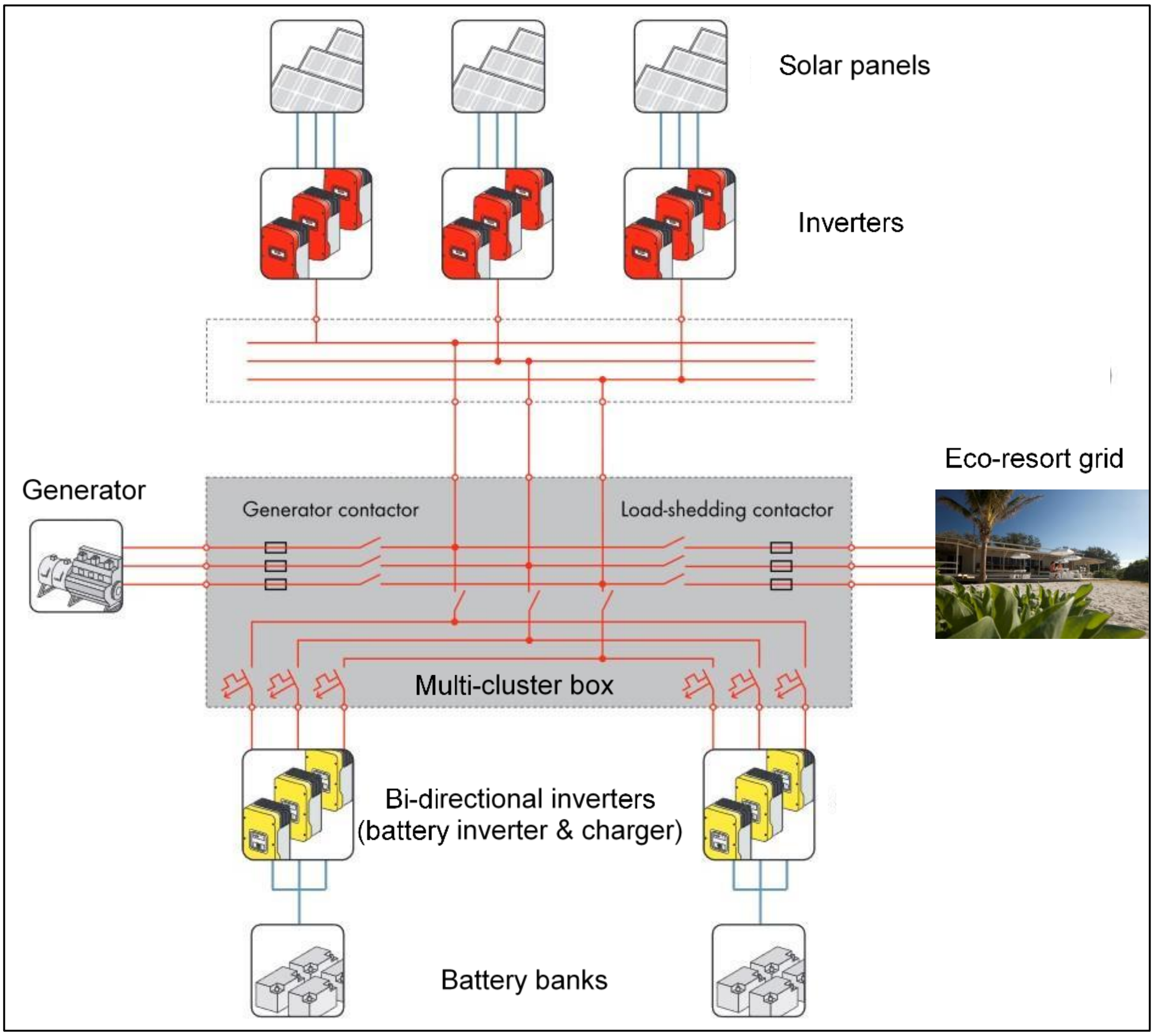

Figure 3. The key components of a hybrid solar power station.

A solar power installation uses the photovoltaic cells in an array of solar panels to produce a Direct Current (DC). This can be used to power DC electrical loads, perhaps with a voltage regulator, or an inverter can convert the DC to single-phase Alternating Current (AC) which can power small AC electrical loads, typically less than 1 kW. Three-phase AC is necessary for larger electric loads and initially this was produced using three sets of solar panels, each served by an inverter. Now the HSP station feeds the output from three sets of solar panels to a single inverter able to output three-phase AC.

