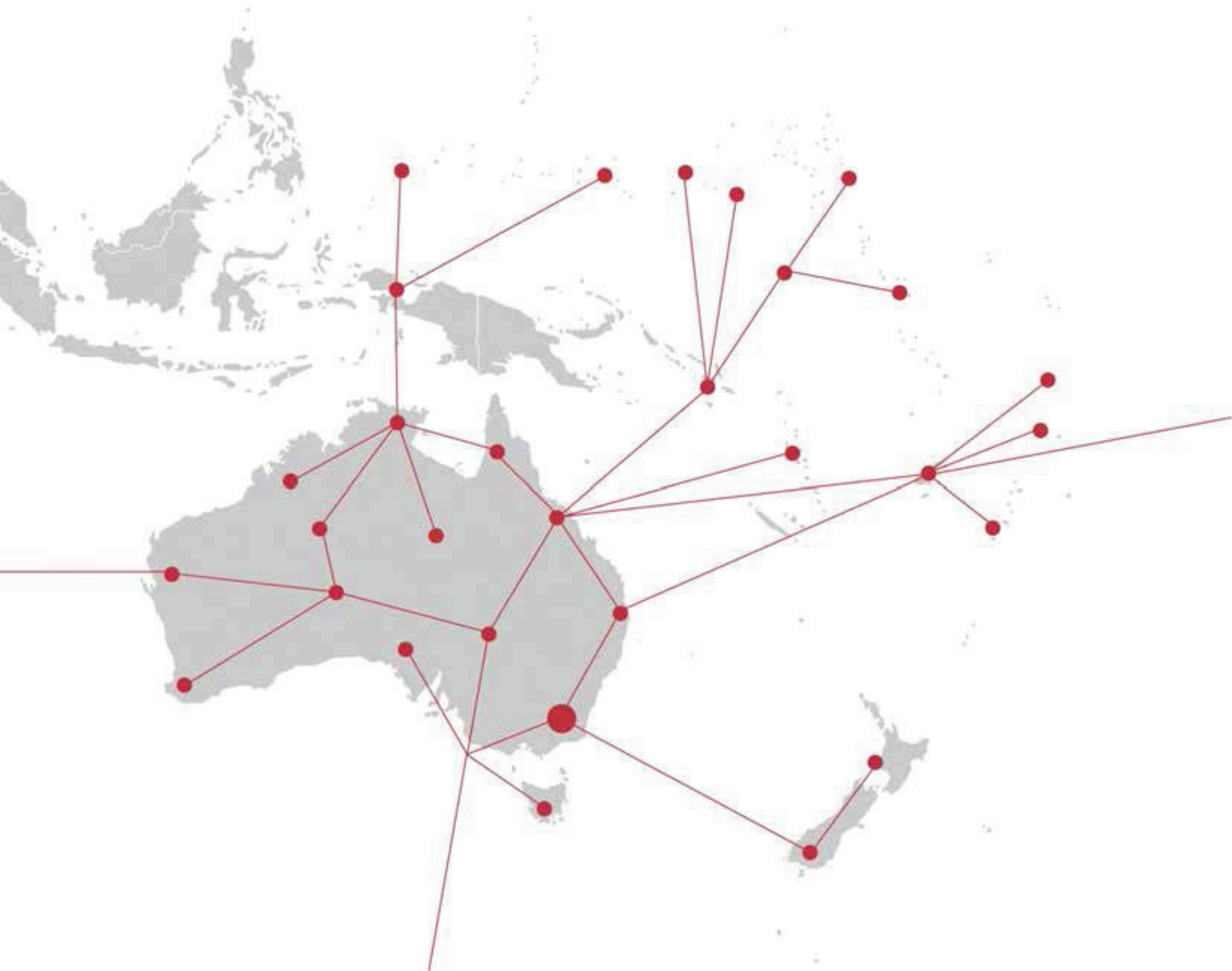
TOKELAU RENEWABLE ENERGY PROJECT REVIEW

Part 1 - Financial Review
Part 2 - Technical Review

December 2013



About IT Power

The IT Power Group, formed in 1981, is a specialist renewable energy, energy efficiency and carbon markets consulting company. The group has offices and projects throughout the world.

IT Power (Australia) was established in 2003 and has undertaken a wide range of projects, including designing grid-connected renewable power systems, providing advice for government policy, feasibility studies for large, off-grid power systems, developing micro-finance models for community-owned power systems in developing countries and modelling large-scale power systems for industrial use.

The staff at IT Power (Australia) have backgrounds in renewable energy and energy efficiency, research, development and implementation, managing and reviewing government incentive programs, high level policy analysis and research, including carbon markets, engineering design and project management.

About this report

This report presents the findings of post installation reviews for three solar-hybrid power systems installed on the atolls of Tokelau. The report is presented in two parts: Part 1 -Financial Review and Part 2 – Technical Review.

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EXECUTIVE SUMMARY

The Tokelau Renewable Energy Project (TREP) saw the installation of solar diesel hybrid power systems on Fakaofo, Nukunonu and Atafu, the three atolls of Tokelau. The systems were commissioned and handed over to the Government of Tokelau in October 2012 and have since been operated by local power station staff.

IT Power (Australia) Pty Limited (ITP) representatives visited Tokelau from 3rd June 2013 to 8th June 2013 to conduct an inspection and review of the post installation operation and performance of the systems. The review included two parts: a financial review of the ongoing costs of the systems and their effects on tariffs, and a technical review of the systems themselves.

The inspection times were limited by the boat schedule and the team had approximately one and a half full working days on each of Fakaofo and Nukunonu and one working day on Atafu.

The systems were inspected according to the principles of the MFAT "Hybrid Power System Post-Installation Inspections - Guidelines and Procedures" document (May 2013). The findings of the financial and technical reviews are listed below.

In general the power stations are being well maintained and the staff involved with the operations are motivated and engaged. The systems are all performing as expected and designed, albeit with room for minor improvements. These improvements are predominately around record keeping and management to ensure the projects longevity.

There is a clear need across the community to better understand the reasoning behind tariffs and what different tariffs mean for the community

The governance and management of the energy supply needs to be updated to reflect the changes in the energy supply and use.

The opportunity to manage the energy use through EE measures may not be significant, due to already low household energy use. While there are opportunities for demand reduction, given the low energy use per capita, we would be looking at, say, a saving of 10% of "not very much". The greater opportunities lie with the infrastructure itself (100% load metering etc).

