Off-Grid Solar Installations in the Pacific Region

A Workshop Report

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The cover photo shows the solar array at Atafu Atoll, Tokelau. (Source: IT Power Australia Pty Ltd)

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EU-GIZ ACSE (Adapting to Climate Change and Sustainable Energy) Programme
FNPF DownTown Blvd, Plaza 1, Level 3
Suva, Fiji
T +679 3305 983
F + 679 3315446
info@acsepacific.org
www.acsepacific.org

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Design and layout
The Greenhouse Studio

Text
Gavin Pereira and Tony Pearson

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TABLE OF CONTENTS

ABBREVIATIONS

AC	Alternating Current
DC	Direct Current
DOD	Depth of Discharge
ESCO	Energy Service Company
FLA	Flooded Lead Acid
GW	Gigawatt
GWh	Gigawatt-hour
kV	Kilovolts
kW	Kilowatt
kWh	Kilowatt-hour
kWp	Kilowatt peak
LED	Light Emitting Diode
MW	Megawatt
MWh	Megawatt hour
O&M	Operation and Maintenance
P-ACP	Pacific Island Nations - Africa, Caribbean and Pacific
PV	Photovoltaic
RE factor	Percentage of renewable energy generation against the total energy being generated
RE	Renewable Energy
SHS	Solar Home System
SOC	State of Charge
SOH	State of Health
VRLA	Valve Regulated Lead Acid
W	Watt
Wh	Watt Hour

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EXECUTIVE SUMMARY

The rapid growth in the uptake of solar photovoltaic (PV) installations in the Pacific Islands is creating new challenges across the region. GIZ identified an opportunity to foster capacity building and knowledge management within the industry by holding a workshop on solar hybrid and off-grid solar systems. The workshop was held in Suva in October 2015 for Pacific Government energy officials and industry stakeholders from regional and international organisations. The workshop was supported by a desktop review of the state of the PV industry in each country and the preparation of case studies and discussion topics to promote knowledge transfer among the participants.

This report details the research on the state of the solar industry in the Pacific Islands region, as well as the findings from group discussions during the workshop. Three case studies from the Pacific region were presented: a solar-home system, a battery-driven mini-grid, and a diesel-driven mini-grid. In each study, the user-energy requirements, installation, system design, energy storage, back-up generation, funding, performance, maintenance and monitoring, and social benefits were discussed. Other systems from around the P-ACP region were also presented.

The workshop participants discussed the presentations and research findings from four different perspectives: technical, financial, maintenance/monitoring, and social/cultural. A list of questions and recommendations was developed to guide the successful selection, design and implementation of solar installation projects in the Pacific.

[1]The P-ACP countries are Cook Islands, Federated States of Micronesia, Fiji, Kiribati, Republic of Marshall Islands, Nauru, Niue, Palau, Papua New Guinea, Samoa, Solomon Islands, Timor-Leste, Tonga, Tuvalu and Vanuatu

1. INTRODUCTION

Technological advancements and steep cost reductions in photovoltaic (PV) manufacturing have helped solar become the technology of choice for the electrification needs of many Pacific Island countries. In the early stages of the industry (from the 1980's), the uptake of solar typically occurred via donor funded solar home system projects. These projects supplied simple solar-lighting systems to meet the most basic electrification needs of Pacific Island rural communities. Due to rapid growth in the solar industry (in the last 5 years in particular) solar is now a popular generation source for national electricity grids, as well as electrification of whole communities through PV hybrid systems. Hybrid systems involve the combination of PV generation, diesel generation and battery storage to deliver continuous and reliable power supply to the intended users.

GIZ identified a need to guide the growth and adoption of Solar Hybrid energy systems within the Pacific. To that end, GIZ hosted a workshop in Suva on PV hybrid systems in October 2015. It brought stakeholders together from across the region to exchange knowledge and lessons learned to improve the implementation of PV hybrid systems. This report details the discussions and findings of this workshop. Further, the report details a desk review of the state of the renewable energy market in Pacific Island communities with a focus on off-grid solar installations, as well as 3 case studies of different size PV systems that were used to provoke and frame workshop discussions.

2. AIMS OF THE SOLAR HYBRIDS WORKSHOP

The aims of the workshop were to:

a) Increase the participants' knowledge of off-grid solar energy development in the Pacific Islands;

b) Increase exchange among professionals working in this area;

c) Generate a publicly available report that identifies the criteria for choosing and maintaining new energy installations that successfully cater for the needs of the community over the lifetime of the system (from 2 to 30 years, depending on community needs and budget) at an affordable cost to the users and the initial funders of the system

3. COVERAGE OF THE WORKSHOP

The solar hybrids workshop described in this report concentrates on combining solar with diesel generation, although much of what was learnt at the workshop would be suitable for larger installations or systems combining any renewable energy source (hydro, wind, bio-fuels, etc.) with diesel generation. The particular focus of the workshop was on single household supply and mini-grid supply for remote village communities or small islands. Mini-grids of up to 1 MW were considered, using different configurations of solar and diesel energy systems.

The workshop also looked into technical, financial/system management, maintenance, and social and cultural issues that affect the choice of system as well as the overall success of solar projects.

[2]Grid-connected systems raise very different technical and managerial considerations and were not considered in this report or during the workshop.

4. AVAILABLE TECHNOLOGIES

The workshop began with presentations on a range of systems and technologies, covering penetration levels, system types, load management and energy storage technologies. These are described below.

4.1 Penetration levels

Penetration levels are an important design decision when designing and installing renewable energies onto grid systems. There are two types of penetration level:

a) Power, or instantaneous penetration, measured in kilo-watts (kW) which is the level of solar power being fed onto the grid as a fraction of the total load at the time; and

b) Energy, or long-term penetration, measured in kilowatt hours (kWh), which is the ratio of energy supplied by the solar installation compared to the total energy consumption over the year.

Penetration levels are a particularly important consideration for electricity authorities in maintaining the stability of their power supply. It is very important for utilities to be able to forecast and dispatch power from its network of generators with a high level of precision and accuracy. A grid that was highly reliant on PV (i.e., with high PV penetration levels) would require control mechanisms to deal with passing cloud, or other causes that would result in sudden drops in PV output.

As such, the complexity of system controls increases with rising levels of renewable penetration, as more controls are required in order to keep the system stable. Typical levels of renewable penetration are shown in Figure 1, but it must be noted that new battery, inverter and generator technologies (such as lithium-ion, AHI batteries; battery inverters and low load diesel generators) are seeing penetration rates rise even for larger utility scale grids.

Penetration Class	Typical System Type	Operating Characteristics	Penetration	
			Peak (kW)	Annual average (kWh)
Low	Utility grid connection or large mini-grid	Diesel generators run full time Renewable energy reduces net load on diesel All renewable energy goes to primary load No supervisory control system	<50%	<20%
Medium	Large mini-grid	Diesel generators run full time All high renewable power levels, secondary loads dispatched to ensure sufficient diesel loading or renewable generation is curtailed Requires relatively simple control systems	50%–100%	20%–50%
High	Small mini-grid	Diesel generators may be shut down during high availability of renewable energy sources Auxiliary components required to regulate voltage and frequency Requires sophisticated control systems	100%–400%	50%–150%

Figure 1 NREL guidelines for renewable penetration levels.
Source: IRENA Pacific Lighthouses Renewable Energy Roadmapping for Islands 2013

4.2 System types

Off-grid solar systems vary in type depending on the energy demand; whether the system covers 1 or more dwellings, or whether the system is feeding into a larger grid to offset diesel generation. The sections below describe the different types of off-grid solar system.

Solar-home systems

Solar-home systems are a step up from solar lanterns and can be sized from very simple systems that consist of:

- A solar panel for power generation;
- A regulator to protect the battery from over or under charge; and
- A battery for storage of the energy (see Figure 2).

In this simplest form, direct current (DC) power is provided directly to lights, a radio and cell phone charging points. The system can be developed to include an inverter to provide alternating current (AC) power and a generator to provide back-up power when needed. These systems can be sized from 100 W to 10 kW or more.

Figure 2 Solar-home system
Source: Tony Pearson

Battery-driven mini-grid

In a battery-driven mini-grid, the battery inverter forms or sets up the permanent grid, and solar power is fed into the system on the AC and/or the DC side of the system, (known as AC and DC coupling respectively). There is usually a back-up diesel generator. For geographically dispersed grids, there could be transformers in the system to raise the transmission voltage to 6 or 11 kV if needed (see Figure 3).

The back-up diesel generator is used only if the battery state of charge (SOC) drops too low or the load gets too big for the installed inverters to cope with. Fluctuations in renewable supply are evened out by the batteries, which can absorb sudden increases in power or sudden loads being added to the system. Lithium batteries are particularly good at this, as they can take much higher charge and discharge loads than lead acid batteries.

This type of grid has historically been limited in size due to: (a) inverter technology, limiting the system size to about 300 kW; and (b) the cost of the batteries, which, as the system size goes up, must also increase in size so they can support it. With advances in both battery and inverter technologies, however, this limit has been removed and it is now purely a matter of financial and other non-technical issues that will decide the choice of PV penetration within the system.

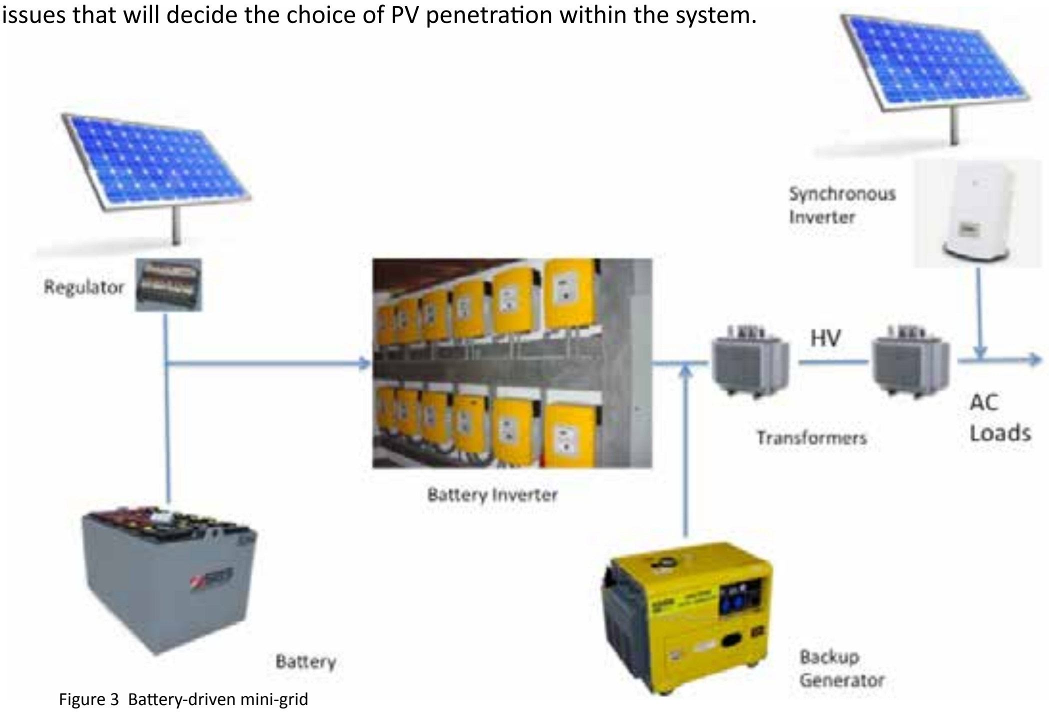

Figure 3 Battery-driven mini-grid
Source: Tony Pearson

Diesel-driven mini-grid

In diesel-driven mini-grids, a diesel generator is running all the time and forms the grid, and the renewable energy systems are connected to reduce the amount of diesel used (Figure 4). This system may sometimes have batteries included. The system has to be actively controlled to ensure that: (a) there is always load on the generator and that the generator has sufficient spinning reserve should the sun be suddenly obscured; and (b) the diesel has enough reserve capacity to provide all the power and be sufficiently loaded so that, if the sun suddenly shines and removes power off the diesel generator, it does not go into reverse power, i.e. the solar system powering the diesel generator.