Battery banks provide energy storage capacity. If the incoming power is AC, then an inverter is needed to convert the power to DC. Stored energy is released as DC, and as with the solar power this can either be used to power DC electrical loads or inverters can convert the DC to either single-phase or three-phase AC.

If the available solar power is more than the eco-resort needs at that particular time, then the surplus power can be used to charge the batteries. If the eco-resort needs more power than is available from the solar panel arrays, then it can be provided by the battery banks.

Figure 4 shows photographs of the HSP station soon after it was commissioned in 2008. It is an open-sided east-west hardwood timber facility that has little environmental impact, resting on simple concrete bearers that have not damaged the underlying coral cay. The HSP station is designed to withstand cyclone-level winds. Worst-case wind loading is when winds are from the south, but that side of the HSP station is a vertical wall, the solar panel array tilts towards the north, and the structure weighs over 80 tonnes so southerly wind loading is not able to exert an upward force on the solar panel array.

Figure 4. Clockwise from top left. The HSP station soon after it was commissioned in 2008, with the green diesel generator just visible under the solar panels; lead-acid battery banks; the three inverters (red boxes) serving the solar panels, and three inverters (yellow boxes) serving one of the battery banks; and the inside of the multi-cluster control box.

The HSP station components have changed over time, as discussed below, but in 2008 were as follows:

- *Solar panels*. 96 x 1.5 m^2 Kyocera solar panels. The panels each produce 205 W at 1,000 W/m^2 of solar radiation*, and together generate ~20 kW of power under these conditions.

- *Inverters.* The solar panels are served by three SMA Sunny Mini Central 7000TL inverters, each producing single phase AC power. Each battery bank is served by three SMA Sunny Island 5048 inverters (one master, and two slaves), which each produce single phase AC power from the batteries and can also charge the batteries.

- *Generator.* An 80 kVA Nippon Sharyo diesel generator, with a DD-6BG1T engine serving an NEA-7504 alternator that produces 56 kW (at 1500 rpm) of three phase AC power.

- *Batteries.* Two x 24 Sonnenschein (Exide) A602/3500 lead acid battery banks.

- *Control system.* An SMA MC12 multi-cluster box. This control system combines the single-phase power feeds from the battery bank inverters, and from the solar panel inverters, into 3-phase 415V AC power. Power from the generator is also managed by the multi-cluster box.

By 2010, the HSP station and energy reduction initiatives together had reduced the eco-resort's diesel fuel usage by 400 litres per day. Diesel fuel in 2010 cost $1.40 per litre but the cost of transporting fuel to the island by barge added $0.50 per litre. A detailed calculation of the pay-back period would include the cost of implementing the energy reduction initiatives, offset by the reduced cost of upgrading the fuel handling and storage systems, but at first pass the eco-resort estimated that it was saving nearly $250,000 per year by 2010, and that the HSP station paid for itself in just under three years.

Importantly, the cost of fuel does not include a Federal Government subsidy of 20 to 30 cents per litre, which the eco-resort qualifies for (along with airlines, haulage companies etc.). Without the subsidy the eco-resort would have been saving more, making the transition to renewable energy even more attractive.

After commissioning the HSP station, the eco-resort has steadily increased and improved its renewable power infrastructure. Figure 5 shows the eco-resort in late 2019 and Table 1 lists the solar panel arrays installed through to late 2019. Table 1 shows that the eco-resort in late 2019 had a total of 165 kW of generating power (at 1,000 W/m^2 of solar radiation*), which equates to a 220 kVA diesel generator with a power factor of 0.8 and a typical fuel usage rate of 40 litres/hour under load.

Batteries have been the worst performing component of the renewable energy infrastructure. Table 2 summarises their history and Table 3 lists the nine battery banks serving the eco-resort in late 2019. The Sonnenschein and BAE batteries are 2V batteries connected in series, so each battery bank is 48V. The Aquion batteries are 48V units connected in parallel. The C-10h capacity is the capacity (Ah) of a battery that is drawn down over a 10-hour period. The battery bank energy is calculated as kWh = capacity (Ah) x voltage (V) / 1000, and the useable energy assumes the battery bank is drawn down by 30 percent before being recharged (70 percent in the case of the Aquion batteries).

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*Standard conditions for assessing solar panel performance are 1,000 W/m^2 of solar radiation, 25°C temperature, and an air mass coefficient of 1.5.

