Grid Connected Photovoltaic Electricity Supply on Tokelau

Part 1

HARDWARE SPECIFICATION

FEASIBILITY STUDY REPORT

August 2003

Abstract: The present study evaluates technical, economical, financial and institutional feasibility of grid connected photovoltaic power generation for the islands of Tokelau. It compares various options and identifies a solution that shows the best Economic Rate of Return. It also defines the hardware requirements for the system configuration preferred by Tokelau Power Systems (TPS). Under this assignment two additional documents have been produced: An Environmental Impact Assessment (EIA) and a Tender Document.

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Abbreviations and Acronyms

ADB	Asian Development Bank
AIEC	Average Incremental Economic Cost
CDCF	Community Development Carbon Fund
CDM	Clean Development Mechanism
CERUPT	Certified Emission Reduction Unit Procurement Tender
DTFS	Daytime Fuel Saving Unit
DBU	Dispatchable Battery Unit
DOD	Depth of Discharge
DSM	Demand Side Mangement
EIA	Environmental Impact Assessment
EIRR	Economic Internal Rate of Return
ER	Electricity Retailer
FIRR	Financial Internal Rate of Return
GM	General Manager
GEF	Global Environmental Facility
I_{sc}	Short Circuit Current
IBRD	International Bank for Reconstruction and Development
ICB	International Competitive Bidding
IEC	International Electrotechnical Commission
IEE	Initial Environmental Examination
IPP	Independent Power Producer
LA	Lead-Acid (Battery)
LCB	Local Competitive Bidding
LEPC	Levelized Electricity Production Cost
LOLP	Loss of Load Probability
LRMC	Long-run Marginal Cost
MIS	Management Information System
NIWA	National Institute for Water and Atmosphere
NGO	Non-Governmental Organisation
NPV	Net Present Value
PO	Plant Operator
PRA	Participatory Rural Appraisal
PV	Photo-Voltaic
RE	Renewable Energy
RoW	Right-of-Way
SFC	Specific Fuel Consumption
SFS	Specific Fuel Saving
SPC	Secretariat of the Pacific Community
SEI	Significant Environmental Impact
TA	Technical Assistance
TPS	Tokelau Power System
ToR	Terms of Reference
UNDP	United Nations Development Program
USP	University of the South Pacific

Executive Summary

The objective of this study commissioned by UNDP/UNESCO Apia is to determine the viability of different solar electrification options for power supply on the three atolls of Tokelau. The report presented here is Part 1 of a series of three documents and is mainly concerned with developing an adequate and feasible configuration of grid-connected solar-based electrification. At present grid-connected electricity supply on Tokelau is provided via diesel generators feeding distribution grids that have been rehabilitated under the ongoing Tokelau Power Project financed by NZAID. Diesel generation has been fraught with a number of technical problems and will continue to be a costly way to generate power in an isolated location such as Tokelau. Supply cost are estimated to be in the vicinity of NZ$ 1.5 per KWh. The supply chain for fuel, consumables and spare parts is long and fuel handling and storage poses considerable environmental risks.

Currently, electricity demand is dominated by household consumption. Institutional consumers such as schools, hospitals and administration are the second significant category. Daily consumption varies between 400 and 450 KWh with peak loads in the order of 30 – 40 KW. Refrigeration load represents more than 50 % of the current demand; lighting follows with approx 15 %. The balance is consumed by a variety of household appliances including washing machines, irons, frying pans, entertainment, computers, power tools and water kettles. Although historic demand data are sketchy, it seems that demand has increased over time; not so much due to population growth but through an ever-increasing variety of household appliances brought to the islands.

With approx 120- 150 KWh per month electricity demand per household is comparatively high in Tokelau. Subsidized tariffs that cover only approx 20 % of supply cost, the lack of energy conservation campaigns and an urban lifestyle of the residents of Tokelau explain the electricity demand pattern on the islands.

Solar energy is considered to be the most attractive renewable energy source for grid connected electricity supply in Tokelau. It has the potential to gradually replace diesel-based generation until full solar-based supply has been achieved on all three atolls. This study compares three options to start replacement of diesel generation:

1. Conversion of existing solar facilities of Teletok and USP to grid supply
2. Grid connected day-time fuel saving units
3. Dispatchable battery buffered unit

Option 1 has been ruled out as there is very little surplus generation that could be fed into the grid. Also, this option would probably meet resistance from the current owner/operators of the units. Option 2 clearly shows lowest cost per KWh solar electricity generated. However, this solution would only generate low quality energy. I.e. the benefits of this solution would mainly accrue due to the replacement of diesel fuel. Option 3 shows higher electricity production cost, but yields a better Internal Economic Rate of Return (IERR approx 6%) if the installation is used as a back-up supply for the hospital and grid support in peak situations. In case the unit is only dispatched as general grid support as suggested by TPS the IERR would be approx 4%. In addition all solar options have non-quantifiable benefits through diversification of energy sources for power generation and increased security of supply from reduced dependence on foreign supplies of fuel.

Main Conclusions and Recommendations

From the consultants point of view it would be recommendable to procure and install a 10 KW battery buffered solar unit at the hospital in Fanuafala, on Fakaofo. The unit would not only provide reliable 24 hours supply for an essential electricity consumer (the hospital has no back-up at the moment) but also feed any surplus power into the grid. In addition, the unit would yield data on solar irradiation and performance of the power plant that will be valuable if not indispensable for the planned future expansion and the possible design of a project of 100% solar electrification of the atolls.

After review of the consultant's draft report, TPS expressed a preference for the battery buffered unit to generally support the grid operation, in particular during peak hours. Such a unit would not result in cross-sectorial benefits (as the hospital unit would) and would only be able to provide back-up power for very short time periods in case of diesel generator failure. Maximum currents that can be handled by inverter and battery bank will also limit grid supply in battery bank stand-alone mode. The unit could, however, defer operation of the second generator during peak hours and thus assist rendering the overall operation of the Fakaofo system more reliable if operated in an efficient manner.

It is recommended that TPS implement a program of consumer education and awareness that aims at reducing electricity consumption. Such a program should be accompanied by a gradual adjustment of tariffs, with the aim to eventually recover at least operating cost of supply. It is believed that these measures are at least as critical for the long-term sustainability of Tokelau's electricity supply than the accelerated use of renewable energy sources.

It is further recommended to market the long-term project of 100% solar electrification to possible international sponsors. The theme of such a funds raising activity could be a nation decides to go 100 % solar in order to demonstrate that international efforts are required to combat greenhouse gas emissions, global warming and sea level rise. After all Tokelau would be one of the first nations on earth to disappear when significant rises of the sea level occur. UNDP/UNESCO could lead the fundraising campaign and use a trust fund to pool contribution from sponsors of the "Tokelau goes Solar" Project.

This report includes a specification of the hardware components required to establish the pilot project as a first step to full solar electrification of Tokelau. It is recommended to procure the supply, installation and operator training for the facility in a competitive tender that leaves some flexibility to the supplier to optimise the system.

1 Introduction

1.1 Background and Objectives

Like most Pacific Island Countries, Tokelau depends on imported petroleum for the major part of its electricity generation and commercial energy supply. What distinguishes Tokelau from other South Pacific Nations is an exceptionally long and expensive supply chain for all petroleum products. This supply chain is also extremely vulnerable to both interruptions and potential environmental hazards that stem from fuel transport, transfer, storage and utilization.

In a move towards a more sustainable energy supply the Government of Tokelau in cooperation with the Government of New Zealand, the Government of France, UNDP-Apia and UNESCO-Apia, has decided to prepare and implement a project "Grid Connected Photovoltaic Electricity Supply on Tokelau". First attempts to harness Tokelau's excellent solar energy potential date back to 1984. Since 1998, the telecommunication facilities on the three atolls as well as the communication facility of the University of the South Pacific (USPnet) station have been successfully powered by stand-alone photovoltaic generators.

Supported by NZAID, the diesel based power generation, transmission and distribution systems have been upgraded on all three atolls, a project that has been nearly finalized on both Atafu and Nukonunu and will presumably be fully commissioned on Fakaofo in 2003. In 1999/2000 a feasibility study was undertaken that investigated various power supply options for Tokelau. The study recommended upgrading of the diesel electrification as the least cost option and confirmed the electrification project already in progress. In 2001 further investigations into possibilities to support the diesel systems with solar power resulted in the recommendation to install on each atoll a limited PV generation capacity without batteries. In 2002 it was decided to expand the investigation further and assess the possibility to integrate the existing PV capacity of the Teletok and USP facilities as grid connected generators.

Against this background the immediate objective of the project presented here is to initiate the utilization of the country's solar energy potential for grid-connected power generation as part of Tokelau's long-term strategy to working towards sustainable energy self-sufficiency.[1] Any project design conceived under the available budget must therefore consider a future expansion of the renewable energy supply, possibly to a complete renewable energy based electrification of the islands. The "vision" of Tokelau goes Solar" which has been discussed with the Faipule for Energy and other stakeholders in Tokelau does not only hold the promise of doing something extraordinary in Tokelau, it is also technically feasible and most probably fundable.

[1] UNDP Project Document Final Version 2003

1.2 Methodology

After reviewing relevant background material the consultant travelled to Samoa and Tokelau in order to collect primary data and consult with the project stakeholders. During the mission, inception and debriefing meetings were held with the client, and Government representatives. The field trip only allowed site surveys in Fakaofo. The boat schedule that was originally agreed upon with the Government of Tokelau was changed on short notice and as a consequence, Atafu and Nukunonu could not be visited.[2] Consultations were however possible with the general managers of both Teletok and the Tokelau Power System (TPS) utility as well as with the resident PB Power electrician. A comprehensive household survey that has been undertaken recently by the General Manger of the power utility provided the additional data and an inventory of existing electric appliances. In addition the GM also made a status paper (from February 2003) on the TPS available to the consultant.

All data obtained on the island were crosschecked with available reports and project documents. In particular the power utilities generation and billing records were used to verify demand and consumption data, payment behaviour and generation data.

1.3 The Report

Work under the Tokelau Sustainable Energy Consultancy comprises three distinguished investigations together with respective reporting[3]:

1. Specification of Hardware for Tokelau PV Project
2. EIA for Diesel and PV Project
3. Tender Management for Selected Hardware

The ToR (Annex 6) require this Hardware Specification Report be organised into three main parts, i.e Part A Feasibility Study, Part B Description of Optimal Supply Option and Part C Hardware Specification Report. It was however agreed with the client to integrate all three parts into one report. Accordingly, the present report (Part I) is divided into sections as follows:

Section 1: <u>Introduction</u>: This section includes a description of the background and objectives of the Study, the methodology and the work program and a guide through the Final Report.

Section 2: <u>Electricity in Tokelau: Current Situation:</u> This section includes a brief analysis of Tokelau's electricity sector and describes the existing power supply system and past efforts in electrification. Emphasis is given to the characteristics of the current supply system including generation and network.

Section 3: <u>Electricity Demand on Tokelau:</u> This section analyses current and future demand for peak power and energy. It reviews current energy use pattern on the islands and assesses future demand for electricity. It also contains

[2] A status report prepared after a visit by the General Manager of the Tokelau Power System in March 2003 provided information on the two islands that could not be visited
[3] See Terms of Reference and Definition of Outputs in Annex 1

the development of various demand scenarios with and without industrial loads. The consumer's preparedness to pay for improved electricity supply is also assessed.