A diesel-driven grid will normally have more than one diesel generator and these can be sized differently to give a high load and a low load option. Larger systems usually have the ability to combine or synchronise the generators to cater for varying levels of higher loads.

Figure 4 Diesel-drive mini-grid
Source: Tony Pearson

This type of system has been suited to large mini-grids, where battery grids have been unfeasible or too costly. A diesel-driven grid has, until recently, been capable of only low or medium penetration, as diesel generators need to run at over 30% of their capacity. Peak renewable generation can be only 70%, which will give an overall penetration of 20%–50%. The higher the penetration, the more complex the control mechanisms become.

Technology has, however, improved over the last few years with the development of the following:

- Low load diesel generators: These can be run at under 30% capacity and even down to zero load without damage. A second advantage of running a low load is that they become a very effective "spinning reserve". Spinning reserve is where a generator is running on stand-by, with the ability to rapidly dispatch power to meet sudden increases in load. This function allows higher grid penetration of solar power as the spinning reserve acts as back up to compensate for any loss of PV generation resulting from sudden blockages of the sun.
- Intricate control mechanisms: These select the optimum combination of diesel generators and control renewable generation. They manage existing control systems and are able to assess the levels of renewable energy and the correct combination of generators to run in a multi-generator set up. They also manage the spinning reserve. This type of system is improved further if at least one of the generators has low load capability.
- Methods that allow generators to be run off load (no or minimum load) and even reverse loaded By controlling the frequency of the renewable generators, it is possible to control the diesel generator to reduce its output and even accept reverse load, at which point it will be running on very little or even no diesel. This again makes the diesel generator operate as an excellent spinning reserve, as it can be loaded almost instantaneously.

These developments have allowed a diesel-driven grid to increase the potential penetration to 95%. A level of energy storage, such as a battery, capacitor or flywheel can also be added to smooth variations in renewable energy output to further increase penetration levels toward 100%.

4.3 Load management

Renewable energy powered mini-grids become even more effective if they include a level of load management so that loads can match the generation closely. Load management functionality is therefore becoming a key criteria in selecting inverters for hybrid systems. Key loads that can be managed are water heating, water pumping, refrigeration and air conditioning. Ideally, the system would make load management decisions (without permission from the users). In practice, load management works by automatically reducing power output to one appliance and diverting it to another in order to prevent battery state of charge from dropping below a critical level.

4.4 Energy storage technologies

There are several ways of storing energy, though the most widely used method is through battery storage. Lead acid batteries remain the industry's most commonly used battery, as the technology is well understood.

System designers should consider the cycle life at the 'expected' daily depth of discharge when selecting the battery technology for their PV hybrid systems[3]. This figure can be read from a cycle life curve, which is commonly available from the battery manufacturer. An example cycle life curve is shown below for the popular Sonnenchein OPzV battery.

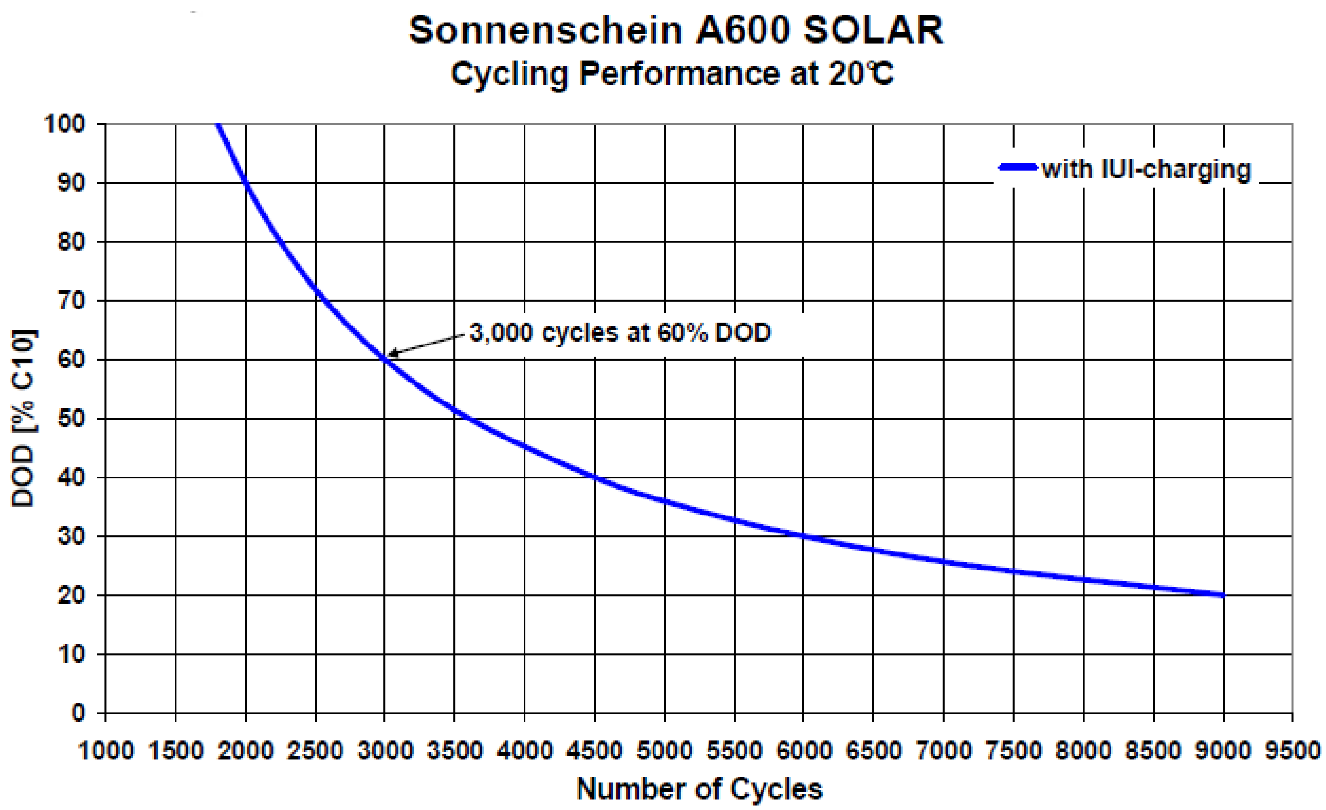

Figure 5 Cycling Performance of Sonnenchein A600 Solar
Source: Exide Batteries

[3]The daily depth of discharge (DOD) is calculated based on the maximum allowable depth of discharge for the battery, and the desired days of full load storage (known as days of autonomy).

If the maximum allowable depth of discharge is 80%, and 2 days of autonomy is chosen, then the daily depth of discharge is calculated as 100% X 80% divided by 2 days of autonomy. So daily depth of discharge is 40%. If the Sonnenchein A600 Solar is used, then we'd expect to receive 4500 cycles, which is around 12 years of life.

With the battery referenced in the above curve, if the maximum daily discharge was 60% for the battery bank (which is on the extreme low side for battery sizing), then the battery bank would deliver 3000 cycles and be expected to last approximately 8 years. If the battery bank was doubled, then the expected maximum daily discharge would be 30% (which is common for smaller hybrid systems with low reliance on diesel generators) and the battery would be able to provide 6000 cycles (or approximately 16 years of life).

Using this curve gives the system designer an understanding of the expected life of the battery and then allows them to make decisions on how 'deep' a battery bank they require, based on their budget. This graphic is also useful to explain the importance of 'state of charge' to system operators, as they will learn the importance of monitoring and controlling battery state of charge.

Emerging battery technologies (such as Lithium Ion, Vanadium Redox or Vanadium flow batteries, and Aqueous Hybrid Ion) appear to be well suited to conditions in the Pacific. Each has advantages and disadvantages and are worth consideration on future hybrid projects in the Pacific region as the technology matures and the price reduces.

5 TECHNICAL CASE STUDY PRESENTATIONS

Three case studies were presented to the workshop participants:

- Tonga outer islands, using solar-home systems;
- Tokelau, with a battery-driven micro grid; and
- Neiafu, Vava'u, Tonga, using a diesel-driven mini-grid.

The case studies illustrated these three basic system types the successes and areas of concern were highlighted. The case studies are shown below.

5.1 Tonga outer island renewable energy installation

The Tonga Outer Islands Solar Electrification Program (TOISEP) has been in operation since 1987, covering the Vava'u and Ha'apai island groups. Solar home systems are provided by Shoreline Power Ltd, a locally-owned private company. Any entity wishing to generate electricity must first obtain approval from Shoreline and a license from the Tonga Electric Power Board. Individual tariffs are established for each island system; there is no cross subsidy from Tongatapu consumers.

Early projects did not do well, but experience has improved the technical and institutional quality of the systems. Systems started to be replaced in 2010. All solar development at the village scale has been organised by an energy service company (ESCO) where the users do not own systems; they are owned by the government, a cooperative or a community, and fees are charged to offset the cost of maintenance. How fee collection is achieved is up to each island, as there has been no national policy to guide this. ESCOs move the direct management away from government, leaving them only an advisory and policy role, empowering the communities to have a stronger say in the system management.

Requirements

The requirement was for a very basic level of power to reduce the amount of kerosene used for lighting. There was no allowance for AC power. Each system comprises:

- Four fluorescent DC lights (2 x 7W, 1 x 11W and 1 x 13W);
- Two DC/DC converter sockets for radio and mobile phone; and
- An LED type night-light (orange colour) to act as street lighting. Households are expected to prevent early battery failure by restricting light use to prescribed hours and DC radio use to a prescribed level.

Available resources

Only solar-PV energy systems were considered, as the availability of solar resource is much easier to determine, and small solar PV systems are at the the appropriate scale to match the needs of households.

NASA satellites measured a solar resource on a horizontal surface of 5.27 kWh/m2/day for the location, but monitoring at Tongatapu gave 4.51 kWh/m2/day. A default figure of 5 kWh/m2/day was used for design purposes.

Technical constraints

Installations were providing power to houses that had no power, so there were no constraints in matching with existing systems.

When batteries require replacement, the new battery has to physically fit into the battery box and be compatible with the charge controller, possibly limiting the capacity and the technology of the replacement batteries.

Geographical constraints

The outer islands are very dispersed and some are not easy to access. This makes it difficult for installation and maintenance programmes.

