CASE STUDIES FROM INTEGRATING RENEWABLES INTO THE GRID

SEIAPI Sustainable Energy

SIDSDOCK SMALL ISLAND DEVELOPING STATES ISLAND ENERGY FOR ISLAND LIFE

WORLD BANK GROUP

PPA PACIFIC POWER ASSOCIATION

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These guidelines have been developed for The Pacific Power Association (PPA) and the Sustainable Energy Industry Association of the Pacific Islands (SEIAPI).

They represent the latest industry practices for utilities in the Pacific Islands.

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List of Abbreviations

A summary of the main acronyms and terms used in this document is listed below:

ADB	Asian Development Bank
BESS	Battery Energy Storage System
CBD	Central Business District
CIREC	Cook Islands Renewable Electricity Chart
EPC	Electric Power Corporation
EU	European Union
FY	Fiscal Year
GCF	Green Climate Fund
GWh	Gigawatt hour
IPP	Independent Power Producer
JICA	Japan International Cooperation Agency
km	kilometre
kW	kilowatt
kWp	kilowatt-peak
m	meter
MFAT	Ministry of Foreign Affairs and Trade (New Zealand)
MW	Megawatt
NA	Not Applicable
NSDP	National Sustainability Development Plan
O&M	Operation & Maintenance
OIREP	Outer Island Renewable Energy Project (Tonga)
PPA	Power Purchase Agreement
PSEP	Power Sector Expansion Project (Samoa)
PV	Photovoltaic
RE	Renewable Energy
SCADA	Supervisory Control and Data Acquisition
SESP	Samoa Energy Sector Plan
SHS	Solar Home System
SLD	Single Line Diagram
TAU	Te Aponga Uira
TBC	To Be Confirmed
TERM	Tonga Energy Road Map
TOP	Tongan Pa'anga
TPL	Tonga Power Limited
UNDP	United Nations Development Programme

Currency Equivalents

(As of 23 June 2020)

Currency units:

United States dollar/s (US$),

New Zealand dollar/s (NZ$),

Samoan tala (WS$),

Tongan pa’anga (T$)

US$1 = NZ$1.55

NZ$1 = US$0.65

US$1 = WS$2.67

WS$1 = US$0.37

US$1 = T$2.27

T$1 = US$0.44

1. Introduction

1.1 Cook Islands

The Cook Islands is located in the South Pacific Ocean northeast of New Zealand, covering a land area of 240 km² and a population of 19,000. The archipelago is comprised of 15 islands, 12 of which are inhabited, divided into two distinct groups: the Northern Group and the Southern Group (Figure 1). Rarotonga, the largest island and located in the Southern group, contains the capital city Avarua and over 70% of the resident population.

Figure 1: Map of Cook Islands (Source: Central Intelligence Agency World Factbook)

Approximately 90% of electricity demand is on Rarotonga, the most visited island with a large tourism industry, whilst the remaining 10% is divided between the smaller outer islands. Te Aponga Uira (TAU), a government-owned power utility, is responsible for the generation, distribution and retailing of electricity on Rarotonga. The power utility has two operating divisions, Generation and Network, with a renewable energy (RE) unit forming a subunit of Network. In Aitutaki, the second most visited island, the electricity supply is operated by Aitutaki Power Supply (APS), a part of the Aitutaki Island Council administration. Other islands are managed by island councils or island administrations.

In 2012, approximately 99% of power generation in the Cook Islands was sourced from diesel, and the corresponding fuel costs equated to $29.8 million, or 25% of the country's total imports. With electricity being generated from imported diesel fuel, the Cook Islands become vulnerable to the risks of a fuel supply which is unreliable, problematic and expensive due to international oil price volatility. To combat this, the Government established a Renewable Energy Development Division (REDD) in 2011 to manage the Cook Islands Renewable Electricity Chart (CIREC) implementation plan, a strategy outlining the steps to achieve 50% electricity provided by RE by 2015, and 100% by 2020. The CIREC is in alignment with the policy targets and metrics articulated in the National Sustainability Development Plan (NSDP) to ensure access to affordable, reliable, sustainable and modern energy. The CIREC is being implemented through the Cook Islands Renewable Energy Sector Project (CIRESP), established in 2014 and co-financed by the ADB and various donors. A priority was placed on the outer islands as they are more isolated, and with the exception of Rarotonga which is more complex due to the significantly larger electricity demand, the electricity needs of all inhabited islands are now met by renewable sources. The contribution from distributed renewable generation in Rarotonga has steadily increased to the current grid limit of 16%, and TAU aims to increase renewable energy contribution to 70% of its customer demand by 2020/21. The shift in Government policy towards renewable energy has so far been a success, reducing the precarious reliance on importing diesel for electricity generation, increasing efficiency both in electricity supply and use, improving access, reducing environmental impacts and enhancing energy security, while ensuring the sector remains financially viable in the long term.

1.2 Samoa

Samoa, officially the Independent State of Samoa and until 1997 known as Western Samoa, is located in the Pacific Ocean between Fiji and French Polynesia covering a land area of 2,842km^2 and a population of over 197,000. Samoa, which shares the Samoan archipelago with American Samoa, consists of nine islands, four of which are inhabited. The two largest and most populated of these inhabited islands are Savai'i and Upolu, followed by Manono and Apolima which are situated in the strait between the two main islands (Figure 2). Upolu is the main island, second largest in size, and contains the capital city Apia.

Figure 2: Map of Samoa (Source: Central Intelligence Agency World Factbook)

Electric Power Corporation (EPC) is an autonomous government owned corporation responsible for the generation, transmission, distribution, and selling of electricity in Samoa since its establishment in 1972. EPC plays a crucial role in the development of Samoa's economy and operates under the energy sector alongside other government bodies, striving to provide efficient, affordable and reliable electricity supply in order to achieve the sector goal of a sustainable energy supply. EPC began by supplying electricity exclusively to the Apia township on Upolu, however they now provide power to 98% of the population of Samoa. A renewable energy (RE) unit was set up in 2007 to manage and develop projects associated with RE activities such as wind, solar, hydro and bio-energy. This includes initiating high-quality research and analysis and providing actual project implementation support to increase Samoa's use of environmentally friendly renewable sources of energy, and reduce reliance on imported fuels.

While Samoa has a negligible impact on climate change, it is likely they will be greatly affected by the consequences in the future. Further, the global financial crisis (GFC) of 2008/09 highlighted their vulnerability to fuel prices as electricity prices dramatically increased in response to foreign markets. Samoa is therefore taking a proactive approach to increase its renewable energy generation and reduce its greenhouse gas emissions. The Government announced a commitment to achieve a 100% renewable energy contribution target for electricity generation by 2025, in line with the previous Samoa Energy Sector Plan (SESP) vision of "improved quality of life for all" in 2012-2016, and updated vision of "sustainable and affordable energy for all" for 2017-2022.

Structural reforms included the establishment of the Energy Division within the Ministry of Finance whose focus is on the coordination of the implementation of the SESP. EPC's RE unit was responsible for the Samoa Power Sector Expansion Project (PSEP) from 2008 to 2016 to implement various improvements such as improving the supply of electricity, construction of a new power station to increase generating capacity to meet growing demand, increasing capacity of transmission and distribution power lines, and a new Supervisory Control And Data Acquisition (SCADA) system. In addition, there are a growing number of RE projects approved to be undertaken under the support of Government with development partners cooperation (Figure 3), as well as investments by the private sector through Power Purchasing Agreements (PPAs). In 2014, EPC secured grant funding for the Renewable Energy Development and Power Sector Rehabilitation Project, which involved the rehabilitation of three hydro stations that sustained the most damage during the flooding of Cyclone Evan in 2012, and the construction of three new hydro power stations. The Island Resilience Partnership (IRP) and GridMarket are supporting Samoa as energy advocates and advisors, to assist in their accelerated transition to renewable energy and resilient infrastructure. Additionally, the Improving the Performance and Reliability of RE Power System in Samoa (IMPRESS) project was introduced in 2017 to improve sustainable and cost-effective utilisation of indigenous renewable energy resources for energy production in Samoa over a five-year period. Overall, these projects are designed to ensure the future supply of electricity and provide for the expected growth in demand.

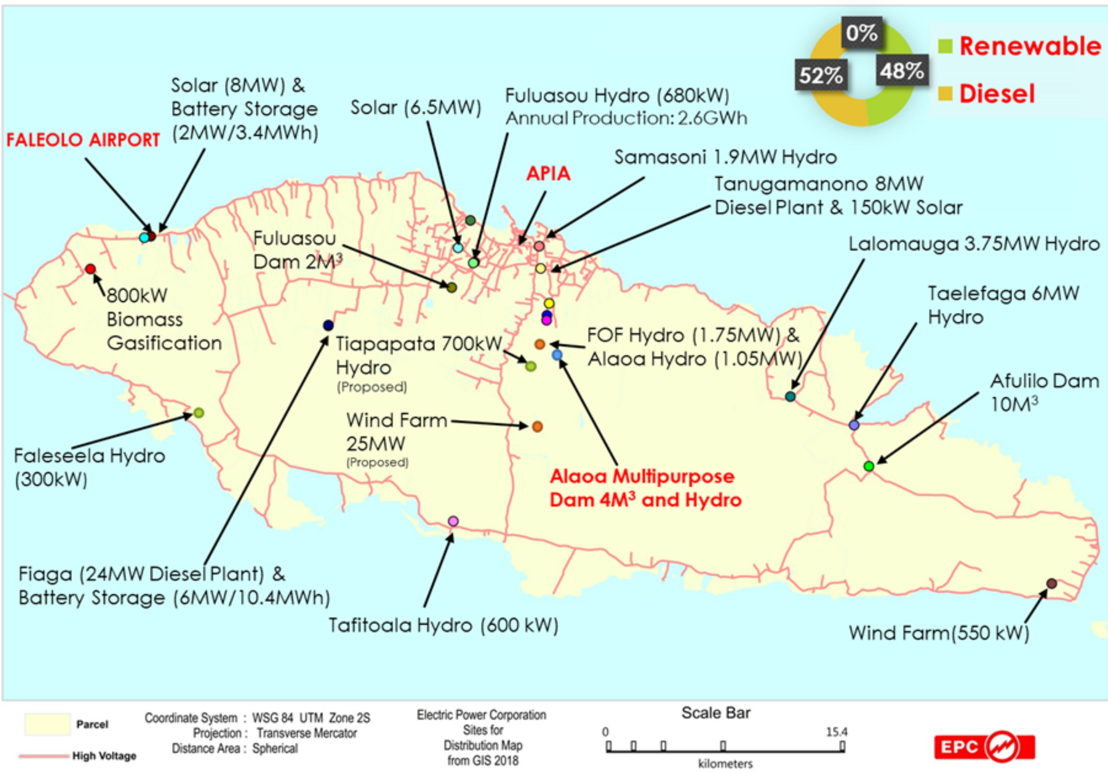


Figure 3: Location of Generation Assets - Upolo Island (Source: EPC)

1.3 Tonga

Tonga is a unique Polynesian Kingdom in the Pacific Ocean between Hawaii and New Zealand, covering a land area of 747km^2 and a population of 105,525. The archipelago is comprised of over 170 islands and made up of four major island groups: Tongatapu group in the south, Ha'apai group in the middle, and Vava'u and Niuas groups in the north (Figure 4). Tongatapu is the main island, largest in size and containing the capital city Nuku'alofa.

Figure 4: Map of Tonga

36 of the islands are inhabited and excluding Tongatapu, are all relatively small in terms of population and electricity consumption. Tonga's electricity sector was re-structured in 2008 when the Government established the Electricity Commission (EC) through the Electricity Act 2007, and purchased the electricity assets from a privately owned entity. Tonga Power Limited (TPL) operates under a strict regulatory framework through the Electricity Concession Contract (ECC) in which tariffs, operational efficiency benchmarks, consumer service standards and penalties are specified between the EC, the Government and TPL. TPL's core business is generating, distributing and retailing electric power to more than 24,000 customers across a four-grid system within Tongatapu, Ha'apai, Vava'u and 'Eua. The major objectives of TPL are to provide a safe, reliable, affordable and sustainable electricity supply throughout Tonga, maximize shareholder value while maintaining prudent levels of exposure to operational and financial risks, and ensure sustained downward pressure on electricity tariffs. In the other smaller islands, electricity is obtained through diesel generation or small/medium solar home systems.

In 2009, the Government of Tonga approved a goal of 50% of electricity to be generated from renewable energy sources by 2020. The overarching government strategy to reach this goal is the Tonga Energy Road Map (TERM), under which several projects including the Tonga Renewable Energy Project (TREP) (Figure 5) and the Outer Island Renewable Energy Project (OIREP) have been developed and funded. The TERM for 2010-2020 outlines the improvements required to reach the government's 2020 50% target, and covers petroleum supply chain initiatives and renewable energy projects. There have also been important energy efficiency, network upgrade and network resilience initiatives under TERM such as the Tonga Village Network Upgrade Project (TVNUP), Nuku'alofa Network Upgrade Project (NNUP), Outer Islands Energy Efficiency Project (OIEEP) and Cyclone Ian Recovery Project (CIRP), without which the networks would be highly unreliable and a significant barrier to incorporating renewable energy.

The TREP is a central and pivotal component of the TERM, and the Government of Tonga has established a high-level taskforce to implement TERM chaired by the Prime Minister. The TREP aims to help Tonga move away from fossil fuels and shift to renewables. The project will deliver utility-scale storage systems to provide base load response and grid stability, paving the way for more renewable energy integration in the main island, while green mini-grids will be installed in the outer islands. While stabilising the grid, this project will particularly address the intermittency of variable renewable energy sources, thus laying the foundation for private sector investments in renewable energy in Tonga. The main objectives of the OIREP are to help reduce the Kingdom's heavy reliance on imported fossil fuels for power generation while also increasing electricity accessibility for new users. For the twelve-month period of July 2018 – June 2019, fuel saving from renewable energy was approximately 1.6 million litres, equivalent to T$3,442,043 in cost savings passed directly to consumers.

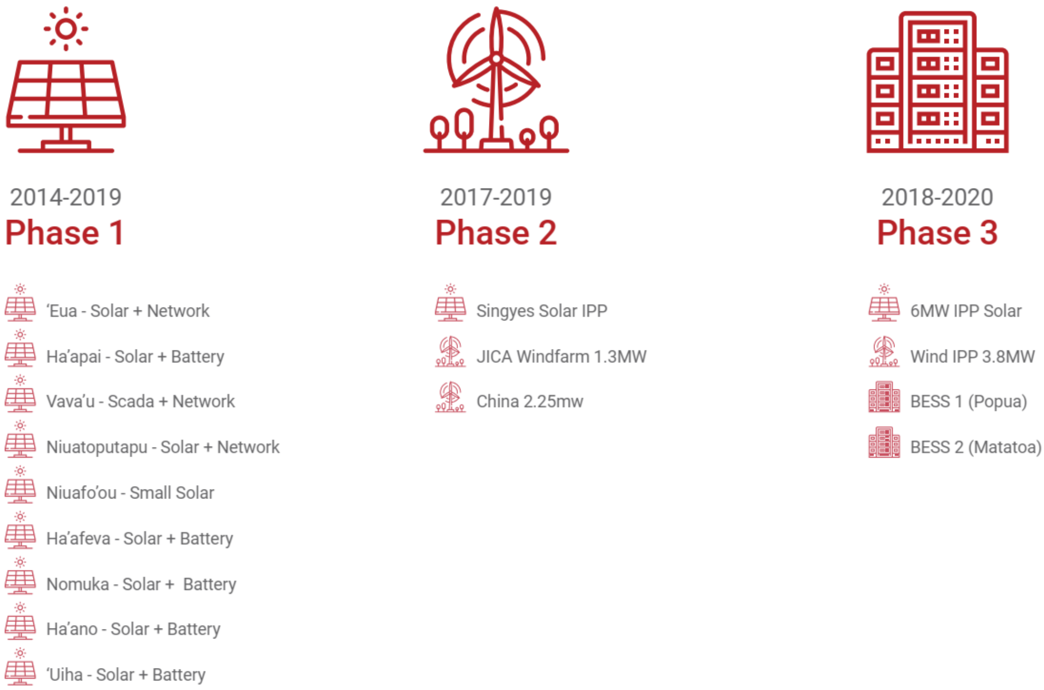


Figure 5: Tonga Renewable Energy Project (TREP)

2. Case Study 1: Cook Islands

2.1 Grid Configuration and Existing Generation Capacity

All inhabited islands in the Cook Islands currently have centralised power supplies, providing single-phase (230V) or three-phase (415V) through a distribution grid to most residential and commercial and industrial customers.

TAU's customer base of almost 6,000 customers is serviced by over 290 km of cabling across the grid network and 80 substations. Distributed renewable generators are scattered throughout the distribution network and contributes to overall generation. In June 2017, there was a total 3.6MW of distributed grid-connected solar photovoltaic (PV) generators around the island, consisting of a mix of TAU-owned and private-owned facilities. The average peak load is 5.1MW and an annual consumption of 28GWh. TAU anticipates load growth averaging 1.4% annually over the medium term.

Rarotonga has an 11 kilovolt (kV) network divided into 6 high voltage (HV) feeders (Figure 6):

- West Coast Feeder (WCF);
- Seaport Feeder (SF);
- Avarua City Center Feeder (ACCF);
- Airport Feeder (AIRF);
- Cross Line Feeder (CLF); and
- East Coast Feeder (ECF).

The distribution network comprises 90km of 11kV underground cables and 200km of 415V low voltage distribution lines.