Section 4: Problem Analysis. Includes an analysis of problems and bottlenecks encountered in supplying current and future demand identified in section 3. The current supply system is analyzed with respect to technical characteristics; constraints and risks that have to be anticipated when operating certain technologies in locations such as Tokelau are also looked into.

Section 5: Technical Options. This section includes a feasibility analysis of the technical options that have been identified. The analysis covers the option to integrate the power supply of the existing telecommunication facilities into the general grid and the option of additional PV capacity.

Section 6: Financial and Economic Analysis. This section outlines the project cost estimates, and determines levelized energy cost for the options under consideration. The least cost alternative to meet the identified demand profiles is determined. Based on the financial analysis economic costs and benefits are compared and the Internal Economic Rates of Return are determined for the alternatives.

Section 7: Risk Analysis: Risk and assumptions of the various project options are discussed here together with recommendations for risk management and mitigation. The results of the stakeholder consultations are also presented together with an analysis of the impacts of various technical options for electrification.

Section 8: Optimal Supply and Recommended Strategy: This section discusses the options described and analyzed in the previous sections and develops a project design together with a plan to implement the recommended solution. It also assesses required skills together with technical assistance and training requirements. The section also includes a discussion of how to finance a long-term project of converting Tokelau's electricity supply to 100 % solar energy.

Section 9: Hardware Specification: Following from section 8 the hardware that will be required to implement the project as described in the previous sections is briefly specified. This section forms the basis of the technical tender document (Part III of the report).

2 Electricity Supply in Tokelau

2.1 General Description

The coral atolls of Tokelau (Atafu, Nukunonu and Fakaofo) are located approximately half way between New Zealand and Hawaii, approx 400 km north of Samoa at a latitude of 9 degrees South of the equator. In the absence of an airport or airstrip, the territory can be considered as one of the remotest locations in the South Pacific[4]. Since 1925 Tokelau has been under the administration of New Zealand. The Tokelau Act of 1948 and various amendments enacted by the New Zealand Government are still the basis of Tokelau's legislative, administrative and financial system.[5] Recent moves towards self-governing and self-determination has resultant in relocating major parts of the administration to Tokelau. However, a skeleton administrative presence is maintained in Apia, Samoa where the Director of the Council of Faipule[6] resides. Although today mostly self-governing, there is still a strong affiliation with New Zealand. Tokelauans use the NZ $ and are citizens of New Zealand. Total population seems to have stabilized at approx 1500, with 500 inhabitants on each atoll. Approx 6000 Tokelauans live abroad primarily in NZ.

On the atolls, Tokelauans live in modern concrete or brick houses of good standards. Private vehicles do not exist on the islands; but every family owns at least one small boat, typically powered by a 25 HP outboard engine. There is no piped water supply. The villagers collect rainwater in tanks that are normally sufficient to cover drinking water needs. There are also operational wells that tap the fresh water lenses of the atolls but their use is limited to times of draught. Each atoll has a school and a hospital, there are also churches and town halls that serve as meeting places.

2.2 History of Electricity Supply

There is no detailed record of Tokelau's power supply system, but it appears that some form of diesel-based generation has been available since the 70ies. Various reports suggest that the diesel-based power supply has always been fraught with numerous problems including fuel shortage, overload of generators, premature break down of technical equipment, and difficulties to generate sufficient revenue from consumers to recover at least operating cost. Although historical data on loads and electricity consumption are sketchy, it can be assumed that in the 80ies and 90ies Tokelau already had a comparatively high load per household characterized by lighting, refrigeration/freezing and numerous other electrical appliances such as fans, washing machines and electronic entertainment.

In 1997 Design Power of New Zealand developed a Master Plan for the rehabilitation of the then unreliable electricity supply. This plan discarded solar power as economically not viable and recommended an upgrading of the diesel systems through the installation of new generation capacity (three generators on each atoll) and a reinforcement of the distribution system using 11 KV cables as the backbone distribution.

[4] E.g. the boat trip Tokelau-Samoa takes between 24-30 hours each way.
[5] Tokelauans were granted NZ citizenship in 1948
[6] Council of the Ministers

Work to replace the old Lister diesels that had been in operation prior to 1996 began in 1997 with the installation of 4 Cummins/Onan generator sets (one each on Atafu and Nukunonu and two on Fakaofo). Subsequently, the ongoing upgrading project was started that included the installation of 11 KV cables and transformers, the relocation of the power houses away from residential areas and the supply of additional generation capacity. Today this upgrading work has been nearly finalized[7] on Atafu and Nukunonu with commissioning of Fakaofo expected in 2003.

In parallel to the upgrading of the general village supply, additional generation capacity was installed to power a fish freezing and chilling unit that on each atoll. These units apparently installed in 2001 consist of 6 cylinder Iveco engines fitted with 60 KVA generators. In 1998 Teletok, the national telecommunication service provider installed 5.5 KW PV generation capacity with battery storage and inverters to make the telecommunication systems independent from the unreliable public power supply. The USPnet remote learning station followed with the installation of an independent 6 KW PV power supply system on Atafu in 2000.

2.3 Current Situation Generation

At the time of the field investigations in April 2003, the ongoing project of refurbishing Tokelau's public electricity supply was still ongoing. The company contracted by NZAID, PB Power still had a technician on site in Fakaofo. The systems on the other atolls also seem to require major work on the generation site before commissioning and hand over to the Government can take place. The following table summarizes the situation on the three atolls.

While power is currently supplied on all three atolls reliability is poor and breakdowns and outages have to be expected to occur.

Table 1: Generation at Fakaofo

Unit	Location	Status
1 Iveco 50 KW	Located at fish freezer, Fale	Serviceable, requires maintenance, currently used for base-load in Fale
1 Cummins 40 KW	At old Fale power house	Serviceable, poor state of repair, control system malfunctioning, shut down during field visit
1 Cummins 40 KW	Stored in packaging at Fale	Awaiting installation in new power house
1 Cummins 30 KW	At old Fenuafala power house	Serviceable, supplies Fenuafala, requires maintenance

[7] The February 2003 status report issued by the Tokelau Power Systems General Manager mentioned various items that are outstanding at both the Nukunonu and Atafu systems

Table 2: Generation at Atafu

Unit	**Location**	**Status**
1 Perkins 48 KW	New Powerhouse	Serviceable, poor state of maintenance, oil leak at crankshaft bearing, no spare parts available
1 Cummins 40 KW	New Powerhouse	Serviceable, good conditions but unable to synchronize with Perkins
1 Cummins 30 KW	Stored at the jetty	Not serviceable, not installed, and awaiting overhaul

Table 3: Generation at Nukunonu

Unit	**Location**	**Status**
1 Iveco 50 KW	New Powerhouse	Not serviceable, poor state of maintenance, unable to synchronize with the Cummins generator
1 Cummins 30 KW	New Powerhouse	Not serviceable, poor state of maintenance, stripped for spare parts
1 Cummins 40 KW	New Powerhouse	Working but in poor state of repair, no protection, new switchboard not yet installed

Unfortunately, there is no standardisation of generation equipment. Maintenance, repair and spare part management – difficult enough in a remote location such as Tokelau - are further complicated by the variety of generator sets in use. There are three different makes that do not share any common parts. Even the Cummins/Onan units are not identical as the 3 older units have 24 V control voltage while the new 40 DG CA types use a 12-volt control system. It also appears that the generator sets have not been specified for operation in a corrosive marine environment. The IVECO sets have been originally supplied as back-up generators for the fish freezing units and do not seem to be designed for base load or permanent operation. In Fale, the unit is however used to supply the base load as the Cummins set located in the old powerhouse has control problems. The General Manager's status report (from Feburary 2003) suggests that generators are generally in a poor state of maintenance, an observation that is shared by the consultant.

At present one single generator is able to supply the load in each system. In order to cope with high start-up currents drawn by the substantial refrigeration and domestic freezing load coming on simultaneously, the operators energize the three phases separately. These high start up currents initially drawn by the compressor motors seem to be responsible for frequency and voltage fluctuations that are typically observed during the first half hour after start-up. The systems stabilize after 20 – 30 minutes of operation. The consultant measured voltage, frequency and power factor on the Fala system and the values after an hour of operation suggest that power quality was within acceptable limits (50.2 +/- 0.3, Hz, 231 - 12 V, 0.75+/- 0.1 power factor).

2.4 Current Situation Distribution

The distribution system has been completely refurbished in the framework of the ongoing rehabilitation project. All distribution is underground with pillar-boxes being the access points. The most significant difference as compared to the old system is the use of 11 KV as a backbone supply instead of 415 V. Although the system becomes more complex through the use of transformers, the high voltage lines together with the reinforcement of the low voltage distribution (16 mm2 cabling to all pillar boxes) will enable the system to cope with significant increases in load. Also, three phases are now carried to all pillar-boxes instead of geographically dividing the supply area and bringing only one phase to the respective subdivision.

As far as solar generation is concerned any pillar-box provides a potential access point for low voltage PV power that is fed into the grid.

At the time of the site visits, only the Atafu distribution system had been fully commissioned. On Fakaofo and Nukunonu, only the low voltage parts of the new distribution systems have been taken into operation. The 11 KV cable and transformers have either not yet been fully installed or are awaiting commissioning. In general the distribution system has been well designed and will be able to cope with increasing demand. No problems are expected with PV interconnections. Any of the newly established pillar-boxes provide access to the three phases of the system. With 16mm2 conductors any of these access points could be used to connect substantial generation capacity without overloading the conductors.

3 Electricity Demand On Tokelau

In recent studies current electricity demand has been described and future demand has been projected for the purpose of designing the ongoing project of upgrading the diesel powered electricity system. PB Power has further developed the Designpower[8] estimates of 1997. In addition PB Power[9] have developed various demand scenarios in order to determine a cost effective PV project of limited size. Additional data have been collected in the framework of a recent household survey performed by the General Manager of the Tokelau Power System. In the following these information are considered together with the consultant's own investigations.

3.1 Current Demand

At present, Tokelau's households consume approx 90 % of the electricity supplied. For a remote island in the South Pacific, average monthly consumption is extraordinarily high. Most households consume well above 100 KWh per month, similar to the consumption pattern of a grid-connected household in New Zealand. For comparison, a household on the Island of Apolima in Samoa, typically consumes approx 30 KWh per month.

3.1.1 Recent Estimates

It is not possible to establish accurate figures of current electricity demand on the basis of power station logs and/or billing records[10]. The former do not include certain consumers (church, town halls) that are supplied without metering. The power station logs on the other hand do not include records of KWh send-out or system peak power (KW peak) supplied during operating periods. Daily accurate fuel consumption records are not available either. Until today all demand estimates are therefore based on Designpower's assumptions that are summarized below:

Table 4: Demand Estimates Designpower

Consumer	Units	KWh/unit/day	KWh/day
Household	85	4	340
School	1	40	40
Hospital	1	40	40
Total			**420**

In PB Power's most recent base case estimate[11] the average daily consumption per consumer/household has been increased to 4.54 KWh per day, uniformly for all three atolls. Assuming 100 connections per system the total average energy consumption would then be 454 KWh per day or 168,845 KWh/p.a. The review projects three other scenarios whose parameters and results are summarizes in the table below. These projections have not been developed for technical design purposes but to estimate revenue requirements for TPS. Nevertheless these estimates are considered as a starting point for more detailed demand projections.