Financial Review

1.1. General Findings

An investigation of the Financial Viability of the TREP over the medium to longer term raises some concerns and demonstrates room for improvement. The current tariff of ~NZD 0.50c per kWh will not generate the revenue required to fully fund the operations (including equipment replacement) of the power stations. However the operational cost, including allowance for replacement of key components, is well below the cost of a diesel only power station. The table below shows the modelled tariffs, based on information available. NOTE all modelling was undertaken at current prices – a brief discussion on the likely impact of rising diesel costs is included in section 1.3. The diesel only scenario is for comparative purposes only and is essentially a “pre-2012 benchmark”.

	Diesel powerhouse – O&M only	Diesel powerhouse – O&M and replacement	Solar / Diesel powerhouse – O&M only	Solar / Diesel powerhouse – O&M and replacement
Retail tariff charged	$0.50	$0.50	$0.50	$0.50
Unit cost required	$0.87	$0.91	$0.15	$0.77
Unit cost w/ return to GoT[1]	$1.00	$1.06	$0.17	$0.89
GoT effective subsidy	>$0.50	>$0.56	~($0.33)	>$0.39

Based on the modeling, a Tariff of around NZD$ 0.77c per kWh is required to fully finance the operations of the power stations (a ‘full cost-recovery’ tariff) but a higher tariff of NZD$0.89c/kWh is required to provide a return to the Government (a ‘cost-recovery and financial return’ tariff[1])

The table above clearly shows that the current tariff of NZD$0.50 per kWh did not cover the cost of generation of the diesel based generation, and will not cover the full lifetime costs of the Solar / Diesel powerhouse in place. However the difference in effective subsidy required of NZD$0.11 per kWh generated demonstrates the benefit of the Solar / Diesel option. On annual generation this equates to around NZD$27,000 in reduced subsidy.

The consultant discussed the likely socio-economic implications of a higher tariff (than the current NZD$0.50 per kWh) with various stakeholders[2] on island. There is a general belief that the tariff was already too high and an expectation that the solar power station would result in a lower tariff.

[1] Nominal 15% to allow for contingency, insurance, management and general return on investment.

While it is difficult to quantify the actual impacts of different tariffs, anecdotal evidence indicates the proportion of household income required for electricity is higher than for the average New Zealand home (noting that the actual Tokelauan consumption is significantly lower).

On Atafu and Nukunono the Taupelaga and consultant had a lengthy and detailed discussion on the merits and consequences of different tariff costs, including the "opportunity cost" aspects of having a lower / subsidised tariff. A clear conclusion of these discussions was the understanding that subsidising energy to homes would mean less funding for projects such as hospital improvements.

Recommendations

The following key recommendations are discussed in greater detail later in the report:

- Establish a specific entity to manage and operate the energy supply.
- Establish the correct tariff
- Ensure all loads are metered if / where practical
- Undertake a country wide energy education campaign that discusses the opportunities and consequences of different tariff models, and opportunities to control household energy use (cost) with minimal lifestyle impact
- Obtain expert ongoing assistance in the initial period of operation (~3 years)

Technical Review

General Findings

- All three systems were fully operational with no major operation or maintenance problems at the time of the inspection.
- Solar fractions exceed 90% on Atafu and Nukunonu, but are estimated at around 89% on Fakaofo. The designed solar fraction for these three islands was 89%, 91% and 86% respectively, indicating that actual performance has exceeded predicted. Further increase in the system performance is expected over the remaining months of the year due to the sunny season falling from April to October.
- The condition of panels, framing and outdoor isolators was very good, with no signs of corrosion or water ingress.
- The condition of indoor equipment was very good with no signs of wear or damage.
- Record keeping on all three islands needs to be improved, particularly for battery and generator maintenance. This is important both for trouble-shooting and also for warranty claims.

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[2] Taupelega, accommodation hosts, general community members and others

- Wasp nests should be cleared regularly from the array, to prevent any excessive buildup of debris.

Recommendations

Fakaofo

- The inverter room was too hot and larger extractor fans should be installed.
- Some areas of the foundations on the swampy side of the array need to be reinforced by adding rock or crushed coral under the foundations, as the wood used will decay over time.
- The fault mute switch was found in the ON position. It should be kept in the OFF position at all times so that operators are quickly alerted to a fault.
- SD cards were missing from two of the Sunny Webboxes and two of the Sunny Islands. We added new SD cards to the Webboxes. Power station staff may have removed the SD cards, so the Acting Director of Energy should investigate this, particularly if it occurs again.
- The “change filter” light on the deionizer was flashing. Operators should replace the batteries, check again, and if necessary replace the filter and order another spare.
- Vegetation around the array was very overgrown and needs to be cut back.
- It is desirable, though not crucial, to repair the second diesel generator for redundancy in times of bad weather or when the PV system needs to be shut down for maintenance.

Nukunonu

- After shutting down due to a lightning strike, the system was restored to normal operation within a week after troubleshooting with assistance from Powersmart and SMA. This is a good result given that this was the first outage that the staff needed to deal with since the system was installed, and it indicates that they are capable of troubleshooting with support.
- Operators should tidy spare parts on in inverter room and put system diagram on wall.
- A new comms board for the spare Sunny Island should be ordered.
- Battery State Of Charge should be monitored regularly, as there appear to be some significant deviations between banks.
- Operators should continue repair work on the second generator for redundancy in times of bad weather or when the PV system needs to be shut down for maintenance.
- Connection of a fish freezer needs to be investigated - monitor load, energy requirement and inrush current on the community freezer over a 24 hr period. Unless any problems are identified the freezer should be connected to the grid.

- Operators should check regularly for any signs of erosion around foundations and build up soil if required.
- Operators should check bolts on array frames for any sign of rust spreading. Tea staining should not spread or cause structural problems.

Atafu

- The inverter room is too hot and needs to be provided with large extractor fans.
- Battery SOC should be checked regularly, particularly Battery 19, String A, Cluster 2 which has been replaced.
- Operators should provide a number for Battery 19, String A, Cluster 2 which has been replaced.
- A new battery should be ordered from Exide under warranty and the faulty battery returned to Exide.
- The inverter room computer is not working and should be repaired or replaced.
- Generator maintenance appears to be lacking and needs to be addressed with the goal of having two operational generators.
- Trees north of the array (on private land) have grown tall enough to shade the array in the mornings. Permission to trim or remove the trees should be sought.

TRIP DESCRIPTION & ACKNOWLEDGEMENTS

The Tokelau Renewable Energy Project (TREP) saw the installation of solar diesel hybrid power systems on Fakaofo, Nukunonu and Atafu, the three atolls of Tokelau. The systems were commissioned and handed over to the Government of Tokelau in October 2012 and have since been operated by local power station staff.