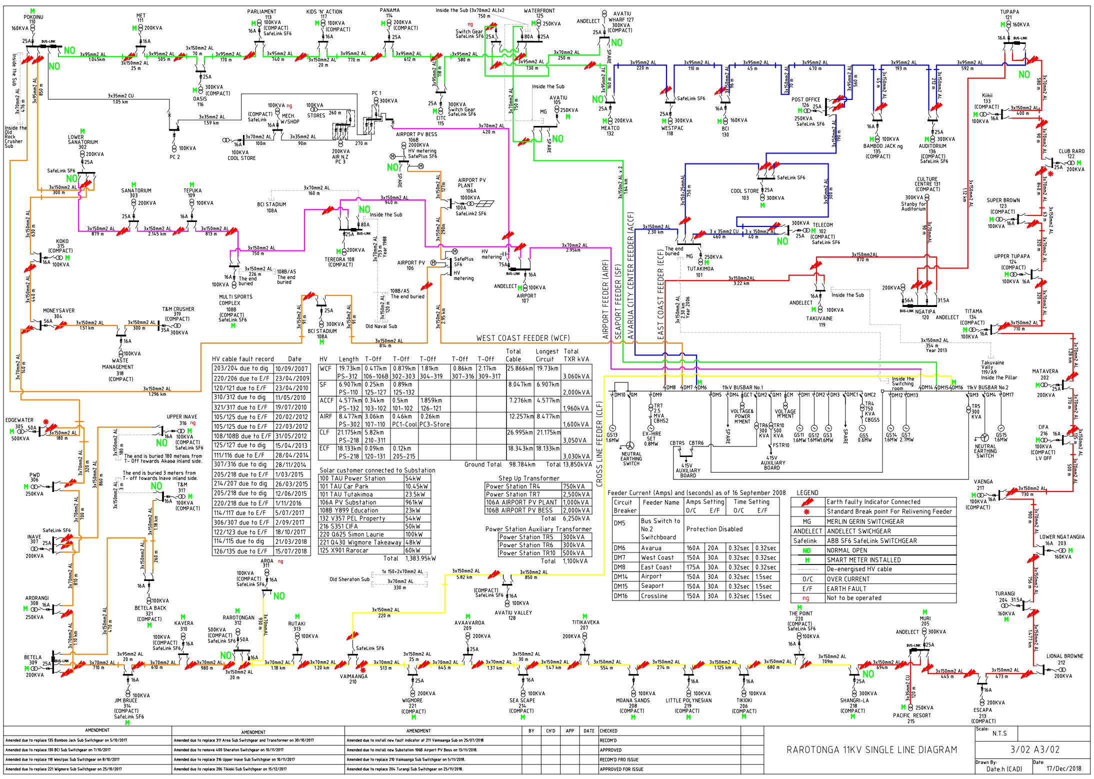


Figure 6: Rarotonga 11kV SLD

2.1.1 Diesel Generators

TAU currently has 7 diesel generators in operation at the Avatiu Power Station in Rarotonga, with a combined installed capacity of approximately 12.3MW. Five of the generators, each with a capacity rating of 1.6MW, were installed in 2016. They have fast responding engines, which are necessary to provide base load, spinning reserve, and maintain overall system stability with the integration of highly intermittent PV and wind generation. These generators are also fitted with computerised engine management systems, which further improve the capability to work with the PV systems and the existing engines.

Table 1: Cook Islands Diesel Generation Capacity

Number Installed	Total Capacity (MW)
5	8
1	2.7
1	0.6

Biofuel is considered a potential diesel substitute and will be tested by TAU to determine if it is a commercially viable option to increase RE contributions further. Engine-driven generators will always be required as backup even for a 100% renewable grid, however if the engines can be run on biofuel, they will be 'renewable' as well. TAU intends to test the market in terms of supply availability, delivery systems, pricing and feasibility.

Although all inhabited islands, excluding Rarotonga, have achieved at least 95% of their electricity being supplied by PV-battery hybrid mini-grid systems, diesel generator backup systems are still in place to guarantee energy security. These systems were installed in the six Northern Group islands (Manihiki, Nassau, Palmerston, Penhryn, Pukapuka and Rakahunga) in 2014/15 for the Northern Group Renewable Energy Project, and five Southern Group islands (Atiu, Mitiaro, Mangaia, Mauke and Aitutaki) in 2018/19 for the CIRESP. These systems are discussed further in section 2.1.2.

2.1.2 PV Systems

PV is currently installed across all twelve of the country's inhabited islands, and is the primary contributor to RE generation. Centralised PV-battery-diesel hybrid systems provide over 95% of the electricity needs from renewable resources in the six Northern islands, as well as five of the Southern islands.

The 'Te Huira Natura Ki Te Pae Tokerau', or Northern Group Renewable Energy Project, has provided solar mini-grid systems to meet the electricity demand of the six Northern Group islands of Manihiki, Nassau, Palmerston, Penhryn, Pukapuka, and Rakahunga to align with the CIREC. The project included the delivery of eight mini-grid PV solar with battery storage and diesel backup systems, commissioned in 2014/15, on the six islands, with a total output of 1.126MWh per annum. Each system is designed to supply up to 95% of annual of the electricity needs for the villages they connect to and deliver power to more than 230 homes and public buildings. Previously all the islands, with the exception of Pukapuka which had its rooftop solar replaced with a solar diesel grid network, were reliant on old generators and expensive imported diesel, and power was only provided at certain periods during the day. The project was implemented by the New Zealand MFAT and involved the design, supply, construction and installation of the solar arrays. All of the Northern group islands now have access to a continuous reliable electricity supply supported by a diesel back-up system, which guarantees energy security.

In 2014, the CIRESP was established to build PV plants in the islands of the Southern Group, implemented by the ADB in two phases. The first phase encompassed the outer islands of Atiu, Mitiaro, Mangaia and Mauke converting from diesel power supply to PV–battery hybrid systems, operating at 95% renewable energy with diesel backup. These four islands have a combined installed capacity of 1,246kW PV systems (Table 2) and battery storage, further discussed in section 2.1.3. The subprojects at Mitiaro and Mauke include new power stations and high-speed diesel backup generators whilst the more modern existing diesel power stations on Mangaia and Atiu have been retained. The addition of these four systems equates to an annual savings of approximately 360,000 litres of diesel and 960 tonnes of carbon dioxide emissions.

Table 2:Cook Islands Renewable Energy Sector Project PV Systems

Island	Year Installed	Capacity
Mitiaro	2018	159kW
Mauke	2018	228kW
Mangaia	2018	477kW
Atiu	2018	413kW
Aitutaki	2019	1000kW

The second phase included initiatives on the remaining two islands, Aitutaki and Rarotonga, which are more complex due to the larger populations and higher power demands. As such, the power systems required upgrading to increase levels of renewable energy generation, and provide control systems and battery storage technology to manage high levels of renewables. The subprojects resulted in the two islands increasing their use of renewable energy to almost 25% by using fully integrated PV–battery–diesel hybrid systems. In Aitutaki, an additional PV system was installed together with 300kW high speed diesel generator, containerised battery energy storage system (BESS) and upgraded switchgear and controls. The subproject for Rarotonga included the installation of BESS, further discussed in section 2.1.3. The Renewable Energy Sector Project will result in a reduction in annual diesel usage of approximately 1.26 million litres, reducing carbon dioxide emissions by approximately 2,793 tons per year.

Rarotonga presently sustains over 450 individual RE generators plugged into the grid, driven by a diesel-powered generation plant at Avatiu. TAU estimates it will require 18MW of PV in its mix of generators in order to reach 70% RE contribution levels. Currently there is 3.6MW of PV installed, consisting of 1.068MW net metered, 1.711MW Independent Power Producers (IPPs) and 862kW TAU owned (Figure 7).

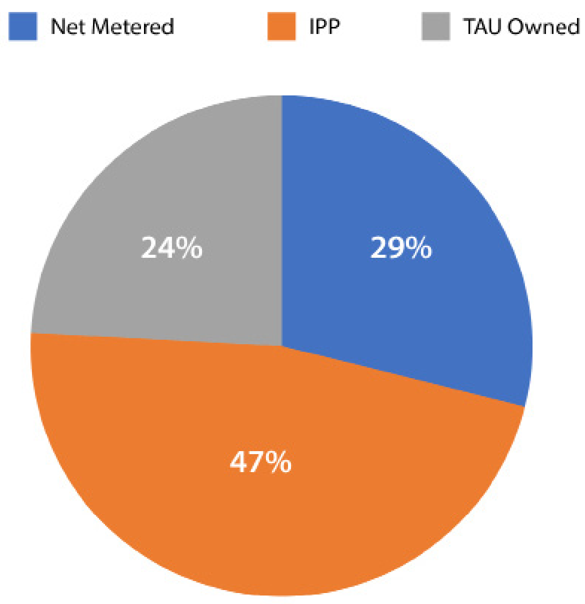


Figure 7: TAU PV Systems

The PV systems installed in Rarotonga are well spread around the island (Figure 8), which is beneficial for the grid by helping to reduce voltage rises and overloading the feeders.

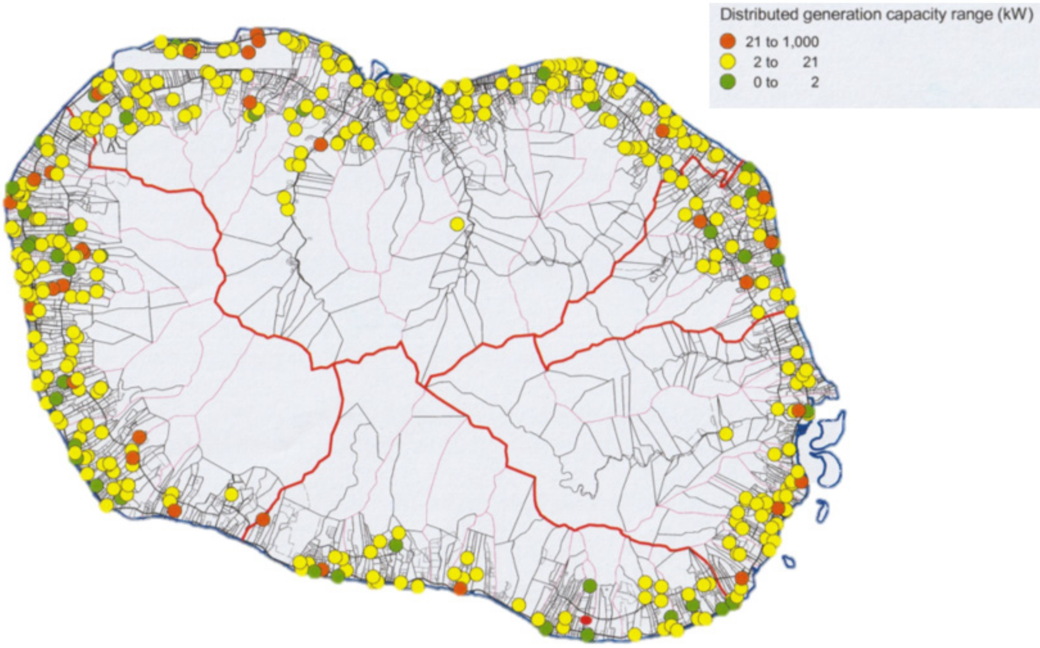


Figure 8: Map of Solar Locations in Rarotonga

The largest PV system in Rarotonga contributing to the CIREC is the “Te Mana o Te Ra” (Power from the Sun), also known as the Rarotonga International Airport Solar Project. The project was completed in 2014 and involved the construction of a 961kWp PV solar facility on the Rarotonga grid at the airport. The project was implemented by MFAT in alignment with the CIREC and NSDP, and is enough to provide 5% of Rarotonga’s electricity needs, expected to reduce diesel fuel consumption by 400,000 litres each year.

In the future, TAU intends to install an additional 3MW of PV to match its storage projects, and the remaining capacity to be derived from the private sector in the future. Private sector engagements will be managed by PPAs, in addition to a small allocation of scaled customer PV systems.

The Government has also been investigating RE options for road transportation on Rarotonga, as the transport sector accounts for 43% of the total emissions in Cook Islands. Electric Vehicles (EVs) will increase the demand for electricity moving forward, with on island EV transport steadily growing and showing potential with over 40 EV owners on Rarotonga as well as several in Aitutaki. TAU is investigating the benefits of a range of charging infrastructure for Rarotonga, including the value they may add when the Rarotonga power system via renewable energy contributions would benefit from EV loads and minimise curtailment, without adding significant cost. On full charge an EV can travel approximately 130 kilometres, four times around Rarotonga. In 2016, TAU took delivery of six electric vehicles (two pickups, two vans and two bikes) which were imported from China. In 2017, TAU launched their 10kW PV Solar Project, Rarotonga’s first electric vehicle charging station located at the head office carpark in Avarua (Figure 9). Previously, EV owners could only charge their EV on their own premises by plugging their car into an adapter and into a home wall socket. The modules at the facility will reduce fossil fuel consumption by approximately 4,600 litres per year.

Figure 9: TAU EV Charging Station

2.1.3 BESS

The intermittent nature of RE based electricity generation such as PV modules and wind turbines can affect the stability of the grid and possibly require the utility operator to maintain a diesel generator spinning reserve. With storage, the levels of penetration of renewables, both in power and energy, can continue to increase. Cook Island's ambitious 100% target of renewable penetration will not be reached without energy storage as it is a critical means of integrating RE into the network. The integration of BESS has allowed all inhabited islands excluding Rarotonga to reach 95% of the electricity needs from renewable resources. TAU placed a hold on private sector RE installations at the end of 2015 due to the network reaching its capacity to absorb further solar generation, and battery storage was considered as the next step. The first installations are to provide time-shifting storage, with additional grid-stability support storage to follow. To reach 70% RE contribution levels, TAU estimates it will require 25MWh of storage tied to PV generators. TAU will have commissioned 14.5MWh of BESS in 2019/20 and connected with its PV plants. The remaining is expected to be coupled with private PV installations and managed by PPAs.

In 2014, the CIRESP was established to build PV plants in the islands of the Southern Group as introduced in section 2.1.2. The first phase encompassed the outer islands of Atiu, Mitiaro, Mangaia and Mauke converting from diesel power supply to PV–battery hybrid systems which have a combined installed battery capacity of 8.4MWh (Table 3).

Table 3: Cook Islands Renewable Energy Sector Project BESS

Island	Year Installed	Rated Output	Battery Capacity
Mitiaro	2018	0.072MW	1.1MWh
Mauke	2018	0.09MW	1.4MWh
Mangaia	2018	0.216MW	3.4MWh
Atiu	2018	0.162MW	2.5MWh
Aitutaki	2019	500kW	502kWh
Rarotonga	2019	1MW	4MWh
Rarotonga	TBC	2.6MW	10.5MWh

In 2019, phase two of the CIRESP began which included a containerised BESS installed with the new 1MW PV system at the power station in Aitutaki, and BESS connected to the Rarotonga grid. In 2017, Australian renewables company MPower secured the contract to install a BESS with a rated output of 1MW and battery capacity of 4MWh, which will help utilise load shifting and curtailment to provide firm output and allow 2MW of additional solar PV installation. The system, added to the Te Mana o Te Ra PV facility, will reduce annual diesel usage by approximately 1.26 million litres, approximately 2,793 tons of carbon dioxide emissions per year. In 2018, New Zealand electricity distributor Vector Powersmart Ltd signed a contract with the Cook Islands Government to provide TAU with the two large utility scale battery storage facilities to be located adjacent to the Rarotonga International Airport, to be coupled with 2MW of solar farms in close proximity. The BESS to be installed is the “Rarotonga BESS Project Airport South” (Figure 10).

Figure 10: Rarotonga BESS Project Airport South

Vector subcontracted Tesla Inc in partnership with TAU, Cook Islands Government, and GCF to install the Tesla Powerpack 2 with a rated output of 2.6MW and battery capacity of 10.5MWh. This system will provide load shifting to offset renewable generation and grid-stabilization to manage the impact of fluctuations in generation on the grid, so as to permit more renewable energy generation to be integrated while maintaining power quality and system reliability. This will also minimise the severity and frequency of events that cause low load at the power station and minimise any curtailment of solar PV facilities that may be necessary to maintain grid stability.

2.1.4 Independent Power Producers (IPPs)

IPPs are privately owned power plants, an entity which owns facilities to generate electric power for sale to utilities and end users. In the renewable energy industry, IPPs are typically large-scale (greater than 1MW capacity), however due to the smaller energy demand and land ownership limitations in comparison to other countries, in Cook Islands these are households or businesses which are much smaller in size. PV systems up to 2kW are net metered, and those 2kW or above are considered IPPs. TAU currently manages a combined 1.711MW of IPPs, the largest being 100kW, with most PV systems typically 21kW due to the size of the land available on a ¼ acre property.

2.2 Lessons Learnt

2.2.1 Equipment Quality and Regulation

There is currently no regulatory system in place for equipment in the Cook Islands, and as a result the regulation environment and equipment quality are not up to certification and standards. Products chosen to be used in systems are often imported as they have the cheapest price, and whilst systems appear to work when inspected after their installation, there is still a failure rate of equipment highlighting the need for more regulation.

The most common equipment TAU has experienced having failure issues is inverters. One issue involved half of their 39 SMA inverters, where the internal relays were malfunctioning and all needed to be replaced. The inverters were only 3 years old at the time, the poor quality suspected to be a result of the sudden boom in PV, and manufacturers needing to meet demand. Another issue is that if an inverter fails and requires replacing, the same product is usually no longer available and the customer may have to purchase a new inverter which is not compatible. For example, previous inverters were rated at 20kW however new inverters were rated at 25kW, which resulted in busbars burning out as the systems were not designed for the different sized inverter. The systems required upgrading as there was no tolerance in the design for upsizing, the cabling required changing to match the new inverter. A possible solution to this issue is to enforce all systems to have cables and switchgear designed for 25 to 50% oversize, and enforce that all installed inverters have passed IEC and AS/NZS 4777 requirements or included on lists such as Australia's Clean Energy Council approved inverters.

2.2.2 Geographical Location

Like many countries in the Pacific, Cook Islands faces challenges based on its geographic isolation. The humid and tropical climate of Cook Islands has also an impact on installed equipment, including:

- High failure rates of inverters due to water ingress. Additionally, the original contractor no longer exists so they cannot be held accountable.;
- Corrosion issues on the Insulation Piercing Connectors (IPCs) on the cable connection in the overhead systems;
- N-Power freight container required painting because it was too rusty; and
- Inverters at the power station having issues with mud wasps, resulting in having to be cleaned.