[8] Designpower "Draft Masterplan for Tokelau Power System" 1997
[9] PB Power "*Grid Connected PV Electrcity Supply*", 20 December 2001
[10] The Designpower report of 1997 has already mentioned the lack of such data, but until now no effort has been made to establish meaningful power station records.
[11] PB Power "*Tokelau Power System Tariff Review*" June 2002

Table 5: PB Power Demand Estimates for 100 consumers per atoll

Scenario	Assumptions	Daily Energy KWh	Annual Energy KWh	Annual Fuel Use Liters
1	24 h no fish freezers	454	165,845	63,610
2	24 h with fish freezers	561	204,806	73,886
3	18 h no freezers	439	160,107	57,013
4	12 h no freezers	396	144,529	48,712

The above estimates and scenarios require some qualification. As photovoltaic generation has very high marginal capacity cost and short run marginal generation cost that approach zero, diligence is required in demand forecasts to avoid costly overcapacity. In order to reassess current and future peak power and energy demand, three consumer categories have been distinguished:

- Households
- Institutions (schools, hospitals, administration, Teletok, USPnet)
- Industrial loads (fish freezing)

3.1.2 Household Demand

Currently electricity is only supplied intermittently with slightly different schedules for the three islands. In general, power is switched on around 7.00 – 8.00 in the morning until 3 or 4 PM. The evening supply starts around 5.30 pm and ends at around 11 or 12 pm adding to approx 13 hours of daily supply. On special occasions such as holidays the schedule can be changed and supply up to 24 hours is possible.

Table 6 Household Ownership of Electrical Appliances

Item	Ownership		
	Average W	% Atafu	% Fakaofo
Incandescent Lights	60	15.5%	14.3%
Fluorescent Lights	160	98.8%	96.4%
TV/VCR	120	54.8%	39.3%
Stereo	40	21.4%	35.7%
Fan	40	97.6%	17.9%
Computer	50	11.9%	17.9%
Printer	40	4.8%	10.7%
Play Station	10	2.4%	10.7%
El Guitar	50	1.2%	3.6%
Amplifier	500	1.2%	3.6%
Fridge	130	23.8%	35.7%
Freezer	230	90.5%	75.0%
Sandwich Maker	700	19.1%	21.4%
El Frying Pan	800	14.3%	21.4%
Microwave	300	1.2%	3.6%
Rice Cooker	500	2.4%	35.7%
Stove	1000	3.6%	7.1%
Iron	1350	9.5%	21.4%
Washing maschine	80	63.1%	39.3%
Water Cooler	200	4.8%	7.1%
Kettle	2200	69.1%	32.1%
Battery Charger	40	1.2%	0.0%
Power Tool	150	88.1%	71.4%

At presents, regular loads consist mainly of refrigeration (fridges and freezers), lighting, water heating, cooking, washing machines and entertainment. The most important load clearly results from widespread use of freezers and fridges. Every household owns at least one unit with big chest freezers drawing between 200 and 280 Watts being the most popular equipment. In addition there is occasional use of power tools (drills, jig saws, grinders).

A recent household survey performed by the General Manager reveals that households typically own a large variety of electric appliances. It appears that the ongoing up-grading of the system with the promise of a more reliable and perhaps continuous 24 hour supply has provided an incentive to acquire additional appliances. Recent estimates have only considered refrigeration, lights, TV/VCR and stereos as typical loads.[12] Table 6 shows ownership of electrical appliances and their power consumption for the two islands surveyed by TPS's General Manager.

The widespread ownership of electrical appliances has lead to a comparatively high system load that is dominated by refrigeration. The prominent role of refrigeration also leads to an unusual peaking behavior in the current operating mode (13 hours supply).

[12] Designpower 1997, PB Power 2001

Unlike the average rural electrification scheme that shows a pronounced evening peak due to lighting and entertainment, the TPS system peaks immediately when the system has been energized after the regular breaks. The reason is that the thermostats of all fridges and freezers sense low temperature and switch the compressors on immediately. I.e. refrigeration load has a diversity of 100 % for quite some time. Only after the set temperatures have been reached the normal diversity of these units (ca 50 %) starts to set in. A 24 hours supply would avoid this characteristic with the refrigeration loads being evenly distributed at a 50 % diversity. 24 hour supply would at the current consumption pattern only add approx 12 – 15 % more electricity supplied. Average loads would be reduced accordingly.

The following table 7 summarizes the results of a load and energy assessment that has been based on the household surveys performed on Fakaofo and Atafu. Nukononu results have been deducted from the Atafu survey, as there was no survey for this island. The full summary tables are attached as Annex 4.

Table 7: Results of Household Survey 2003 Energy and Loads (Base Case)

Location/case	**Fridge**	**Freezer**	**Lights**	**Others**	**Total**	**Peak Load**
	KWh/d					KW
Fakaofo 13 hours	48.6	189.1	46.6	156.6	440.9	37.3
Fakaofo 24 hours	51.8	201.7	67.1	183.1	503.7	32.4
Atafu 13 hours	29.3	196.7	33.1	174.6	433.6	36.4
Atafu 24 hours	31.2	209.8	47.6	204.1	492.7	31.9
Nukunonu 13 hours	26.3	177	29.8	157.1	390.2	34.5
Nukunonu 24 hours	28.1	188.8	42.8	183.7	443.5	28.6

On the basis of the table above the annual energy consumed in the TPS systems is in the order of 136-176 MWh making allowance for approx 200 hours of unsupplied demand due to breakdowns.

3.1.3 Institutional Demand

Institutional consumers on Tokelau include Government administration, schools, hospitals, the USP station and Teletok. Government offices mainly have lights and low powered office equipment. They need power mainly during daytime and on weekdays. Schools are also daytime consumers; they also have longer periods of zero demand (holidays). The electricity consumption of the hospitals is more evenly distributed over the day, they also operate lights when there are in-patients. Teletok is a significant consumer in Fakaofo where its head office is located. The two other Teletok stations consume significantly less electricity as their communications equipment is supplied by their solar systems.

Peak load contributions from institutional consumers are less than 4 KW in Fakaofo and approx 2.5 KW in Atafu and Nukononu. In terms of energy consumption the institutional consumers do not show a significant difference between 13 and 24 hours supply. Most of the electricity is consumed during office hours, i.e. during the time that is already covered by the 13 hours supply.

Table 8 below summarizes the current consumption pattern of the institutional sector in Tokelau.

Location		Fakaofo		Atafu		Nukononu	
Consumer	**Hours/d**	**Installed W**	**KWh/d**	**Installed W**	**KWh/d**	**Installed W**	**KWh/d**
Administration	3	1000	3	800	2.4	500	1.5
School	8	850	6.8	850	6.8	850	6.8
Hospital	12	2600	14.2	2600	10.2	3600	10
Teletok	5	1400	7	400	2	400	2
Total Institutions		3850	31	2650	21.4	2350	20.5

3.1.4 Industrial Demand

Industrial demand is expected from the fish freezer/chiller units that have been supplied to Fakaofo and Atafu under a fisheries project financed under the American Treaty Fund. This project also included the supply of independent power generators for the fish freezers (IVECO Generators) and two long-lining boats for both Fakaofo and Nukononu. The idea of the project is to create an income generating export industry in Tokelau.

Obviously, electricity demand will only materialize once a successful and sustainable export fishing operation has been established. The project is supposed to target Albacore and Yellofin tuna together with associated pelagic species. The Albacore would have to be marketed to the canneries in American Samoa, as it is the closest and cheapest market to access. This could be done direct or through an agent in Samoa (one of the existing tuna companies there). The other species will be more difficult to sell at a good price, as the markets require these species fresh. Unfortunately, Tokelau's isolation and lack of transport links dictate that all fish will need to be frozen for transport and marketing.

The next step in the fishing project will be trials to be conducted with SPC support at the earliest in 2004.[13] These trials will use the existing twin hull long lining boats and the existing freezers. While these trials will help to establish the economics of the fishing venture a number of limiting factors militate against the viability of the project. One of the limiting factors is that the M/V Tokelau only has a 40 m3 freezer hold. I.e. maximum carrying capacity is 20 t of fish per trip. The freezers at each of the two complexes (blast and storage combined) can hold 40 m3. In addition, the schedule of MV Tokelau does not easily accommodate regular trips to American Samoa. This mismatch between transport and holding capacity would lead to extended periods of storage in Tokelau. The other factor is the cost penalty that would be incurred through multiple handling of the catch. While it is beyond the scope of this study to assess the viability of an export fishing operation in Tokelau, the chances for a commercially attractive operation appear to be small.

At present neither the fishing boats nor the freezer units are in use. According to the GM of TPS the blast freezer unit in Fakaofo is no longer operational. While the original design of the fisheries project made provisions for isolated independent power supply for the freezer units, the TPS rehabilitation foresees the integration of the fisheries generators into the village supply. In fact the IVECO generator on Nukononu has already been re-located to the new powerhouse, i.e. the freezer unit can no longer be independently supplied.

[13] Personal communication with Lindsay Chapman, fisheries expert SPC

PB Power has estimated the load of the fishing facilities as depicted in table 9.

Table 9 Load Fish Freezer

Equipment	**Load estimated PB Power (KW)**	**KWh/week**
Blast Freezer	9	160
Chiller/Freezer	9	450
Processing Area	2.5	15
Ice Maker	1.5	20
Total	**22**	**645**

It should be noted here that icemaker and processing facilities have not yet been installed, but will become necessary when the fishing operation starts.

In principal, the question if the fisheries project will take off has no significant impact on the first phase of the solar project. The need to run two generators in parallel could lead to a slightly higher SFS penalty as discussed in section 5 but this is not considered significant. Given the uncertain nature of industrial demand, this category is not taken into consideration in further analysing power requirements.

The following charts depict the current demand situation for Fakaofo and Atafu, the islands where recent household surveys have been performed. Note that powerhouse records have not verified these load curves. At the time of the site visit to Fakaofo this load was still supplied by two independent generators. The 11 KV cable connecting the two villages Fale and Fenuafala on Fakaofo has not yet been commissioned. The demand curve for Nukononu is assumed to be very similar to Atafu with slightly lower loads and lower energy consumption. Peak loads are around 40 KW, energy consumption is between 400 and 460 KWh per day.

Chart 1 : Current Load in Fakaofo.