ITP representatives visited Tokelau from 3rd June 2013 to 8th June 2013 to conduct an inspection and review of the post installation operation and performance of the systems. The review included two parts: a technical review of the systems themselves, and a financial review of the ongoing costs of the systems and their effects on tariffs.

The inspection times were limited by the boat schedule and the team had approximately one and a half full working days on each of Fakaofo and Nukunonu and one working day on Atafu.

ITP staff were accompanied on site visits at Fakaofo and Nukunonu by John Bosco, Tokelau's Acting Director of Energy. At Atafu the ITP staff were accompanied by local operator Wallace.

ITP would like to sincerely thank the large number of people who assisted with the work program, in many cases interrupting other priority activities to assist our staff.

We would particularly like to thank the people of Tokelau for the hospitality and friendliness shown to our staff during the visit.

PART 1 – FINANCIAL REVIEW

1. Introduction

ITP conducted a Financial Review of the TREP systems according to the principles defined in Section 4 of the MFAT "Hybrid Power System Post-Installation Inspections - Guidelines and Procedures" document. The results and recommendations as a result of the review are detailed in the following sections. Concerns around the financial sustainability of the TREP systems are attributable to two main factors:

- Difficulty in obtaining reliable information with regards to: energy generation and consumption; billing and revenue collection; and system operation and maintenance
- A lack of understanding of the actual costs of electricity generation on the atolls, and the subsequent lack of an appropriate tariff structure

1.1. Difficulty in obtaining consumption and revenue data:

During discussions with the various stakeholders, there seemed to be a lack of general knowledge on fairly basic questions of the manner in which the financial aspects of the electricity supply are managed. Indeed, asking the same question of three different stakeholders often resulted in three different, and fairly incompatible, answers. Consequently, a number of parameter values from the Financial Review (Section 4) principles of the MFAT "Hybrid Power System Post-Installation Inspections - Guidelines and Procedures" were unable to be determined.

Unmetered Loads

During discussions with the Council of Elders (Taupulega) and other stakeholders on Fakaofo it was stated that all loads were metered. A follow-up question regarding loads such as the meeting room in use and a nearby streetlight found that the streetlight wasn't metered, and those present didn't know if the meeting room was metered. Later inspection by the ITP consultant found the meeting room and several other community buildings were not metered. This is the case across all three atolls.

While it is not unusual to have un-metered loads, knowledge of these loads was lacking. Even in the event that all loads were metered, technical losses in the transmission and distribution equipment would result in a discrepancy between the energy generated and energy sold. It is therefore critical to know both: if all major loads are metered, the difference between generated units and metered units should be less than 10%. Greater than 10% the source of these losses should be investigated, as they could be caused by undersized wires, ground leakage, short circuiting, etc.

Tariff Rates and Collection

Discussions with the Taupulega on all three atolls demonstrated the requirement to connect the costs of generation of electricity with the tariff charged to the end user. On Atafu the Taupulega expressed surprise when informed of the likely true cost of generation, estimated (by the consultant) to be around double the tariff being charged to customers.

The confusion arises from revenue collection and operation and maintenance of the power stations being the remit of separate entities. The Taupulegas on all three atolls stated that the village collects the income from the electricity sales, but the central government pays all the operational costs, excluding the general labour cost. This statement was later contradicted by information from another source, saying that the central government collected revenue. It was not possible in the time available to reconcile this incompatibility, however the key issue of the power sector involving multiple entities remains.

ITP assumes that the village collects the tariff in the same way the local office of revenue collects accommodation or TeleTok charges. It could not be determined if this was “passed” on to the central government directly, and as part of a general accounting reconciliation.

1.2. Difficulty in obtaining generation and operation and maintenance data:

As above, several key criteria are not being adequately recorded with regards to energy generation and operation and maintenance.

Generator fuel consumption allows for the efficiency of the generator operation to be determined, as well as providing strong indications of the effectiveness of the PV mini-grid installations. No log sheets of generator run times or diesel fuel use are kept and, as such, no such analysis is possible without estimation.

Similarly with respect to labour costs, there appears to be no records of time spent on various tasks on any of the three atolls. Key personnel are employed by the central government and though the consultant was unable to obtain the salary and operations costs applied to these staff at the time of the site visit, some of this information was provided at a later date. As the labour pool works on the generation assets as needed, without any system to account for time spent on each task, determination of operation and maintenance costs was not possible from the information available.

The PV system has the ability to automatically record many aspects of the system’s operation. The Sunny Webboxes connected to the Sunny Boy inverters and Sunny Islands log generation and grid data at each site. However, upon inspection, the SD cards from two of three of Fakaofo’s Webboxes were missing, and the third was not inserted correctly. As a result, data was not available for this island and alternate and inferior data sources were necessary (see Section 2.3).

In establishing an appropriate tariff to cover O&M and future equipment replacement costs, an understanding of how many units of electricity are generated and how many units are sold is necessary.

ITP has estimated the full costs of generation in the following sections, with the intention of informing the Taupulega for further dissemination. From these generation costs, suitable tariff rates have been determined in Section 3.

2. Parameter Values

In the analysis below ITP has assessed the performance of each system over the same time period, 1st November, 2012 until 31st May, 2013, such that the comparative performance of each system may be determined. Conducting the review on a since-commissioning basis was thought to be less informative, given the differing commission dates between each system.

Due to the sunny season in Tokelau falling between April and October, actual PV generation over the course of one year can be expected to be greater than that determined below. Similarly, diesel usage would be expected to fall.

On Atafu and Nukunonu, energy generation data was available from the SD cards of the three Sunny Webbox installed.Oon Fakaofo the SD cards were missing from to of the three webbox's, with the third inserted incorrectly. Consequently, the data necessary to conduct this review was unable to be collected for this system as desired. In its place, ITP used data available from the web via Sunny Portal, along with the assumptions listed in Section 2.3, to determine the performance of this system.