The physical characteristics of the country also make it particularly vulnerable to the effects of a changing global climate, in particular the number of cyclones, which have had a devastating impact on the economy, environment, homes and livelihoods of the Cook Islands people. This has required TAU and outer islands to undertake proactive measures in order to increase their resilience to extreme weather events, reduce loss of power, and allow the network to return to a normal state of operation faster. Following the aftermath of Cyclone Pat in 2010 which destroyed the majority of Aitutaki's electricity grid such as distribution and transmission lines, the country has further increased the amount of underground cables installed in the network, as well as designing systems with more robust materials.

2.2.3 Personnel Training

Whilst there are competent licenced electricians present in the Cook Islands, few are sufficiently trained to install renewable energy systems. TAU have identified that more training is required in this industry, involving repetitive and practical training as the students are predominantly kinesthetic (hands-on), rather than visual learners who can understand simply through reading text. Incorporating exercises such as fault-finding training where they learn to fix common issues and gain a diagnostic ability will benefit them much more than simply providing manuals and resources, which are often forgotten. The ideal approach would be to have a model system setup in Rarotonga where faults can be simulated. The staff also need to be encouraged to continuously keep up-to-date by reading manuals, preferably with visual images, as there is lack of motivation to do so if a system is working well. By making minor adjustments, some issues can be avoided by taking preventative control of the systems. TAU is currently collaborating with ADB and global company Ecotech to run training sessions.

The importance of personnel training has been emphasised by the issues involving one of TAU's installed systems, the MPower 1MW/4MWh BESS installed at the Mana o Te Ra PV facility. An oversight during the design phase resulted in a control system in which the inverter and battery were not able to communicate with each other due to language differences, and it was difficult for the TAU team to diagnose the issue. The installed system would work for one or two days at a time before a failure would occur, with numerous failures occurring it took a long time to get the system operating. It was determined that the cooling system was contributing to the failures and the system shut down due to overheating, and the installed equipment have very small tolerance levels for each of the components. The complexity of determining which of the different devices and equipment available in the market are compatible is a key area in which TAU staff need to be trained, without having to rely solely on the contracted system designer.

Another key issue with training is the lack of expertise available in the outer islands. There is a common assumption that the level of knowledge in rural areas and outer islands is the same as the main island of Rarotonga, however these electricians are usually only trained for two weeks which is not sufficient to learn the adequate skills involved. In some cases, there have also been communication barriers with technical issues on the outer islands, requiring training in the native language Maori or basic language. Even if remote monitoring access is available for the systems in the outer islands, there must still be a supervisor physically present in case any issues arise. Further, there is the issue that those with expertise will choose to leave rural areas in the hopes of obtaining a higher salary in urban areas. TAU has recognised those who may be more willing to stay are those who are older and want to stay with their families. The worker should also be employed on a permanent basis to inspect the systems, rather than only when an issue arises and needs fixing, incentivising them to keep up with training and become invested in learning how to operate and maintain systems.

2.2.4 Community Engagement

In an effort to reduce diesel consumption, the government introduced a net-metering policy in 2009 to stimulate the growth of rooftop PV and encourage renewable energy development from commercial and residential customers. The policy provided economic incentives to customers interested in grid-connected renewable energy installations under 10kW capacity, allowing for credits to accumulate over a period of 12 months from the excess energy fed back into the grid. The response from the public was overwhelming, partly fuelled by the 2011 announcement to go "100% renewable" by 2020, and by the end of January 2012 59 projects were installed with a total capacity of 288kW. However, due to network safety and power quality concerns, TAU was required to issue an amended net-metering policy in 2011 to limit the individual installed capacity to under 2kW. A process of assessment and approval by TAU is now mandatory before any grid-connected PV project can proceed. This has resulted in a strained relationship between TAU and its customers, as the utility is blamed for not carefully planning the policy. Residents connecting new systems also question why they are not eligible to receive the same benefits that were previously available, putting pressure on both the government and TAU, who must bear the economic burden. The lesson from this is that perhaps the Pacific Islands are not an ideal environment for a net-metering policy, and when designing new policies in the future, the utility should ensure they are not too generous. However, the high cost of electricity is still driving the high demand of PV installations, particularly for businesses where energy costs are significant. Even without net-metering benefits, many grid-connected PV systems are still considered viable.

Despite the fact that PV systems have been operating in Cook Islands since 2014, there still remains the common misconception that solar energy is cheap or free. There is an assumption that there should be reduced energy costs because of the reduction in diesel, however the size of savings could be affected by the overall increase in energy consumption and by requirements for the tariff charged to meet depreciation of the assets. The community needs to understand that there is a cost involved to have a reliable supply of power, and this message must be clearly conveyed with the increase in number of renewable energy projects. For example, as a result of the increasing demand of residential grid-connected PV systems, TAU purchased 50 new lead-acid batteries in order to assist in grid-stability. However, these all experiences failures due to overloading of the network, and had to be returned to the manufacturer for testing. An additional cluster was suggested to be built to account for the growth, as the diesel was then required to run full-time as spinning reserve. There was a miscommunication with the community, as they were not told these could not be discharged less than 50%. TAU have recognised the importance of this issue, and have set up a 2kW PV system with storage featuring zero export to demonstrate and educate the contractors/installers and the public.

More customer outreach and awareness programs will need to be introduced in the future in order to sustain a positive relationship with the community.

2.3 Operational Changes

2.3.1 Generation Dispatch Information

TAU, in its ongoing role of managing island wide stability and reliability of electricity to all grid connected customers, requires an advanced and dynamic control system that will synchronise all network assets to match the customer consumption patterns instantaneously. The load shape in Rarotonga is relatively flat, with the highest loads occurring on rainy summer days. The load shape has a typical early morning peak driven by commercial and residential loads, followed by a second peak at approximately 8pm driven by residential air-conditioning and other evening loads.

A well-functioning Supervisory Control and Data Acquisition (SCADA) system is an important foundation element of control, especially as generation becomes increasingly distributed. In 2016, SCADA was first introduced during the automation of the Avatiu Power Station and installation of high-speed diesel generators. The airport PV system installation was subsequently interconnected to the SCADA system, enabling live monitoring and control of the site from Avatiu Power Station control centre via a fibre optic link to issue command signals. The current primary function of the system is the acquisition of operational data. The SCADA system is expected to evolve to include key distributed elements as required to support TAUs expanding electricity supply network.

A project to install a new hybrid power control system and upgrade the existing SCADA system at the Avatiu Power Station and the TAU central office was put out for tender in 2018. The control system coupled with a communications network is expected to be installed over the coming year, following which new IPPs will be able to be installed and connected to the grid network, allowing Rarotonga to go beyond the existing RE limit. System modelling software, such as PowerFactory used by TAU, is essential to forecast new renewable energy generators being added to the grid, and ensure that accurate information is obtained to confirm if a system will overload the feeder. All future renewable energy generators must be able to receive and adhere to control commands from the central power station via the power system controller, including curtailment. This will allow the entire power system to maintain system reliability and delivery to all customers connected to the TAU power network.

2.3.2 Diesel Generator Controls

Stability of the grid is critical as TAU's centralised diesel generation of power at Avatiu Power Station may be impacted by the island-wide spread of solar generation sources. The two energy sources are essentially incompatible (one fixed and managed – the other intermittent and unconstrained) unless a sophisticated system of enabling and control is applied, along with advanced communications technology.

In 2016, TAU upgraded 8MW of its diesel generators to high-speed diesel generators. These generators are necessary to provide base load, spinning reserve, and maintain overall system stability with the integration of highly intermittent PV and wind. There are usually four of these high-speed diesel generators in operation to maintain the spinning reserve. The aim for the future is that once there is enough confidence in the battery energy storage systems, is will be possible to turn off all the diesel generators.

2.3.3 Spinning Reserve Methodology

TAU has a spinning reserve policy that provides uninterrupted power supply in case the largest generator trips. Currently the average system peak demand is 5.1MW, reaching as high as 5.6MW in February, experienced during the day when air conditioners are being used. The peak demand is expected to be further reduced due to recent PV installations and the on-going energy efficiency program. With the total available capacity TAU can keep up with the n-2 criterion. However, there are issues to be addressed to ensure long-term power supply quality.

The current spinning reserve methodology after the installation of renewables is:

Total Generation = 1360kW + Load + (0.8 x 780kW)

The 1360kW represents one of the 1.6MW high speed diesel generators (de-rated capacity), and the 0.8 x 780kW is designed to cater for situations where there is a sudden change in PV input, such as cloud coverage. However, this formula excludes private solar systems, approximately 3.6MW currently installed, which decreases the value of the Load and provides economic savings to the utility.

2.3.4 Tariff Structure

The outer islands each have their own tariffs for diesel generation systems which have been set by each island council and incorporates various subsidies. In Rarotonga, the tariff is set by the utility and there is no subsidy. TAU applies different tariff rates to certain categories of customers, which is determined by customers providing the relevant information to indicate which of the following categories they belong to:

- Domestic tariff applies to private residents, school premises (principally used for educational purposes), community halls, social and sporting clubs (not used for commercial purposes), churches (principally used for public worship), and living quarters for members and staff of religious orders;
- Commercial tariff applies to shops, offices, professional rooms, warehouses, factories, workshops, social and sporting clubs (used for commercial purposes), residential premises operated as commercial premises (where the customer is not the resident), and other business premises;
- Dual tariff applies to premises used for both a private domestic residence and for commercial purposes; and
- Demand tariff applies to large commercial customers.

The average tariff amongst customers is NZ$0.74, which is dependent on the cost to recover TAU's expenditures such as forecasted fuel costs.

2.4 Future Targets and Proposed Generation Capacity

TAU aims to increase renewable energy contribution to 50% on Rarotonga by the end of 2020, however with plans to reach 100% in the future further renewable energy sources in addition to PV must be explored. The utility has determined that an additional 18MW is required in order to reach this target, and that help will be needed from private investors and IPPs. To reach 70% RE contribution levels, TAU estimates it will require 2MW of wind capacity with the possibility of increasing should the resource be available. There are 5 existing private wind sites, however these are not currently in operation. The contribution of wind will help provide night time supply and avoid further storage cost. It is expected these will be through private sector investments feeding into the TAU network managed under PPAs, and TAU anticipates the interconnection of wind generation in 2020/21.

TAU is working towards achieving zero diesel contribution of energy to its power system for increasing lengths of time, while maintaining overall system stability. To enable this goal, TAU will acquire a range of enablers based at the power station. The sizing and specifications of these enablers will be dictated by the TAU control system which will be installed over the coming year. Whilst the short to medium term storage solution determined for Rarotonga is battery storage, which has a limited lifespan, TAU views the long-term solution as pumped hydro storage and has conducted pre-feasibility studies both on commercial and technical requirements. A full feasibility is required including a Light Detection and Ranging (LiDAR) survey, which will also assist with wind resource location, which will dictate locations. There is potential for public private partnerships of these systems given the land and financing requirements.

3. Case Study 2: Samoa

3.1 Grid Configuration and Existing Generation Capacity

Each of the four inhabited islands in Samoa has their own grid network. EPC operates 22kV transmission networks on Upolu and Savai'i and has performed upgrades to the transmission and generation infrastructure through the ADB funded Power Sector Expansion Project (PSEP) over recent years. While the bulk of Samoa's existing transmission network is via overhead cable, newer sections of the network include 33kV underground cabling. Savai'i's network consists of a 22kV ring main around the island, with some 11kV sections remaining as upgrade works continue. Savai'i's load profiles are predominantly residential, with a steady daytime load of 600kW – 1MW and an evening peak of up to 3MW. Upolu's network (Figure 11) consists of a ring main around the island, a cross-island feeder, and a 22kV/11kV network around Apia. The majority of Upolu's load is located in the Apia area, with the remainder spread out around the coastal ring main and the cross-island road. The average peak demand is 28MW, increasing up to 30MW on very rare days such as Christmas or holidays.

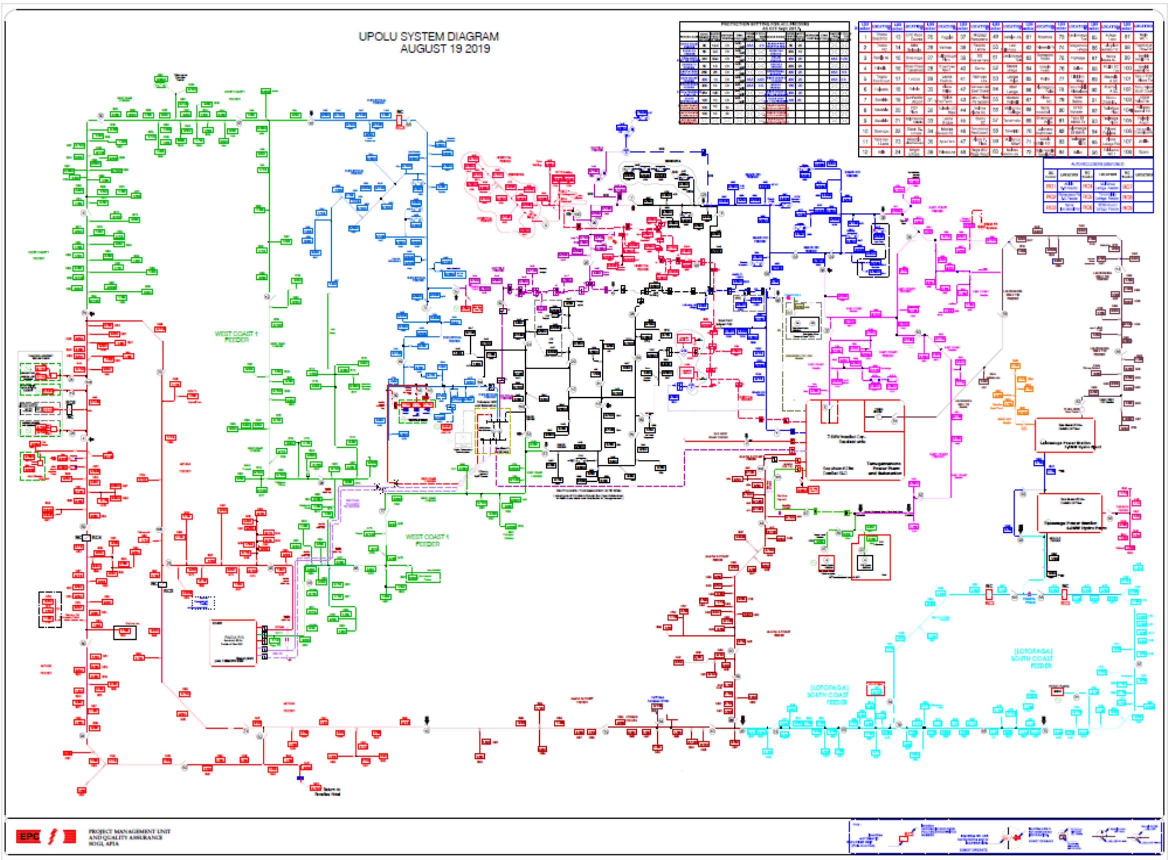


Figure 11: Upolo Network SLD

During the dry season, electricity is generated by the diesel generators at Fiaga power plant and transmitted to Tanugamanono via Fuluasou, and then distributed to the eastern parts of Upolu. During the rainy season, electricity is generated from hydropower plants on the eastern side of Upolu, and then transmitted via Tanugamanono to Fuluasou where the power is distributed to the western parts of Upolu. Electricity for some villages on the far western side of Upolu are sourced directly from Fiaga, while power for parts of Apia and the rest of the western areas of Upolu are sourced from Fuluasou.

Table 4 provides an overview of the production of electricity at the end of the 2018/19 FY with the previous FY values. The electricity production increased 9% from the previous year and total diesel production increased by 7%.

Table 4: Electricity Production by Island/Source

ISLANDS/SOURCE	FY 2018 - 2019		FY 2017 - 2018	
	kWh	Contribution %	kWh	Contribution %
UPOLU ISLAND				
Diesel	80,398,040	48%	74,936,848	49%
Hydro	48,815,938	29%	42,814,365	28%
Solar (EPC)	3,664,755	2%	2,972,343	2%
Solar (IPP)	19,586,448	12%	17,818,143	12%
Wind	216,100	0%	134,122	0%
UPOLU TOTAL	**152,681,281**	**91%**	**138,675,821**	**91%**
APOLIMA ISLAND				
Solar (EPC)	7,955	0%	9,896	0%
APOLIMA TOTAL	**7,955**	**0%**	**9,896**	0%
SAVAII ISLAND				
Diesel	15,264,755	9%	14,033,996	9%
Hydro	360,270	0%	-	
Solar (EPC)	311,147	0%	339,120	0%
Solar (IPP)	2,375	0%	8,954	0%
SAVAII TOTAL	**15,938,547**	**9%**	**14,382,070**	**9%**
GRAND TOTAL	**168,627,783**	**100%**	**153,067,787**	**100%**

Approximately half of the country's total electricity production is currently still sourced from imported diesel. EPC remains committed to increasing the diversity of its renewable energy generation sources, particularly where this will lower the costs of electricity for the people of Samoa, and as illustrated in Figure 12 has made significant increases in the amount of renewable generation. Since 2015, EPC has added 39 GWh of renewable generation (23% of total generation). This is estimated to have saved WS$16 million in 2019, and avoided 26,000 tonnes of carbon dioxide emissions.