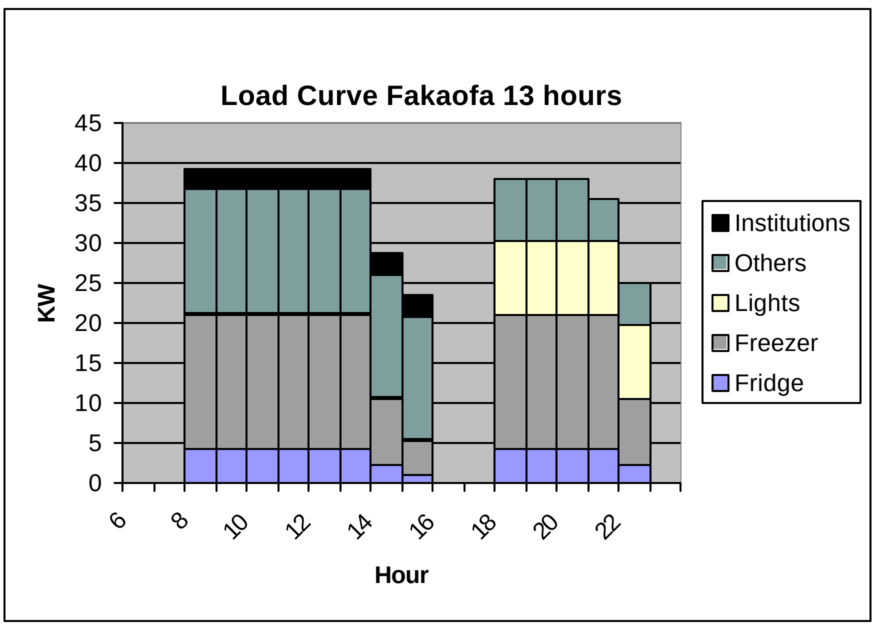
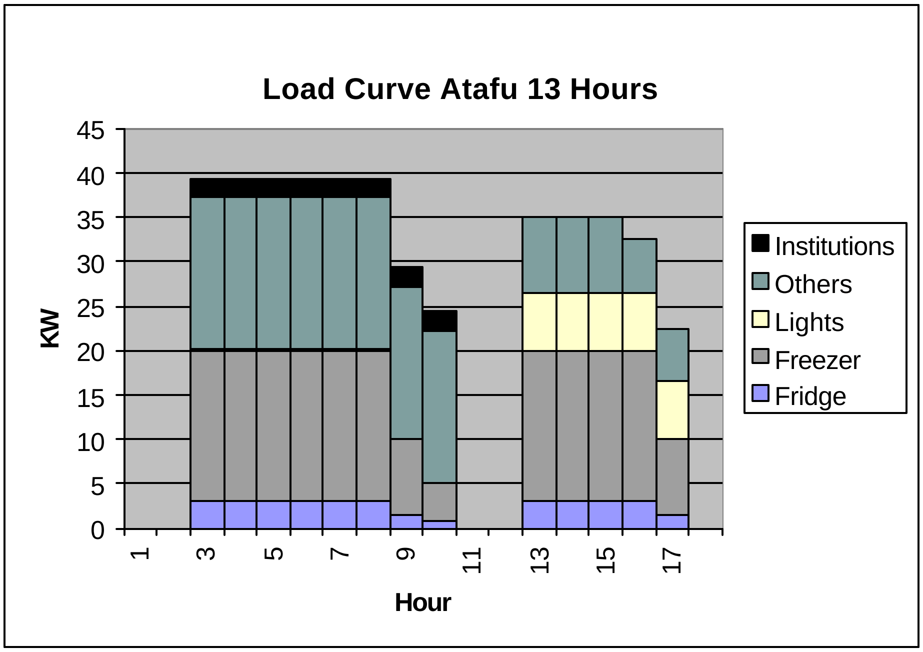


Chart 2: Current Load in Atafu



3.1.5 Future Demand

The electricity demand projections presented here are based on the analysis of the current demand pattern. The options of potential productive and income generating uses of electricity are practically limited to the fishing project already under way. No other potential industrial/productive use could be identified. No attempt has been made to refine the energy and load forecasts for the fishery project. Any prediction would have to be highly speculative in nature and thus not helpful for the purpose of this study. Only after fishing trials have been performed and the processing, storage and transport modalities have been established together with the frequencies of fishing trips a meaningful refinement of the load forecasts will be possible. Thus, consumptive household demand and a limited contribution from institutional users are assumed to remain the main drivers of Tokelau's electricity sector. It is assumed that 24 hours supply will be established soon. There seems to be considerable pressure from the villagers to provide uninterrupted supply.

Two scenarios have been developed: Scenario 1 is the "Business as Usual" case. It is based on an unchanged subsidized tariff of 0.3 NZ$/KWh and 24 hours supply. Demand will grow in line with recent developments of increasing use of electric kitchen appliances including stoves, frying pans and kettles.

The use of air conditioning, which has also been contemplated for offices, is also considered to a moderate degree. There will be no efforts in DSM and no educational campaigns that aim at introducing energy conservation. This scenario would probably lead to a 2 % growth in peak loads together with a 3 % increase in annual energy consumption. It is assumed that with increased use of appliances the diversity would improve and thus impact of growing consumption on peak load would be lower than on energy.

The result of this scenario is a peak load of approx 60 KW after 15 years corresponding to an increase in energy consumption from under 200 MWh per year per system to about 400 MWh. In order to maintain system reliability and firm power capacity, larger generators (approx 60 KW) would have to be considered in year 8. The following charts depict the effects of scenario 1 over the planning horizon of 15 years. It is assumed that electricity is supplied for 345 days per year (20 days downtime).

Chart 3 Load Growth Scenario “Business as Usual”

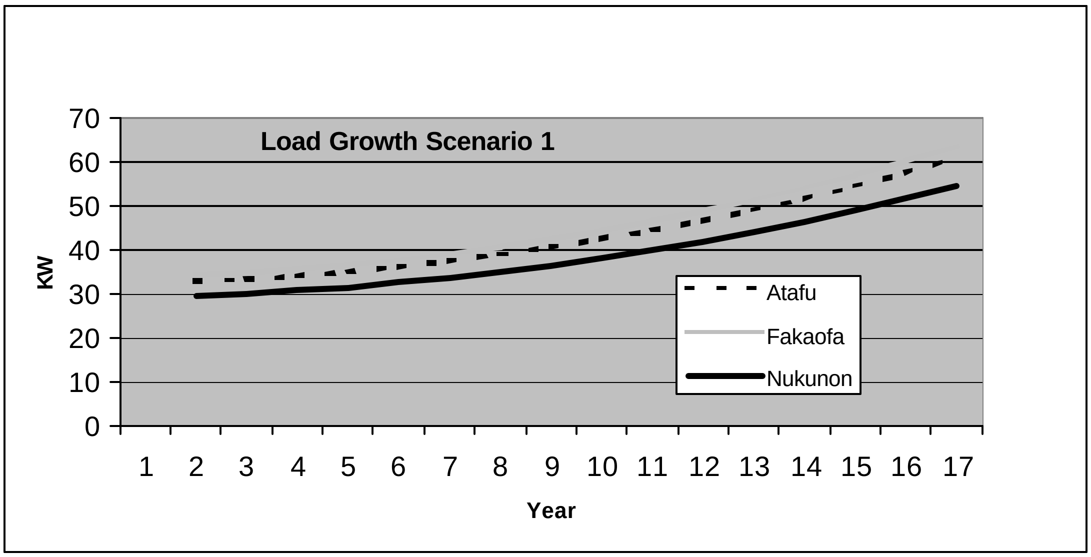
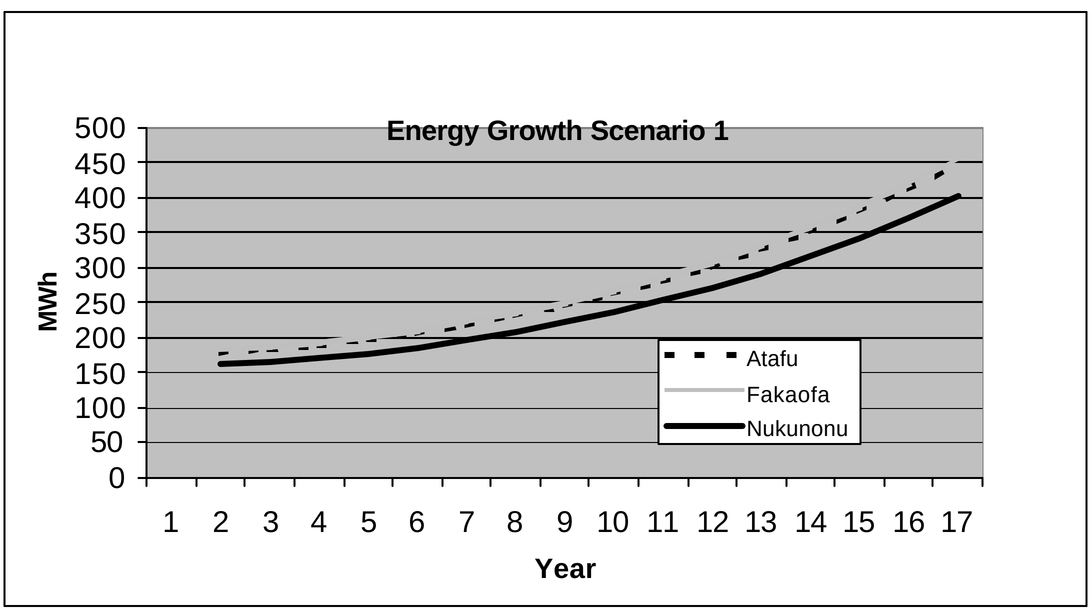
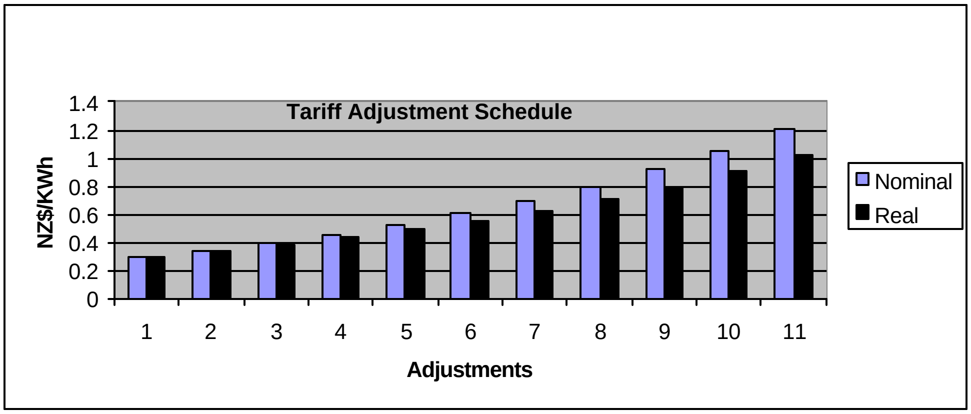


Chart 4: Energy Growth Scenario “Business as Usual”



Scenario 2 also assumes that electricity will be provided for 24 hours. Tariffs, however, will be adjusted to at least reflect operating cost of the electricity supply. In line with PB Power's suggestions, the adjusted tariff is assumed to be approx 1 NZ$. Tariff adjustments are assumed to take place over a period of at least five years as tripling the current tariffs is not considered politically feasible.

Chart 5: Tariff Adjustment Schedule Scenario 2



With the first increase in tariffs (say by 15-20 %) TPS would launch a campaign of consumer education and assist its clients in DSM. This campaign would –as a minimum- actively discourage the use of high-powered "convenience" appliances such as frying pans, electric kettles and sandwich makers.

It is assumed that these measures would stabilize both load and energy at the current level. Chart 5 depicts a proposed tariff adjustment schedule that would support Scenario 2. After 10-15 % adjustments (six-monthly) a target tariff of 1.2 NZ$ would be reached in nominal terms. Allowing for 2 % inflation rate, this would correspond to a tariff of 1 NZ$/KWh in real 2003 terms.

The scenario results in the following consumption figures for load and energy. Annual energy is calculated based on 20 days loss of load per year. Essentially Scenario 2 aims at maintaining this consumption pattern using tariff adjustments, consumer education and assistance in DSM.