System design

System design has improved with experience. Early projects were undersized and batteries were not appropriate for long life. Early systems were roof-mounted, while later installations used external poles and now also battery boxes in order to avoid roof damage and to ensure panel-mounting in minimum shade areas.
The technical design of the 2002 PREFACE (Pacific Rural/Renewable Energy France-Australia Common Endeavour) installations included:

- Two 36 cell 75 Wp photowatt PV panels providing 150 Wp per installation;
- A 12 V Hawker-Oldham open cell, a tubular positive plate, deep discharge battery with a capacity of 108 Ah at C10; and
- A Total Energie charge controller

The system is sized to allow the external light to be left on all night to act as street lighting, thereby avoiding the problems associated with installing and maintaining separate systems for public lighting.

Energy storage

Batteries and controllers are in a locked, weather-tight box placed at the base of the pole, instead of in the house as in earlier projects. This enables maintenance when occupants are away and discourages tampering. Problems with external battery boxes include a tendency to be shifted by pigs rubbing against them and, during heavy rains, some have been flooded. A further problem is that the boxes get too hot, reaching 40°C, which will significantly shorten the life of the battery. The boxes need to be raised to the top of the pole to prevent pig and flood damage and then, when covered under a panel would be shaded by the solar panel.

Funding

Funding of solar home systems (SHS) power supplies, including recent upgrades, have all been provided by donor grants but the size and design have been driven by donor policies and not by the community's needs and aspirations. Many changes have been implemented that have improved the system management, including a major change from a government-run SHS model to an incorporated community-run SHS model in 2002. Efforts have been made to reduce the installation costs but SHS projects revenue collection continues to be unsustainable.

Projects are currently managed by individual village committees, with the Vava'u group taking a more communal payment approach and the Ha'apai group placing responsibility on individual households. Committees collect the fees and give them to Tonga's Energy Planning Unit (EPU) to offset the cost of maintenance. Basic system maintenance was the responsibility of the committees and EPU was called upon for more complex maintenance. Repairs often took a long time.

These problems made it difficult to impose a rigid disconnection policy. Fee collection was generally poor (no more than 40% typically) with Vava'u payments less consistent than those from Ha'apai. A simple solution to this would be the use of pre-pay meters, which ensures 100% collection and automates the disconnection and reconnection procedure.

System performance

Almost 90% of the population of these outer islands now has electricity, with roughly 2000 systems, amounting to 230 kWp of solar energy and 2600 kWh of stored energy. User acceptance has risen as installations become more reliable, even with increased user fees rising from TOP 2 per month in the 1980s to the current TOP 13–20, depending on the project location.

Earlier systems were unreliable due to poor system design and choice of equipment. However, later system designs have much better reliability with battery life in excess of eight to nine years and in some cases exceeding ten years.

Spares remain a concern, particularly for the lamps, with one survey showing 47% of lights not working.[4]

System monitoring, maintenance and cost

Solar-home systems are too small and numerous to monitor results or performance remotely. Monitoring relies on informal assessment and occasional surveys carried out by technicians during planned or unplanned (proactive and reactive) maintenance.

It is currently difficult for users to control their consumption, as they do not know the state of the batteries. A simple LED indicator or SOC meter would assist users in maintaining healthy batteries and fully functioning systems.

A monthly fee is paid that was to cover maintenance and replacement when needed, but this fee was initially based on affordability and the equivalent of payments for kerosene, and did not cover the maintenance and repair costs. Even with the higher payments it is doubtful the figure covers all the costs and it is still higher than purchasing kerosene. There are, however, significant advantages, such as stopping harmful environmental emissions, improved fire safety, and health benefits (e.g. fewer respiratory and skin problems).

Energy systems that are regularly maintained have high operational reliability, as was the case in the Ha'apai island group.

Conclusions

- The systems are now operating as expected but there is concern about the delays in the provision of replacement lights.
- The system has allowed for more socialisation in the evening and for women to work longer hours to improve their income. The evening hours can be used more productively than hitherto.

The most important lessons learned from the Tonga experience are:

- People are willing to pay substantially more than conventional 'ability to pay' surveys predict;
- The rate of collection of user fees is directly related to the quality of service obtained;
- Local, community-based institutions are not adequate for sustainability; for long-term success, the greater technical, financial and management resources of an external institution are needed;
- Revenue collection by pre-pay meter would help generate income and ease difficulties of disconnection and reconnection;
- Components must be chosen for the harsh environmental conditions;
- Projects need to build on prior experience to prevent repeat mistakes;
- The more remote the site, the greater the need for good quality equipment; in the long term this is more cost-effective, as there will be fewer expensive repairs needed.
- Preventive maintenance improves long-term reliability; most problems with PV systems are the result of an accumulation of small problems, not catastrophic failures; and
- The use of a mini-grid would have allowed for personal, system and economic growth.

[4]Sefana, Ofa and Syngellakis, Katerina. 2015. A case study: Outer islands solar rural electrification in Tonga.

5.2 Tokelau renewable energy installation

The Tokelau Renewable Energy Project installed a photovoltaic-diesel hybrid system with battery storage on each atoll in the Pacific Island nation of Tokelau. Previously, the three atolls – Fakaofo, Nukunonu and Atafu – used diesel generator sets to provide electricity on a centralised distribution network. The new solar power systems were designed to provide at least 90% of the islands' electricity needs from solar power, and are expected to save roughly NZD 900,000 per year in diesel costs (for a capital cost of NZD 8.45 million). In fact, expectation has been exceeded and Tokelau is the first country to have almost all its electricity needs met by solar power.

Requirements

The system was required to replace the existing diesel systems with an annual consumption of 775,000 kWh per year as shown in Figure 6.

The typical loads on the island include fridges, freezers, fluorescent lighting, fans, microwaves and washing machines. Electric ovens, water heaters and air-conditioning units are banned on the atolls.

Total 24hr Demand	Fakaofo	Nukunonu	Atafu	Unit
Maximum Recorded Demand	80	66	68	kW
Minimum Recorded Demand	28.2	22.1	24.5	kW
Average Daily Consumption	1,002	698	776	kWh
Diesel Generator Capacity	3 x 100	3 x 80	2 x 80 and 1 x 100	kW

Figure 6 Existing loads and requirement
Source:PowerSmart.com:http://www.seanz.org.nz/files/file/312/Shane+Robinson+Powersmart+Solar+-+Tokelau.pdf

Available resources

Solar radiation and coconut oil were used for the system design. The aim was to generate 90% of the load using solar panels, with the remaining 10% provided by running the diesel generators on local coconut oil. Other types of energy were not considered.

Technical constraints

Each atoll had its own centralised 230 V three-phase distribution system with a number of diesel generators that could be synchronised for higher loads. However, the synchronisation was not fully operational and often only one of the diesel generators would be available.

Geographic constraints

The atolls are 530 km north of Samoa and have a population of about 1400. There is only 11 km2 of land area. The atolls are low-lying with the highest point five metres above sea level. They are difficult to access as there is no port and all equipment has to be taken onto the islands by barge. The size and weight of the equipment is limited to what can be fitted on the barge and lifted by the crane.

System design

The system chosen was the standard mini-grid system used by New Zealand Ministry of Foreign Affairs and Trade, and consists of multi-cluster SMA Sunny Island inverters with battery back-up, and both Sunny Island MFAT regulators and Sunny Boy inverters feeding both the AC and DC buses as shown in Figure7.

Solar power is all centrally generated in a single large solar array with inverter and battery room. The solar system for each atoll is sized to suit its requirements, as shown in Figure 8.

Energy Storage

The batteries used are 2 V flooded lead acid batteries giving autonomy of 1.6 days to a 50% depth of discharge (DOD). Normally, at the beginning of the rainy season (November) the batteries' DOD drops to between 75% and 60%. During the rainy season they regularly drop to 50%.

Back-up generation

The diesel generators have been retained for back-up generation. The SMA inverters have the capability of starting the generator automatically if the load exceeds the inverters' capability or if the batteries drop to a predefined state of charge. However, Tokelau has decided to start the generators manually if required for three key reasons: (i) so that the operators get to know and understand the system; (ii) to prevent automatic generator starts from masking a fault in the system; (iii) to bring human intelligence to bear when deciding whether to start the system, i.e. if the sun is about to come out then it is worth delaying a generator start, as it may not be needed. The danger in this system is human failure, allowing the battery state of charge to drop too far, thereby damaging the batteries.

Funding

The project was funded by the Government of New Zealand, approximately NZD 8.5 million as a four-year advance in the aid money given to Tokelau.

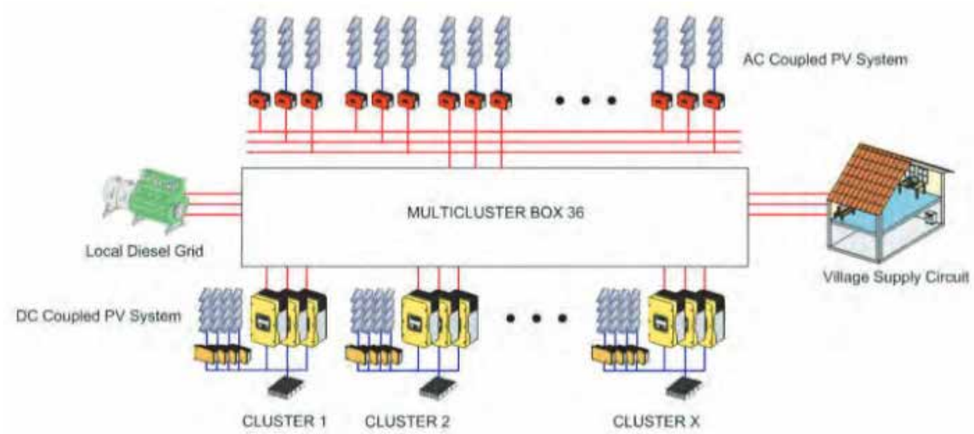

Figure 7 Multicluster system overview (from)
Source: Tokelau Renewable Energy Project Case Study March 2013, Government of Tokelau

	Cluster	Fakaofo	Nukunonu	Atafu	Total
PV capacity	33.12 kWp	365 kWp	265 kWp	300 kWp	**930 kWp**
No. of 230W PV panels	144	1,584	1,152	1,296	**4,032**
Capacity of string inverters	21 kW	231 kW	168 kW	189 kW	**588 kW**
No. string inverters	7	77	56	63	**196**
Capacity of DC charge controllers	9.6 kW	106	77	86	**269**
No. of DC charge controllers	4	44	32	36	**112**
Capacity of battery inverters (at 35°C)	13.5 kW	150	110	120	**380**
No. of battery inverters	3	33	24	27	**84**
No. of batteries	48	428	384	432	**1,344**
Total battery storage (nominal)	288 kWh	3,168 kWh	2,304 kWh	2,592 kWh	**8,064 kWh**
No. of clusters	1	11	8	9	**28**
Peak load	-	75 kW	44 kW	51 kW	**-**
Daily demand	-	985 kWh	660 kWh	715 kWh	**2,360 kWh**
Solar fraction (Nov '12 – Feb '13)	-	86%	91%	89%	**88%**

Figure 8 Technical specifications of Tokelau PV system
Source: Tokelau Renewable Energy Project Case Study March 2013, Government of Tokelau

Power is sold using pre-pay metering, thereby avoiding the need for billing and the problems that come with it. The village councils collect the revenue and use it where they see fit, including buying the diesel for back-up generation and paying the village maintenance technicians (employed by the council).