2.1. Atafu

Parameter	Notes	Value
A. Energy generated by the diesel generators (kWh)	This information was collected from the Sunny Islands' Sunny Webbox. The value of 14,985 kWh from 1st November, 2011 until 31st May, 2013, a period of 211 days, was used to predict daily and yearly generation without consideration of changing environmental conditions.	25,922 kWh/yr 71.0 kWh/day
B. Energy generated by the PV system (kWh)	This information was determined from time series data collected from the three Sunny Webbox from 1st November, 2011 until 31st May, 2013, a period of 211 days. The value of 183,816 kWh from this period includes the energy generated by the PV to the batteries (45,840 kWh), and the energy generated by the PV to the grid (137,976 kWh). The data was used to predict daily and yearly generation without consideration of changing environmental conditions.	317,976 kWh/yr 871.2 kWh/day

C. Total energy exported to grid (kWh)	Not available	
D. Peak power demand (kW)	Not available	
E. Generator fuel consumption (L)	This value has been estimated (See Section 1.2) based on diesel generator energy generation data from Parameter A. It assumes a generator efficiency of 3kWh/L.	8,641 L/yr 23.7 L/day
F. Unplanned power outages (h)	Not available	
G. Energy billed (kWh)	Unable to be determined. See Section 1.1	
H. Amount of money billed ($)	Unable to be determined. See Section 1.1	
I. Electricity tariff structure	Determined via discussion between ITP consultants and the Taupulega. *Note: Value is not instructive due to inconsistency of tariff collection*. See Section 1.1	$0.50/kWh
J. Total funds collected since commissioning ($)	Unable to be determined. See Section 1.1	
K. Funds spent on operation and maintenance ($)	Unable to be determined. See Section 1.1	

From the data collected from the Sunny Webbox, the specific performance of the PV arrays connected directly to the grid (199kWp) was determined to be 1,060 kWh/kWp/yr. This compares well with the tender specifications (>830 kWh/kW/yr). *Note: this excludes consideration of system downtime, and the likely increase in production through the sunny months from April to October.*

Benchmark	Description	Notes	Value	Target
Total generation (kWh)	Total energy generated by the PV system and the diesel generators	Scaled from 211 days to 365 days.	343,898 kWh/yr	N/A
Solar fraction (%)	This is the percentage of energy generated by the PV system relative to the total amount generated.	May increase due to sunny months being Apr-Oct while data available was from Nov-May.	92.5%	>90%
Internal losses (%)	This is the percentage of energy that is lost due to efficiency losses in the batteries and self-consumption by the battery building and generator building (lights, computers, etc).	Not available		<5%
Generator specific fuel consumption (kWh/L)	This measures the fuel efficiency of the generator. If there is no fuel meter on the generators, this will be a difficult parameter to calculate as generation is intermittent and anecdotal evidence may be inaccurate (although better than nothing).	Unable to be determined. See Section 1.2 *ITP assumed 3 kWh/L in its analysis.*		>3.5 kWh/L
Unplanned power outages (%)	This is the percentage of time that there was an unplanned power outage since the PV systems were active (start date to be taken as Nov 1st 2012). This data will be available on the WebBoxes. Sunny Portal cannot be used for this as missing data may be due to a bad internet connection rather than a power outage.	Not available		<1%
I Percentage technical and non-technical losses (%)	This is the percentage of energy that is unaccounted for by electricity sales. The cause of these losses may be technical (resistive losses through the wires of the distribution network) or non-technical (unmetered loads, electricity theft, malfunctioning meters). Separating the technical from the non-technical losses is difficult and requires an in-depth study of its own.	Unable to be determined. See Section 1.1		<10%
Financial collection rate (%)	This is the rate at which funds are collected by the utility, and represents how much outstanding debt it has. A figure below 100% means that the utility is	Unable to be determined. See Section 1.1		>95%

	collecting less than it is billing for.			
Funds required for equipment replacement ($/mo.)	This is the amount of money required for replacing equipment as it fails, and for replacing the entire system at the end of its life. It does not take into account unplanned failures (these should be covered by manufacturers' warranties). This will be set as Parameter L	See below		N/A
Funds required for entire project: operation, maintenance, capital expenses ($/mo.)	This is the amount of money that the utility needs to collect every month so that it has enough funds for running the system, as well as replacing equipment when it fails. The figure is given in dollars per month, to make it easier for the utility to track whether or not it is collecting enough money on a monthly basis. A 5% contingency figure is also included.	See below		N/A
Collection shortfall/excess (%)	This ratio indicates how well the utility is collecting money for its O&M costs and for its equipment replacement. A ratio of under 100% means that there is a shortfall (e.g. a ratio of 70% means that the utility is collecting only 70% of the funds required to replace equipment at the end of its life and replace the PV system after 25 years).	Unable to be determined. See Section 1.1		>90%

2.2. Nukunonu

Parameter	Notes	Value
A. Energy generated by the diesel generators (kWh)	This information was collected from the Sunny Islands' Sunny Webbox. The value of 11,982 kWh from 1st November, 2011 until 31st May, 2013, a period of 211 days, was used to predict daily and yearly generation without consideration of changing environmental conditions. The *diesel fraction,* as a percentage of total generation, is also given.	20,728 kWh/yr 56.8 kWh/day 6.5%
B. Energy generated by the PV system (kWh)	This information was determined from time series data collected from the three Sunny Webbox from 1st November, 2011 until 31st May, 2013, a period of 211 days. The value of 173,237 kWh from this period includes the energy generated by the PV to the batteries (42,591 kWh), and the energy generated by the PV to the load (130,646 kWh). The data was used to predict daily and yearly generation without consideration of changing environmental conditions. The *solar fraction*, as a percentage of total generation, is also given.	299,676 kWh/yr 821.0 kWh/day 93.5%
C. Total energy exported to grid (kWh)	Not available	
D. Peak power demand (kW)	Not available	
E. Generator fuel consumption (L)	This value has been estimated (See Section 1.2) based on diesel generator energy generation data from Parameter A. It assumes a generator efficiency of 3kWh/L.	6,909 L/yr 18.9 L/day
F. Unplanned power outages (h)	Not available	
G. Energy billed (kWh)	Unable to be determined. See Section 1.1	
H. Amount of money billed ($)	Unable to be determined. See Section 1.1	
I. Electricity tariff structure	Determined via discussion between ITP consultants and the Taupulega. *Note: Value is not instructive due to inconsistency of tariff collection*. See Section 1.1	$0.50/kWh

J. Total funds collected since commissioning ($)	Unable to be determined. See Section 1.1	
K. Funds spent on operation and maintenance ($)	Unable to be determined. See Section 1.1	

From the data collected from the Sunny Boy inverters' Sunny Webbox, the specific performance of the PV arrays connected directly to the grid (177 kWp) was determined to be 1,131 kWh/kWp/yr. This compares well with the tender specifications (>830 kWh/kW/yr). *Note: this excludes consideration of system downtime, and the likely increase in production through the sunny months from April to October.*