Table 10 Summary Scenario 2

Location	Fridge KWh/d	Freezer KWh/d	Lights KWh/d	Others KWh/d	Total KWh/d	Annual MWh	Peak Load KW
Fakaofo	51.8	201.7	67.1	183.1	534	176	35.4
Atafu	31.2	209.8	47.6	204.1	513	172	33.9
Nukunonu	28.1	188.8	42.8	183.7	463	155	30.5

The following load curves are expected to materialize immediately when a 24 hours supply scheme has been introduced. While energy consumption will be higher than with today's 13 hours supply, peak loads will be lower. The reason is the diversity of 50 %

that can be expected from the refrigeration load. At the same time the freezers and fridges will draw more energy in 24-hour mode because their thermostats would maintain the set temperature all the time. The high refrigeration load results in a load factor for 24 hours supply (average load/peak load) of approx 0.63, still a very good value for small diesel systems.

Chart 6: Load Curve Fakaofo Scenario 2

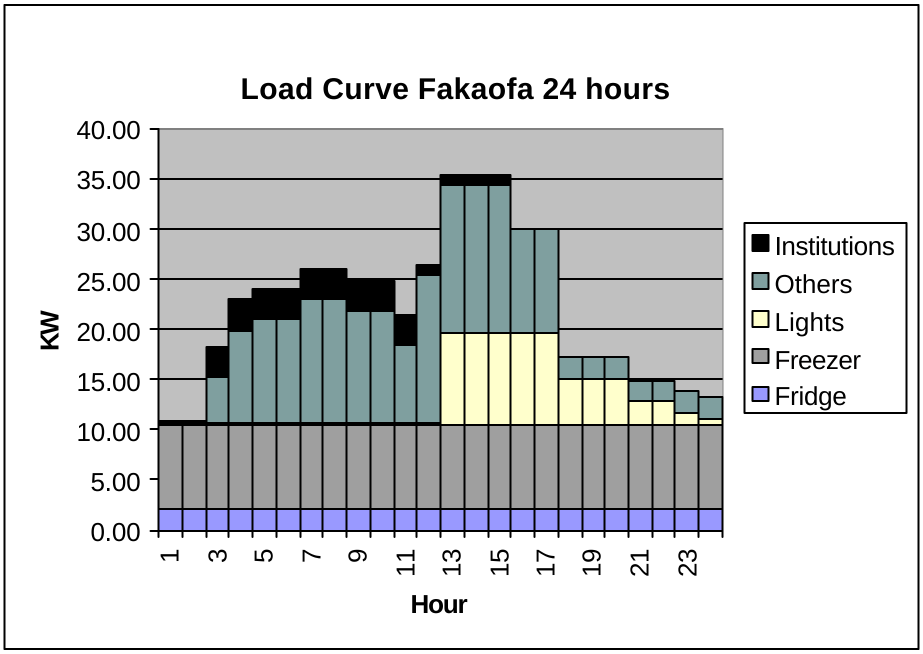


Chart 7: Load Curve Atafu Scenario 2

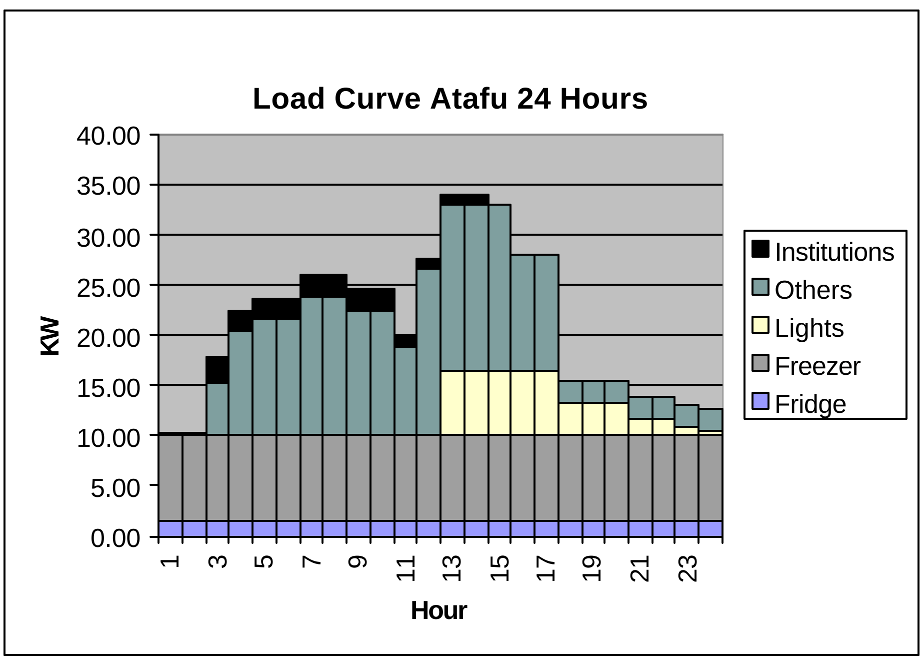
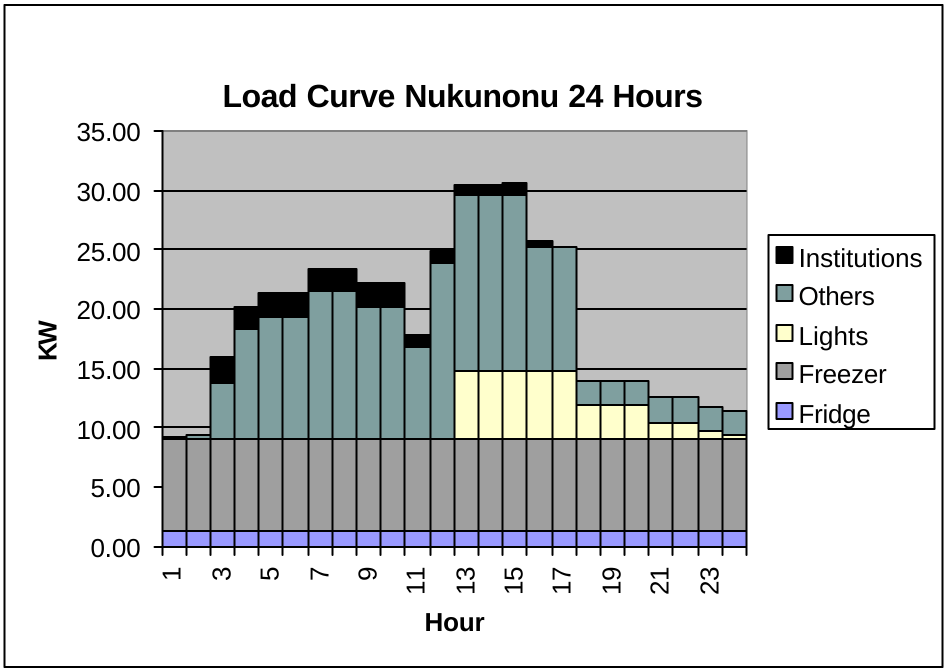


Chart 8: Load Curve Nukunonu Scenario 2



Obviously, Scenario 2 would be a desired outcome, given the difficulties and cost to supply electricity to a remote location such as Tokelau. Achieving a zero growth would also be a prerequisite for a sustainable long-term supply based on solar energy.

4 Problem Analysis

Electricity supply on the atolls of Tokelau currently faces a number of problems that need to be addressed. From the perspective of the consumers of the islands there is a lack of 24 hours supply. This problem will be addressed in the framework of the ongoing project of refurbishing the systems. Simply providing electricity for 24 hours in response to the consumers' demands will, however, not resolve the more fundamental problems related to diesel generation, the lack of skilled labour, consumer behaviour and institutional/economic (demand side) problems. These problems are that are described and analysed below.

4.1 Diesel Based Generation

4.1.1 Generic Problems of Diesel Generation

Diesel based generation poses a number of generic problems in a remote location such as Tokelau. Even the most efficient system relies on a long supply chain for consumables and spare parts. A major break down that requires substantial spares, which are not held on site, can only be fixed after considerable delays in transporting the spares to the islands. The generic problems of maintaining diesel generators in good conditions are exacerbated in Tokelau because generation equipment is neither standardized nor specified for the extremely corrosive, marine climate in which these machines have operate.[14] Due to a lack of stringent engineering and long term planning there are a variety of makes and models currently in operation on the three islands. Some machines already require repair or overhaul. The problem of unreliability could obviously be resolved through acquisition of new generators and the stocking of essential spare parts for these machines. This would of course involve additional cost.

4.1.2 Fuel Supply Problems

Diesel generation also brings with it a number of problems that are related to fuel supply. In the absence of large (and costly) storage capacity, there is always the risk of supply interruptions. The MV Tokelau and/or other supply boats are the weak links in the supply chain. When MV Tokelau hit a reef and was not operational, fuel stock were exhausted and supply had to be interrupted.

Storage and handling of fuel is potentially hazardous. Inadequate handling or accidents could cause environmental damage through oil spills and perhaps more importantly a threat to life and property in case of a fire. These aspects are discussed in further detail in the Environmental Impact Assessment (Part 2 of this Report). As Tokelau has no control over fuel prices, there is also economic uncertainty related to fuel price fluctuations either on the world market or on the local market in Samoa (taxes, duties etc).

[14] This problem has already been discussed in the Designpower report of 1997, unfortunately without triggering any remedial action.

4.1.3 Management and Operation of the Systems

Even a perfect diesel system that is standardized, well stocked with fuel, consumables and spares requires skilled operators to supervise the operation, perform regular maintenance and repair the generators in case of a breakdown. For an utility to function properly, there is also a need of sound management, corporate planning and monitoring of performance. A common problem for TPS is the outward migration of Tokelauans who have had training that enables them to perform as plant operators. Operators have also given up their jobs even if they stayed on the islands. The causes for this are varied and perhaps difficult to address. While it is commonly believed that unattractive salaries and the prospects of better work in New Zealand causes these staff movements another cause for poor steadfastness of operators appears to be the low social status the operators perceive to have. Obviously, mechanical work has traditionally not ranked very high in the scheme of live on remote Pacific islands.

There is of course a solution for these problems: To an extend operators can be substituted for by remote supervised and even remotely controlled generation. With the comparatively reliable telecom service that is also independent from the village power supply, key parameters such as V, A, temperature, oil pressure etc could be monitored anywhere and faults diagnosed by the remote supervisor. Together with programmed maintenance this procedure would contribute to solving the problem. Generators could even be remotely switched. What cannot be done is performing major repairs or even overhauls. This problem could be addressed by a) sending a Samoa based technician around to perform programmed maintenance and repairs and b) sending the generator sets back to Samoa for major repairs and overhauls. The later proved to be problematic in the past as removing the generator sets involves the risk of additional damage, particularly on the way between the powerhouses and the supply ship.

The problem of management has been addressed by hiring a competent utility manager Mr. T. Tafia currently based in Fakaofo. This is considered a short-term solution with the intention to replace the expatriate manager by a local as soon as practical and once a corporate structure has been set up for TPS. What remains a problem, is access for the manager to the islands of Nukunonu and Atafu. While he can address problems on Fakaofo immediately, he is obviously severely constraint by the shipping schedule as far as interventions on the other islands are concerned.