The Tokelau Energy Department installs and maintains the pre-pay meters. Negotiations are in hand for the department to collect the revenue with a view to becoming self-sustaining. The nominated cost of NZD 0.50 per unit (kWh) has been agreed by the government but NZD 0.87 per unit is needed to break even and cover the cost of replacing equipment. This has significant implications on future equipment replacements.

Installation concerns

The system was designed and installed by a New Zealand Company, PowerSmart, based on system design criteria within the tender documentation. The criteria set out certain performance requirements and stipulated that the installation would be a battery mini-grid.

Being a tropical island nation, corrosion is a major concern and to help slow the corrosion the solar cables were all run in an aluminium channel and ultra-violet (UV) stabilised conduit and everything was manufactured from either 316 stainless steel or anodised aluminium. The framework was pre-drilled and cut in New Zealand before being anodised, and all fasteners were coated in lanolin grease.

Another area of concern is battery temperature and care was taken to ensure that battery and inverter rooms were well ventilated with passive heat controls to keep them cool. Techniques included using a concrete construct for the large thermal mass, lining roofs with foil, keeping a roof space to keep hot air away from the rooms, building verandas to keep direct sunlight off the rooms, and making judicious use of windows and doors to stimulate good air flows.

The quality of concrete could not be guaranteed so reinforcement was increased to counter any reduction in strength.

System performance

There is now only an average of 6200 litres of fuel used per month, a saving of about 82% in fuel usage from before solarisation.

There is currently insufficient generation from the solar array, as consumption has climbed and there has been increasing cloud cover over the last two and a half years. This has made a significant reduction to the renewable energy factor.

Programmes have been instigated to educate consumers on how to save power and money and encourage them to purchase more efficient white goods and use energy-saving lighting. These programmes have already started to reduce consumption. If the demand fails to reduce to a sustainable level, then the cost per unit of electricity will have to be increased to force consumers to use less.

Back-up generation was not upgraded with solarisation and was inefficient and poorly maintained, struggling to boost charge the batteries. Regular deep discharging below 50% SOC and high consumer demand have degraded four battery arrays at Fakaofo Station below 70% state of health (SOH) that to date has not been recovered. A new 220 kW generator set was fitted at each station in 2014 and deterioration has slowed. Other than that, the batteries are performing satisfactorily. One bank on Nukunonu indicated below 70% SOH, but was restored after a series of boost charges.

With the increased cloud cover in recent years, back-up generation has increased the need to top up batteries for night use. Evening generator use is an average of two to four hours, and up to eight hours for a boost charge once a month if the solar system is unable to complete the boost. The design discharge is 25%–30% overnight but has increased to 35%–40%. It is recommended that SOH be maintained by ensuring SOC stays above 60% to avoid plate sulphating effects. Should a deep discharge occur below 50% SOC, the operator is instructed to carry out an immediate boost charge to dissipate the sulphating effect on the plates.

Obtaining urgent parts can be an issue. Down time usually depends on the availability of spare parts or equipment and can be anywhere between two hours and one month. Power black-outs are generally rectified within two hours with the use of portable generators that can supply full village load until the fault is repaired.

System maintenance and monitoring

The system is fully monitored using the SMA Sunny Portal (the online monitoring software that links to the SMA Sunny Island inverters) that allows remote diagnostics to ensure system performance is maintained and fault diagnosis can occur. Routine maintenance is very simple but important and includes topping up batteries and downloading data from the inverters to send to the monitoring teams. This scheduled maintenance requires semiskilled staff. Unplanned problems are addressed as required by the Tokelau Energy Department staff; if the monitoring contractor finds a problem, he or she will contact the relevant station supervisor by phone, skype or email.

There is a monthly report on each of the three mini-grids with performance statistics, condition, defects and recommendations. The report is understood by all station supervisors and most of the staff.

The Tokelau Energy Department receives no revenue and maintenance and project works are funded by the government. The funding of large-scale replacement/maintenance (particularly of batteries) must be of major concern. Attempts are being made to integrate revenue collection into the Energy Department, which would then be responsible for battery replacement and other maintenance.

Social/community comparisons

Uninterrupted power has brought vast benefits to the village quality of life, as has the use of most modern technology. It has allowed for the introduction and availability to everybody of satellite television and digital communication, including the internet, and the use of mobile phones is in the immediate future. Most appliances and power tools can be used, including commercial freezers, welders and all night street-lighting, and hospital and school facilities are improved. The availability to all residential customers of uninterrupted electricity is now fully normalised and expected.

Potential improvements to the new system

The increasing demand is working the batteries too hard so, in order to maintain a healthy SOC at sunrise, there are plans to install a further 33 kW of PV and one 48 v bank of batteries at each station. There is also a wind trial planned which, if successful, will create a hybrid system that should reduce the load on the batteries considerably. Increasing the cost per unit may reduce the increased demand and help fund future replacements.

Tokelau was an early adopter and many of the lessons learnt there have now been put to good use elsewhere, such as ensuring that the back-up generation is adequate to supply demand and boost charge, that the building design is efficient for tropical weather conditions, and that the design has sufficient capacity for an increase in future demand.

Bio-fuel from coconuts has been considered as a replacement for diesel oil for the standby generators. Tokelau coconut plantations are, however, mostly old and the nuts produce little oil. Landowner issues and high labour costs also inhibit sustainable production. Using pure coconut oil and a blend of diesel and coconut oil were considered but the cost of setting up the processing plant locally was not viable compared to importing ready blended oil. Gasification is another possibility, using coconut by-products and wood.

Conclusions

- The system is 8%–10% above expectation. The hybrid system was designed to provide 90% of the electrical needs of Tokelau. The first year renewable energy factor was 92% but this declined to 88% in the following two years with the need for more frequent battery top-ups.
- Keeping on top of the maintenance programme can be an issue. Capacity training is in progress to raise the level of electrical skills among staff.
- The reduction in diesel costs from pre-solar days has dropped by 84%. If there are seven hours of bright sunlight there is no need for back-up generation.
- The availability of 24/7 power has been perhaps the biggest improvement to the quality of life in the atolls, allowing the use of most modern amenities (apart from electric stoves that are banned, and air-conditioners that are restricted to essential areas only).

5.3 Neiafu, Tonga, renewable energy installation

Neiafu, Tonga's fifth largest city, is situated on the island of 'Utu Vava'u, the largest island in the Vava'u archipelago. Neiafu lies beside the port of Refuge, a deep-water harbour, so infrastructure is advanced and access is good.

In November 2013, Tonga Power Ltd connected a 500 kW solar array onto the diesel grid of Neiafu, using the SMA Fuel Save technology in order to maintain grid stability. The system achieves fuel savings of approximately 170,000 litres of fuel per year, and avoids the emissions of 500 tonnes of CO2-equivalent greenhouse gas emissions. The 500 kW array provides up to 70% of the energy demand at mid-summer noon.

Requirements

The system was required to supplement the existing diesel grid that has a daily consumption of about 14 MWh, as shown in Figure 9.

The typical loads on the island include fridges, freezers, lighting, air conditioning, fans, microwaves and washing machines.

Parameter	Value	Units
Maximum Recorded Demand	850 kW	kW
Minimum Recorded Demand	450 kW	kW
Average Daily Consumption	13956 kWh	kWh
Diesel Generator Capacity	2 x 600 kW	kWh
	2 x 186 kW	
	1 x 300 kW	

Figure 9: Neiafu System Parameters
Source: Tony Pearson

Available resources

Solar energy was the only renewable energy resource considered for this project. The aim was to generate up to 70% of the island load at any time using solar panels, with energy storage used to help mitigate the problems that can result from drops and spikes in solar output that is caused by clouds.

Technical constraints

Neiafu has a centralised 6.6 kV high voltage three-phase distribution system with five diesel generators of varying sizes. The generators can be synchronised to match the required load with some spinning reserve. The addition of 500 kW of solar power onto the existing system without added controls would cause instability of the grid and could possibly damage the diesel generators by running them at too low a load.

System design

The system is a hybrid PV farm with 1,680, 305-Watt Trina modules and 21 SMA Sunny Tripower 20 kW inverters. It is fully integrated into the existing diesel network. It can provide up to 70% of 'Utu Vava'u's energy demands during the time of maximum demand and up to 17% of the island's total energy consumption. There is also a 240 kW gel cell battery bank with SMA Sunny backup inverters in the system. These store the excess day-time generation for use during the peak hours in the evening. The system is controlled using the SMA Fuel Save Controller. By interacting with SMA inverters, it coordinates the photovoltaic feed-in by selecting the optimum combination of diesel generators (including an allowance for spinning reserve) and reducing the solar output if the diesel generation cannot be reduced any further. The Fuel Save solution provides a secure energy supply whilst maximising the efficiency of the diesel generators.

The solar power is centrally generated and is situated next to the power station to reduce the control cabling between the solar inverters and the generators. With the solar power being AC-coupled, it allows the solar transmission to be at high voltage (approximately 500 V).

Energy storage

There is a relatively small battery bank for the size of the system but it is not designed for long-term storage, only for peak lopping and smoothing. It uses 2V VRLA (dry lead acid) batteries. The roles of these batteries are to:

- Store excess daytime energy generation, which reduces generators peak load in the evening (as shown in Figure 10) so that the grid can operate with its smaller generator, thereby saving fuel
- Act as an immediate buffer should the load suddenly increase or drop or the solar generation suddenly reduce due to cloud cover. This can reduce the spinning reserve required from the diesel generator and thus potentially allow for a smaller duty generator.

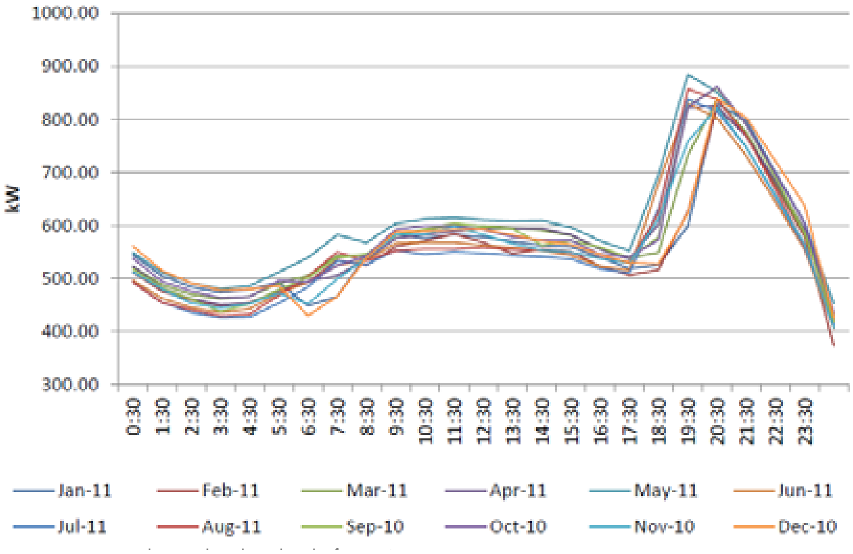

Figure 10 Load Profile
Source: Pacific Power Association Volume 23 Issue 2 June 2015, page 5

The battery bank uses a five-cluster system of SMA Sunny Backup inverters (15 in all), giving 75 kWh of stored energy to a 30% depth of discharge of the batteries. Sonnenschein gel cells were chosen, largely for the reduced maintenance load.

Funding

The project was funded by a grant from the Abu Dhabi Fund for Development and managed by Masdar, the Abu Dhabi government owned energy company.