Figure 5. The eco-resort in September 2019. See Table 1 for details of solar panel arrays.

Table 1. LEI solar panel arrays, excluding 18 kW of stand-alone solar hot water units.

Solar panel array	Specification	Power
HSP. Hybrid solar power station (2008)	144 m^2, 96 REC panels, 205W rating	20 kW
A. Breezeway (2012)	52 m^2, 32 REC panels, 245W rating	8 kW
B. Lodges (2013)	96 m^2, 60 REC panels, 250W rating	15 kW
C. Dive shop roof (2014)	104 m^2, 65 REC panels, 260W rating	17 kW
D. Main office (2014)	96 m^2, 60 REC panels, 260W rating	16 kW
E. Kitchen (2016)	96 m^2, 60 REC panels, 260W rating	16 kW
F. Education centre (2016)	94 m^2, 56 Qcell panels, 235W rating	13 kW
G. Runway (2017)	70 m^2, 42 Qcell panels, 235W rating	10 kW
H. Near HSP (2019)	280 m^2, 170 REC panels, 290W rating	50 kW
		165 kW

In 2016, the eco-resort decided to move away from using lead acid batteries. They are not environmentally friendly and must be fully charged regularly, which is difficult given that solar power supply and the eco-resort's power demand both fluctuate. The air temperature on Lady Elliot Island is also often above the 20°C optimum temperature for lead acid battery operation, significantly reducing battery life. In 2016, the eco-resort trialled Aquion batteries which were advertised as having none of these issues with more draw-down / recharge cycles, but they have not performed well, and the supplier has now gone out of business, so unfortunately subsequent purchases have continued to be lead acid batteries.

Table 2. History of the LEI battery banks.

2008	Two battery banks installed, each with 24 Sonnenschein A602/3500 lead acid batteries.
2011	A third battery bank was installed using 24 BAE 24 PVV 4560 lead acid batteries.
2014	LEI selected the best 24 of the 48 Sonnenschein batteries. The eco-resort made one bank from these 24 batteries and replaced the other 24 with BAE 4560 batteries.
2016	A fourth battery bank was installed using 36 Aquion Energy S30P salt water batteries.
2018	A fifth battery bank was installed using 24 BAE 24 PVV 4560 lead acid batteries.
2019	Four more battery banks were installed, each using 24 BAE 24 PVV 4940 lead acid batteries.

Table 3. The nine battery banks of the eco-resort's renewable energy system in 2019.

	Battery	**Capacity C-10h Ah**	**No. batteries**	**Bank energy kWh**	**Useable energy kWh**
2008	Sonnenschein A602	3000	24	144	43
2011	BAE 24 PVV 4560	3470	24	167	50
2014	BAE 24 PVV 4560	3470	24	167	50
2016	Aquion S30P	40	36	69	50
2018	BAE 24 PVV 4560	3470	24	167	50
2019	BAE 26 PVV 4940	3650	24	175	52
	BAE 26 PVV 4940	3650	24	175	52
	BAE 26 PVV 4940	3650	24	175	52
	BAE 26 PVV 4940	3650	24	175	52
				1414	**451**

In Table 3 the useable energy assumes a 30 percent battery bank drawdown, which is close to what happens every night as the batteries supply power to the eco-resort. The warranty conditions actually require the batteries to be drawn down by no more than 20 percent of their capacity, but it is too costly to operate the batteries with such a small draw down.

6. Station operation

The eco-resort has a real-time power monitoring system. Figure 6 shows the power usage overview display at noon on 28 October 2019 (the system can be used to examine the status of each component of the HSP station). The solar panel arrays were generating 130 kW of power, the eco-resort power demand was 50 kW and the multi-cluster box was directing the remaining 80 kW to charge the battery banks, which were at 83 percent capacity. The display shows that the eco-resort used 831 kWh of energy in the previous 24 hours, generated entirely by the solar panels. The generator had not been used at all.