4.2 Demand Side Problems

4.2.1 Consumption Pattern

TPS faces a number of problems that are not directly related to generation and distribution of electricity but to its use. Firstly, it appears that there is a lack of consumer education. In the past emphasis was clearly on supply, i.e. the difficulties to keep the generators running overshadowed everything else. Consumers in the meantime have acquired a large variety of electrical appliances and consumption pattern are similar to an urban context in New Zealand where supply is very reliable and significantly less restricted as far as the generation is concerned.[15]

Although all households have gas stoves to perform their major cooking tasks “convenience items” such as electric rice cookers, frying pans and particularly electric

[15] Note that even New Zealand launches massive DSM campaigns in dry years, when hydro supply becomes constraint

kettles have become popular. These appliances draw currents up to 10 A. I.e. when all of them are coming on line simultaneously overload of the generators can easily occur. For example the 58 water kettles on Atafu that were identified in a recent survey represent a combined load of 128 KW which is more than the total installed capacity of the three generators.

Table 11 High Performance Thermal Appliances

Appliance	Ownership Atafu	Ownership Fakaofo
Sandwich Maker	19.05%	21.43%
El Frying Pan	14.29%	21.43%
Rice Cooker	2.38%	35.71%
Stove	3.57%	7.14%
Iron	9.52%	21.43%
Kettle	69.05%	32.14%

Source: Survey by General Manager TPS 2003

It is not entirely clear if households follow certain fashions here or if relatives living overseas just send these items as gifts. These high-powered items such as water kettles and electric pans can be purchased at very low prices in New Zealand or Australia. While perhaps convenient, these devices do not perform any task that could not be handled on a gas stove. At the same time they pose a threat to the security of the power supply. The existence of a large number of high-powered appliances also makes load forecasts difficult. Consumer education and awareness building seem to be urgently required to address these problems. If this does not show the desired results, it might be necessary to ban certain devices or consider the use of load limiters.[16]

4.2.2 Tariff Problems

The problem of almost capricious use of electrical appliances is exacerbated by electricity tariffs that are far too low to cover supply cost. I.e. for years the consumers in Tokelau have received distorted price signals encouraging profligate utilization of electricity.

At the current tariff of 0.3 NZ$/KWh the revenues do not even cover operating cost, let alone full supply cost. The low tariffs do not only send the wrong signals to consumers they also jeopardize the financial viability of TPS. At this tariff level the utility will never be able to achieve financial independence with respect to operating cost. From the consultant's point of view, a tariff that covers at least the operating cost of supplying electricity would be a minimum requirement.

The problem is that even strong efforts in consumer education geared towards electricity conservation may not succeed without providing price signals that encourage such behaviour. An increase in tariffs will almost certainly meet political resistance and should go hand in hand with a program that assists the households to conserve energy.

Tariffs that are too low and therefore economically inefficient are known to cause another serious problem. They create a situation where a utility is chronically under financed. I.e. the utility must regularly request financial support form government

[16] Load limiters are similar to fuses. They only allow a certain current to pass. When the set current is exceeded, the device disconnects power supply and allows reconnection only when the current is below the maximum setting

sources. This in turn inhibits any incentive for management to control cost and rationalize its operations. Under these condition TPS will neither achieve financial viability or even a commercially sustainable operation. In other words the heavily subsidized tariffs are probably the most serious single problem that TPS currently has to deal with.

4.3 Institutional Problems

At present electricity is the responsibility of a Faipule within the Council of Faipule. Financial matters including revenue collection are the responsibility of the Finance Department. In the past few years several studies have analysed issues, options and constraints related to an effective institutional set-up of the Tokelau Power System. The most recent report by Tony Johns[17] formulates 16 recommendations with respect to institutional issues. The report emphasizes the need to appoint a General Manager, a point that has already been addressed. It also recommends structuring TPS as a Government Department together with a clear delineation of the responsibilities between the villages and the central management. One of the key recommendations is to create a separate account for electricity that would be closely monitored. According to further recommendations the General Fono should allocate subsidies on an annual basis. Subsidies should be coming out of each atolls annual budget, i.e. each atoll should have the right to decide upon tariffs.

The consultant agrees with T. Johns considerations in particular with respect to the need to separate accounts and the political nature of the electricity tariff issue. It seems, however, be appropriate to reflect further on a longer-term vision of an institutional development for TPS. While the Government Department structure probably will be adequate for some time to come, leaving the decision on subsidy levels entirely to the villages is not considered conducive to the creation of a sustainable power supply.

Without sending clear signals to the consumers, that reflect scarcity of resources and cost of supply, neither a government department nor a corporation will ever be able to operate efficiently. There should for instance be a minimum tariff that cannot be undercut by the Taupulega. This tariff should be designed to recover operating cost and provide incentives for prudent electricity use. The consumers should be assisted in their efforts to conserve electricity; high-powered convenience devices such as water kettles should be strongly discouraged and possibly banned.

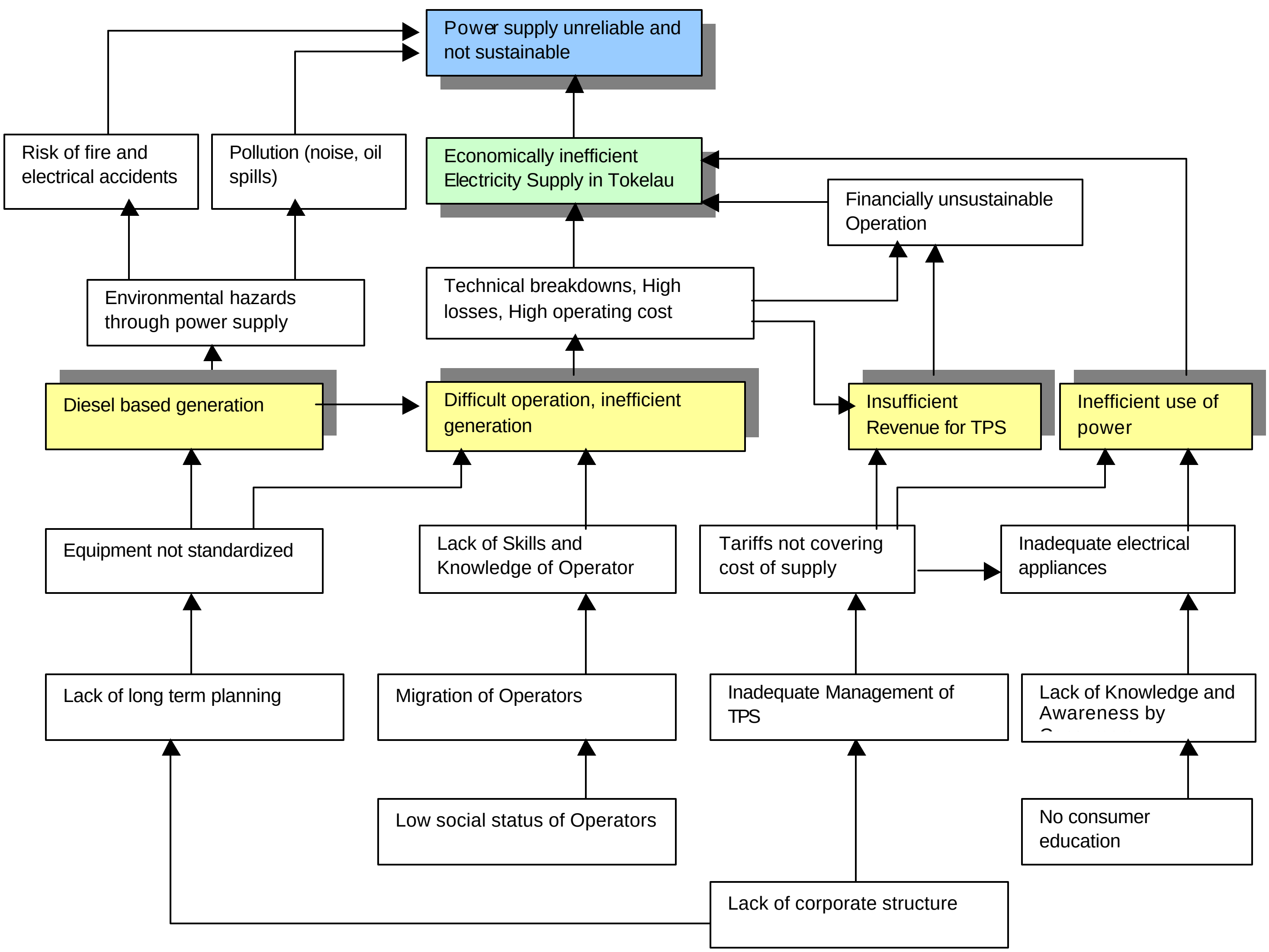
Section 3.1.5 above contains an adjustment schedule that would bring tariffs within 5 years to a level that covered operating cost of the systems. The tariff would have to be increased in 15 % increments every 6 months to bring the level to 1 NZ$/KWh (in real terms) after 5 years.

[17] Johns, T. "*Managing and Financing Power Supply in Tokelau"* , draft, 12 July 2002

4.4 Problem Tree

The following tree chart attempts to establish the main cause effect relationships between problems identified in the Tokelau electricity supply. Obviously, in complex systems such as electricity supply where supply and demand are intrinsically connected these relationships often have feed back loops and multiple links. The chart is intended to structure the main problems and show some areas where interventions are likely to contribute to solving the main problems. The project outline in section 9 will further address the issues of effective interventions.

Chart 9 Problem Tree Tokelau Electricity Supply



5 Technical Options

In the following sections, possible renewable energy solutions to the problem "Diesel based generation" will be described and discussed. The section mainly addresses options that fit into the budget frame for the project. In section 8, however, the longer-term vision of completely replacing diesel generation by solar is outlined.

In 1984 PV was installed to provide power to the high frequency (HF) single side band radio on each atoll, which formed the only reliable telecommunications with the outside world. Deterioration did occur over the years. Most of the performance degradation has been due to corrosion at the panel/terminal interface although a number of the panels experienced internal delamination. In 1998 preventive measures were taken and at that time it was estimated that the PV arrays could continue to operate for at least five years. In Atafu for instance the PV arrays now have been dismantled and are no longer in operation, but the panels still are in workable condition.[18]

5.1 Conversion of Teletok and USP Stations

The ToR require to assess the feasibility of interconnecting four existing solar generators to the TPS grids. The four working solar systems on Tokelau are: Three identical 5.5 KW peak stations provide independent power to the Teletok exchanges on each of the atolls. In additions a similar 6 KW peak station supplies the satellite communication facility of the USP Net Remote Learning centre at Atafu. All these facilities are actually connected to the existing TPS network, but via one-way rectifiers that allow only charging of the systems' battery banks. Both Teletok and USP decided to install their solar systems as independent power supply after experiencing frequent supply interruptions either caused by failure of their own diesel generation equipment or because of loss of load in the village systems.