The power that is generated directly replaces electricity that would normally be generated from imported fossil fuels. The electricity tariff in Tonga is structured such that approximately half the tarriff covers the cost of fuel and the other half covers the cost of maintaining and running the electricity supply. Any fuel displacement reduces the portion of the tariff directly linked to fuel costs. The cost of maintaining and running the electricity supply also includes the cost of replacing and maintaining assets such as the solar farm. If the asset is donated, as in this case, it is not immediately put on the books for replacement value, as this would cause the tariff to go up. Replacement costs are still being discussed, with the option of creating a ‘sinking’ fund being considered.

Installation process

The system was designed and installed by Ingenero Pty Ltd.

Access was easy (not always the case in the Pacific) but, being a tropical island nation, environment corrosion is a major concern. Aluminium was used for all the framing to help slow the corrosion.

System performance

Monthly generation figures are shown in Figure 11. They vary between about 35,000 and 72,000 kWh, equating to about 870 MWh per year or 17% of the island's total energy consumption.

With peak generation designed at 70%, there is little wastage of solar generation, i.e. generation that has to be curtailed due to there being nowhere to put it. Any higher penetration could give rise to 'wasted energy' without having a load to divert this surplus to.

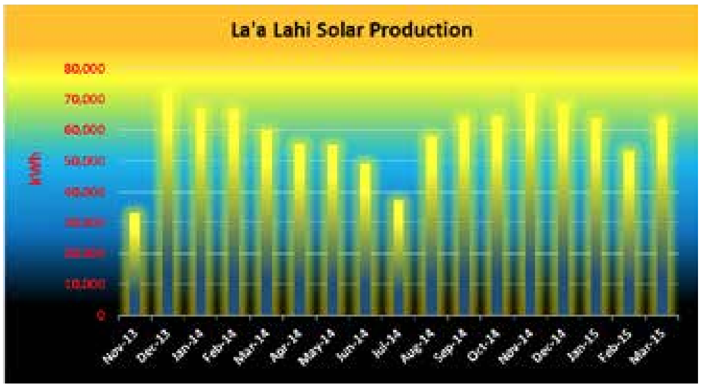

Figure 11 Monthly solar production at La'a Lahi Solar Facility, Neiafu
Source: Tonga Power Limited

The system is credited with reducing the electricity tariffs across the whole of Tonga by 1%–1.5% (depending on diesel prices) and provides about 3% of Tonga's overall consumption.

The project's unprecedented level of penetration (up to 70%) with two years of performance data shows the rapid growth of renewable energy (RE) technology in Tonga. In recent years, the maximum RE accepted level of instantaneous penetration averaged only 20%–30%. This reinforces the business case for further RE deployment and reduces fuel import needs.

System maintenance and monitoring

The system is fully monitored in both Tonga and Masdar, which allows a good level of remote diagnostics to ensure system performance is maintained and helps with any fault diagnosis. Weekly, monthly and daily check sheet proactive maintenance is undertaken on the system. Reactive maintenance has been necessary on the battery management system.

The Tonga Electric Power Board monitors the system with both on-line and on-site checks. These are recorded in monthly reports.

However, as mentioned, the cost of replacement is still uncertain, with the option of creating a 'sinking' fund being considered.

Cost comparisons

The system is working reliably and is saving 170,000 litres of diesel and 500 tonnes of CO2 emissions per year, with pay back estimated at about five years for the fuel-saving system. It should be noted that, although there is substantial reduction of diesel usage, the efficiencies have dropped from 3.9 kWh/l to 3.8 kWh/l (2.5%) because the diesel generators are operating at lower loads.

Social/community aspects

Community benefits have come from a small reduction in tariffs to the whole of Tonga. This level of reduction has caused no noticeable increase in consumption.

There are no other benefits to the community well-being, but one distinct advantage to the Tonga Electric Power Board is the generation can be monitored remotely from Tongatapu.

Potential improvements to the new system

The battery back-up system would be more useful if it were substantially increased in size. Alternatives to batteries for helping with smoothing could be the use of flywheels or dynamic grid interfaces.

Closer collaboration from an early stage of project development was needed with the electricity utility. The development was effectively exclusive of the electricity utility until project implementation, meaning a number of design considerations were excluded.

Adding to the renewable energy generated to the system would require one of:

a) getting it from a different source, such as wind, so it does not add significantly to the midday solar peak generation (in high winds there may be not so much solar generation);

b) adding more storage capacity to store the excess energy at peak generation;

c) installing a low load diesel generator to run at peak generation times to increase the acceptable penetration level to 90%;

d) installing any new solar equipment facing east or west to increase morning or evening generation without adding too significantly to midday generation;

e) accepting a greater wastage of energy at midday to improve the penetration levels through the rest of the day; and

f) shifting load to the midday peak generation period, thereby reducing the penetration level to allow for more generation.

Careful consideration would have to be given to the cost benefit of these options.

Conclusions

- The solar system is working well except for the battery support side. This is undersized and uses old technology.
- The system has reduced operations and monitoring costs, and there are obvious savings in fuel, but maintenance of the diesel generators is costly.
- Social/well-being improvements have been restricted to a small reduction in tariffs across all of Tonga, not just for the direct recipients of the power.

5.4 Synopsis of findings from the case studies

The three case studies highlight the different options now available to get a renewable energy-powered mini-grid. Smaller systems, under 100 kW, are still best provided with a battery-driven mini-grid, and very large systems are better with diesel-driven mini-grids with or without a small battery bank. Mid-sized grids of 100 kW to 1 MW now have an option of using diesel-driven or battery-driven grids and the choice will ultimately be financial, depending on how quickly the grid needs to be converted to 100% renewable electricity.

Key points highlighted by the case studies are as follows.

1. Ensure that existing infrastructure is suitable for the new installation.

2. Remotely monitor the systems, using external expertise if this is not available in-house.

3. Work out full maintenance, repair and replacement cost structures at the planning stage, and know what method of funding replacement batteries and other equipment will be used at the end of their life.

4. Ensure that tariffs are set to achieve what they are designed to do, i.e. cover maintenance or maintenance and replacement.

5. Ensure that revenue is ring-fenced for the purpose it is being collected for.

6. When trying new equipment, be second or third, not first off the block. Learn from other installations around the world, not only Pacific Island installations (e.g. the battery bank for Neiafu in Vava'u).

7. There is a lot of suitable technology that has been used in similar environments that should not be discarded because it has not been tried and proven in the Pacific.

These case studies show that there are now many different ways a renewable energy system can get very close to being 100% renewably powered without excessive expense. The last 2% or 3% remains economically challenging unless it is possible to use a form of bio-fuel to run the diesel generators. If it is politically or morally important to reach 100% renewable power, then it may be better to import the small quantities of bio-fuel needed, based on the economics of on site bio-fuel production.

6 Presentations on other systems in the P-ACP region

A few other islands in the tropical areas of the Atlantic were also researched, showing some of the different technologies available. Many of these systems are based on or include wind turbines, which were not specifically included in this workshop. However, because many of the diesel-driven mini-grid control systems were developed for wind turbines, there is more data available. The technology is transferable to solar installations and is now being used for both hybrid wind and solar installations.

Denham Power System

Denham is an isolated town in the Shark Bay World Heritage Area of Western Australia 800 km north of Perth. The population is approximately 900 permanent residents and the town is a popular tourist destination. The Danvest control system controls the wind turbine surges using a dynamic grid interface and controls the generator selection to ensure optimisation of the generators. The system is achieving 80% power penetration and 40% energy from the wind turbines. There is currently no solar energy on the system.

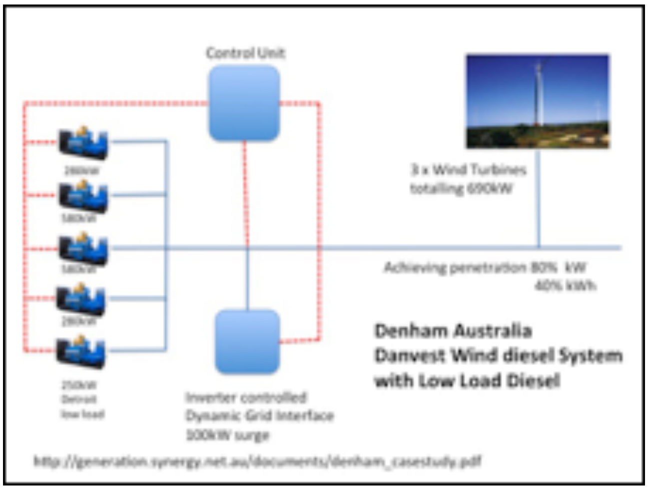

Figure 12 Denham Power System, Source: Synergy Case Study

Coral Bay, Western Australia using ABB Power Store System

Coral Bay stands at the gateway to the Ningaloo Reef World Heritage Area, 1,100 km north of Perth in Western Australia. The picturesque tourist town is home to approximately 140 permanent residents, although this number increases significantly during the summer months with the influx of tourists.

ABB use flywheel storage to smooth the volatility of the wind turbines and the micro-grid controller manages the power flows and generator schedules. This system achieves up to 95% power penetration and 45% energy penetration. Again, there is no solar energy on the system, which would increase the energy penetration significantly.

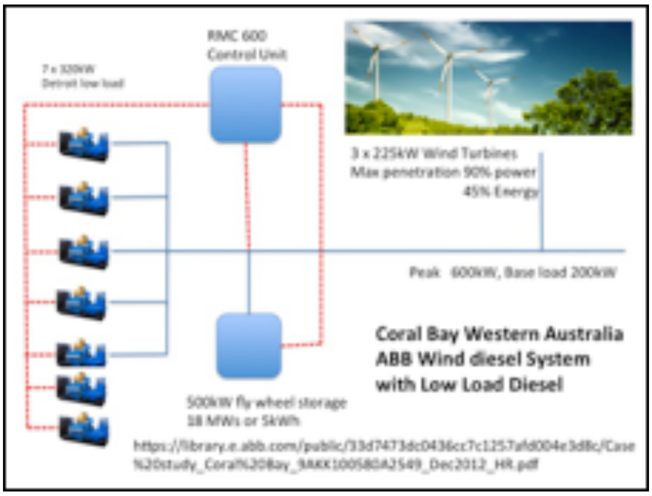

Figure 13 Coral Bay power system
Source: ABB Case Study

St Helena and Peter Island (Caribbean) using the WES control system

St Helena Island started installing renewable energy systems with two wind turbines in 1999 but over the last two years has ramped up the installation of these systems and now has 12 x 80 kW wind turbines and about 700 kW of solar installation. They have reached 33% energy penetration. There is another installation on Peter Island, an island in the British Virgin Islands, where 2 x 250 kW turbines are providing over 100% power penetration and 70% energy penetration. They are planning to install solar systems, when they expect to get about 95% energy penetration.

Matiu-Somes Island

Matiu-Somes Island in Wellington Harbour is a nature and scientific reserve and has up to 65 overnight visitors and residents. The island is powered by a combination of a 6 kW wind turbine and 4 kW solar installation and has reached about 98% energy penetration using a battery driven micro-grid. Being a nature reserve, there has been an extensive survey on bird strikes and the Department of Conservation has proven that the turbine is not a danger to the indigenous birds on the island.