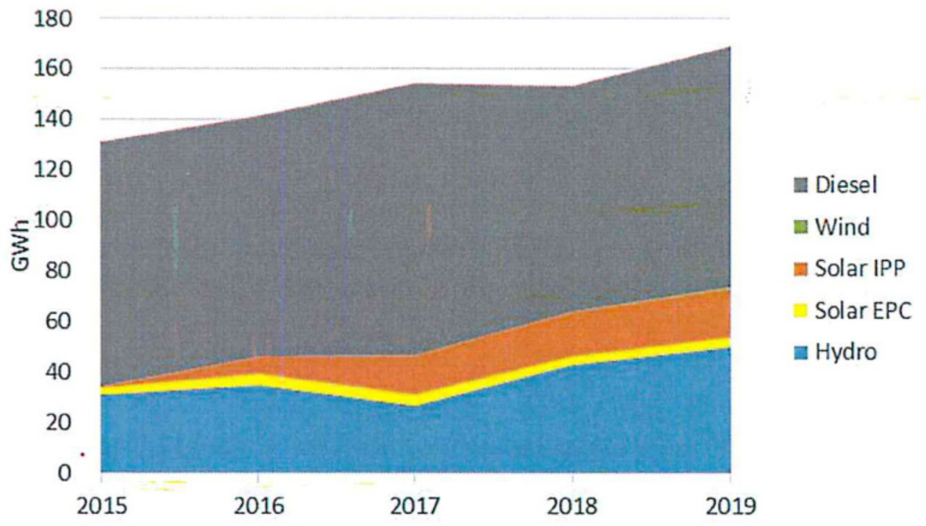


Figure 12: Generation Capacity of Samoa

In 2019, renewable energy produced a record output of 73.6 GWh which contributed 43% of total generation (Figure 13), an increase of 1% from the previous year. The focus on hydro generation saw it increase by 16%, and is proving to be a cost-effective contributor which now represents 29% of total EPC generation. In addition, total solar output increased by 12% and now contributes 14% of EPC total generation.

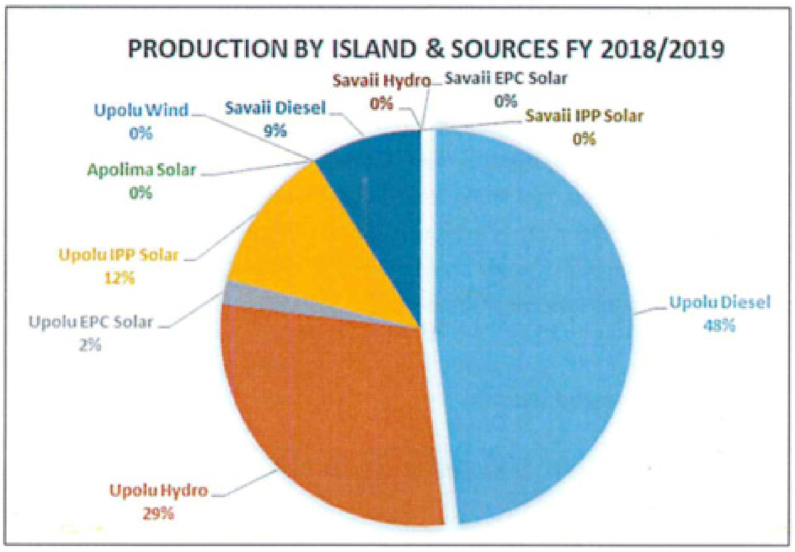


Figure 13: Production FY 2018/2019

3.1.1 Diesel Generators

Diesel power contributed to more than two-thirds of the nation's electricity generation as recently as 2011. All diesel generators in Upolu and Savai'i are currently in operation and owned by EPC, excluding two hires in Savai'i which are owned by Aggrega. The total diesel capacity for both islands is 39,500kW, 30,700kW in Upolu and 8,800kW in Savai'i (Table 5). The Fiaga diesel power plant in Upolu, commissioned in 2013, provides the baseload power generation and has significantly improved reliability of power generation for EPC's 35,000 residential, commercial, and government customers.

Table 5: Samoa Diesel Generators

Island	Generator	Manufacture	Year Installed	Installed Capacity (kW)	Available Capacity (kW)
Upolu	Fiaga 1	MHI 18KU30A	2013	5750	5700
Upolu	Fiaga 2	MHI 18KU30A	2013	5750	5700
Upolu	Fiaga 3	MHI 18KU30A	2013	5750	5700
Upolu	Fiaga 4	MHI 18KU30A	2013	5750	5700
Upolu	Tanu No7	Mirrlees MK2	1999	4200	2000
Upolu	Tanu No12	Mirrlees MK1		3500	1000
Savai'i	Kohler 1	Transdiesel MTU	2014	1000	900
Savai'i	Kohler 2	Transdiesel MTU	2014	1000	900
Savai'i	Kohler 3	Transdiesel MTU	2014	1000	900
Savai'i	Engine No15	Cummins	2011	1200	700
Savai'i	Engine No16	Cummins	2011	1200	700
Savai'i	Enginer No18	Cummins	2011	1200	700
Savai'i	Hire 1	Aggrego	NA	1000	900
Savai'i	Hire 2	Aggrego	NA	1000	900

Diesel based electricity on Savai'i is currently generated solely by EPC's diesel power station at Salelologa, the main town. The total installed capacity is approximately 5.5 MW (the actual figure depends on the degree of engine de-rating applied), comprising three Cummins engines and three larger Caterpillar engines. If high levels of renewable energy penetration are implemented, some of these diesel generators will need to be maintained as spinning reserve, to maintain grid frequency and voltage stability, and provide redundancy.

3.1.2 Hydro Generators

Hydro generators, the largest RE contributors to Samoa's electricity generation, are all owned and operated by EPC and those currently in operation are shown in Table 6. The total installed capacity is 15,460kW, 15,260kW in Upolu and 200kW in Savai'i. Traditionally, the baseload for Samoa was provided by diesel power stations, with hydropower stations used as peaking stations to cater for the daytime peak loads. Consequently, they continue to average capacity factors of no more than 35% due to lack of storage.

Table 6: Samoa Hydro Generators

Island	Generator	Manufacture	Year Installed	Installed Capacity (kW)	Available Capacity (kW)
Upolu	Taelefaga 1	Control Electronics	1993	2000	2000
Upolu	Taelefaga 2	Control Electronics	1993	2000	2000
Upolu	Taelefaga 3	HNAC Tech	2019	2000	2000
Upolu	Lalomauga 1	Control Electronics	2020	1750	1750
Upolu	Lalomauga 2	Control Electronics	2020	1750	1750
Upolu	Samasoni 1	Vortex Group NZ	2017	950	900
Upolu	Samasoni 2	Vortex Group NZ	2017	950	900
Upolu	Fale o le Fe'e	Vortex Group NZ	2017	1750	1750
Upolu	Alaoa	Vortex Group NZ	2010	1000	1000
Upolu	Tafitoala	Vortex Group NZ	2019	550	500
Upolu	Fuluasou	WKV German	2019	560	500
Savai'i	Vailoa Palauli	Vortex Group NZ	2018	200	200

In 2014, EPC secured grant funding for the Renewable Energy Development and Power Sector Rehabilitation Project, which involved the rehabilitation of three hydro stations that sustained the most damage during the flooding of Cyclone Evan in 2012 (Samasoni, Alaoa, and Fale ole Fe'e), and the construction of three new hydro power stations (Tafitoala, Fuluasou, and Vailoa Palauli). The overall project is expected to increase hydro capacity to meet 20% of the total demand of the islands, and demonstrates Samoa's continuous efforts to increase renewable energy sources for electricity generation.

The Fausaga and Vailoa Palauli hydro power plants were constructed with the primary objective to increase the deployment of renewable energy sources and boost the power sector's resilience to natural disasters. Both projects were implemented under a turnkey-type arrangement and took approximately 18 months to construct. Transmission works, which for both projects involved a short spur line of the existing transmission, were undertaken by EPC. Due to lender and local requirements, both projects went through rigorous environmental and social safeguard checks, which were further enforced through the various contractual mechanisms and by EPC's safeguards team. Such requirements included employment of local villagers during construction, gender diversity, education and training.

The Tafitoala system is a dual-intake scheme tapping into two tributaries of the same river basin. Both tributaries are perennial, with vast sub-catchment areas. Any one intake is able to sustain the plant for prolonged periods of time. This has contributed to the scheme's high annual generation, with a capacity factor to average 42% due to prolonged availability of water at rated flow. The project has a gross head of 104 m and rated flow of 0.48 cubic metres per second, and contains a four-jet vertical Pelton turbine. The scheme offsets 433,000 litres of diesel generation annually and has created greater access to electricity generated from hydropower. The run-of-river Faleata hydropower scheme increased the renewable energy generation contribution by about 790 MWh annually and translates to a 14% increase in the hydropower contribution to the energy mix of Savai'i. The project has a gross head of 83 m and rated flow of 0.3 cubic metres per second. The powerhouse contains a four-jet vertical Pelton turbine. The intake for the Faleata scheme was constructed alongside an existing Samoa

Water Authority (SWA) intake. Detailed planning was undertaken to ensure that water security to the SWA plant was not compromised during construction of the Faleata Scheme. The SWA plant is now primarily supplied from the tailrace of the Faleata Scheme. The old connection can be used as a system redundancy in event of a Faleata scheme shutdown.

In 2019, EPC completed various projects to further improve the hydro generation network. The rehabilitation of Lalomauga hydro plant included replacing the governor control systems of two generators and refurbishment of all associated equipment, alternators, and power station; refurbishment of the headpond and intakes, building of a new screen inside the headpond, installation of a velocity control valve, and installation of 10 MVA transmission transformers to upgrade the transmission line between Lalomauga hydro plant and Tanugamanono power plant. The alternator for the No. 2 generator at Taelefaga hydro plant was also replaced.

Plans to increase future hydro capacity in Samoa include installing a hydro plant at Tiapapata and a pump system at Vaipu which will be used to pump water from Vaipu stream to Afulilo Dam, to increase water levels and thus generation at the Taelefaga hydro plant. Planning has also begun for the Alaoa Multipurpose Dam Project to construct a 55-metre high dam with an estimated storage capacity of 4 million cubic metres of water to prevent flooding and support seasonal water supply, in addition to a 0.26MW run-of-river hydropower plant. The project will address disaster resilience by helping prevent floods, support climate change adaptation by ensuring a reliable water supply during drought, and improve Samoa's fuel security by installing a new source of renewable energy for power generation.

3.1.3 PV Systems

Each of the four inhabited islands (Upolu, Savai'i, Manono and Apolima) has their own grid network. Manono is sourced from Upolu via an underwater cable. Residents of Apolima, the fourth largest island, previously received electricity for only 4 to 5 hours a day due to the high cost of running the island's diesel power generator. In 2007, Apolima launched a mini-grid comprising of a 13.5kW PV system with a lead-acid battery storage system to supply residents with 100% renewable energy (Figure 14). The system was over-sized to meet the expected increasing energy demand of 100 residents living on the island, although they agreed not to use high-power electric devices like electric kettles and electric cookers during cloudy periods and only purchase energy efficient equipment. The system incorporates stacked inverters rather than a single central inverter for scalability purposes in the future.

Figure 14: Apolima Solar Array

Following the success of the completely self-sufficient PV system in Apolima, EPC has continued with the implementation of the Photovoltaic Rural Electrification Program to provide remote non-electrified households with an off-grid electricity supply. Upolu and Savai'i, the two largest islands, have installed a total 15,080kW of PV capacity to date (Table 7), 14,720kW in Upolu and 360kW in Savai'I, equating to approximately 14% of EPC's total generation.

Table 7: PV Systems in Upolu and Savai'i

Generator	Island	Owner/ Operator	Year Installed	Installed Capacity (kW)	Available Capacity (kW)
Faleolo Airport IPP 1	Upolu	Sun Pacific Energy	2015	2200	3800
			2018	1800	
Faleolo Airport IPP 2	Upolu	Green Power	2015	2000	2000
Faleolo Airport IPP 3	Upolu	Solar for Samoa	2016	2500	2500
Racecourse IPP 2	Upolu	Green Power	2016	2000	2000
Racecourse IPP 3	Upolu	Solar for Samoa	2016	1500	1500
Racecourse EPC	Upolu	EPC	2014	2200	2200
Racecourse Gym3	Upolu	EPC	2014	240	240
Vaitele Solar	Upolu	EPC	2014	250	250
Tanugamanono Solar	Upolu	EPC	2014	150	150
Mapu-i-Fagalele Solar	Upolu	EPC	2016	80	80
JICA Solar	Savai'i	EPC	2012	160	160
NZ MFAT Solar	Savai'i	EPC	2012	140	140
LDS Solar	Savai'i	LDS	NA	60	0

International donor agencies have contributed significantly to help Samoa reach the 100% renewable energy contribution target for electricity generation by 2025. Samoa commissioned its first grid connected solar project in 2012, which was funded by the government of Japan under the Pacific Environment Committee (PEC) through the Pacific Islands Forum Secretariat. Three installations in Vaitele (Figure 15), Tanugamanono and Salelologa have been funded by Japan International Cooperation Agency (JICA), while the New Zealand Government has funded two solar facilities including the 2.2MW system inside the Tuanaimato Race Course and 240kW on the rooftop of Gym 3 at Tuanaimato and a 140kW system in Salelologa.

Figure 15: Vaiete Solar Array

Since 2010, Samoa has promoted private sector investment in its renewable energy sector, and has successfully attracted three Independent Power Producers (IPPs) to introduce PV systems. There are currently five IPP systems installed in Upolu. The Sun Pacific Energy IPP at Faleolo airport sells the power to EPC under a 20-year Power Purchase Agreement (PPA). Each year the 4MW solar plant is expected to produce 5.5 million kWh, increase diesel savings by approximately 1.6 million litres of diesel, reduce emissions by an estimated 1,644 tons of carbon dioxide emission, and improve fuel security in Samoa.

There are plans to increase future PV capacity in Samoa, with a memorandum of understanding (MoU) signed between the government of Samoa and United States firm GridMarket to assist EPC in collecting information and data to produce a strategic plan in accelerating the reach of 100% RE target. The first phase of the plan, to be completed by 2022, involves installing 20MW of additional PV capacity with 40MWh of battery storage, and will require installing infrastructure equal to the current size. Under the partnership with GridMarket, EPC will ensure they deliver the right generation mix for their network.

3.1.4 Wind Generators

Currently, Samoa only has one wind farm which is located in Upolu (Table 8). The Vailoa Aleipata wind farm, completed under the US$50 million United Arab Emirates (UAE)-Pacific Partnership Fund in 2014, is owned by EPC and currently in operation. The cyclone-proof facility has a total capacity of 550kW, and is expected to supply 1,500MWh of power per year, delivering US$475,000 in annual fuel cost savings and reducing the island's carbon footprint by more than 1,000 tons of carbon dioxide per year. The wind farm includes two 55m high turbines that can pivot at the base, and be lowered and locked in place in less than one hour. This collapsible design helps to avoid damage from the region's numerous cyclones.

Table 8: Samoa Wind Generators

Island	Generator	Manufacture	Year Installed	Installed Capacity (kW)	Available Capacity (kW)
Upolu	Vailoa 1	Vergnet Pacific	2014	275	275
Upolu	Vailoa 2	Vergnet Pacific	2014	275	275

There are plans to increase future wind capacity in Samoa under the MoU signed between the government of Samoa and GridMarket. The second phase of the plan involves installing 20MW of wind generation with 40MWh battery, which includes 1.5MW of generation and 6MWh of battery in Savai'i.

3.1.5 Biomass

In addition to being a source of clean energy, biomass can also provide significant economic and social benefits to the community. Bioenergy helps stimulate regional economic development and employment by providing new, decentralised and diversified income streams, particularly for rural residents, from growing and harvesting biomass, transport, handling, and through procurement, construction, operation and maintenance of bioenergy plants. Biomass also provides an opportunity to turn environmental challenges into energy assets. Samoa is currently facing the rapid spread of invasive Merrimia vine, a vine that has so far killed more than 60% of Samoa's forests. But the vine, as biomass, can potentially also be fuel for bioenergy. Samoa will now develop biogas energy systems fuelled by the vine, other invasive weeds and green agricultural waste, which is otherwise disposed of by burning. Other feedstock that is suitable for gasification includes invasive species such as Pulumamoe, Pafiki and Puluvao, and coconut husks and shells.

In 2014, a biogas project emerged from the regional Pacific Island Greenhouse Gas Abatement through Renewable Energy Project (PIGGAREP), implemented by the United Nations Development Programme (UNDP). Samoa installed two small-scale biogas systems in Upolu, one on the island's public golf course, and one in the village of Piu. The purpose of the systems was to demonstrate the value of biogas as an alternative clean fuel for production of electricity and transport, and help power the Small Island Developing States (SIDS) conference. Biogas was used to fuel the production of electricity to charge the vehicles used in the SIDS venue and the golf course.

The project gathered valuable data on operation and management of biogas-based power generation and to improve the understanding and knowledge of management and operation of biogas energy systems in the Samoan context.

In 2017, the Government of Samoa and the UNDP launched the Improving the Performance and Reliability of Renewable Energy Power System in Samoa (IMPRESS) project. The development of the 750kW Afolau Biomass Gasification Plant at the Samoa Trust Estate Corporation's (STEC) plantation in Mulifanua, located near Faleolo International Airport on Upolu, demonstrates how Samoa is starting to apply advanced renewable energy technology in addition to their existing solar and hydro resources. This project is the first biomass plant in Samoa which will be utilised for power generation and supporting stability of electricity grids, and will establish a Geographic Information Systems (GIS) based forest inventory, biomass harvest and management plan, design and construct a drying shed, procure machineries for biomass harvest and transport, and conduct harvest and feedstock production trials for a gasification power plant. Direct GHG emission reduction over the lifetime of the project is estimated to be 25,267 tonnes of carbon dioxide emissions. The construction for the plant was completed earlier in 2020, however the launch was postponed as a result of the Government-declared state of emergency due to COVID-19.

Biomass has proven to be a success so far, and there are plans to increase future wind capacity in Samoa under the MoU between the government of Samoa and GridMarket. The third phase of the plan involves installing 20 tonne waste biodiesel refinery and a 4.48MW IPP.

3.1.6 BESS

As electricity generation from renewable energy sources has increased, the grid in Samoa has struggled with reliability. The unpredictability and intermittent nature of solar and wind can make the grid unstable, and in some cases lead to power outages. In order to reach the 100% RE target by 2025, battery storage is required to provide time-shifting and grid-stability support storage.