5.1.1 Technical Characteristic of Existing Systems

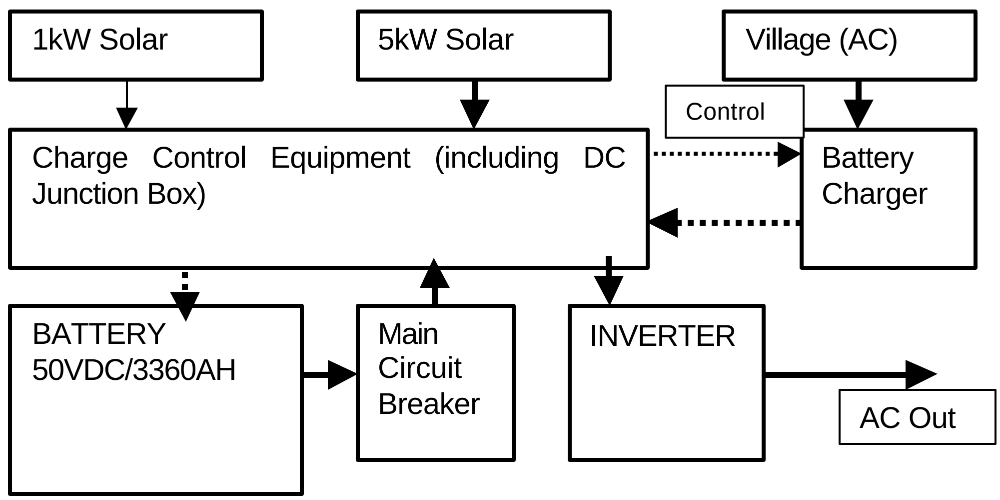
The USP system consists of the PV array and a battery bank having a capacity of 3360 AH at 50 V (168 KWh), one charge controller and an inverter. The specification of the equipment provides that a portion of the photovoltaic generator with peak output of approximately one kilowatt need not be controlled, as this is approximately equal to the continuous station load. There is no provision for bypassing the batteries or the inverter and feed the communication equipment directly via the rectifier. The system design allows operation of the communication equipment for up to 80 hours if a discharge of the battery bank down to 50 % is allowed. A block diagram for the USP network is provided below. It is not clear what the design discharge rate is, but it can be assumed that the batteries can be safely discharged to approx 80 % providing independent supply for approx 20 hours.

The Teletok stations are similar in design, but provide redundancy with three parallel rectifiers and inverters. Battery capacity is only 1125 Ah (56 KWh). Continuous load of the Teletok exchange, DAMA modem SES transceiver and ancillary equipment is approx 1.7 KW. With a limited battery capacity the systems are only independent for approx 16

[18] Information obtained from Mr. Levi, TeleTok during UNDP- & UNESCO-Apia mission in June 2002.

hours at full load allowing exceptional discharge down to 50 %. Design discharge is only to 90 % providing regular independence for only 3 hours i.e. for a short period of time.

Chart 10 Block Diagram USPNet



Source: USP Specifications

Table 12 Teletok PV System

Parts	Number	Type
PV panels	64	Solarex VLX-80 80 watt panels in 4 arrays.
Inverter	3	Sinetec HPI series 40 A
Battery	2	48 V banks Absolytte IIP 3-90A23, 1,930 Ah
Rectifiers	3	Switchtec E27333 with E40 monitor
Racks	4	Galvanized and painted steel structure

5.1.2 Operating Experience

The Teletok and USP systems have performed satisfactorily since 1998 and early 2001 respectively. The USP system experienced an early inverter failure that was critical because unlike the Teletok systems, USPNet power supply had been designed using only one inverter. There is also no possibility to bypass the batteries and feed the 48 V communication equipment directly from the rectifier. I.e. the single inverter becomes the weakest link in the power supply chain.

There are only limited data with respect to the output of the systems. P. McQuarrie reports the following output from the Teletok stations during their first year of operation:

Table 13 Performance Teletok PV Stations July 98 – Jul 99

Location	Output KWh/a	Net Output (KWh/KW/d)
Atafu	6889	3.5
Fakaofo	4528	2.3
Nukononu	Similar to Fakaofo	2.3

It is not clear how these figures have been recorded but a cross check with average irradiation data of 5.5 KWh/m2/d suggest that the net energy input into the telecommunication system has been recorded. At 5.5 KWh/m2/d (5.5 peak sunshine hours) a de-rating for the panels of 0.75, 90 % inverter and 95 % battery efficiency, the net daily output after inverter would be 3.5 KWh per KW_{peak} installed. It appears, however, that only the value for the Atafu station corresponds to an output value that can be expected from a 5.4 KW array under a 5.5 sunshine hours per day solar regime. It appears that all four stations regularly use their connection to the village power supply to top up their batteries.

Assuming that the Atafu figures hold for all three sites, the daily average electricity supply of the Teletok PV systems were in the range of 18 KWh, providing sufficient energy to supply peak load of the essential equipment for approx 11 hours.

5.1.3 Technical Feasibility of Conversion

Both the Teletok and USP systems could be modified to allow supply of surplus power to the village systems at the 240 V level. Technically there are two options. One is to replace the existing inverters by bi-directional or interactive inverters. These units are able to synchronize with the grid power and are commonly used in hybrid systems. Interactive inverters include relatively complex power electronics and are more expensive than mono-directional units.

Interactive inverters are programmable to perform a number of functions according to the settings used. In principal they act as battery chargers (rectifiers) and inverters at the same time. Switching is very fast and can be performed within half a cycle. Additional advantages of interactive inverters include the capability to supply surge loads jointly with the generator set in operation. They can also compensate for lagging power factors of AC loads. I.e. in addition to supply KWh to the grid, these units have the capability to improve the quality of the power supply in the system they are connected to. Interactive inverters normally have a function that avoids “islanding”, i.e. electricity supply through the inverter when parts of the grid are switched off for repair purposes or when generation is shut down is made impossible.

In order to provide maximum protection for the communication facilities the interactive inverters had to be set in such as way that supply to the grid is only enabled if:

- The village generators are on (avoiding islanding)
- Battery voltage gets close to the cut of point for charge current, i.e. in the vicinity of 52 V
- Battery is fully charged and the battery charge current is cut off.

It would be possible to allow short term synchronized supply of short term surge loads, as this could significantly contribute to improving the quality of the TPS power supply. Surge loads are a problem when the total refrigeration load comes on almost simultaneously after the generation pauses that are still common practice. I.e. when all freezers have lost their set temperature the compressors are activated when power is switched on again. Typically, the surge load of a freezer/fridge unit is approx 3 times the regular current drawn by the electric motors. Taking advantage of this specific feature of the interactive inverter would, however, undermine the priority of the communication facilities. As the design of the PV arrays does not provide for ample surplus the option is not recommendable under the given set up.

A minimum of two interactive inverters would be required in order to provide redundancy. In fact this type of refurbishment would enhance the reliability of the USPNet power supply rather than deteriorate it as the single inverter installed there remains a technical weakness in the existing system. Rating of the inverters would be in the order of 5 KW. Costs would be approx NZ$ 14,000 per unit (inverters, wiring, terminations, small parts) plus transport and installation.

The second option is to keep the existing equipment and simply install an additional inverter/controller that has the sole function of supplying surplus energy to the grid. These units would be fed from the main DC bus bars and would essentially be controlled by the battery voltage (charge). The simplest setting would be to allow the inverter only to supply the grid when the battery is full. I.e. only current that flows directly from the solar panels would be converted to AC and fed into the grid. This would of course not be a stable situation, as even a small drain of the battery would disable the grid supply until the maximum cut off voltage (approx 53 V) has been reached again. In order to maximize surplus energy supplied to the system this solution requires a setting of the control in such a way that it operates at the top range of the battery voltage without draining the batteries to a point where the telecommunications operation is jeopardized. A conservative setting for the inverter in the 48 V systems would be a range above 51 V. Protection against islanding had to be included.

This configuration would only require one inverter. The solar component would not supply any essential load and inverter failure would not jeopardize network performance. Size would be in the output range of the PV arrays i.e. 6 KW, cost approx NZ$ 7000 (inverter, wiring, terminations, small parts) plus transport and installation.

5.1.4 Net Output and Supply Cost

The expected net contribution of the units described above is difficult to estimate. It would certainly be zero for the Fakaofo Teletok station. This station, which is also the head office of Teletok, draws a minimum of 300 KWh per month from the TPS. The office is separately wired for solar and mains supply and can use all surpluses that are occasionally generated by the solar unit in house. As TPS power is regularly used to top up the batteries there is little chance that a significant surplus will ever be produced. To the contrary, electricity consumption seems to be steadily growing, undermining the self-sufficiency of the system.

For the other Teletok systems the picture might be slightly better. Assuming however, the recorded PV production for Atafu as a standard (6900 KWh/a) the average daily solar production works out at approx 19 KWh. The minimum electricity consumption of essential equipment running for 24 hours is:

Exchange:	12 KWh
SES transceiver:	10 KWh
DAMA modem:	4 KWh

The average demand of 26 KWh without lights, computer, testing equipment etc exceeds average supply by such a large margin that surplus will only be available in exceptional cases of prolonged high sunshine periods that coincide with periods of low demands. It is highly unlikely that this surplus will exceed 10% of the current solar production.

Under this scenario, the economics of installing even the cheapest version i.e. the single mono-directional inverter are not very attractive. At a total installed cost of NZ$12000 per unit[19] the cost annuity at 15 years lifetime and 6 % discount rate is NZ$ 1235, the corresponding electricity supply cost at an assumed surplus of 690 KWh/a are 1.79 NZ$/KWh. Obviously this is not an option that results in a meaningful contribution of renewable energy to the village systems.

5.1.5 Conclusions

Although the connection of the telecommunication and USP facilities as surplus suppliers is technically feasible, it should not be considered as a viable option. Firstly, supply cost for the small surplus margin would be prohibitive. Secondly, the increased technical complexity would increase the risk of system failure. Thirdly, the option would institutionally be barely feasible as both USP and Teletok have expressed reservations about the idea.[20] The option should thus not be further pursued at this stage.

5.2 Daytime Fuel Saving (DTFS)

This option, which consists basically of PV arrays together with inverter capacity, has been stipulated in the terms of reference as the desired design. PB Power identified this configuration as the least cost option of a PV solar generator feeding into the TPS network. The system would consist of (crystalline) PV panels, inverter capacity and the required balance of system components such as racks, cabling, terminations etc.

5.2.1 Decentralized versus Centralized Plant

Technically, so-called embedded decentralized generation has some merits. The most important one is usually, the possibility to bring generation as close as possible to the loads, thus reducing distribution losses. In Tokelau’s new system with generously dimensioned conductors, savings would hardly exceed 2 %, if the location of decentralized units would be strictly optimised. The disadvantages of such an approach outweigh these benefits.

Firstly, there is the administrative problem of achieving an agreement with any number of land or house owners to install solar capacity. If units are installed on residential houses and operated by them, there would be also a need to install new meters. A power sales and tariff arrangement had to be made with the individual producers together with arrangements for maintenance and repair. Secondly, there is the issue of finding roof or other space that allows for the proper, north facing orientation of the panels and is structurally sound to accommodate solar panels. Thirdly, a distribution of generation requires substantially more effort in supervision and management. In conclusion it is recommended to focus on a centralized solution.