7 DESK REVIEW – CURRENT STATE OF RENEWABLE POWER SYSTEMS IN THE PACIFIC

A desk review of solar installations using different technologies and variously sized (with and without diesel generators) in the Pacific area was undertaken. No attempt was made to analyse any of the countries in detail, but what follows does highlight the state of renewable power systems in the Pacific.

Although this research was concentrating on mini-grids under 1 MW, the full range of renewable power systems in the Pacific was included, as all the main island grids could be considered as mini-grids and the technologies discussed above would, in many cases, be suitable to increase the level of renewable energy on those grids.

Cook Islands

The northern group of islands has, or is well under way to having, mini-grids installed throughout, and plans for this to extend to the southern group are well under way.

Raratonga and Aitutaki are increasing the level of grid-tied systems but will soon need to address the extension to medium to high penetration on these systems.

Figure 15 Rakahanga
Source: Power Smart

Figure 16 Nadarivatu Dam
Source: Fiji Electricity Authority

Fiji

Fiji has the advantage of having a well-established hydro source providing a significant proportion of its power. With an installed capacity of 269 MW, Fiji is still dependent on oil for 44% of its supply. On-grid solar is slowly developing. Fiji has a wind farm and geothermal power is a possibility. Only 80% of rural Fijians have access to power, and solar and micro hydro power have been used a lot in remote areas. Many resorts are installing solar systems.

French Polynesia

French Polynesia is 75% powered from diesel generators; the remaining 25% is largely hydro power with 19 hydro power stations throughout the islands. They have installed seven, with plans for a further four hybrid micro-grids of about 50 kWp of solar power providing between 50 and 100% of the energy, depending on time of year. Some of the resorts are investing heavily in renewable power systems and technologies that reduce the power consumption significantly, such as sea water air-conditioning.

Federated States of Micronesia (FSM)

The Federated States of Micronesia has recently installed a series of 2.5 – 10 kW micro-grids (without generator back-up) in schools and dispensaries that did not previously have power, along with two larger community micro-grids. There has been some recent improvement of the main grid, making it much more stable and suitable for some grid-tied solar installation. It is understood that there are plans to install some soon.

Figure 17 Recent micro-grid installations Source: Peter Konings

Kiribati

There are about 2500 solar installations around Kiribati on 18 islands. Solar and wind power are also widely used for water pumping. There are plans to fit five systems amounting to 916 kWp to the grid. This is about the maximum the grid will take without installing higher penetration systems.

Figure 18 Marshall Island Hospital
Source: H Wade

Republic of the Marshall Islands (RMI)

There are about 2,700 solar home systems, ranging from 160 W to 230 W throughout the islands. There have also been at least 12 micro-grid installations fitted to schools. There has been a significant number of grid-connected solar installations, with system sizes ranging from about 10 kW to 800 kW. With the two main grids having 18 and 5 MW capacity, there is still enough room to add simple grid-tied systems, but control mechanisms need to be considered early so that development of renewable energy can be undertaken as part of a long-term plan.

Nauru

Nauru has about 60 solar home systems and 155 solar street lights and solar pumps. Grid-tied systems started with Nauru College but there is now a total installed capacity of 660 kW, including 130 kW being installed to offset the power required for a new reverse osmosis plant. They have 9 MW of diesel generation capacity and so there is still room to add more grid-tied solar systems.

New Caledonia

New Caledonia has a wide range of generation sources, including a 68 MW hydro dam, around 50 MW of wind power, and a biomass generator, as well as seven oil- or coal-powered stations. Tiga Island is powered by a solar hybrid mini-grid and there is significant use of solar power for water pumping. There is a 2.1 MW solar power station but not much more, other than private installations.

Palau

Palau has recently installed over 600 kW of grid-tied solar systems but with a mid-day consumption of 10 MW there is plenty of room for additional solar generation. Off-grid solar-home systems were installed in the 1980s but these were too small and not well maintained and many have failed. They were replaced with larger installations, including inverters to run fridges, washing machines and videos, but the majority of these systems face equipment failure. Barring communication systems, the only other off-grid solar application is for street lighting.

Figure 19 Palau Airport
Source: Kyocera

Papua New Guinea

In 2010, only about 13% of Papua New Guinea's (PNG) population had access to electricity. The country aims to provide power to 41% of the population by 2020 and 70% by 2030. PNG has a significant level of hydro generation within its national grids. Private generation, mostly undertaken by large mines, plantations and other resource extraction industries, use hydro, biomass, and geothermal energy, in addition to diesel-powered generation. There is as a lot of private generation, which has a much broader renewable energy mix than the public generation.

There has been no widespread push to develop solar power systems, partly because of the availability of hydro power, keeping the cost of electricity lower than other Pacific nations. There have been over 4000 solar-home systems sold privately and there are a lot of solar hot water systems in Port Moresby, although most of these have failed due to poor installation and maintenance and theft problems. PNG Telecom has over 200 kWp of solar installations spread around their stations. There have also been Japanese and Chinese donations of wind and solar technologies but there is little information on how well these are working. There are plans for wind assessments around Port Moresby to assess the viability of a wind farm there.

Samoa

Samoa has some run-of-river hydro, which peaks at 11 MW and in a wet year can provide up to 36% of the national consumption. The wind is good for wind turbines and the country now has about 26 MW of wind generation in two wind farms. There is a project using bio-fuel from an invasive weed, Merremia tuberosa, for cooking and lighting and for a 'diesel' mini-grid.

In 2008, 5% of the population (1600) homes had no power. This has been at least partially addressed with some solar home installations. Grid-connected systems have recently been installed with nearly 3 MW of installed capacity.

Solomon Islands

The Abu Dhabi Government renewable energy company, Masdar, in partnership with the NZ Government, helped commission the Solomon Islands first solar farm installation in 2016. The installed capacity of the solar farm is 1MW. The Solomon Islands Government has also partnered with the World Bank to develop the a 15MW Hydro Power station on Guadalcanal, which is scheduled for completion in 2019. At the time of writing, there have not been any major 'mini-grid' installations in Solomon Islands, but the NZ government funded a 100kW stand-alone PV hybrid power installation at the Fred Hollows eye hospital in Honiara, and Solomon Power has plans to install two PV hybrid systems in Taro and Seghe in 2016. There are many thousands of government and donor funded solar home systems that provide basic energy services (lighting and mobile phone charging) for rural households throughout the country.

Timor Leste

Timor Leste has a very low access to electricity. In Dili, the capital, only 85% of houses have power. In other district capitals this drops to 18% and in the rural areas it is only 5%. There is one main grid for Dili and the surrounding area, and there are a further 57 smaller 'micro' grids. Power reliability and revenue collection are a major concern and there is a plan to move to pre-pay meters. There is virtually no renewable energy inspite of the plentiful renewable energy resources, with good solar irradiance, good winds (at least in the hills) and a substantial hydro resource. These can all be utilised for the utility grid and also for mini-grids and solar home systems.

Tokelau

Tokelau has progressed to the basis of a fully renewable grid, based on battery-driven mini-grids on each atoll, and now only needs to fine-tune its system to increase the level of renewable energy by:

- Adding wind generation into the system;
- Adding additional solar installations; and
- Adding additional storage
- This may be an ongoing process if the load creep continues

Tonga

After initial failure of the solar home systems, new systems are being put together to prevent similar failings. The committee management structure was built on the long-existing administrative structure of each island group. An office has also been established to provide secretarial duties to the committee and to employ two technicians on each island to provide technical assistance and maintenance services. Tariffs seem to be working, with high collection rates and money available for equipment replacement. Solar hybrid mini-grids are also being used and solar energy is being used for street lighting and water pumping.

Tuvalu

The main grid has substantial solar installations on it, about 700 kW, which is about 15% of the day-time load. The main grid has approximately 700 kW solar generation connected to it, which comprises roughly 15% of the day-time load.

Vanuatu

Only 80% of urban and 17% of rural residents in Vanuatu have access to electricity. Vanuatu has a very good mix of renewable resources and, although it currently uses very little solar power (measured in kW), it has about 4 MW of generation under consideration. It does have 3 MW of wind power, 1.3 MW of hydro power and a 4 MW geothermal plant that is expected to be in operation by 2020. The main grid has a total capacity of 29 MW with a week-day load around 10 MW, so there is plenty of capacity to implement new renewable systems. There needs to be a big push to provide the 83% of rural residents with access to power, and the fastest way is with a solar home system.

7.1 Conclusions from the Desk Review

Across the Pacific, the use of both SHS and mini-grids is becoming extensive throughout the smaller islands and remote areas of the larger islands. The system size and the choice of system type need to be looked at closely to ensure they meet the user-demands and allow for system growth. Maintenance of the system needs to be assured, otherwise it quickly fails.

Many of the provincial centers across the region are connecting large solar installations to their utility grids and will soon 'max-out' and reach the maximum penetration levels that can be achieved (without added controls). Most of these grids can be categorised as mini-grids and many of the technologies discussed in this report are transferable to these large grids.

An increasing number of resorts in countries with significant tourism industries are installing their own power systems, which is good as it increases the level of renewable energy share, but care must be taken where these are grid-connected because, as the resorts take less power from the grid, it could increase the fixed cost to other users of the grid.

It would be beneficial to hold discussions with each Pacific Island state to get comprehensive information on the state of renewable energy power systems in the Pacific. This would help in assessing priorities for further aid funding and highlight where research needs to be undertaken to increase their penetration on both large and small systems. It would also give clear information on what systems have survived and which have not.

8 DISCUSSION OF DESK REVIEW AND INTERVIEW FINDINGS

Before the workshop, a selection of experts in the Pacific energy industry were interviewed on a range of topics relating to solar installations in order to get an indication of what affects the success or otherwise of renewable energy systems in Pacific Island countries. Their views, and the information already disseminated to the workshop participants, were discussed in detail by the participants under the following headings: selection of a community, pre-conditions, stakeholders, planning and design standards, definition of success, maintenance, payment structure, and user awareness. The main points of the discussion are given in the next few pages.

Criteria for choosing a community

Unfortunately, the criteria for choosing a community do not always get addressed properly. It was strongly felt that the community must want and even push for a system and have a stated need for it, otherwise they will not treasure it or look after it.

Sometimes communities do not necessarily want light so much as water pumping or water treatment, which will improve their health, productivity and lifestyle and will deliver far greater benefits than just getting more light.

There is some confusion about the relative benefits of SHS compared to mini-grids. This was discussed at length in the workshop and it comes down to a political decision on what the aims of the project are: to provide a little power to a lot of people (solar home systems) or additional power to encourage growth but possibly for only a few people if the budget is limited (mini-grids). There may also be land access issues with mini grids that are bypassed with SHS, as a mini-grid may require communal land for a centralised solar array or wind turbine and access through a village for cabling.

Criteria for choosing a community

- Remoteness of the community
- Needs and aspirations of the community
- Existing supply
- Views on existing national policies
- Views of the various community groups
- Mapping of renewable resources
- Economic viability
- Choice of system: household system or mini-grid?
- Whether to use the diesel model for three years and then hand it to the community

Pre-conditions

It was felt very strongly that system ownership is a critical factor and has to be sorted out at the initial planning stage and this might have a knock-on effect on the choice of system.

Without local council support, the chosen management option is likely to fail over time. Also, it is absolutely critical to size the system correctly to prevent either frustration from the community (too small) or over investment (too big) when money could have been better spent helping more people. The community must also know from the very first planning stages that there are costs and obligations on them to maintain the system, and they must be willing to contribute to this in order to stave off system failure.