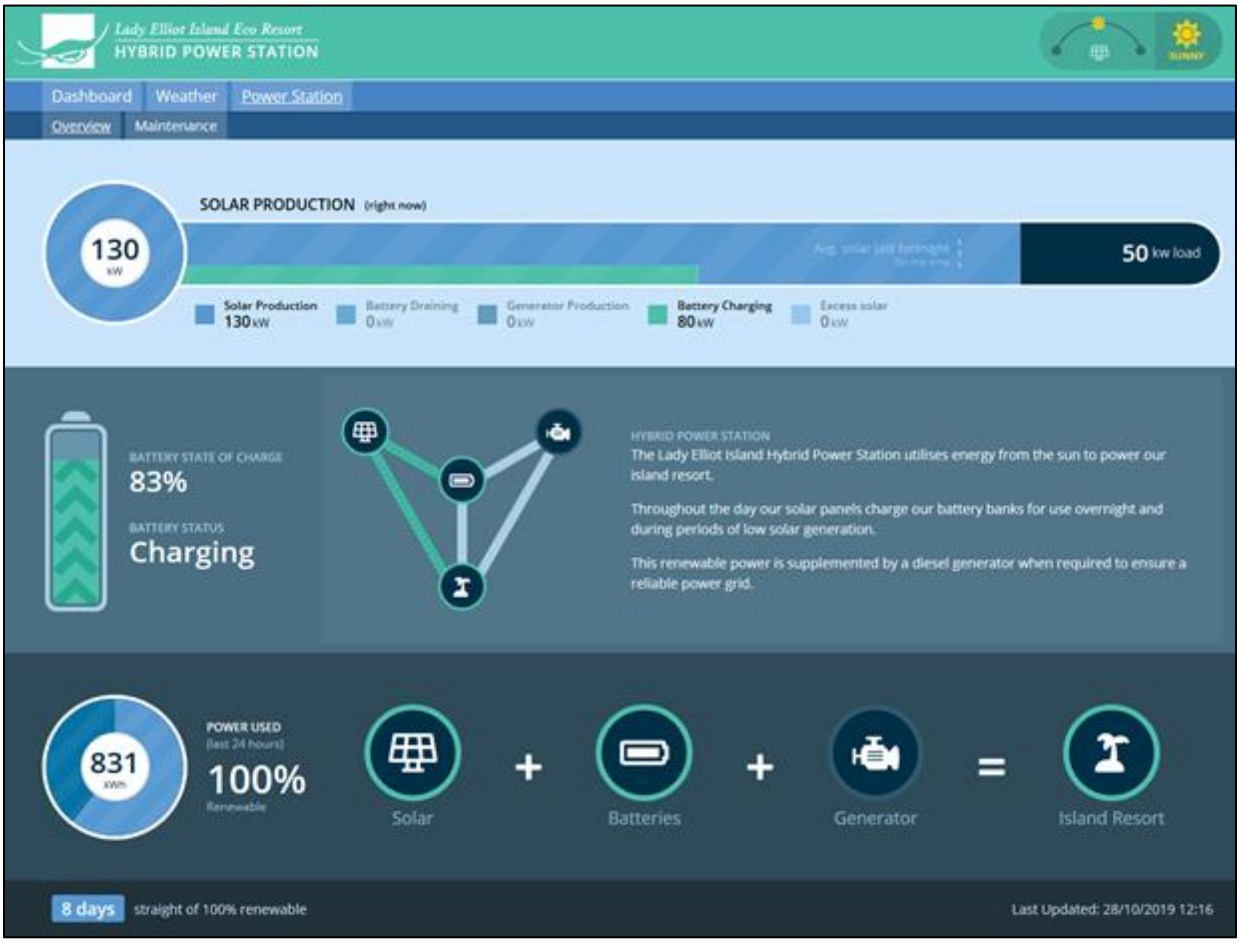


Figure 6. The live power usage display. https://staff.ladyelliot.com.au/powerstation/

Figure 7 shows the monthly energy balance in October 2019 (top plot) and the power balance for 13 October 2019 (bottom plot). Considering the monthly energy balance in October 2019:

- 24.7 MWh of energy was generated by the solar panels, with 13.5 MWh used by the eco-resort and 11.3 MWh used to charge the battery banks.
- The eco-resort used 21.9 MWh of energy, with 13.5 MWh provided directly by the solar panel arrays and 8.4 MWh provided by the battery banks.
- The daily solar energy production varied from 629 to 937 kWh and the average was 813 kWh.
- The daily eco-resort energy demand varied from 553 to 831 kWh and the average was 721 kWh.