In 2018, EPC successfully completed the installation of the micro-grid controller and two BESS systems under the PSEP, funded by the ADB, government of Japan through JICA, government of Australia and government of Samoa, to assist with stability of electrical grid. Both systems are installed in Upolu, one at Faleolo Airport with a rated output of 2MW and 3.4MWh capacity, and the other at Fiaga with a rated output of 6MW and 10.2MWh capacity (Figure 16). The contract was awarded to Solar City (Tesla) in 2017 and took 12 months to complete. The BESS store electricity generated from solar energy, and automatically inject that electricity to the grid when there is a sudden increase in demand or sudden loss of power generated. The micro grid controller is a computer-based system which automatically controls and regulates the operation of not only the two new battery systems, but also all EPC power plants and independent solar farms. EPC is currently working on the fine tuning of this micro grid controller to maximise renewable energy and at the same time consider reliability of electricity supply. The two main objectives of this project are to stabilise the grid given the large amount of solar now connected, and to enable the effective operation of the grid and efficiently achieve least costs by reducing the number of diesel generators to operate at any time. The implementation of the two BESS has improved grid stability and the efficiency of which electricity is stored and released to customers, and has provided EPC the option of running its Fiaga diesel generators at a lower capacity and standby mode.

Figure 16: BESS at Fiaga Power Station

There are plans to increase future BESS capacity in Samoa under the MoU signed between the government of Samoa and GridMarket. The first phase of the plan, to be completed by 2022, involves installing 20MW of additional PV capacity with 40MWh of battery storage, the second phase involves installing 20MW of wind generation with 40MWh battery, and the fourth stage involves installing thermal energy storage at Fiaga Power Station.

3.1.7 Independent Power Producers (IPPs)

Whilst EPC remain committed to achieving the Governments renewable energy target through new RE projects to provides long-term and sustainable generation for customers, the challenges of ensuring the additional renewable electricity is cheaper and more reliable than the diesel which it is replacing will become more significant. This will require the improvement of the economics and PPA's of all future RE projects, to share the risks and rewards amongst involved parties and ensure that the cost of generation remains reasonable and thus sustainable. Based upon recent experience, the PPAs that EPC entered into had factored in significant market risk into its feed in tariff, resulting in IPP renewable energy being more expensive than diesel costs. Under the MoU partnership between EPC and Grid Market, a new procurement methodology will be developed to assist EPC in collecting information and data to produce a robust strategic plan for future projects.

In the 2018/19 FY, a record 19.6GWh PV was generated by IPPs, representing a 10.1% increase in production year on year, this however meant IPP costs increased by 8.8% or WS$1 million. The cost of PV generation is 12% more costly than the avoided diesel costs due to the fact that solar PV infrastructure is very capital intensive, and the current IPPs have a significant return on capital for their infrastructure, which impacts the feed-in tariff paid by EPC to the IPP. This feed-in-tariff is greater than the current cost of EPC's own diesel generation, despite contract clauses which have enabled EPC to cap those payments to the price of diesel generation. This price needs to be paid to IPPs, even if they are generating at times when the amount of solar, wind and run-of-river hydro generation is greater than Samoa's demand for electricity. In contrast, if demand is low and EPC does not need to run its diesel generation, it does not incur any costs. As the proportion of renewables increases, paying for IPP generation at times when supply exceeds demand will be a challenge EPC will increasingly need to address to ensure that the cost of generation does not rise excessively. The lack of sufficient battery storage for the solar generation also required EPC to run the Fiaga diesel generators at a higher capacity on standby mode in order to cover for the variability of the IPP PV generation such as cloud coverage, thus contributing to the increasing diesel costs.

3.2 Lessons Learnt

3.2.1 Equipment Quality and Regulation

Whilst the Samoan Government's Ministry of Commerce, Industry and Labour has a monitoring role for certain equipment such as refrigerators, there is currently no regulatory system in place for RE equipment in Samoa and as a result there have been several issues involving the quality of equipment installed. For example, EPC came across issues with all of the equipment in PV systems installed by a certain company being faulty, and which they later discovered do not meet any Australia or New Zealand standards. As a result, EPC have become more vigilant in checking equipment to ensure they have been properly tested and meet standards, and are included on lists such as Australia's Clean Energy Council approved inverters and modules. They have also requested the Government become more aggressive in the way in which they monitor all electronic equipment coming into the country.

3.2.2 Geographical Location

The continuing adverse effects of climate change on the reliability of electricity supply is and will also be a future risk that is unavoidable. However, EPC in collaboration with stakeholders in disaster management has in place plans and counter-measures to ensure impacts in the event of natural and/or man-made disasters are kept to a minimum. Samoa is regularly subject to cyclones, earthquakes, droughts and flooding, which can reduce generation capacity or cause damage to infrastructure. The risk of prolonged drought and damaging cyclones pose a threat to Samoa's national energy security and there is a need to diversify the nation's renewable energy sources. EPC is fully aware of the risks posed by natural disasters on its operations and its infrastructure, and have a risk management strategy which includes a service continuity and response plan in place. The plan ensures that necessary actions are taken not only for the safety of staff, but also safeguards and minimises any damages to its assets and in ensuring the continuity of electricity supply to the whole country before, during and after a natural disaster. There is also an approved disaster recovery plan safeguarding all of EPC's information communications technology (ICT) hardware and software data in the event of a natural and/or man-made disaster.

A key criterion for the design and construction of projects is their resilience to natural disasters and climate change. Challenges driven by unpredictable weather patterns are highlighted by the lingering effects of events such as Cyclone Evan in 2012, and the damage caused to several hydro-generation plants and the transmission network infrastructure including penstocks completely washed out, and generators, turbines and control systems damaged from flooding. Rehabilitation of power plants can be extremely costly, and fallen or damaged power lines can be very dangerous as they carry a high amount of energy. The logistical planning that is required on small island projects significantly increases for unique developments such as hydropower construction. All supplies into Samoa must be carefully planned and coordinated with shipping schedules, which are fortnightly and subject to regular delays due to bad weather. A minimum of three days is typically required to get specialised products to project sites, and means using commercial flights from New Zealand, Australia or Fiji.

Most of the hydropower generation is from run off river power plants that are exposed to variations and fluctuations of rainfall, which is exacerbated by the small sizes of catchments and limited water storage capacity. Wind and solar on the other hand are intermittent by nature, and EPC expects serious grid stability problems from these sources. EPC's generation portfolio is unbalanced leading to reduced reliability and high average cost of generation, especially if EPC has to invest in large scale storage in order to compensate for the intermittency of the RE sources currently used. EPC can mitigate these problems by increasing the share of power provided by its diesel generators, however this contradicts the government's desire to enhance energy security and generate all electricity from renewable sources.

3.2.3 Personnel Training

As Samoa continues to work towards their 100% RE contribution target for electricity generation by 2025, EPC recognises the importance of ensuring that their employees are adequately trained in using modern technologies. Whilst a majority of manufacturers provide support services for their equipment, it can be difficult for certain countries such as Samoa to solve their issues in a timely manner due to their location and geographic time difference. In addition, some require the use of translators making it increasingly more difficult. Recently, EPC have begun ensuring that the equipment installed in their systems have a customer service team in close proximity such as Australia, New Zealand or Fiji in order to attain faster support. Another possible solution is to install a limited number of brands and conduct regular training on these models, such that employees can more easily become familiar with how they operate, fault codes, and troubleshooting.

At the national control centre, it is crucial that workers are prepared to understand the flexibility of different variants of technologies and the application of unit costs when generating electricity from various sources. In particular, an emphasis should be placed upon planning of dispatchment, which is a more advanced method to the current form of decision-making. There is currently no support from donors for training as it not under their jurisdiction, and a third party will likely be required to prepare capacity building and develop this new mindset of electricity business. Decisions for the dispatch based on unit costs are to be determined from the installed SCADA system and database, however the current system will require upgrading in order to collect information in a more commercialised standard and deliver based on accurate information. Upgrades required include more detailed data such as whether a customer is using a revenue graded meter or a low-level accuracy meter, as well as the kWh produced from feeders, generators, transformers, etc. By assessing the existing infrastructure and undertaking the relevant upgrades, EPC will be more prepared when liaising with IPPs who may be potentially interested in projects in Samoa. For IPPs to integrate into the system, EPC need to prove they are ready and ensure they can provide accurate information by itemising their costs, to give the IPPs confidence in doing business with them. This information is also useful in sector planning including assessing financial and technical assistance from potential donors.

3.2.4 Community Engagement

Although Samoa has installed a significant amount of RE generating sources, there is still a significant number of misconceptions in the community. There remains the incorrect belief that solar energy is cheap or free. To combat issues such as this, requirements for projects have become more socially engaging to include employment of local villagers during construction, gender diversity, education and training. There has also been increasing interest of customers installing their own PV systems, motivating the regulator to modify the grid code and allow use of private solar. However, EPC have determined this scenario is only possible if the grid code specifies that any instability issues are governed by the customer, and must be consulted to confirm there is available capacity on site, to prevent overloading the distribution transformer or instability in the residential area. Installing inverters which can ramp down their output according to AS/NZS 4777, or limit the export can also help with this issue.

When creating contracts and determining the deliverables required, it is vital to provide accurate information and that future capacity is taken into consideration. One of the biggest lessons experienced by EPC was a case in which not enough information was provided to create flexibility for the IPP to assist with their grid stability. The IPP was reluctant to make any changes due to the significant costs it would involve to install new equipment, and although they had experience in grid stability systems, they were unable to amend their activities as there were no provisions for the changes in the contract.

3.3 Operational Changes

3.3.1 Generation Dispatch Information

EPC's power generation division based in Upolu is responsible for the generation of electricity using RE sources and imported diesel fuel. They work towards ensuring sufficient generation capacity is available at all times and optimising performance of renewable energy generating projects. SCADA is a centralised database management that will assist EPC in improving its operation efficiency, reduce unplanned outages, and provide early detection of such outages and early restoration responses. Two SCADA system towers have been constructed at Fiaga Power Station in Upolu and Salelologa Power Station in Savai'i, with another yet to be constructed at the proposed Vaiaata Power Station in Savai'i. A SCADA system is necessary to provide each generating asset the capability to locally operate automatically and communicate to a third-party system, providing round-the-clock monitoring and control for all of EPC's generation and key distribution sites on the main islands of Upolu and Savai'i.

As part of the PSEP, Fuluasou Substation was built in Apia in 2014, incorporating a national control centre and SCADA system. Integrating all control systems provides a holistic overview of the generating assets under one controller, and extracts information from each individual asset to deliver to the national control centre to maximise operational efficiency. The successful implementation of the SCADA system called for major communications infrastructure works including the installation of 30km of multi-core fibre optic cable (both underground and overhead), installation of high-capacity radio links to Savaii and eastern region sites, construction of 25 metre and 30 metre radio towers, and UHF radio links to remote hydro supply sites.

Combining accurate online data combined with an archive of historical data allows EPC to better forecast power generation needs, optimise relative allocations of renewable/thermal power facilities on an hour-by-hour basis, reduce reactive maintenance response time and improve preventative maintenance regimes. For example, rather than having to manually contact the operators at the power stations to reduce the load, they are now able to do so from the national control centre, by sending setpoints to the generating assets which respond accordingly due to upgraded electronic governors and automatic functionality. However, there are still limitations to the current SCADA system, as they do not receive all parameters from each site. At the national control centre, they can only gather the necessary information to confidently ensure an engine is working, as well as start, stop and change the setpoint of the engine. The grid controller is a real time automation system that EPC designed for dispatchable generating assets, and the control objectives include:

- Automate start, stop and power setpoint of generating assets;
- Maintain sufficient system upward and downward spinning reserve;

- Manage energy levels in stored energy reservoirs;
- Maximise renewable energy usage;
- Prioritise asset utilisation based on cost;
- Respond to abnormal grid and asset operation; and
- Integrate with system controller action and maintenance activities.

At Salelologa in Savai'i, a 22kV substation and back-up mini control centre also operates full time, duplicating the functions of the Fuluasou national control centre and provides an additional level of back-up in the event of disaster. The mini control centre, commissioned in 2014, also contains a SCADA system to closely monitor control generators and other facilities remotely.

3.3.2 Diesel Generator Controls

The increased penetration of utility-scale solar PV systems that feed directly into the national grid has proven to be problematic for EPC in the context of reliability. The variability of solar resources during daytime peaks has often resulted in brown-outs and in the worst cases total system failure, with system frequency going well below safety levels. As a countermeasure, EPC is forced to run expensive diesel generators to provide spinning reserves during peak hours.

The implementation of the battery storage at Fiaga and Faleolo in 2018 has improved grid stability and the efficiency of which electricity is stored and released to customers. The systems also mean that EPC now has the option of running its Fiaga diesel generators at a lower capacity and standby mode, whereby they previously required a higher capacity in order to cover for the variability of the IPP solar PV generation (for example, when clouds quickly sweep across the solar farms), and thus contributing to increased diesel costs. In addition, the flexibility of storage on a number of the schemes has allowed EPC to use PV during the day and hydropower during peak times (typically early morning and early evening) when solar is not available.

3.3.3 Spinning Reserve Methodology

Prior to the implementation of renewable energy sources, spinning reserve was based on the data available of the same day for the previous week, and all data was recorded manually. Currently, there is a different spinning reserve and determined based on the time of day, shown in Table 9.

Table 9: Upolo Spinning Reserve Requirement

Hours of Day	Days of Week	Months of Year	Load Range (kW)	Upward Spinning Reserve Requirement (kW)	Downward Spinning Reserve Requirement (kW)	Droop Requirement (kW)
2000-0800	All	All	0-1,000,000	3300	500	4000
0800-1600	Sat-Sun	All	0-12,000	3300	1200	5000
0800-1600	Sat-Sun	All	12,000-1,000,000	3600	1200	5000
0800-1600	M-F	All	0-12,000	3300	1000	5000
0800-1600	M-F	All	12,000-1,000,000	3600	1000	5000
1600-2000	All	All	0-12,000	4000	4500	4000
1600-2000	All	All	12,000-1,000000	4500	500	4000

If high levels of renewable energy penetration are implemented, some of the diesel generators will need to be maintained as spinning reserve. The system controller maintains the upward and downward spinning reserve requirements in order for the system to be stable and safe, and these decisions are made during the planning for the next day. EPC commonly have 3300kW as the upward spinning reserve requirement, and 1000kW as the downward spinning reserve requirement. There is a condition that two engines must be running at any given time, based on the installed PV capacity, as the amount of solar injection in the system on weekends or very low demand is 13MW. In situations where there is a sudden change in PV input, such as cloud coverage, one generator is not sufficient to ramp up and cater for that drop, and thus two diesel generators have been determined as the minimum requirement to maintain grid frequency, voltage stability and system security. As the network configuration continues to change, a planning team will be required to adjust automatic dispatching based on the experience of how the grid controller behaves in order to optimise operations according to the available generators.

3.3.4 Tariff Structure

There are three main components of the tariff calculation currently used in Samoa: energy charge, debt charge and usage charge. All EPC customers pay a broadly uniform variable rate for electricity, which is charged on energy consumed and measured in kWh. The level of the rate is broadly equal to the total costs EPC expects it needs to recover for the year divided by the total kWh expected to be consumed by all its various customers (domestic and business) during the year. The costs EPC needs to recover are grouped into three main categories:

1. Energy for recovery of the variable costs of generation (diesel costs, payments to IPPs for generation);
2. Debt to recover the costs of servicing the main loans that EPC has; and
3. Usage which recovers all other EPC costs.

Domestic cash power customers pay a reduced (by approximately 19%) rate for their first 100kWh each month (the so-called low usage users of electricity). Non-cash power customers (domestic and non-domestic) have a slightly higher variable charge in order to recover costs from such customers.

In 2019, the average sales price across all customers was 78 sene/kWh – a 5% reduction on the previous year, and a 25% reduction on the sales price in 2015. These reductions are testament to the commitment of EPC to continue to reduce tariffs in the face of increasing cost pressures. EPC remains committed to delivering on its objective of improving the affordability of electricity for the people of Samoa, by ensuring that the tariffs are structured in such a way that all consumers are bearing a fair share of the significant investment in electricity infrastructure.

EPC also moved to a new tariff structure for its large industrial customers in 2019, with a significant proportion of the fixed costs of providing electricity services to such customers now recovered by fixed charges (matched with reduced variable charges). EPC discovered that with the low diesel prices, the largest consumers could run their diesel generators rather than purchasing electricity from the EPC, which resulted in cost-shifting the recovery of debt and usage costs onto other consumers. Hence the fixed charge will recover a large proportion of the costs that would have been recovered from the variable debt and usage charges. This change has resulted in a fairer recovery of EPC's fixed costs between consumers, and will have reduced Samoa's overall electricity costs. The 100 largest customers pay a daily fixed charge plus a variable rate (Table 10), which is lower than the variable rate for other customer categories. These rates are determined such that a customer with the average consumption level for that category will pay the same annual bill as if they had been charged the standard variable rate (and no fixed charge) applying to all other customers.

Table 10: Daily Fixed Charge and Variable Rate for 100 Largest Customers

Category	Proportion Discount	Daily Fixed Charge	Total Variable Rate
1	75%	WS$1,520	WS$0.55
2	75%	WS$1,140	WS$0.55
3	75%	WS$840	WS$0.55
4	50%	WS$380	WS$0.65
5	50%	WS$240	WS$0.65
6	50%	WS$130	WS$0.65

As Samoa is gradually reducing their reliance on fossil fuels and increasing their use of renewable resources, EPC have developed a plan to reform the tariff structure in stages over several years. The program of reform is designed to better align prices with underlying costs of supply so that price signals support more efficient use and development of EPC's network. This should promote better economic, social and environmental outcomes. The pace of reform is intended to balance the benefits of early reform with the downsides of rapid change, while also staying in sync with supporting technologies and analysis. EPC is currently in the process of rolling out smart meters that will provide richer information about electricity demand in Samoa and can be used to support new types of tariffs.