Preconditions

- System ownership is sorted out at the planning stage
- Maintenance and repair are affordable, available and manageable
- The system is correctly sized
- Plan for needs, given that not all needs are the same
- Support of local councils
- Understanding that charges will be levied and there are community obligations

Stakeholders

It is very important to identify the stakeholders early in the planning stage as each one could have a significant input into the system. For example, if a utility is responsible for the maintenance of the system, it should be involved with selecting the easiest and cheapest options to maintain, which might not necessarily be the cheapest to purchase.

The consumers must be identified down to group level, i.e. men, women, youth, elderly, schools, clinics, etc. They all have special needs, requirements and expectations that must be met or managed for an installation to be successful.

Stakeholders

- Local government
- Civil society
- Church
- Non-governmental organisations
- The private sector
- Youth groups and women's groups

Planning structures and design standards

There was some concern over the variety of different standards that have to be worked to, which does have the potential to cause confusion for people working across the region.

There may be some conflict between government and community plans that needs to be addressed at an early stage. Equipment has to be proven and reliable, due to the limited level of maintenance available and the time and cost to carry out repairs in remote areas.

Planning structures and design standards

- There are different standards: USA in the North Pacific, NZ/AUS in the South Pacific
- SEIAPI (Solar Energies Industry Association) standard designs
- Donors stipulate their own technology and hardware
- Gender considerations
- Government/community plans
- Proven equipment in harsh environments
- Continuity of equipment
- Country-specific standards to suit conditions

Definition of success

- Implementation and long-term sustainability
- The project runs to time and budget, no accidents, achieves its aim
- Battery and equipment survival in harsh conditions
- Training follow-up and levels of training – for users and maintenance staff
- Self-funding of maintenance and equipment replacement (batteries in particular)
- Improved livelihoods, health, education, and more free time for other pursuits
- Satisfaction of end-users and whether their needs are being met
- System working to specification after 5…10…20 years

Definitions of success

Many factors contribute to success. It largely depends on the choice of equipment, and the sustainability and longevity of the system. It depends on the user interacting with the system as per the expected design load. Further, it depends on equipment reaching its design or expected life, and whether there are funds available for planned and unplanned maintenance. It depends on whether there is a proactive maintenance structure to limit premature failure and whether the consumers are treating the system with due care and respect. Finally, it is defined by whether the system is achieving its initial aims and has improved the life style and well-being of the community. Is the community satisfied with the system?

Who maintains the system?

The question of maintenance comes up consistently as critical to the success of the system. There was no consensus as to an optimum system but it was agreed that there are many factors that will indicate the preferred options for different communities. It is recognised that remote monitoring by an experienced technician is an advantage.

These options were discussed in detail in the workshop sessions.

Who maintains the system?

- A utility company
- Local councils
- A private company
- Local maintenance workers (their selection, training, payment)
- Possibility of some maintenance being partially undertaken by remote monitoring

What are the payment structures?

It was unanimously agreed that payment structures are critical to the success of a system. However, before a structure can be developed, a tariff has to be set. This actually requires a political decision on how system replacement is going to be funded and whether the tariffs have to cover full replacement or just ongoing proactive and reactive maintenance. This needs to be addressed at the first planning stage as it is fundamental to setting the tariff. Different payment options were discussed in the workshop, although it was agreed that there is not a one-type-fits-all option. Pre-pay meters were discussed; there was a lot of interest in developing that model.

What are the payment structures?

- Utility company/ local council
- Cash payment – barter system
- How/when/who collects the money
- Pre-pay meters
- Fixed fee / usage benefits and disadvantages
- How to deal with non-payment
- Can disconnection be automated
- How to ensure payments are saved to use for replacement equipment

User awareness

- Management of energy expectations that differ within and between communities
- Which system gives best value: diesel or solar
- Overuse of systems and killing batteries
- Consumers' needs are often assumed
- Consumers' obligation not to touch the system
- Physical size of the system in a small house
- Will the system increase poverty
- Do people want to work longer hours

User awareness

User awareness is important to ensure that a system both lasts and is accepted. If the initial expectations are unrealistic through either unrealistic political promises or poor design communication, the consumers will never see the system as successful.

Not understanding the constraints of the system leads to over-use and abuse, causing early system failure.

Sometimes consumer requirements are assumed and it is important to survey the consumers and be aware of their needs and wants. It is also important to ensure that providing a system reduces poverty – not increases it.

Summary of research findings and discussion

The research findings highlighted the importance of the planning stage, and the key questions from the research are detailed below.

- What are political aims of the project, including what level of power can be provided?
- What are the cultural aims of providing power? What is the project trying to provide to the community: basic needs or the opportunity to grow?
- What are the consumers' needs at present and what are their aspirations?
- What is the management structure going to be and who owns the system?
- What are the tariff requirements: to fund a full system replacement at end-of-life or just provide proactive and reactive maintenance?
- Who is going to maintain the system and collect tariffs?

If these questions are not answered at the planning stage, the result is likely to be a poorly designed system that does not suit the needs of the community.

9 GROUP DISCUSSIONS

After the presentations of the technologies, case studies and the discussion of the research findings, the workshop participants were split into four groups: technical, financial/system management, maintenance and social / cultural. Each group was asked to discuss the points below from the perspective of their stakeholder group:

(a) The community selection and system design process

(b) Implementation and management

(c) Assessment and system success

They were also asked to note what has or has not worked and why; make recommendations for future projects, and develop a list of questions or topics for discussion during the selection and design process.

The groups then presented their findings and some very interesting discussions ensued. The following sections summarise the findings of each group and **the list of questions from each group can be found in Annex 1 of this report.**

9.1 Technical group

The technical group listed the items that they felt were absolutely required in order to design and implement a successful system. One key requirement was for the community to actively want a system and to be proactive and request one. However, it was considered that in many instances they would not have the expertise to develop an application and would definitely not have the experience to provide all the necessary information. It was felt there should be a facilitator available to travel to the community and assess their real needs and aspirations and help develop a request with sufficient information to design a suitable system.

In the whole group discussion it was stressed that this would be useful prior to applying for a grant, but it would also be imperative that the community knew that there was no guarantee of getting a system until the necessary finance was secured.

Another important point is that the design process must include maintenance requirements and capabilities to ensure an optimum solution for design is the optimum solution for the full life of the system, not just the purchase and the first two or three years of operation.

What has/ has not worked well

Items that were considered not to work well are: (a) the Tonga outer islands project Phase 1, because the system was too small and the equipment was unreliable; and (b) the Nabouwalu Wind/PV Hybrid Power System, because there was no ongoing operation and maintenance, the technology was immature in combining three generation sources, it was hard to source parts from Europe and USA, and there was no local support or warranty back-up.

Key recommendations

- Provide a facilitator to act as a link between the community and the project decider/donor/ government.
- The facilitator to research community requirements and list them for the assessment of funding and to drive the system design.
- The facilitator to research resources – technical, managerial, cultural and natural – to help assess what is the best fit model to run the renewable energy system.
- Use designs, equipment and technology that have been proven in the P-ACP region.
- Verify consultants' designs with the facilitator.
- Keep operation and maintenance in mind when designing/choosing a system.

9.2 Financial / System management group

This felt strongly that disconnection penalties did not work well and are very expensive to manage. Also, that local staff do not like disconnecting people within their communities. They had experience of pre-pay meters in Yap that are working well and felt that was a good way to progress. This group's list of questions can be found in Annex 1.

They also raised the issue of using women in the community as managers who could collect the revenue on days when they go to the local market to sell their produce and therefore have money.

What has/ has not worked well

Items that were considered to work well were individual systems management (rather than group fees structure) and the pre-pay meters as used in Yap. Items considered not to work well are complete government or community ownership and disconnection penalties, which entail complex and expensive logistics.

Key recommendations

- A government policy is required to guide the tariff model, and it must be flexible to allow the best model for the environment to be chosen.
- The tariff model needs to be based on partnerships: community/utility company/government and, if applicable, the private sector.
- Women are to be employed as managers.
- Pre-pay meters are to be used where acceptable.

9.3 Maintenance

The maintenance team found that there is no single optimum solution and a mixture may have the best result. They recommended that maintenance activities be contracted out to the private sector rather than being done by community groups; although the apprentice scheme works well in training technicians, they usually leave after their return of service is completed.

In terms of maintenance, 'Utility operated and maintained' is probably the best option if the utility has a local presence on an island or can easily access every island. Samoa is a good example of this, where the utility company has two people employed on every island, at least one of whom is an electrician. This enables them to respond quickly to defects and undertake routine maintenance at a cost-effective rate. However, in many cases the utility does not have this level of coverage for the model to be feasible.

What has/ has not worked well

Items that were considered to work well are: (a) the Samoan utility company, as there were two employees on each island, one of whom is an electrician; (b) government scholarships with three years' service on home island except that this meant a constant turn-over as the apprentices tend to move on after three years. Establishing a renewable energy service company (RESCO) was considered not to have worked well as it is would have been entirely dependent on government funding. The group tabulated their findings, as shown below.

Model	Worked	Has not worked	Recommendation
Selection and design			
Utility company	Systems well maintained Pre-pay meters	Manual tariff collection	Government support
Community owned	No land issues Good communication between management and consumers	Tariff not well calculated	Have a policy and framework for community-owned model
RESCO	System well-maintained		
Implementation and management			
Utility company	Has capacity and resources	Coverage of remote sites	Government needs to give subsidy Community services obliga-tions
Community owned	Quick response	Capacity to maintain	Training of locals
RESCO	Quick response	Profitability (tariffs)	Training of locals
Assessment of system success			
Utility company	Previous experience Record keeping	Access to remote sites	Establish island representa-tives
Community owned	Flexible system	Reliabiliy No spares	
RESCO	Previous experience Record keeping		

Key recommendations

- Contract out maintenance to the private sector, if possible.
- Train maintenance technicians in their own language, or failing that, with an interpreter.
- Use whatever means available for monitoring and communications. This could be the internet or GSM.
- Ensure that the legal status of ownership is clearly defined, not just a friendly agreement.

9.4 Social / Cultural group

This group found that project sustainability is a major factor, with funding and maintenance support being key to maintaining an operable system.

It was very clear that consultation with the community was vital and the point was raised that electric power may not actually be their prime concern; access to good clean water may be more beneficial for a range of reasons, including health and using time spent collecting water for more productive pursuits. A single communal power source for charging cell phones and radios may be all that is wanted in terms of power supply.

Early consultation is recommended so that fully fleshed-out proposals can be given to potential donors to ease the funding process. To avoid future disappointment, great care needs to be taken to ensure that communities are in no doubt that this is only a proposal and there is no guarantee of success.

The aims and benefits must be understood from day one so that the appropriate system can be designed and implemented. Aims to be considered are:

- Improved livelihoods;
- Climate change mitigation; and
- Capacity building.

A challenge to a successful system is affordability. It is important to ensure that supplying electricity to a community does not increase their poverty level by making them pay for something they cannot afford. Land issues and underground cabling is another challenge, particularly for grid systems where there are communal generation facilities; maintenance and security of the system; and shifting the mind set to a user-pays philosophy, retaining finance separate from traditional obligations and controlling the expectations of the systems.