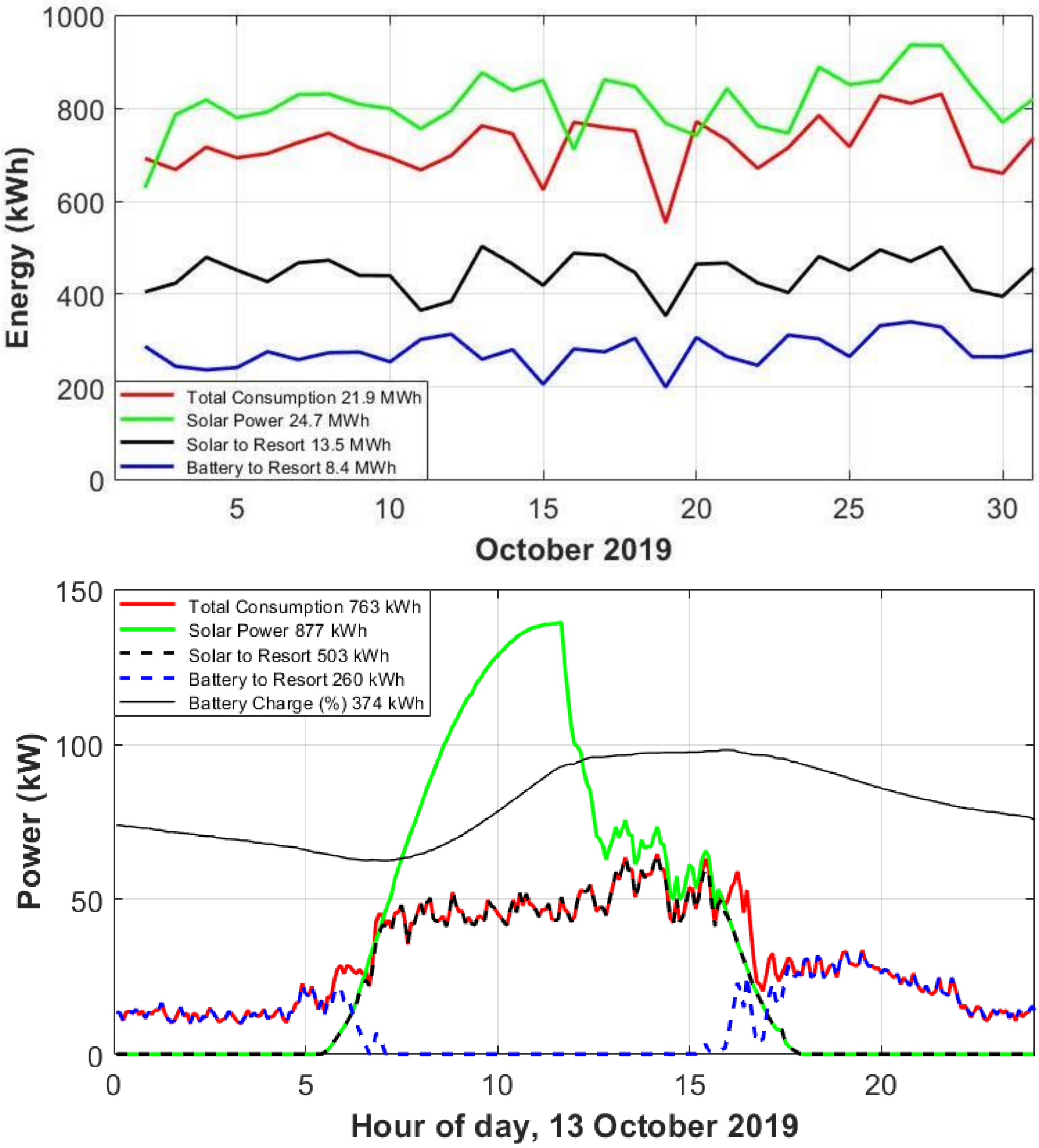


Figure 7. The eco-resort's daily energy balance in October 2019 (top plot) and on the 13 October 2019 (bottom plot).

October is approaching peak tourist season and peak energy demand, but there were only two days in the month for which the energy demand of the eco-resort was less than the energy generated by the solar power arrays, confirming that the eco-resort's transition to renewable energy is nearly complete. Considering the power balance on 13th October 2019:

- 877 kWh of energy was generated by the solar panels, with 503 kWh used by the eco-resort and 374 kWh used to charge the battery banks.
- The eco-resort used 763 kWh of energy, with 503 kWh provided by the solar panel arrays and 260 kWh provided by the battery banks.

The eco-resort's power demand at night was only 10 to 15 kW, and this demand was met by the battery banks. At about 5am the power demand began to grow as the kitchen prepared breakfast for staff and overnight guests, rising to 45 kW by 7am. Dawn was just after 5am and by 7am the solar panels were meeting all the eco-resort's power demand. By this time the battery banks had been drawn down to 63 percent and surplus solar power was being used to recharge the batteries.