3.4 Future Targets and Proposed Generation Capacity

The vision for 2025 is for Samoa to achieve 100% renewable energy generation and to be the cheapest electricity provider in the Pacific region. EPC have a long-term plan to increase renewable energy (RE) investment and generation, however to add more RE to the network will become even more costly. The MoU between the government of Samoa and GridMarket through the Island Resilience Partnership to facilitate and accelerate its transition to a clean energy economy, will utilise GridMarket's platform to aggregate and analyse all relevant energy and related data. GridMarket have proposed a strategic three-phase approach to achieving Samoa's 100% RE goal by 2025 using a comprehensive strategic energy transition plan. Phase one, to be completed by 2022, involves installing 20MW of additional PV capacity with 40MWh of battery storage, phase two involves installing 20MW of wind generation with 40MWh battery, phase three involves installing a 20-tonne waste biodiesel refinery, and phase four involves installing thermal energy storage at Fiaga Power Station. The proposed RE developments with BESS should be able to manage the dispatch of power onto the point of interconnection, normally on the 22kV distribution line. Each RE development will need to be modelled and simulated as a holistic network for stability and system security using power flow assessment.

EPC is advancing a programme to reduce reliance on imported fuels and increase use of renewable resources. In future, this is likely to include arrangements to enable customers to install their own solar PV systems. There is also prospect that, like many other countries, Samoa will turn to electric vehicles as an opportunity to replace imported liquid fuels. Electric vehicles have more efficient motors and can make a significant contribution to reducing fuel imports and greenhouse gas emissions, especially if they are powered by an electricity supply with predominantly renewable generation.

Samoa will continue to move towards energy self-sufficiency with reduced reliance on imported fossil fuels. Research, development and use of alternative RE sources will be increased, and developments of these projects are the main focus in the energy sector for at least the next two years under the Samoa Energy Sector Plan 2017-2022. A number of large projects will be implemented to ensure the future supply of electricity and will provide for the expected growth in demand, and an increased number of projects will be implemented through partnerships between the private sectors, government and communities.

4. Case Study 3: Tonga

4.1 Grid Configuration and Existing Generation Capacity

The grid configuration of Tonga is separated into four grids, one for each of the major island groups: Tongatapu, ‘Eua, Ha’apai, and Vava’u. While TPL provides electricity on these major grids, the outer islands are looked after by the Tonga Government’s Department of Energy. The four grids do not feature any sub-transmission circuits or trunk feeders as one would see in larger and more densely populated areas internationally. This makes all of TPLs grids largely radial in nature, with little ability to interconnect or mesh the networks to provide multiple transmission routes to key customers or core areas of service. The only area where there is scope for interconnection and sectionalising of feeders is in and around Nuku’alofa, Tongatapu. Low voltage reticulation for all islands is at 415/240 volts.

Table 11: Network Cable Lengths

Island Group	Area (km^2)	Distribution Network (kV)	Overhead Line (km)	Underground Cable (km)	Submarine Cable (km)	Low Voltage Lines (single and three phase) (km)
Tongatapu	260.5	11	197	9	0.8	567
‘Eua	87.4	11	13			42
Ha’apai	109.3	11	14	2		38
Vava’u	138	6.6	76	2		95

Tongatapu is divided into 3 feeders (Figure 17):

- NUK 1: covers the west side of island
- NUK 2: covers the CBD and is the most heavily loaded
- Vaini: covers the east side of the island, including the airport

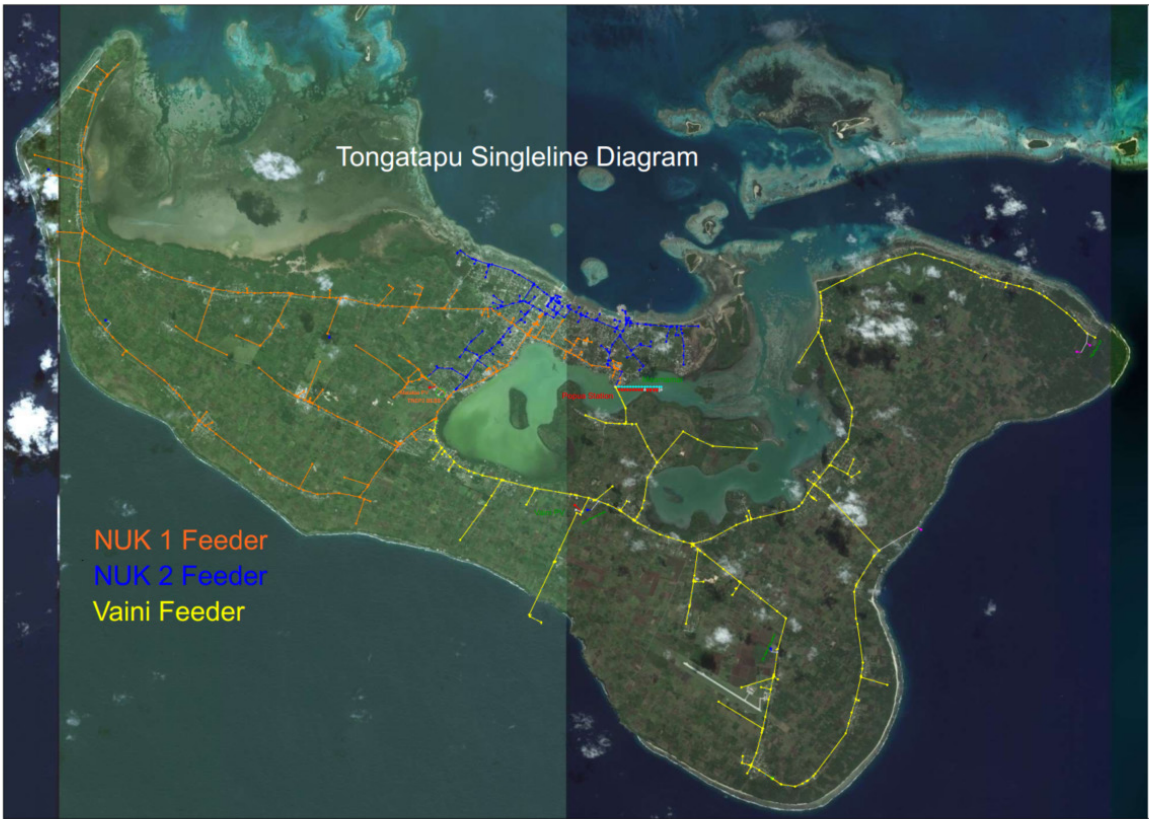
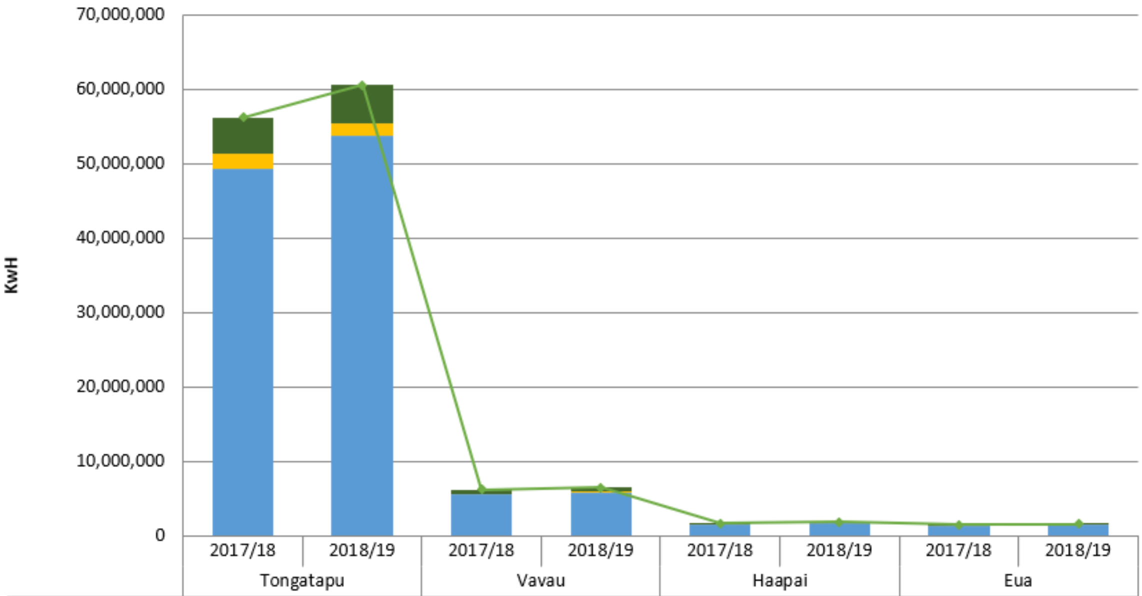


Figure 17: Tongatapu SLD (Satellite View)

For the 2018/19 FY, the total generation produced by TPL was approximately 70.6GWh. 62.8GWh of generated power was billed to the customers, and parasitic and line losses contributed to 1.8GWh (2.57%) and 5.9GWh (8.43%) respectively. The maximum (peak) demand is 10.4MW, currently with a night time peak however daytime demand is growing and is expected to take over in the near future. The breakdown of the individual island generation and consumption values are shown in Figure 18.



	Tongatapu 2017/18	Tongatapu 2018/19	Vavau 2017/18	Vavau 2018/19	Haapai 2017/18	Haapai 2018/19	Eua 2017/18	Eua 2018/19
Line Losses	4,905,824	5,217,714	600,024	565,618	91,106	102,420	104,754	63,991
Parasitic Losses	1,892,270	1,580,371	106,437	139,452	42,909	63,109	17,515	28,508
Billed	49,412,001	53,802,793	5,555,630	5,800,396	1,586,984	1,697,116	1,352,008	1,491,638
Generation	56,210,095	60,600,878	6,262,097	6,505,466	1,720,999	1,862,645	1,474,277	1,584,137

Figure 18: Tonga Electricity Consumption 2017/18 vs. 2018/19

Currently, Tonga produces around 11% of renewable energy annually including the outer islands. Figure 19 shows all generation mix (diesel plus renewables) connected to the grid and how each sector contributes to overall generation.

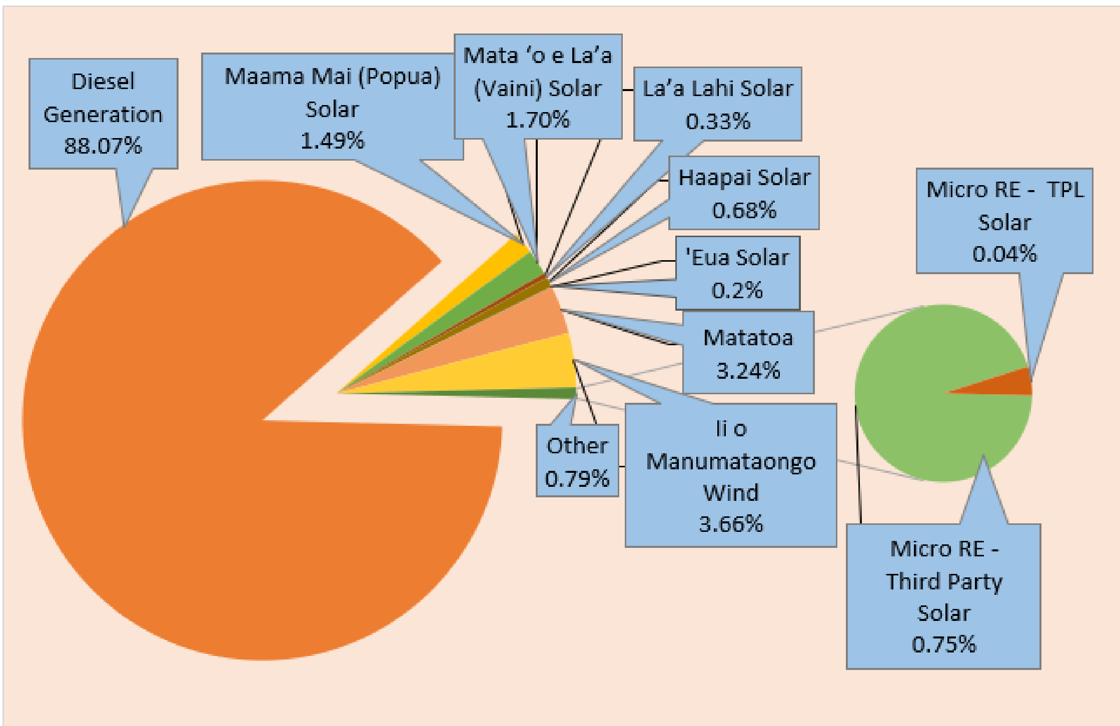


Figure 19: Portfolio of Energy Generation (%) from 2018/19 FY

The total renewable energy generation was 6,424MWh, contributed by various solar and wind plants (Figure 20). Matatoa's contribution was the highest at 38.0%, then Mata 'o e La'a at 19.5%, Maama Mai at 17.6%, and third-party micro solar plants contributed 7.9% of the total renewable generation. Third-party refers to companies who generate their own electricity and connect to TPL's main network.

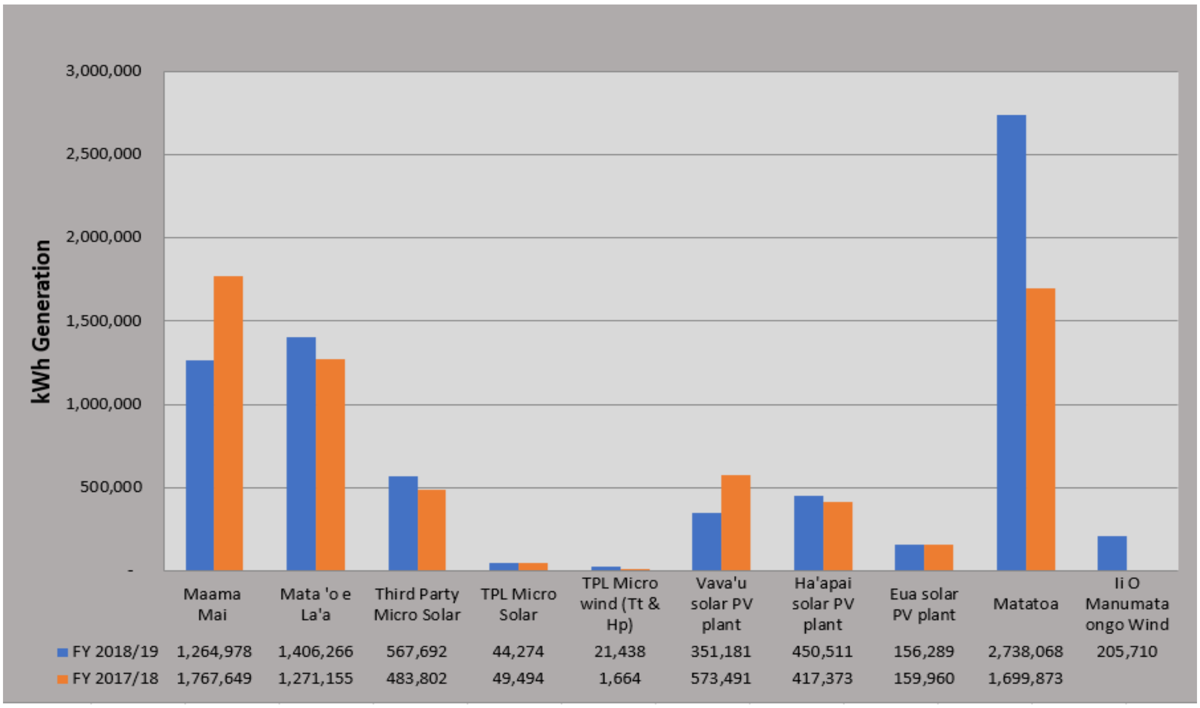


Figure 20: Renewable Generation 2017/18 vs. 2018/19

4.1.1 Diesel Generators

Tonga has currently installed diesel generating capacity of 18.35MW in all four islands (Table 12).

Table 12: Tonga Diesel Generation Capacity (Source: ADB Proposed Grant and Administration of Grants for Kingdom of Tonga)

Island Group	Description	Capacity (MW)
Tongatapu	Popua Power Station 6 x 1.4 MW + 2 x 2.8 MW + 1 x 1 MW	15
'Eua	Power Station 2 x 186 kW + 1x420kW	0.79
Ha'apai	Power Station 1x320kW + 2x186kW	0.69
Vava'u	Taumu'aloto Power Station 2 x 600 kW + 1 x 320 kW + 2 x 186 kW	1.87

Tongatapu's capacity is approximately 15MW with 10.5MW peak demand during the month of February. Popua power station has six CAT (Brand of the company Caterpillar) generators (3516B) and two MAK generators (6CM32). Tongatapu is well served from the Popua power station where there is sufficient capacity to meet current peak demand even with one of the diesel units out of service (N-1 reliability). The 11kV switchboard in the power station also helps to provide flexibility and reliability of supply. TPL's aim is to have sufficient renewable energy generation in the future such that only one of the 1.4MW generators is required to operate during the day. Vava'u also meets the N-1 security with a total of five generators, where two 600kW Cummins units are supported by smaller units (two 186kW and one 320kW units). Ha'apai has one 320kW and two 186kW units which also provide N-1 security. In 'Eua, two 186kW Cummins units and one 420kW leased unit are installed. The peak demand at 'Eua is such that for a relatively small number of hours, both Cummins generators need to be operational to meet the peak demand.

TPL currently has only one bulk storage tank installed at the Popua power station. The present storage tank has a capacity of 250,000 litres and supplies fuel to diesel generators for 10 days (25,000 litres supply per day). However, in the event of catastrophic damage to the present tank due to a disaster (e.g. earthquake, fire etc.), the power station does not have any redundancy or plans for additional storage of fuel for generation of electricity. Therefore, installing renewable energy generators and BESS is crucial to securing Tonga's energy supply.

4.1.2 PV Systems

Under the TERM with TPL direct operational input, six major solar plants over 200kW have been constructed to date including one IPP (Table 13).