Benchmark	Description	Notes	Value	Target
Total generation (kWh)	Total energy generated by the PV system and the diesel generators	Scaled from 211 days to 365 days.	320,403 kWh/yr	N/A
Solar fraction (%)	This is the percentage of energy generated by the PV system relative to the total amount generated.	May increase due to sunny months being Apr-Oct while data available was from Nov-May.	93.5%	>90%
Internal losses (%)	This is the percentage of energy that is lost due to efficiency losses in the batteries and self-consumption by the battery building and generator building (lights, computers, etc).	Not available		<5%
Generator specific fuel consumption (kWh/L)	This measures the fuel efficiency of the generator. If there is no fuel meter on the generators, this will be a difficult parameter to calculate as generation is intermittent and anecdotal evidence may be inaccurate (although better than nothing).	Unable to be determined. See Section 1.2 *ITP assumed 3 kWh/L in its analysis.*		>3.5 kWh/L
Unplanned power outages (%)	This is the percentage of time that there was an unplanned power outage since the PV systems were active (start date to be taken as Nov 1st 2012). This data will be available on the WebBoxes. Sunny Portal cannot be used for this as missing data may be due to a bad internet connection rather than a power outage.	Not available		<1%
I Percentage technical and non-technical losses (%)	This is the percentage of energy that is unaccounted for by electricity sales. The cause of these losses may be technical (resistive losses through the wires of the distribution network) or non-technical (unmetered loads, electricity theft, malfunctioning meters). Separating the technical from the non-technical losses is difficult and requires an in-depth study of its own.	Unable to be determined. See Section 1.1 *No knowledge or records are kept of metered and unmetered loads.*		<10%
Financial collection rate (%)	This is the rate at which funds are collected by the utility, and represents how much outstanding debt it has. A figure below 100% means that the utility is	Unable to be determined. See Section 1.1		>95%

	collecting less than it is billing for.			
Funds required for equipment replacement ($/mo.)	This is the amount of money required for replacing equipment as it fails, and for replacing the entire system at the end of its life. It does not take into account unplanned failures (these should be covered by manufacturers' warranties). This will be set as Parameter L	See below		N/A
Funds required for entire project: operation, maintenance, capital expenses ($/mo.)	This is the amount of money that the utility needs to collect every month so that it has enough funds for running the system, as well as replacing equipment when it fails. The figure is given in dollars per month, to make it easier for the utility to track whether or not it is collecting enough money on a monthly basis. A 5% contingency figure is also included.	See below		N/A
Collection shortfall/excess (%)	This ratio indicates how well the utility is collecting money for its O&M costs and for its equipment replacement. A ratio of under 100% means that there is a shortfall (e.g. a ratio of 70% means that the utility is collecting only 70% of the funds required to replace equipment at the end of its life and replace the PV system after 25 years).	Unable to be determined. See Section 1.1		>90%

2.3. Fakaofo

The only information available to ITP regarding the performance of the Fakaofo system regarded the AC output of the Sunny Boy inverters. This was available from Sunny Portal web data. Sunny Portal relies upon both power and web connectivity and as such, is less reliable and less comprehensive than data logged on Webbox SD cards. The Sunny portal data was used to estimate the parameter values in the table below according to the assumptions listed.

Parameter	Notes	Value
A. Energy generated by the diesel generators (kWh)	Using the PV to grid output from Sunny Portal from 1st November 2012 until 31st May 2013, the diesel generation was estimated by extending the strong correlation between generation fractions on Atafu and Nukunonua, to Fakaofo, scaled according to the designed solar fractions for each.	54,033 kWh/yr 148.0 kWh/day
B. Energy generated by the PV system (kWh)	Using the PV to grid output from Sunny Portal from 1st November 2012 until 31st May 2013, the generation of the PV to the grid and the PV to the batteries was estimated by extending the strong correlation between generation fractions on Atafu and Nukunonua, to Fakaofo, scaled according to the designed solar fractions for each.	437,172 kWh/yr 1,197.7 kWh/day
C. Total energy exported to grid (kWh)	Not available	
D. Peak power demand (kW)	Not available	
E. Generator fuel consumption (L)	This value has been estimated (See Section 1.2) based on diesel generator energy generation data from Parameter A. It assumes a generator efficiency of 3kWh/L.	18,011 L/yr 49.3 L/day
F. Unplanned power outages (h)	Not available	
G. Energy billed (kWh)	Unable to be determined. See Section 1.1	
H. Amount of money billed ($)	Unable to be determined. See Section 1.1	

I. Electricity tariff structure	Determined via discussion between ITP consultants and the Taupulega. *Note: Value is not instructive due to inconsistency of tariff collection*. See Section 1.1	$0.50/kWh
J. Total funds collected since commissioning ($)	Unable to be determined. See Section 1.1	
K. Funds spent on operation and maintenance ($)	Unable to be determined. See Section 1.1	

From the data collected from Sunny Portal, the specific performance of the PV arrays connected directly to the grid (243 kWp) was determined to be 1,198 kWh/kWp/yr. This compares well with the tender specifications (>830 kWh/kW/yr). *Note: this excludes consideration of system downtime, and the likely increase in production through the sunny months from April to October.*

Benchmark	Description	Notes	Value	Target
Total generation (kWh)	Total energy generated by the PV system and the diesel generators	Scaled from 211 days to 365 days, and considering designed and actual generation fractions as per Atafu and Nukunonu.	491,205 kWh/yr	N/A
Solar fraction (%)	This is the percentage of energy generated by the PV system relative to the total amount generated.	Scaled considering designed and actual generation fractions as per Atafu and Nukunonu. May increase due to sunny months being Apr-Oct while data available was from Nov-May.	89.0%	>90%
Internal losses (%)	This is the percentage of energy that is lost due to efficiency losses in the batteries and self-consumption by the battery building and generator building (lights, computers, etc).	Not available		<5%
Generator specific fuel consumption (kWh/L)	This measures the fuel efficiency of the generator. If there is no fuel meter on the generators, this will be a difficult parameter to calculate as generation is intermittent and anecdotal evidence may be inaccurate (although better than nothing).	Unable to be determined. See Section 1.2 *ITP assumed 3 kWh/L in its analysis.*		>3.5 kWh/L
Unplanned power outages (%)	This is the percentage of time that there was an unplanned power outage since the PV systems were active (start date to be taken as Nov 1st 2012). This data will be available on the WebBoxes. Sunny Portal cannot be used for this as missing data may be due to a bad internet connection rather than a power outage.	Not available		<1%
I Percentage technical and non-technical losses (%)	This is the percentage of energy that is unaccounted for by electricity sales. The cause of these losses may be technical (resistive losses through the wires of the distribution network) or non-technical (unmetered loads, electricity theft, malfunctioning meters). Separating the technical from the non-technical losses is difficult and	Unable to be determined. See Section 1.1		<10%