By noon the batteries had recharged to 94 percent capacity and the system started to automatically reduce solar power production by adjusting the grid frequency which the solar inverters use as a signal to ramp up or ramp down production. The LG solar system output calculator (www.lgenergy.com.au/solar-calculators/solar-system-output-calculator) estimates that a well-installed facility at Lady Elliot Island should generate 31.2 MWh in October, based on solar irradiation data from the Bureau of Meteorology. The calculator then reduces this estimate by 14 percent to allow for various losses, to 26.8 MWh. Overall the 24.7 MWh of solar power generated in October by the eco-resort's solar panels compares favourably with this estimate, the shortfall being mainly due to the system automatically reducing solar power production once the batteries are recharged, and also because some of the solar panels are oriented to catch the early morning and late afternoon sun.

The eco-resort encountered a number of problems during its transition to renewable energy.

Solar panels.

The solar panels have been the best performing component of the renewable energy infrastructure, with very few operational problems. The solar panels installed in 2008 continue to operate well, and their performance guarantee is that after 25 years they will still generate at least 80 percent of the power generated at the time of purchase. The island is home to numerous seabirds, but they do not like to perch on the solar panels, so bird faeces has not been a significant problem. The eco-resort cleans the solar panels daily in the summer on a schedule that cleans each array once a month.

There have been some minor equipment issues. Two solar panels on the HSP building are currently suffering from an insulation break down. They are still generating power, but they are unsafe to operate and have been disconnected from the system. And the panel manufacturer has gone out of business. One solar inverter failed but was replaced under warranty.

Another problem was that solar thermal hot water units installed to serve the visitor accommodation quickly succumbed to the harsh environment: the eco-resort is now installing solar PV units which have proven far more durable. The lesson from this problem is to trial new equipment when possible, to minimise the consequences if it doesn't perform well.

Another important lesson learned was the benefit of orientating some solar panels to catch the early morning and late afternoon sun. As shown in Figure 8, this smooths out the power production and gives the eco-resort a longer solar window which means less reliance on batteries: solar panels are cheaper, easier to maintain, and last longer than batteries.

Generator.

Before 2008, the eco-resort operated three diesel generators housed in a shed that was always hot and dry, with at least one generator running at any time. Soon after the HSP station was commissioned its generator was being used daily but not all the time, which caused problems. The control system turned the generator on and off in response to small changes in power demand and supply which was not good for the generator.