Table 13: Tonga PV Systems

Description	Island Group	Year Installed	Capacity	Generation
Maama Mai	Tongatapu	2012	1.4MW	1,264MWh
Mata 'o e La'a (Vaini)	Tongatapu	2015	1MW	1,406MWh
Matatoa (Singyes) IPP	Tongatapu	2017	2MW	2,738MWh
Huelo 'o e Funga Fonua	'Eua	2017	200kW	156MWh
Ha Masani (Lifuka)	Ha'apai	2017	550kW	450MWh
La'a Lahi	Vava'u	2013	500kW	351MWh
Liukava, Fualu, and Masilamea (Sunergise) IPP	Tongatapu	TBC	6MW	10GWh
'Uiha	Ha'apai	TBC	100kW	
Nomuka	Ha'apai	TBC	100kW	
Ha'ano	Ha'apai	TBC	100kW	
Ha'afeva	Ha'apai	TBC	60kW	
Niuatoputapu	Niua	TBC	150kW	
'O'ua	Ha'apai	TBC	59kW	
Tungua	Ha'apai	TBC	71kW	
Kotu	Ha'apai	TBC	71kW	
Mo'unga'one	Ha'apai	TBC	50kW	
Niuafo'ou	Niua	TBC	250kW	
Solar PV Farm with BESS	'Eua	TBC	350kW	
Solar PV Farm with BESS	Vava'u	TBC	300kW	

There are currently three solar farms operating in Tongatapu: Maama Mai, Mata 'o e La'a, and the Matatoa IPP. The Maama Mai ('let there be light') solar farm (Figure 21) was the first solar facility to be built in Tonga and the first step towards the TERM's goal to reduce Tonga's reliance on fossil fuels. Maama Mai, located at Popua power station, has been saving the country approximately 460,000 litres of diesel and carbon emissions by more than 2,000 tonnes per annum. The Mata 'o e La'a solar farm was the first in Tonga to introduce a stabilising capacitor and micro-grid control system to ensure compatibility with Maama Mai. The micro-grid controller at Vaini and Popua solar facilities automatically optimise the output from a mix of renewable energy and diesel generation whilst stabilising the frequency. The Matatoa solar farm is owned by the Chinese firm Singyes Solar Technologies and operated by TPL. The commissioning of Matatoa marked a new milestone in private sector investment in the development of renewable energy generation in Tonga as the first large scale IPP facility installed.

Figure 21: Maama Mai Solar Plant (Source: TPL)

The OIREP has played a major role in achieving the TERM goal, with an aim to construct and install PV systems with a total capacity of 1.32MWp across 9 outer islands of Tonga. Phase 1 of the OIREP, completed in 2017, involved the on-grid generation to install the Huelo ‘o e Funga Fonua system in ‘Eua (Tongatapu group) and the Ha Masani system in Lifuka (Ha’apai group), as well as repairing the existing SCADA system to improve operational efficiency of the existing network in Vava’u (Vava’u group). The Huelo ‘o e Funga Fonua solar farm generates approximately 19% of electricity for the people of ‘Eua, and the Ha Masani solar farm allowed Ha’apai to become the first island in Tonga to reach 50% renewable energy. The La’a Lahi solar farm, located next to the Taumu’aloto power station in Vava’u, is controlled to curtail output when the diesel generator output falls to 30% of capacity, therefore limiting the solar plant to 420kW peak output.

Phase 2 of the OIREP is still underway, and involves installing mini-grid renewable-based hybrid systems consisting of 510kW solar PV coupled with 4.3MWh BESS in total in five outer islands, four in the Ha’apai group (‘Uiha, Nomuka, Ha’ano, Ha’afeva) and one in the Niuas group (Niuatoputapu). All consist of effective diesel back-up and the assets will be connected to the existing community owned mini-grid generation. The design for the four Ha’apai islands is to install a centralized solar PV generation site next to the existing diesel power station. Furthermore, TPL owns 65kW of rooftop solar capacity and 510kW of third-party micro solar capacity is owned by private entities. There are approximately 40 private rooftop systems, the largest being 150kW.

Plans to increase future PV capacity in Tonga include the signing of a PPA in March 2019 with Sunergise from New Zealand, to finance, build, and operate three 2MW (6MW total) sites on Tongatapu at Liukava, Fualu, and Masilamea. The solar plant will be the second largest in the Pacific and the second that TPL has established with an IPP. This plant will form an integral part of TPL’s Renewable Energy Program with 10GWh capacity, equivalent to 15% of the whole of Tonga’s anticipated electricity demand by 2020. Under the TREP, an additional 4 islands in the Ha’apai group (‘O’ua, Tungua, Kotu and Mo’unga’one) and one in the Niuas group (Niuafo’ou) will also receive solar-battery hybrid systems as indicated in Table 13.

4.1.3 Wind Generators

Current wind generation consists of two micro wind turbines in Nakolo (Tongatapu) and Foa, as well as the Ii ‘o Manumataongo wind farm (Table 14).

Table 14: Tonga Wind Generators

Description	Island Group	Year Installed	Capacity
Nakolo micro wind	Tongatapu	2013	11kW
Foa micro wind	Ha’apai	2015	11kW
Ii ‘o Manumataongo wind farm	Tongatapu	2019	1.375MW
Chinese Investors	Tongatapu	TBC	2.25MW
Wind farm IPP	Tongatapu	TBC	3.8MW

TPL micro wind consists of the Nakolo and Foa wind turbines, with a total generation of approximately 21,438kWh (Figure 18). Both micro wind systems, manufactured in the United Kingdom and designed by Gaia Wind, were installed to assess the viability of wind generators in their respective regions and increase wind generator capacity installed in the future. The Nakolo wind turbine was the first wind turbine to be installed in Tonga and the first of its design ever built. The turbine generates power once the wind speed reaches 3.5m/s and is expected to reach a capacity of up to 11kW when the wind speed reaches a constant 9.5m/s or more. At maximum capacity, the twin-blade turbine is capable of generating 27,000kWh of electricity each year, enough to power approximately 23 homes in Nakolo. It is located on a piece of land close to the sea with strong and consistent wind speeds, making it an ideal place for a wind turbine. The objective of the wind turbine project was to help TPL staff gain experience on how to operate and maintain a wind turbine in Tonga. The Foa wind turbine is the first turbine installed in the outer islands by TPL with similar features to the Nakolo turbine, and the project is expected to generate 27,000kWh of electricity each year saving an estimated 7,400 litres of diesel.

Tonga’s first large-scale wind farm project, the Ii ‘o Manumataongo wind farm (Figure 22), was funded by the Japanese Government’s JICA (Japanese International Cooperation Agency) with the aim of cutting the cost of Tonga’s diesel fuel import for the existing plant by 1.5 million Tongan pa’anga per year. The wind farm consists of five 275kW wind turbines, each with 38m towers, fixed-tilt, micro-grid controller and energy storage for frequency support and is owned and operated by TPL. The wind turbines can be folded away in advance to avoid damage from the rages of a cyclone and maintenance work can be done just 3m above the ground due to the current elevation level of TPLs work vehicles. The location of the wind turbines at the end of island has resulted in loss of utilisation due to the electricity distribution in the area failing at times, however because of that TPL are strengthening the grid.

Figure 22: Ii'o Manumataonga Wind Farm (Source: TPL)

Plans to increase future wind capacity in Tonga include building two wind farms, both in Tongatapu. A 2.25MW project is being developed by the Government of China as a gift to the people of Tonga and is currently being designed for the Eastern side of the island. It was originally hoped to be complete by end of 2020, however there have been significant delays due to COVID-19. There are also plans for a 3.8MW IPP wind farm also on the Eastern side of the island under a PPA with TPL. The rules that guide the introduction of wind turbine generators to the Tongatapu electricity grid include requiring to use pitch regulated turbines with frequency governor and not have a vertical cut out profile at high wind speeds.

4.1.4 Biomass

Tonga is looking at alternative solutions such as the biomass project in 'Eua, and exploring poultry as part of the "Tonga Circular Economy System". The capacity of the 'Eua biomass project is 250kW and comprises a 250kW gasifier and 250kW gas engine, generating 1GWh per annum using 2,000 tons of wood chips with direct diesel displacement. The average load of 'Eua is approximately 130kW, with an evening peak reflecting a load profile driven largely by domestic demand.

4.1.5 BESS

BESS are a vital component to reaching Tonga's 50% renewable energy target by the end of 2020. Although renewable energy adds to the existing generation capacity, the intermittency of the energy sources means it cannot be relied on to provide firm capacity unless energy storage is installed. Battery storage is required to allow increased integration of renewable energy, particularly from the private sector. Once the additional renewable energy is constructed, TPL will become reliant on battery storage for a significant proportion of its revenue, and therefore has a strong incentive for operating and maintaining battery storage. In the event that the proposed BESS under TREP do not take place, planned solar PV and wind farms to be developed would not be realized, because TPL's grid cannot fully cope with intermittent electricity generated from those renewable energy generation facilities. Table 15 shows currently installed BESS.

Table 15: Tonga BESS

Description	Island Group	Year Installed	Rated Output	Battery Capacity
Mata ‘o e La’a solar (Vaini)	Tongatapu	2015	0.5MW	11kWh
Mata ‘o e La’a solar (Maama Mai)	Tongatapu	2015	0.5MW	11kWh
Ha Masani solar	Ha’apai	2017		660kWh
La’a Lahi solar	Vava’u	2013	0.2MW	185kWh
Ii ‘o Manumataongo	Tongatapu	2019	1MW	13kWh
‘Uiha	Ha’apai	TBC		210kWh
Nomuka	Ha’apai	TBC		210kWh
Ha’ano	Ha’apai	TBC		210kWh
Ha’afeva	Ha’apai	TBC		110kWh
Niuatoputapu	Niuas	TBC		295kWh
Akuo Energy (Popua power station)	Tongatapu	TBC	5.1MW	2.5MWh
Akuo Energy (Matatoa solar)	Tongatapu	TBC	5MW	17.4MWh
‘O’ua	Ha’apai	TBC		470kWh
Tungua	Ha’apai	TBC		580kWh
Kotu	Ha’apai	TBC		580kWh
Mo’unga’one	Ha’apai	TBC		390kWh
Niuafo’ou	Niua	TBC		2.275MWh

The Mata ‘o e La’a solar facility, Tonga’s first solar facility with stabilising capacitor and micro-grid control system, has 1MW of PV capacity installed with two sets of 500kW stabilising Lithium-ion battery banks. The Mata ’o e La’a solar facility, donated from the Government of Japan through JICA (Japan International Cooperation Agency), incorporates a microgrid control system to work in tandem with the Maama Mai solar facility and other future renewable projects in Tonga. One of the battery banks is installed at the Vaini site and another 0.5MW is installed at the Maama Mai solar facility in Popua Power Station (Figure 23), each with 11kWh capacity. The Mata ‘o e La’a and Maama Mai plants are supplied with short-term (60 seconds) energy storage to reduce the effects of power fluctuations and throttling of the generators to compensate for cloud cover, and are currently being used for frequency control. The battery storage has a total approximate annual saving of 831,465 litres of diesel.

Figure 23: 0.5 MW BESS at Popua Power Station

The Ii ‘o Manumataongo wind farm in Tongatapu has a similar BESS to the Mata ‘o e La’a solar facility, consisting of a 1MW stabilising Lithium-ion battery bank with short-term (30 seconds) frequency support for the grid.

Furthermore, the OIREP has contributed to the increased battery energy storage in Tonga. Phase 1 involved installing battery storage at the Ha Masani solar farm with a capacity of 660kWh, enabling Ha’apai to be the first island in Tonga to reach 50% of electricity generation from renewable energy sources. Phase 2 of the OIREP is still underway, and as mentioned in section 4.1.2, involves installing renewable-based hybrid systems consisting of solar PV coupled with BESS, four in the Ha’apai group (‘Uiha, Nomuka, Ha’ano, Ha’afeva) and one in the Niuas group (Niuatoputapu). There will be three 210 kWh storage installed, one in each of ‘Uiha, Nomuka and Ha’ano; 110kWh storage for Ha’afeva and 295kWh storage for Niuatoputapu. All consist of effective diesel back-up and the assets will be connected to the existing community owned and managed mini-grid generation.

Plans to increase future energy storage in Tonga include two systems already under development, both in Tongatapu. The first system will be Tonga’s first ever large scaled BESS (current installed battery capacities all less than 1MWh), built at the Popua Power Station. In July 2019, TPL signed an agreement with French company Akuo Energy SAS to design a grid stabilisation BESS which will allow the installation of further renewable energy. The BESS will be connected to the power station main switchgear and SCADA and is intended to provide advanced control and grid stability functionality including automated reserve capacity, reactive power, voltage, and frequency support, and smoothing functionality. The system is scheduled to be commissioned mid-2020.

The second system is also a large-scale BESS which will be installed at the Lakalakaimonu Multi-Utility (TPL Headquarters) compound near the Matatoa (Singyes) solar facility, and is set to become the largest storage project in the South Pacific to date. In November 2019, TPL signed an agreement with Akuo Energy SAS to install a system that’s main function will be load shifting to facilitate increasing capacity of renewable generation in the grid by storing solar generation for use during evening peak and at night. Akuo will set up its innovative modular energy storage containers Storage GEM® to help secure Tonga’s grid. This project is funded through the TREP project which is co-financed through ADB, GCF fund and DFAT along with contributions from government of Tonga and TPL. The project is expected to begin its planning and construction mid early 2020 and the plant is to be commissioned in late 2020, however delays are expected due to the COVID-19 situation.

Under the TREP, an additional 4 islands in the Ha’apai group (‘O’ua, Tungua, Kotu and Mo’unga’one) and one in the Niuas group (Niuafo’ou) will also receive solar-battery hybrid systems as indicated in Table 15.

4.1.6 Independent Power Producers (IPPs)

In order to reach the 50% target by 2020, IPPs will play a major role in taking Tonga towards its renewable energy goal. Rapidly transforming the sector requires substantial investments in a short period of time. The ability of Tonga to access public and private financing for such investments is limited, therefore engaging private ownership is encouraged. With the company and shareholder limited debt-bearing capacity, the available resources are insufficient to finance the structural shift from diesel generation to renewable energy. Reaching the region's energy targets presents prospects for the private sector to deliver the technical solutions and financing models that will ensure their sustainability. There is currently a 2MW PV site in operation, with plans for a 6MW PV plant and 3.8MW wind farm to be commissioned in the near future (Table 16) as previously mentioned in sections 4.1.2 and 4.1.3.

Table 16: Tonga IPPs

IPP	Type	Site/s	Capacity	Year Installed
Singyes Solar Technologies	Solar	Matatoa	2MW	2017
Sunergise New Zealand	Solar	Liukava, Fualu, and Masilamea	6MW	TBC
TBC	Wind	Tongatapu	3.8MW	TBC

However, there are major factors which deter investors from small countries such as Tonga. These include small project size, poor financial returns on investments, lack of previous experience and perceived risk, and incomplete data sets and analysis. Further, the Foreign Exchange Control Act prohibits foreign contractors from completing works in Tonga if they have off-shore accounts which means Special Purpose Vehicle (SPV) companies must be setup specifically for a project. However, donors cannot sign off on an SPV to complete work if they do not have any experience or financial history as this is required for contract awards. Developing appropriate PPAs with IPP owners and managing outcomes also present a challenge to TPL. At the same time TPL has to incur additional expenses including the cost of automation to monitor IPP's RE generation facility to ensure safety and stability with fuel savings being passed through to customers. With up to 11MW of renewable generation that could be provided by IPPs, regulatory reform and a donor-supported risk reduction facility have been planned to enable investment. As a result of the Green Climate Funding approved in late 2018, TREP will support potential IPP transactions and areas for IPP involvement (e.g. drafting and/ or reviewing PPAs to be entered with IPPs).

4.2 Lessons Learnt

4.2.1 Geographical Location

The climate in Tonga is attractive for certain forms of renewable power generation including solar, wind, and biomass. However, the four grids are exposed to extreme weather conditions, primarily strong winds that often cause indirect damage from vegetation (e.g. coconuts) that become loose in the wind. A significant amount of vegetation management is on-going, however the networks are still vulnerable to falling coconut palms. Tonga is prone to both earthquakes and tropical cyclones, which often destroy TPL's network and generation assets extensively. Even though insurance and surplus of donor funds are available to reconstruct the damaged network, this takes a considerable amount of time to bring the network back to a normal state of operation. For example, it took approximately four and a half days to complete repairs and fully restore power on the main island after Tropical Cyclone Harold in 2020 and there was quite a lot of damage from storm surge. Other notable instances include a 2009 magnitude 8.1 earthquake and subsequent tsunami, as well as 2014's Cyclone Ian (Figure 24), which struck Ha'apai directly, damaging or destroying 90% of distribution lines. These instances impose various economic and safety risks to the people of Tonga when the nation experiences prolonged outages. However, with continuing upgrades to the network such as the Nuku'alofa and Vava'u projects, TPL expect to see improvements in cyclone resilience.

Figure 24: Damage Caused by Cyclone Ian (Source: TPL)

TPL have planned several strategies to respond to the challenges of their geographical location. Foundations and racking systems for PV arrays must be designed to withstand powerful cyclones and hurricanes, which will reduce any potential hazard of modules being lifted and blown onto adjacent properties. To deal with the issue of cloud cover, TPL have installed energy storage and disbursed PV systems around the island. Other actions include overhauling and repairing network switches to help manage interconnection issues under the NNUP; progressively introducing asset condition monitoring in order to enhance reliability of supply and safety; identifying locations of old assets (insulators, transformers, reclosers, street light control boxes, poles and undersized conductors etc.) and replacing/maintaining them; ongoing vegetation clearance plans; having a reliable insurance plan in place; and utilising innovative technologies such as Acoustic Inspections and Thermal Imaging Inspection on overhead distribution assets to identify defects such as corrosion, pitting, tree contact, overheating, contamination, cracks, loose connections, and electrical discharges etc. The defects contribute to network losses and when rectified will reduce network faults in the field.