	requires an in-depth study of its own.			
Financial collection rate (%)	This is the rate at which funds are collected by the utility, and represents how much outstanding debt it has. A figure below 100% means that the utility is collecting less than it is billing for.	Unable to be determined. See Section 1.1		>95%
Funds required for equipment replacement ($/mo.)	This is the amount of money required for replacing equipment as it fails, and for replacing the entire system at the end of its life. It does not take into account unplanned failures (these should be covered by manufacturers' warranties). This will be set as Parameter L	See below		N/A
Funds required for entire project: operation, maintenance, capital expenses ($/mo.)	This is the amount of money that the utility needs to collect every month so that it has enough funds for running the system, as well as replacing equipment when it fails. The figure is given in dollars per month, to make it easier for the utility to track whether or not it is collecting enough money on a monthly basis. A 5% contingency figure is also included.	See below		N/A
Collection shortfall/excess (%)	This ratio indicates how well the utility is collecting money for its O&M costs and for its equipment replacement. A ratio of under 100% means that there is a shortfall (e.g. a ratio of 70% means that the utility is collecting only 70% of the funds required to replace equipment at the end of its life and replace the PV system after 25 years).	Unable to be determined. See Section 1.1		>90%

3. Tariff Determination

In order to improve the financial sustainability of the TREP systems, ITP has conducted an analysis to determine an appropriate tariff structure for the atolls. The methodology is detailed in the following sections.

For comparison purposes ITP also modelled a Diesel only scenario, based on the existing diesel generation assets. For all modelling a project life of 25 years was used, and replacement of components as per the table below:

Component	Lifetime	Replacement costs (NZD)	Years																								
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
PV modules	25 years	1,000,000																									
Batteries	8 years	4,000,000																									
Inverters	12.5 years	1,200,000																									
Diesel generators	15 years	240,000																									

3.1 Operating costs for different scenarios

Estimated fuel costs against tariff income:

Data from the diesel gensets is calculated from sales records, combined with any information on run times and loading and ITP's knowledge of similar generators and setups.

Using one atoll as the model example[3]:

12 months sales: NZD 93,139 – rounded to **income of NZD 93,000**

Tariff: NZD 0.50 per kWh

Total units sold:

$$\frac{NZD\ 93{,}000}{NZD\ 0.50\ per\ kWh} = 186{,}000\ kWh$$

Assume metered loads equate to ~75% of load at the generators[4]

Total units generated:

$$\frac{metered\ units}{75\%} = actual\ units\ generated$$

$$\frac{186{,}000\ kWh}{75\%} = \mathbf{248{,}000\ kWh}$$

The fuel consumption of diesel gensets ranges from 0.28 litres per kWh to 0.4 litres per kWh, depending on condition and load. It is common for smaller scale systems that have variable loads to consume ~0.33 litres per kWh generated (or generate 3 kWh per litre of diesel)[5].

Total annual fuel use:

$$\frac{248{,}000\ kWh}{3\ kWh/l} = 82{,}700\ litres$$

Diesel costs, landed on Tokelau, have been reported as: \$1.16 per litre; \$1.52 per litre and "over" \$2.00 per litre. Diesel fuel wholesale in Samoa is around NZD 1.20 per litre, so allowing for

[3] No atoll has complete data for all aspects of generation. Most reliable data for consumption was Fakaofo at the time of writing, so Fakaofo is the modeled system.
[4] 70 to 90% of total load metered is common on similar grid systems, and matches with ITP's investigations on island.
[5] High efficiency and well-managed gensets achieve in order of 4kWh per litre consumed. Poorly maintained, older gensets are below 3kWh per litre. Given the age, type and state of the gensets on Tokelau, 3kWh per litre is a fair assumption.

freight and handling costs this report uses NZD 1.50 per litre. This is in keeping with known diesel costs in other, similar remote locations.

Total annual fuel cost:

$$NZD\ 1.50\ per\ litre\ x\ 82{,}700\ litres\ pa = NZD\ 124{,}050\ pa$$

Margin / Loss based only on fuel costs:

Income – Fuel cost = margin

$$NZD\ 93{,}000 - NZD\ 124{,}050 = -NZD\ 31{,}050$$

3.1.1 O&M of diesel power house (estimated):

Allowing for spares, labour and operations, but excluding fuel and replacement of major items (generator engines etc), the estimated O&M cost of the diesel power house is NZD 33,000 to 40,000 pa. ITP used **NZD 38,000 pa. for O&M costs**.

Total Operational Cost of diesel based electricity generation:

$$\frac{Diesel\ cost + O\&M\ cost}{Units\ metered} = unit\ cost$$

$$\frac{NZD\ 124{,}050 + NZD\ 38{,}000}{186{,}000\ kWh} = NZD\ 0.87\ per\ kWh$$

Based on these calculations we can say that a **Tariff of NZD 0.87 per kWh** was required to meet just the operational costs of the diesel powerhouse.

3.1.2 O&M and replacement costs of diesel power house (estimated):

The table below provides the assumed capital replacement costs over the 25-year life of the diesel powerhouses, across all three atolls:

Item	Estimated cost	Number of replacements	Cost over asset life
Diesel gensets - replacement	$ 35,000	12	$ 420,000
Diesel gensets - rebuild	$ 10,000	12	$ 120,000
Balance of System/ Misc	$ 30,000	1	$ 30,000
		Total	$ 570,000
		per annum	$ 22,800
		Per system per annum	$ 7,600

The pre-solar powerhouse gensets were a mixture of condition and age. This table assumes that two on each atoll would need replacing, two on each atoll would need a major rebuild, and this would happen twice in the 25 year asset life. This is likely to be conservative, as environmental and operational conditions would indicate a greater frequency of replacement / major rebuilds.

The full operational cost for the diesel based electricity generation system is:

$$\frac{Diesel\ cost + O\&M\ cost + replacement\ costs}{Units\ metered} = unit\ cost$$

$$\frac{NZD\ 124{,}050 + NZD\ 38{,}000 + NZD\ 7{,}600}{186{,}000\ kWh} = NZD\ 0.92\ per\ kWh$$

Based on these calculations we can say that a **Tariff of NZD 0.92 per kWh** was required to meet the full operational cost of the diesel powerhouses over their useful life.