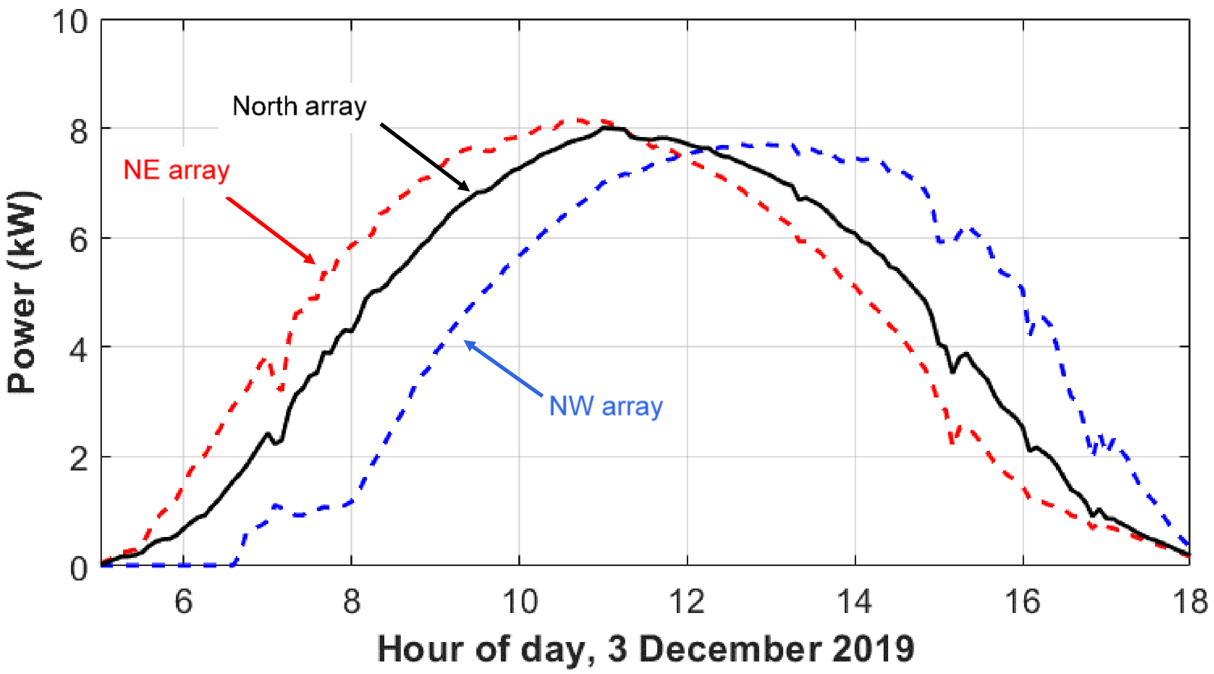


Figure 8. North-east facing solar arrays provide more power in the early morning than conventional north-facing solar arrays, and north-west facing solar arrays provide more power in the late afternoon than north-facing solar arrays. This helps to reduce battery draw down, which has clear cost benefits.

Although it was a waste of diesel fuel to operate the generator when its power was not needed, the eco-resort took operation of the generator away from the HSP control system and started it by a timer at 5:30 am, operating it continuously until stopped by the control system in the afternoon.

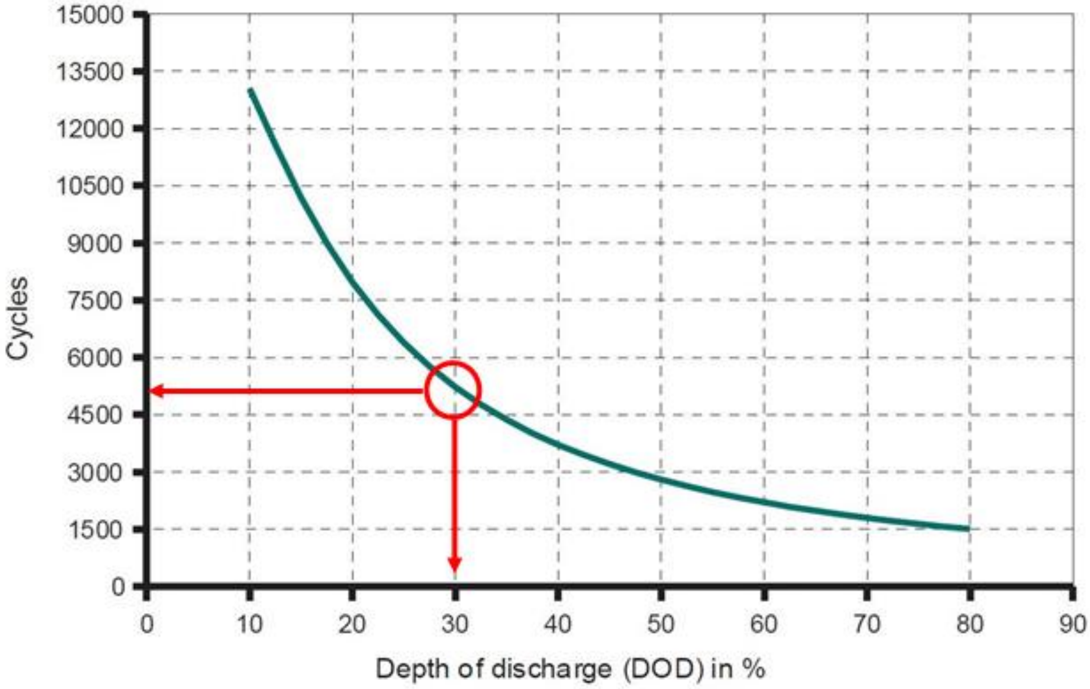
Another problem was that the generator cooled after being switched off, causing the alternator to fail because its wiring insulation absorbed moisture from the air. The solution was to duct hot air from the generator's engine to heat the alternator ahead of switching off the generator to keep it warm overnight; and the generator windings were treated to help with moisture and insolation.

In addition, the generator sometimes over heated inside the HSP building. Generator overheating is usually solved by fans and externally mounted cooling systems, but these solutions all use power. The eco-resort instead solved the overheating problem with building modifications, avoiding the extra energy required for other solutions.

Batteries.