What has/has not worked well

There has been more efficiency and productivity at home, but not enough understanding about the capacity and limitations of the system. More education and warning displays to indicate battery state of charge are needed amongst solar projects.

10 SYNOPSIS OF WORKING GROUP FINDINGS

The results of the discussions show that the participants clearly recognise that there is no optimum system or management method. This can vary for many reasons, including depending on budget, political choice on how to spend money, and community requirements and capabilities.

Key aspects that came through from all groups were compiled into a system questionnaire.

- What are the aims of the project i.e. what is it to achieve? This will drive the size and type of system.
- What are the consumers' needs and what are their aspirations in terms of the growth of the system?
- Have all parts of the community been included in consultations? This is vital, as everyone's needs are different.
- Who are the other stakeholders and what is their input into the project at all stages in the project cycle?
- What are the policies driving the system, including donor, government and council?
- Who is going to be the system owner – government, a utility company, a renewable energy service company (RESCO) or the community – and how is this going to be managed?
- How is the tariff to be set and what are its aims: to cover only ongoing maintenance or the complete system cost and system renewal at the end of its expected life?
- How and by whom is the revenue to be collected?
- How is revenue ring-fenced so that it remains available for the intended purposes?
- What are the technical constraints in terms of existing infrastructure and potential land issues?
- Who undertakes monitoring and maintenance of the system? (Getting the private sector involved was a preference but this is not always a feasible option.)
- Is the equipment of proven good quality and suitable for the harsh tropical conditions of the Pacific region?

It was felt that a standardised process was a much more effective way of getting the best solution, rather than having rigid guidelines as to system types and configurations. If there is a standardised and formal process, then all the correct questions will be asked and everyone will have their input into the process. It will then be up to the decision makers to make a fully informed decision on the managerial and technical system to be chosen.

With additional workshop time, this initial set of questions could have been refined further. It was considered that these questions are absolutely intrinsic to getting the optimum solution for an individual community and without them there is a severe danger of installing a poorly designed or constructed system that would cause dissatisfaction in the community. (The word system is here used in the sense of management, funding, maintenance, etc.)

It is further felt that there is potential for this questionnaire to be developed in order to make the best choices of ownership, system, maintenance, etc. This could be a master's research project, as it will need a level of academic rigour to ensure that all the correct questions are asked and that it details relevant and sensible solutions for every situation. Such a project could enhance this questionnaire but it is felt that it would be beneficial to use it even in its current format.

11 CONCLUSIONS

Off-grid solar installations are improving throughout the Pacific. Lessons are being learnt from experience, via general conversation and limited formal assessments. A formal assessment of projects three to five years after commissioning (when systemic faults become evident) would give considerably more knowledge to those instigating renewable energy projects and ensure that errors are not repeated.

The workshop presentations were considered very useful by the participants, who became more aware of the potential solutions that are available beyond the technologies that are widely used already. The small group discussions ensured that everyone was heard and could have their say, which brought out a lot of experience that may not otherwise have been heard.

A formalised systems approach to selecting, designing and installing renewable energy projects that could be used throughout the Pacific would help to ensure that projects are suited to their users' needs and produce the best result for available funding.

12 RECOMMENDATIONS

The recommendations arising from the work shop are listed below.

- Develop the list of questions into a more formal process for guiding the selection, design, implementation and ongoing management of renewable energy systems in the Pacific Islands and elsewhere.
- Deliver similar combined training and workshop events to develop and spread knowledge throughout the Pacific region.
- Encourage a university to engage in developing the existing questionnaire into a balanced scorecard or other approach to help decision makers make accurate decisions.
- Develop a review process to assess key installations after a period of between three and five years of operation to indicate any defects or frailties, and disseminate the assessment findings.
- Develop and maintain a register of renewable energy installations in the Pacific with details of current grid capacity to record the levels of renewable power systems that can be installed without modifications to the grids.

REFERENCES AND NOTES ON SOURCES

The desktop review was reliant upon numerous informal discussions and the industry contacts and experiences of the author. Where possible, the author has provided formal links to reports and resources. Where discussions were made, these have been referenced in text and a list of these provided below.

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DISCUSSIONS

The below parties were consulted during compilation and are acknowledged below.

Tonga Electric PowerLimited regarding off grid and hybrid power systems in Tonga

Clay Engineering/ Vanuatu battery-driven mini-grid

Tokelau Energy Department personnel regarding hybrid power systems

Fiji Electricity Authority on Nadarivatu Dam

Peter Konings on recent micro-grid installations in FSM

Gary Braasch regarding installation at Kiribati

Herbert Wade regarding installation at Marshall Island Hospital

ANNEX : WORKSHOP PARTICIPANTS

Mr Hubert Yamada	Federated States of Micronesia	Assistant Secretary, Energy Division
Ms Lydia Bobola	Papua New Guinea	Senior Project Officer
Mr Sione Foliaki	Samoa	Assistant CEO
Mr John Korinihona	Solomon Is	Director of Energy
Mr Kapuafe Lifuka	Tuvalu	Director of Energy
Mr Greg Decherong	Palau	Director of Energy, Palau Energy Office
Mr Wiliam Reiher	Republic of the Marshall Islands	Independent consultant
Mr Ravinesh Nand	Fiji	Deputy Director, Department of Energy
Mr Rupeni Mario	SPC North Pacific	North-REP Team Leader
Ms Koin Etuati	SPC Suva	Energy Policy Officer
Mr Tazil Mohammed	Fiji	Senior Works Engineer, Clay Energy
Mr Atul Raturi	USP	Associate Professor
Mr Gabor Sasvari	GIZ	GIZ Adviser, Climate Change and Food Security
Mr Craig Bohm Management	GIZ	GIZ Adviser, Climate Change, Fisheries and Coastal
Mr Tony Pearson GIZ	GIZ Consultant	
Ms Katerina Syngellakis	GIZ	GIZ Advisor, Energy

ANNEX 1: QUESTIONS FOR DISCUSSION FROM WORKSHOP GROUPS

As outlined in section 9.1 above, a key focus of the workshop groups was to develop questions to guide the process of community selection, system design and financial management. The sections below contain these questions.

A1. Selection of Community

The questions below are to guide the selection of the community.

Size of grant

How much money is there to spend? If there is not enough money to meet needs then further financing should be sought.

Area of priority

Are there any existing priorities for first allocations?

National policies

Is there an existing policy on renewable installations?

Is the priority to get basic access for as many as possible or to get a good quality, reliable supply to selected communities?

Is the policy needs-based or growth–based?

Community desire

Has the community expressed the need for a power system and asked for one?

Community application

What facilitation body is required to put together a project proposal for the community? Could be a non-governmental organisation, or provincial office of the department of energy.

Can the facilitator go to the community for one or two days to gain insight into the requirements of women, men, youth, the elderly and community groups/services, e.g. church, school, medical offices?

What are the immediate needs?

What are the aspirations, i.e. what would they like power for?

___

What can they afford?

___

What is their preferred payment option?

___

Will sufficient power stimulate income growth?

___

What are the geographical constraints?

___

Are there any land ownership constraints concerning equipment and cabling?

___

Resources

Is there a current system and if so what is it and what capacity does it have?

___

How much kerosene is used (in litres and price)?

___

Solar lanterns, solar home systems, diesel grid, existing hybrid grid?

___

Is this to replace the existing system or enhance it?

___

What are the enhancement requirements?

___

What resources are available?

___

Solar

Are there sunny spots by each house?

___

Is there a suitable sunny spot for a combined installation?

___

Are there solar radiation figures in the area, or experience?

___

Wind

Is there a suitable spot to install a wind turbine?

___

Are there any data on wind speeds?

____

Hydro

Is there a suitable source of water for a mini-hydro?

____

Quantity of water flow: how long does it take to fill a two-litre bucket?

____

Height of drop (altitude): what is the height from where you can collect the water to where you place it back into the stream?

____

Other requirements

What are the quantifiable requirements for individual households? Are these the same or variable? Do these vary throughout the year or are they constant?

____

What is the kWhr figure required? What is kWh usage for the whole community i.e. all households and community usage? Does this vary throughout the year or is it constant?

____

Payments

What are the preferred methods of payment?

pre-pay meter (phone or card from local shop top-up)

collection by utility

payment at post office/shop

collection by community

collection by a RESCO (renewable energy service company)

other

Appraisal and Final Decision of Community Selection

Who decides on final recipients: donor, government or council?

____

At this point the facilitator would pass the application, with some of their own recommendations, to the organisation carrying out the selection and the awarding of funds.

A.2 Design process

Once a selection process has been completed and the funds awarded, the design process can be started. This may need to be done prior to granting the award in order to get a full costing, but care will need to be taken that the donor does not dictate their own requirements, making any previous design useless. The design process will need to include the following items:

a) the standards the system being designed to;

b) the resources available;

c) the immediate level of power needed;

d) the potential levels of power desired or likely to grow to;

e) the cost of alternative systems;

f) how the system is going to be managed and by whom;

g) the maintenance capability available to maintain alternative systems;

h) any geographical constraints to alternative systems (technical, maintenance and managerial);

i) any cultural constraints to alternative systems (technical, maintenance and managerial);

j) what equipment has been proven to withstand the conditions; and

k) remoteness and cost of replacing equipment.

The design process should include an assessment of potential risks. This includes identifying:

a) potential points of failure (technical and governance) and mitigation procedures; and

b) the availability of:
- maintenance staff;
- spares;
- expert assistance; and
- remote monitoring.

A.3 Financial Management and Maintenance

How much are the beneficiaries paying for the current service (electrical or otherwise)?

___

What does the current service comprise?

___

How are the beneficiaries paying?

___

- by consumption
- flat fee
- a combination of these

How is the fee collected/paid?

___

- pre-pay meter
- payment at post office
- collection by utility company
- collection by a RESCO (renewable energy service company)
- collection by the community

Who is going to own the system?

What is the community preference for paying?

- by consumption
- flat fee
- a combination of these

How would they like to pay?

- pre-pay meter
- payment at post office
- collection by utility
- collection by a RESCO
- collection by community

What are beneficiaries willing to pay for?

- existing level of service
- improved level of service

What do they want from an enhanced level of service?

___

How much are they willing to pay for existing level of service?

___

How much are they willing to pay the enhanced level of service identified above?

___

What are government guides or constraints on the tariff model?

___

What are the donor's guides or constraints on the tariff model?

___

Does the government want to distance itself from management of the system?

___

Do the clients want the government to distance themselves from management of the system?

___

What are the clients' views on system ownership, management and maintenance?

Is there or could there be a RESCO?

Does the utility company have a presence in the locality?

Is the utility experienced and capable of working in the area?

What are the utility's views on operating/maintaining the system?

Is there a private sector company available in the area that could cope?

Is there enough work to facilitate the development of a private/public works company in the area?

What special considerations are there, i.e. working in remote areas?

What support is available for maintenance and system managers?

What are the women's views on power management?

Can women be used to collect revenue at the markets after selling their produce?

Can collection be incentivised with a commission on tariffs collected?

Is the whole process – from selection to implementation and ongoing management – transparent?

acsepacific
info@acsepacific.org
www.acsepacific.org

EU-GIZ ACSE
Module 2, Level 3, Plaza 1
Downtown Boulevard
33 Ellery St, Suva
P.O. Box 14041
Suva, Fiji Islands.
T (+679) 3305982 or 3305983