3.1.3 O&M of solar /diesel power house (estimated):

Using the same load figures as above of 248,000 kWh of generation in twelve months.

Data obtained from the PV recording equipment shows the diesel generators generated circa 14,000 kWh in the six months immediately after the PV systems[6] were commissioned. Extrapolating to the modelled system over twelve months yields an annual diesel generation of circa 30,000 kWh. However, the data was recorded in the initial period of operations (when final operational issues were being rectified), and also featured a PV "outage" which is considered a very rare occurrence.

The system design is for significantly less diesel usage per annum, hence for the purposes of this model the diesel component used is **20,000 kWh pa**.

Diesel fuel cost (using above method and assumptions):

$$\frac{20{,}000\ kWh}{3\ kWh/l} = 6{,}700\ litres$$

Total annual fuel cost:

$$NZD\ 1.50\ per\ litre\ x\ 6{,}700\ litres\ pa = \mathbf{NZD\ 10{,}050}\ pa$$

As the PV component of the new solar/diesel hybrid system does not consume any fuel, only O&M costs are incurred as running costs. These are assumed to be **NZD$12,000 pa**.

Allowing for spares, labour and operations, but excluding fuel and replacement of major items (generator engines etc), the estimated **<u>O&M cost of the diesel power house is</u>**

<u>NZD 5,000 pa.</u>

$$\frac{Diesel\ cost + O\&M(diesel)cost + O\&M\ (solar)\ cost}{Units\ metered} = unit\ cost$$

$$\frac{NZD\ 10{,}050 + NZD\ 5{,}000 + NZD\ 12{,}000}{186{,}000\ kWh} = \mathbf{NZD\ 0.15\ per\ kWh}$$

Based on these calculations we can say that a Tariff of **NZD 0.15 per kWh** is required to meet just the operational costs of the solar/diesel hybrid system.

[6] Atafu system – this is a smaller system with a smaller load than the modeled system.

3.1.4 Cost (excluding initial capital) of solar / diesel power house (estimated):

This section includes all costs as per section 1.3, and costs of replacing significant componentry within the asset lifetime (25 years).

Item	Estimated cost	Number of replacements	Cost over asset life
Batteries	$3,750,000	2	$ 7,500,000
Inverters	$1,000,000	1	$ 1,000,000
Diesel gensets - rebuild	$ 10,000	4	$ 40,000
Balance of System / Misc	$ 50,000	1	$ 50,000
		Total	$ 8,590,000
		per annum	$ 343,600
		Per system per annum	$ 115,000

Diesel fuel cost: NZD$10,050

O&M cost of the diesel powerhouse: NZD 5,000

O&M cost of the solar power system: NZD 12,000

Replacement equipment cost: NZD 115,000

The full cost of solar / diesel based electricity generation:

$$\frac{Diesel\ cost + O\&M(diesel)cost +\ O\&M\ (solar)cost + Replacement\ costs}{Units\ metered} =\ unit\ cost$$

$$\frac{NZD\ 10{,}050 + NZD\ 5{,}000 + NZD\ 12{,}000 +\ NZD\ 115{,}000}{186{,}000\ kWh} = NZD\ 0.77\ \ per\ kWh$$

Based on these calculations a **Tariff of approximately NZD 0.77 per kWh** is required to meet the O&M and fuel cost of the solar/diesel hybrid system, including allowing for replacement of key components over the lifetime of the system.

3.2 Modelled Tariffs

NOTE all modelling was undertaken at current prices – a brief discussion on the likely impact of rising diesel costs is included in section 1.3. The diesel only scenario is for comparative purposes only and is essentially a “pre-2012 benchmark”.

	Diesel powerhouse – O&M only	Diesel powerhouse – O&M and replacement	Solar / Diesel powerhouse – O&M only	Solar / Diesel powerhouse – O&M and replacement
Retail tariff charged	$0.50	$0.50	$0.50	$0.50
Unit cost required	$0.87	$0.91	$0.15	$0.77
Unit cost w/ return to GoT[7]	$1.00	$1.06	$0.17	$0.89
GoT effective subsidy	>$0.50	>$0.56	~($0.33)	>$0.39

Based on the modeling, a Tariff of around NZD$ 0.77c per kWh is required to fully finance the operations of the power stations (a ‘full cost-recovery’ tariff) but a higher tariff of NZD$0.89c/kWh is required to provide a return to the Government (a ‘cost-recovery and financial return’ tariff[1])

The table above clearly shows that the current tariff of NZD$0.50 per kWh did not cover the cost of generation of the diesel based generation, and will not cover the full lifetime costs of the Solar / Diesel powerhouse in place. However the difference in effective subsidy required of NZD$0.11 per kWh generated demonstrates the benefit of the Solar / Diesel option. On annual generation this equates to around NZD$27,000 in reduced subsidy.

[7] Nominal 15% to allow for contingency, insurance, management and general return on investment.

3.3 Diesel fuel price factors

Further, the cost of diesel in all modelling above was taken to be NZD $1.50 per litre. Should the actual cost of diesel landed on Tokelau be confirmed as significantly different to this figure, the required tariff may be marginally higher than above. Also it must be noted that should the actual cost of diesel be higher than used in the model, the benefit of changing to solar based generation becomes proportionally greater.

The table below models different scenarios of diesel cost and increase in diesel costs.

	Diesel powerhouse – O&M only	Diesel powerhouse – O&M and replacement	Solar / Diesel powerhouse – O&M only	Solar / Diesel powerhouse – O&M and replacement
Retail tariff charged	$0.50	$0.50	$0.50	$0.50
Unit cost required @ 1.50 per litre	$0.87	$0.92	$0.15	$0.77
Unit cost required @ 1.75 per litre	$0.98	$1.02	$0.15	$0.77
Unit cost required @ 2.00 per litre	$1.09	$1.13	$0.16	$0.78
Unit cost required @ 2.50 per litre	$1.32	$1.36	$0.16	$0.80

Tariff at different fuel costs, excluding return to GoT

The modelled tariffs do not include an allowance for the fluctuating cost of diesel. A number of economic studies have been undertake to try and predict the where diesel fuel prices might go over the coming few years, however there is no consensus as to what actual costs will be in 2014 or 2020 etc.

Applying a nominal 5% per annum increase to the diesel cost gives an indication of the likely gain changing from diesel to solar-based generation. Applying 5% per annum to a starting cost of $1.50 per litre gives a benefit to solar of around $0.10c per kWh. This increases dramatically over time, as diesel based generation is directly effected where solar based generation hardly changes:

- $0.20c difference at 4 years
- $0.30c difference at 7 years
- $0.52c difference at around 11 years.