The frequency of battery bank cycling, the depth of energy discharge (drawdown), and the effectiveness of the charge cycle are the key determinants of battery life, and air temperature is also important. As noted in Table 2, the worst 24 Sonnenschein batteries were replaced in 2014 after only 2,000 discharge cycles and this was a wake-up call about the need to better manage battery discharge since it is expensive to replace batteries. Over the last 11 years the eco-resort has been monitoring and tracking the degradation of the batteries over time and, using these data, has set a 30 percent depth of discharge as the best balance between battery use and life time. Figure 9 shows the batteries should last 5,000 cycles. The goal is for battery banks to last 10 years before needing to be replaced.

Figure 9. Battery life depends on the depth of discharge. This curve is for a BAE battery.



Control system.

- The master inverters serving the battery banks initially had difficulty working together, due to incompatibilities in their driving software, a problem solved by a software upgrade.
- Recently the eco-resort had an issue whereby the older battery inverters would not work with the new battery inverters and needed to be replaced (under a heavy discount from the supplier).
- The master battery inverters were not correctly monitoring the state of health of the battery banks, which resulted in the battery State of Charge (SOC) measurement becoming less accurate over time. The battery SOC began to fluctuate which in turn created issues for control functions that rely on the SOC. The eco-resort solved the problem by doing their own battery testing and setting the battery health at the correct level. This is now an ongoing maintenance procedure.
- The control system has a problem in that it only puts the batteries into full charge mode when they are drawn down by at least 30 percent, which is the maximum daily draw down and doesn't happen every day. But the batteries need to enter full change mode every day in order a get a proper charge, which is essential to prolonging battery life. Batteries not being charged properly is the single biggest issue seen by the eco-resort when liaising with operators of other renewable energy systems, some of whom report batteries that have failed within two years due to under charging. The control system manufacturer is working on a solution and in the meantime the eco-resort has worked around the issue by telling the control system the batteries are at 50 percent charge when they are really closer to 70 percent charge. This work-around has been successfully used by other operators faced with the same issue.
- As noted, while commission the HSP station, system power was fed back into the generators, damaging two of the three generators beyond repair. The fault was traced to a change-over switch.

- Soon after commissioning the HSP station, the control system caused several generator failures. An investigation found the HSP station's programming allowed power to flow from the system back into the generator. The manufacturer of the control system was requested to provide a software fix and in the 12 months it took this to happen the eco-resort operated a manual generator shutdown procedure which protected the generator during this time.

Supplier issues.

Without going into detail, several problems with suppliers have arisen since commissioning the HSP station in 2008. As noted, such problems were anticipated and therefore were a barrier to change. As expected, some suppliers didn't realise that their equipment would need to operate in such harsh conditions, or they underestimated the effort needed to service equipment on a remote island. In addition, some of the technology in the renewable energy system was quite new and not supported by industry knowledge of how it worked. In other words, some suppliers were promoting equipment that they didn't really understand, and it was left up to the eco-resort to figure it out. However, there has been a noticeable increase in industry knowledge as the renewable energy sector has grown over the past decade.

7. Looking ahead

The eco-resort's transition to renewable energy is not quite complete because the generator must still be used from time to time, notably when cloudy days have reduced the effectiveness of the solar panel arrays. In addition, the kitchen's gas-fired ovens are about to be replaced by electric units which will increase the eco-resort's total daily electric energy requirement, with high power demand during the breakfast and dinner periods. This additional power demand will be met by solar panels oriented to catch the sun when it is low in the sky in the early morning and late afternoon, and possibly by a small wind turbine that can take advantage of the easterly trade winds that are associated with the south-east part of the island where the eco-resort is located.

Considering the bigger picture, the LEI team has two principal sustainability goals. First, the eco-resort's management and staff view themselves as custodians and stewards of the island with a duty to pass it on to future generations in good condition. Second, they want to play their part in addressing global issues such as climate change and they do not consider the fact the eco-resort can do little to address global problems to be a reason to do nothing.

Education and knowledge-sharing can help to achieve these goals. In early 2013, the eco-resort completed an upgrade of its reef education centre (Figure 10), which has facilities and resource material able to cater to guests, school groups, and university people. Raising public awareness of LEI's environmental and ecological importance motivates people to help protect the Great Barrier Reef and other such places and showcasing the island's renewable energy systems motivates people to follow suit and start their own transition to a sustainable future.

Figure 10. The LEI reef education centre provides a platform for education and knowledge sharing.

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