4.2.2 Common Faults

The poor-quality network prior to 2008 presented several risks including high level of line losses, estimated to be up to 20%, voltage fluctuations causing damage to household appliances and safety hazard to the public. With the recent successful completion of TVNUP, the ongoing NNUP and outer island network upgrades, total system losses have significantly improved to less than 11%. However, Nuku'alofa CBD and Vava'u network status still requires further improvement. The poor state of equipment on these networks includes de-rated cables, broken insulators, weak poles, broken airbreak switches, incorrect HV/LV fuses, and over utilized transformers and connectors. Improvements in Vava'u are currently in progress, while the Nuku'alofa Network Upgrade Project (NNUP) is scheduled to complete site works for Areas 1 and 2 in 2020, and Areas 3, 4, and 5 in the future (Figure 25). The total number of reported faults and outages reported by the Fault Unit decreased by 12.6% from 3,933 reported faults/outages in the year 2018 to 3,436 at end of June 2019, reflecting largely the improved network. Most of the reported faults during the period were mainly in areas of the CBD – covered in the NNUP.

Figure 25: Nuku'alofa Network Upgrade Project (Source: TPL)

TPL have discovered an issue with the Matatoa (Singyes) solar plant as the cable ground faults are shorting to earth on the d.c. cables. Although Matatoa is an IPP, TPL have the O&M contract and therefore are required to rectify the unforeseen problem. The primary cause of this issue is believed to be due to the cables not installed in conduit or being armoured cable, and to overcome this they have had to install aerial cables. In the future TPL will ensure that for the installation of all new solar systems, the d.c. cable is undertaken in conduit and installed to prevent any water ingress into the conduit.

Plans to improve the operation of the grid and reduce the number of faults in the future include:

- having the regulators enforce the use of the Tonga Grid Operation Code,
- implementing network reinforcement to prevent the network being overloaded,
- implementing a "ring" so there are 2 routes to go back to the power station which is particularly important during cyclones or faults to get back up running faster, and
- installing a control centre with readers to detect faults.

Once a ring philosophy is adopted it will provide adequate power quality and reliability particularly through improved fault clearance times which most renewable generation plant can ride through if certain generation connection requirements are followed. The network's reliability will also improve overall as feeder faults will no longer result in the loss of all load on that feeder. The real benefit is that the network will be able to absorb renewable energy and the main challenge will be upskilling and up sourcing human resources to manage the changed philosophy of asset operation and maintenance.

4.2.3 Personnel Training

Whilst employees are competent in their roles, TPL believe ongoing training is still required. Areas they would like to focus upon include training on analytics, data mining, dispatching, and long-term operations. There is also particular interest in virtual reality training and videos, and building training capacity at the Tonga Institute of Science & Technology (TIST) particularly for technicians.

4.2.4 Community Engagement

Community engagement is a vital aspect for TPL, as one of the biggest misconceptions by customers is believing "solar energy is free" and that their electricity bills will be reduced by 50% once the government's 2020 50% renewable energy target is met. Whilst there will be a sizable reduction in the tariff due to displacing 50% of diesel, it will not be 50% off the tariff as some expect. In order to combat this, TPL have introduced more customer outreach and awareness programs through talk back radios and TV programmes, all to provide their customers with safe, reliable, affordable and sustainable electricity services and greater customer awareness. The board has also approved the TPL Green Power campaign with an objective to better inform all electricity and energy stakeholders of the drivers for shifting to renewable energy.

4.3 Operational Changes

4.3.1 Generation Dispatch Information

In general, there are two (2) electricity peak demands on weekdays, i.e. late morning to early afternoon peak and then an evening peak. The major contributors to daytime load are commercial customers (primarily air-conditioning and lighting). The decrease in commercial sector activities in the afternoon is replaced by the increase in the residential sector activities (primarily lighting and cooking) resulting in an evening peak at around 8pm. In general, mid-day peak demands during weekdays are higher than weekends and the differences are estimated around 30% or more especially in the hot season. On Sundays, instantaneous solar penetration levels can reach 35% as the requirement for diesel generation declines due to low demand usually on Sundays.

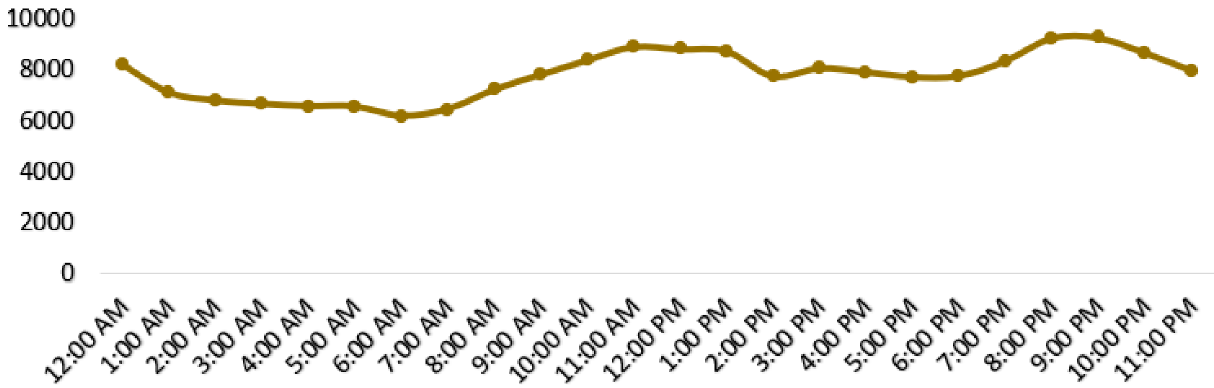


Figure 26: January Daily Load Curves (Source: TPL)

The Tonga Grid Operation Code has been developed by Danish Energy Management in 2018 and funded by the EU. Generation Dispatch is the process of scheduling and issuing dispatch instructions to generation units and BESS to achieve economic operation while maintaining Reliability and Security of the Distribution System. TPL shall undertake the week-ahead load forecasting and dispatch scheduling based on the following operational criteria:

a. The generation capacity shall be sufficient to match, at all times, the forecasted distribution system demand and the required Primary, Secondary and Backup Reserves;
b. The technical and operational constraints of the system, the generating units and the BESS shall be properly considered;
c. The security and stability of the grid shall be ensured;
d. The variability of Variable Renewable Energy (VRE) Generation Plants shall be properly considered; and
e. The operational cost, subject to the constraints indicated above, shall be minimized.

Primary reserve means the amount of reserve provided by a generation unit, generation plant or BESS due to primary response, released increasingly from zero to five seconds from the time of frequency change. Secondary reserve means the amount of reserve provided by a generation unit, generation plant or BESS, as it corresponds, through secondary response which could be sustained for at least 30 minutes. Backup reserve means the generation capacity provided by a generation unit, generation plant or BESS, as it corresponds, which is available but not synchronized to the distribution system.

The dispatch scheduling results, which will be communicated to the Control Centre Operator and all involved generation companies and BESS companies, shall include:

a. Starting and disconnecting times for each generation unit;
b. Hourly loading set-points for all generation units which are not providing Primary or Secondary Reserve;
c. Hourly operating modes of the BESS (charging mode or discharging mode);
d. Hourly loading set-points, either in charging or discharging modes, as it corresponds, of BESS which are not providing Primary or Secondary Reserve; and
e. Hourly expected production of VRE Generation Plants.

TPL shall determine, and communicate to the Control Centre operator, the amount of Primary, Secondary and, if necessary, Backup Reserves to be maintained at each moment in the distribution system to control system frequency within the targets established. The following values shall be utilized as Primary, Secondary and Backup Reserves:

a. In case of Isochronous Control Mode
    i. Primary+Secondary Reserves Up: 1.3MW
    ii. Primary+Secondary Reserves Down: 1.3MW
    iii. Backup Reserve (Up): 2.5MW (Largest dispatched Generation Unit)

b. In case of Droop Control Mode
    i. Primary Reserves Up: 0.8MW
    ii. Primary Reserves Down: 0.8MW
    iii. Secondary Reserves Up: 0.7MW
    iv. Secondary Reserves Down: 0.7MW
    v. Backup Reserve (Up): 2.5MW (Largest dispatched Generation Unit)

Isochronous control mode means a mode of controlling the output of a generation unit, generation plant or BESS, as it corresponds, which maintains the system frequency to a pre-set value in response of a change in load and/or the output of other generation units or plants. Droop Control Mode means a method of controlling the output of a generation unit, generation plant or BESS, as it corresponds, which requires a deviation of system frequency (frequency error) in order to activate the primary reserves associated with these facilities. Up reserve means the portion of the reserve which reduces a decrease in system frequency, either increasing generation or adjusting the output of BESS. Down reserve means the portion of the reserve which reduce an increase in system frequency, either decreasing generation or adjusting the output of BESS.

As mentioned in section 4.1.1, TPLs aim is to have sufficient renewable energy generation in the future such that only one of the 1.4MW diesel generators in Tongatapu is required to operate during the day. As the CAT engines are electric starters, they can come on automatically. Whilst they would like to be able to turn off all generators, they must also consider fault current issues which may arise.

Real-time Dispatch Scheduling shall be implemented by the Control Centre operator through:

a. Generation Plants and or BESS which are under its direct control:
    i. Starting or stopping Generation Units;
    ii. Setting the mode of operation of BESS (charging or discharging modes);
    iii. Setting loading set-points to generation units or BESS; and
    iv. If necessary, VRE Curtailment.

b. Generation Plants or BESS which are not under its direct control:
    i. Issuing appropriate dispatch instructions to the operators of such facilities and monitoring its actual compliance.

The Control Centre operator shall continuously monitor the conditions in the Distribution System, particularly that:

a. The System Frequency is within the tolerances indicated in Table 17;

Table 17: Frequency Ranges (Source: Tonga Grid Code)

System State	Frequency Range
Normal	49.7 – 50.3 Hz
Alert	49.0 – 51.0 Hz
Emergency	48.5 – 51.5 Hz

b. The Primary and Secondary Reserves are equal or higher than the values mentioned previously;
c. Voltages at the selected monitored Connection Points are within the tolerances established in Table 18.

Table 18: Allowed Voltage Variations (Source: Tonga Grid Code)

Voltage Level		Allowed Variation
LV	240V	± 10%
	415V	± 5%
MV	11kV	± 7%

d. There are not symptoms of System instability.

Due to the intermittent nature of renewable generation, weather can also have a major impact on generation so precautions must be taken to maintain operation of the grid. For example, if solar farms are limited in size and dispersed geographically then fluctuations caused by cloud impacts have less impact than a power plant trip and will therefore be manageable. In case one or more of the monitored parameters falls outside the permissible values with a significant risk, the Control Centre operator shall declare the distribution system in alert or emergency state, as it corresponds, and implement any action it considers appropriate to return the Distribution System to the Normal State as soon as practicable. For the avoidance of doubt, in alert or emergency states the Control Centre operator may issue dispatch instructions of VRE generation curtailment. Manual load shedding can also be implemented as a last resort action.

4.3.2 Diesel Generator Controls

SCADA is a control system architecture that uses computers, networked data communications and graphical user interfaces for high-level distribution system monitoring and tele-control. The SCADA systems installed at Popua power station (Tongatapu) and Vava'u have been a useful tool for generation (for ongoing monitoring of the engines and generators) and distribution network planning. In the power station, each generator can be monitored on a shift by shift basis for fuel use and efficiency. The data is helpful in monitoring any fuel losses including theft as well as engine condition monitoring. However, there are limitations to TPL's current SCADA capabilities such as the absence of a supervisory control in each SCADA as well as integration of the existing systems.

SCADA is used at Popua power station to monitor diesel generation as well as monitoring solar generation at the solar farms and the wind generators on Tongatapu. The generation from the diesel generators and solar farms on Vava'u, Ha'apai and 'Eua can be telemetered to Popua, however there has been difficulty in getting the data from the other islands due to remote communication capabilities. The existing SCADA will not support advanced generation and distribution management functionality such as automated generator dispatch, smart grid, outage management, demand response and smart meter applications. Ha'apai and 'Eua do not have SCADA systems; these power stations use utility metering with logging capabilities to capture electrical parameters, with the engine parameters monitored locally.

In addition, SCADA parameters on Ha'apai and 'Eua cannot be monitored from the Tongatapu main power station due to lack of remote communication capabilities.

In order to improve TPLs impact in the future, several initiatives have been suggested to be implemented. TPL will establish a new combined control centre that combines the functions of generation monitoring and distribution monitoring and maintenance and fault crew dispatch at the new TPL offices, and procure a replacement SCADA or upgrade the existing SCADA and add to that functionality. A generator dispatch will be purchased in addition to advanced distribution management modules to support remote control, load control, outage management, smart meter applications and fault crew dispatch. TPL will also re-establish the existing control room at Popua power station into a disaster recovery site for the new centralised control centre should that be rendered inoperable. The centralised control centre will allow for comprehensive monitoring of the outer island generation and distribution networks which is not currently available.

4.3.3 Spinning Reserve Methodology

Due to the intermittent nature of third-party renewable generation, TPL is still required to maintain a large spinning reserve, keeping existing firm (diesel) generation operating at inefficient levels. This would see TPL incur extra diesel or other fuel costs and likely an accelerated rate of deterioration of existing diesel and other firm generators. Contingency reserve could be provided either by already connected equipment (spinning reserve) or by off-line equipment which have fast start capability.

TPL's Security of Supply Policy ensures enough firm (diesel) generation capacity is available at short notice to cover faults or to meet sudden changes in consumer demand. In other words, if the largest capacity generator is out of action due to a breakdown, other generators in the fleet must be able to continue to supply power to meet the consumer demand at any time of the day. The solution for the N-1 redundancy policy is to duplicate the largest generator in each of TPL's four power stations. The policy assumed intermittent generation (solar and wind) cannot be relied on at any time and are excluded. Currently Tongatapu and all three outer islands meet the N-1 security policy; however, there is slight ambiguity of maintaining the reliability of supply due to potential load growth as a result of the NNUP.

The Frequency Regulating Reserves shall include Primary Reserve and Secondary Reserve. The Contingency Reserve shall include Primary Reserve, Secondary Reserve and Backup Reserve with Fast Start capability. Primary and Secondary Reserve could be either Up Reserve or Down Reserve. Backup Reserve will be only Up Reserve. The amount of Up and Down Reserves operating under the frequency control scheme, provided both by the connected Generation Units under governor control and by BESSs capable to provide frequency regulation, are enough to keep the frequency within the range [49.5 – 50.5] Hz in case of any expected load increase or decrease, as it may be reasonably expected; and reasonable expected variations in the output of VRE Generation, those being positive or negative.

4.3.4 Tariff Structure

A uniform tariff rate is charged for all electricity consumers of TPL, which is composed of a fuel and non-fuel tariff component. The fuel component of the tariff is adjusted regularly for forecast fuel costs, forecast electricity demand as well as to return previously over- or under- recovered fuel costs. The non-fuel part of the tariff is adjusted for inflation over the tariff period using a consumer price index. As almost 90% of the electricity on the TPL grid is supplied from diesel generation, the price of diesel fuel is the major component of the electricity tariff. The tariff structure of "one tariff for all" was adopted in 2009 through regulation which makes the tariff consistent across all the four island groups and means the savings produced by the renewables is shared by all consumers.

Diesel prices dropped from T$1.6906 per litre in October 2019 to T$1.5091 per litre in March 2020. The accumulated price reduction is driven primarily by the ongoing price war between Russia and Saudi Arabia since 8 March 2020, as well as the current economic impact of the worldwide COVID-19 pandemic. Therefore, the new published rate for all electricity will reduce by a total of T$0.1016 (12.2% reduction) per kWh to T$0.73 per kWh from the current tariff which was set back in

1 November 2019. The previous tariff of T$0.8316 per kWh was subsidized by the Government of Tonga to remain at T$0.7990 per kWh up to March 2020. The new electricity tariff rate of T$0.73 per kWh was approved by the Electricity Commission to be effective from 1st April 2020.
From 1 April 2020, the Government of Tonga will further subsidise T$0.08 per kWh Lifeline Tariff (known as Government Policy Obligations or GPO) to residential customers' first 100 kWh or less kWh of electricity, that is further reducing the tariff from T$0.73 to T$0.65 per kWh.
The Lifeline Tariff is funded by the Government and is not available to commercial consumers.

In the future, TPL see the benefit of alternative tariffs and making tariffs more costs reflective, especially when RE penetration is high to allow consumers to reap the benefits. Using price signalling to shape and move loads to fit with the available RE generation is also a potential option to be explored.

4.4 Future Targets and Proposed Generation Capacity

TPL will continue with the strong development of renewable energy, in support of the Government's commitment to achieve 50% of all energy requirements from renewable energy sources by 2020, 70% by 2030 and 100% by 2035. A five-year Business Plan covering the period 2020-2024 was developed systematically and constructively to achieve TPL's mission of "Providing safe, reliable, affordable and sustainable services for Tonga with at least 50% of electricity requirements through renewable sources by 2020 whilst remaining financially stable". It also supports the Government core purpose for the Energy sector of "Reducing Tonga's vulnerability to oil price shocks, and achieve an increase in quality access to modern energy services in an environmentally sustainable manner".

The plan takes into account international, regional and national developments in the energy sector, and in the electricity industry in particular. The plan forms the implementation phase of the company's strategic direction for the period 2020-2024. It also contains detailed activities to be implemented in the next five years that will propel TPL to achieve the six strategic objectives of the Business Plan as outlined below:

i. Achieving 50% electricity generations from Renewable Energy generation by 2020 in order to achieve the government TERM target and realistic tariff reductions.
ii. Adopting technologies to manage the complexities arising from a digitized and decentralized renewable future.
iii. Improving the network by replacing ageing assets to improve safety, efficiency and reliability of supply.
iv. Promote a hazard free safety environment to minimize any danger to both the public and staff.
v. Improving the business processes to enhance customer/employee satisfaction while supporting a healthy and competent team.
vi. Manage all external funding and internal financing sources successfully in order to increase shareholder value.

Strategies to further increase renewable energy penetration to be explored include biomass, heat recover, tidal, wave, geothermal, more customer owned solar and wind, and EV as a form of BESS.