Based on today's costs, sales and generation figures, Tokelau can expect a "saving" of around NZD$15m [8]through the reduction in diesel usage over the life of the project.

[8] In 2013 dollars, not including discount rates etc

4 Recommendations

4.1 Recommendation #1 – Create a utility

"Tokelau Power"

It is critical that all levels of government in Tokelau understand and agree to the concept that the entity with the liability for the operations of the generation asset must also have the ability to set and collect the tariff.

The three key areas to be developed are: Ownership, Responsibility and Authority;

Ownership is the easiest to define, as the entity should be a wholly owned government authority, along the lines of a statutory authority. The shareholder will be the Government of Tokelau, and the shareholders nominated representative would be the Minister with the responsibility for Energy.

Responsibility: The entity would be given total responsibility for the operations of the generation assets, including;

- Supply of a defined quality of energy (frequency, volts, PF etc)
- Reliability of supply – 24 hr guarantees or less? What is acceptable outage?
    - These first two points need not be one definition for all customers – eg: the hospital may have a stricter definition that allows for sensitive electrical equipment and guaranteed 24 hour supply, where a less sensitive load might have a lower obligation
- Maintenance of the asset required to meet quality and reliability
- All future capital expenditure
    - This will include building a funds reserve for replacement of batteries etc, but may also require the entity to purchase, own and maintain emergency portable gensets to meet reliability requirements of hospitals etc. Essentially all these potential requirements need to be investigated
- All of the above only with regard to the distribution grid
- To ultimately provide return to the GoT.

Authority: To be able to meet the imposed requirements, the entity will need to have the following authority:

- Collect a tariff that covers all or the bulk of the costs required to meet the responsibilities[9]
    - As above, the tariff may be different for different customers – eg: a cost only tariff for essential services (that are government funded anyway). Also tariffs that move large loads from night to day would be beneficial to the generation assets, and could be looked at. Likewise future large loads, especially commercial loads, may be offered a higher tariff than current loads[10]
- Conduct operations as required to meet the responsibilities. Meaning run without undue interference.
- Allow or deny, and set the requirements for, any new loads (beyond simple domestic growth)
- Allow or deny and set the standards for any new generation on the grid
    - This last point is critical. For example the utility must have control over a private entity wishing to construct a generation asset and connect into the grid etc. This may be a householder or church or similar wanting a PV array to reduce their electricity cost. If handles well this can be a benefit to the utility, however it also represents a significant risk to the viability of the entity, and rules and guidelines need to be established early.

Cost issues: All the costs involved in the O&M of the generation assets need to be covered by the utility. At present the general labour costs come from the village, the management / technical staff are paid by central government, as are the fuel, parts etc costs. These need to be moved across to the utility.

Where costs are shared, such as with the village labour pool, a fee can be set for this work and then the utility can pay this to the village on a, say, quarterly basis.

The utility MUST NOT cover costs that are not directly related to the operations of the generation assets. Every litre of diesel purchased by the utility must be used to generate electricity. Likewise any tools, spares, etc.

Recording issues: The utility must keep very detailed records of all operations, as these will be needed to alter the tariff charged. Unless a full understanding of the operational costs is available, only modelling estimates can be used.

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[9] Ideally and simply the entity should collect enough tariff to cover all possible costs, however it may be worth investigating allowing the entity to borrow for significant capital purchases, and spread the cost over some years at a lower tariff.
[10] We do not recommend multiple tariffs for single customers, as the metering currently in place is not capable of multiple tariffs and the cost to upgrade would be prohibitive. This could be looked at for future loads.

4.2 Recommendation #2 – Setting the Tariff

This will be possibly the highest risk aspect of the transition to a utility model, and the tariff setting should be done by an independent entity. This entity should include representatives of the GoT, Fono, Tapelega and utility. We also recommend outside, totally independent assistance in the first three years.

The tariff can only be set once the full costs of the operations of the utility are known and understood.

The GoT needs to make a decision on whether the full cost of operations (running the utility) will be obtained through electricity sales, or if a subsidised tariff will be used and some of the utility costs will be funded out of general revenue or similar. Alternatively a model whereby the tariff charged would both fully fund the operations of the utility, and provide a return to the GoT, could be worth considering.

The argument for a subsidised tariff arrangement is that a full recovery tariff may stifle economic activity, particularly investment in commercial activity. If this is attractive to the GoT, it must be understood that the costs of operating the generation assets must still be found, and these costs will then have to be allocated out of funds that may be better used elsewhere, such as construction of critical infrastructure.

Our recommendation is that a full recovery tariff be applied for the first three years, and that the tariff structure be reviewed after two years, with any changes applied at the end of the three years. The three-year period gives stability to anyone contemplating investment, and also provides the new utility with space to develop its role and activities with one less worry.

4.3 Recommendation #2.a – metering all loads

All loads to be metered where possible. Currently a number of “community” loads are not metered, such as meeting rooms, wharf lights and street lights. It may not be viable to meter such things as streetlights, but an effort should be made, over the coming year, to meter as many loads as reasonable.

Without all loads metered, it will be impossible to analyse generation data against tariff income and loads, and locate any unnecessary losses or future tariff movement.

4.4 Recommendation #3 – Independent assistance

Staff involved with the ongoing operations of the TREP have received training on the systems, including maintenance and operations. However while some operational tasks are required regularly, other issues and tasks will rarely need to be undertaken. It is likely that staff will have forgotten some aspects of certain system operations or issues by the time the knowledge is needed.

For example an inverter may fail after 24 months of operation. It is doubtful the staff on site will recall all the details of an inverter swap out after this time.

Further staff turnover is likely to take place, especially with younger staff who may choose to relocate for a period, or take a role elsewhere with the GoT.

Our recommendation is that a three year contract be established with a company that can undertake an annual visit to do a full operational “health check” on the systems, and provide refresher courses to current staff.

It may also be worth including a support role in this contract, whereby the company provides remote support to the Tokelauan staff for any issue they are concerned with.

Ideally as part of this the Tokelauan staff would provide copies of O&M testing and logs to the service company. This both allows the service company to see trends and react faster, and helps ensure the records are kept.

The costs associated with this recommendation would need to be included in the operational budget of the Utility. The cost estimate, provided only to assist with consideration of this recommendation, need not increase the required tariff by more than NZD 0.15c per kWh sold. Alternatively this recommendation may be a good fit for aid based funding.