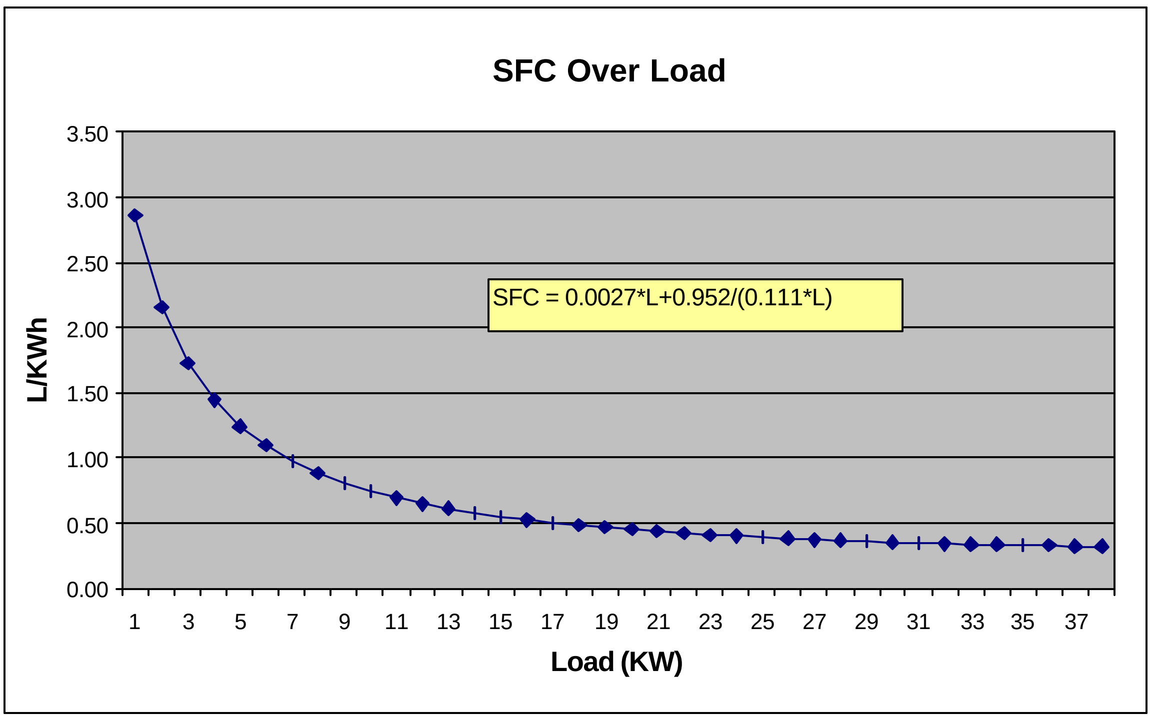
[19] Hardware plus transport and installation by a qualified technician
[20] Communication P. Mcquarrie, USP and Teletok General Manager

5.2.2 Sizing of PV Units

There is no lower limit for connecting PV power to a diesel grid. The size of an individual panel is the practical limitation for this option. This opens two general possibilities to support the TPS grids with PV power: through a single solar generation plant or through several decentralized units that feed into the grid at various points. Irrespective of the option chosen, there are technical and economical limitations with respect to the maximum PV capacity that can be connected to the existing grids. These limitations are imposed by two technical characteristics of diesel engines: Firstly most diesel engines do not react favourably to prolonged periods of operation at very low loads. I.e. if in comparison to the system load the solar contribution is large enough to force the second merit order generator into a continuous operation near idle, problems with coking of injector nozzles and increased wear and tear will have to be expected.

Secondly, and perhaps more importantly there is a trade off between gain in solar power and diesel efficiency. Nearly all diesel engines in the 50 KW output show a significant increase in efficiency with load. I.e. the fuel consumption per KWh generated decreases as the load of the engine increases. The following chart shows this relationship for a generator set.

Chart 11 Specific Fuel Consumption and Generator Set Load



The technical solution without battery storage is essentially a fuel saving device. Thus, the appropriate measure of its performance is fuel saved per unit of time and per KW installed. As shown in above chart, the impact of lowering the bad on specific fuel consumption (SFC) is moderate between 40 and 20 KW, and then starts to increase significantly. The chart shows that loads below 10 KW are best avoided as the SFC penalty becomes high.

Clearly, at a certain size of solar capacity, the efficiency of the generator drops to such low levels that there is no marginal gain in fuel saving. An exact quantitative prediction of this effect as a function of the installed solar capacity is of course impossible. Any combination of the two variables “solar output” and system load leads to a different load that the generator has to provide. If a generator set behaves as depicted in the above chart (an almost all sets in the class discussed here do) any solar load leads to a drop in overall efficiency.

This characteristic also leads to different results with respect to the impact of PV generation in different operation modes. A 24 hour supply with a balanced load in the 25 KW range as forecasted in section 4 is less favourable for solar than 13 hours supply with a high average load above 35 KW. The situation becomes even more complicated when 2 generators are operating, a mode that could become necessary in Fakaofo soon. Ironically, this behaviour of diesel generator sets also militates against the net impact of demand side management. The more the load is reduced; the lower is the specific effect of DSM.

In order to arrive at reasonable estimates for fuel savings obtainable as a function of various solar capacities installed the extreme or worst case has been modelled. This case is defined by the solar array providing its peak power output between 9 am and 16 pm i.e. for 7 hours. The solar power in KW is then deducted from the forecasted demand as detailed in section 4. In reality the solar arrays will only produce a net average of approx 3.7 - 4 KWh/KW/d[21], corresponding to an average of 5.5 sunshine hours per day. The simulation run has assumed the maximum possible solar contribution of 7 KWh/KW/d.

The following table shows the results of the simulation run for the load forecasted for Fakaofo. The first two columns show daily fuel consumption for 13 and 24 hours supply. Columns 3 and 4 depict fuel savings per day assuming maximum power output of the solar generator. Columns 5 and 6 show specific maximum fuel savings per KW installed solar capacity.

Table 14 Fuel Savings Solar in Fakaofo

Solar Gen	**Fuel Use litres/d**		**Fuel Savings liters/d**		**Specific Fuel Saving litres/KW/d**	
KW	13 Hours	24 Hours	13 Hours	24 Hours	13 Hours	24 Hours
0	156.4	239.2	0	0	0	0
3	152.6	236.7	3.8	1.26	0.83	0.631
4	151.4	236.0	5.0	1.25	0.81	0.625
6	149.1	234.6	7.3	1.21	0.77	0.607
8	147.0	233.3	9.4	1.18	0.74	0.588
10	145.0	232.2	11.4	1.14	0.7	0.570

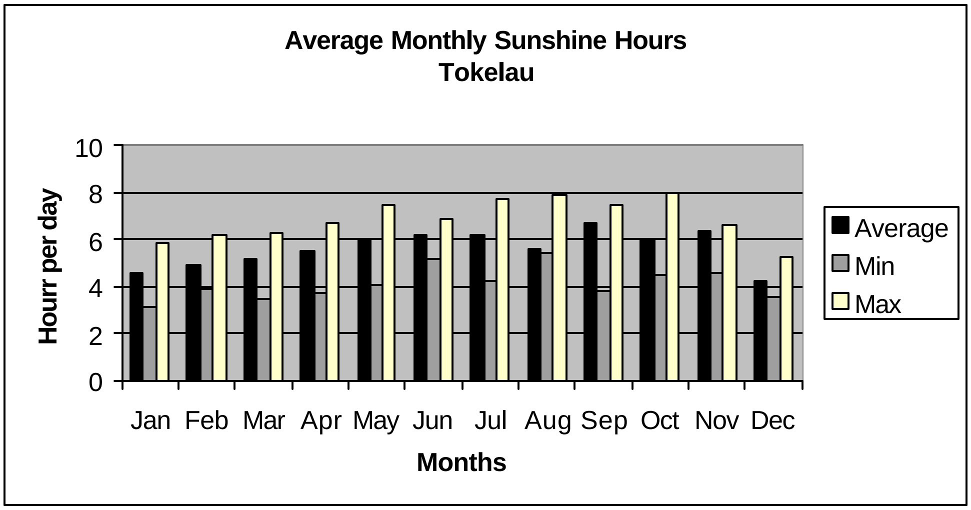
5.2.3 Total Energy Yield and Conclusions

For practical purposes it can be assumed that the solar generator will provide a net average output of 3.7 KWh/KW/d. Monthly variations of solar yield will be moderate. Although only limited solar radiation data are available, the NIWA measurements

[21] Panels derated at 0.75 for hot climate and 90 % combined efficiency of inverter

between 1983 and 1994 are sufficient to arrive at a prediction of average solar yields with an accuracy of approx +/- 5%. Chart 12 shows a summary of the NIWA recordings. Clearly, the lowest solar radiation is to be expected in December and January with average values below 5 sunshine hours.

Chart 12 Sunshine hours in Tokelau



Further adjustments have to be made because the solar generator does not produce its maximum output at all times. Inverter efficiency is approx 90 %, the panels have to be de-rated for hot climates (factor 0.75). A good approximation would be to assume that the real SFS of a 6 KW PV generator lies in the vicinity of the value of the 3 KW generators above because the <u>average annual net output</u> would only be half the maximum output that has been assumed in the simulation run[22]. The table below shows the adjusted results for a 6 and an 8 KW PV generator. A larger PV capacity would result in too high an efficiency penalty and also exceed the available budget for the first phase of this project.

Table 15 Adjusted SFS and total net annual yield for 6 and 8 KW solar unit

PV Size	**Av Net Yield**	**Adjusted SFS l/KW/d**		**Fuel Savings l/a**	
	KWh/a	13 hours	24 hours	13 hours	24 hours
6	8103	1.261	0.834	2762	1826
8	10804	1.251	0.811	3652	2367

Although the 8 KW unit clearly results in a higher total fuel saving, the 6 KW unit shows higher specific savings per installed KW of solar power. The effect is less prominent for 13 hours supply, in the 24 hour scenario, however, the difference in SFS between 6 an 8 KW solar capacity is already 3%.

In conclusion, the calculations support previous estimates with respect to a capacity that could be installed. 8 KW solar capacity per system should not be exceeded without battery storage. It should be noted here that the above calculations are based on the

[22] Average output according to Atafu recordings at Teletok station with 95 % inverter efficiency

assumption that only one 40 KW generator supplies the load. As soon as a second generator is operated in parallel, the loss SFS will of course increase until both generators operate close to their maximum capacity.

5.3 PV Generator with Battery Storage

5.3.1 Benefits of Battery Storage

PB Power has rejected this solution because of higher supply cost per KWh of solar electricity. While it is quite obvious that batteries add substantially to the capital cost of a solar system, their use has a number of merits that do not accrue in a simple fuel saving mode as described in 5.2 above. I.e. just comparing cost per KWh does not show the full picture. The following points have to be considered:

- Battery storage creates capacity credits, i.e. it is a direct substitute for diesel capacity that need not be installed. This represents a direct economic benefit
- Battery storage allows to avoid mismatch between diesel and solar loads and the SFS penalty discussed above
- Battery storage provides dispatchable firm power and allows “load shaving”, i.e. batteries can be operated when the benefit for the system is largest (e.g. surge loads and at peak times)
- Battery storage allows quiet power supply during night hours
- Battery storage creates the opportunity to provide back-up or UPS supply to parts of the system (hospital, other essential users)
- Battery storage becomes a necessity when solar generation is expanded beyond the scope of saving some diesel.

These six specific benefits are substantial and should be considered when comparing the options. Technically, any solar capacity up to full solar supply capability could be installed on the atolls, provided there is adequate battery storage. Full solar capability would be reached at approx 100-120 KW peak PV generation capacities per atoll. In reality, the system would remain in a hybrid configuration, even if solar provides all energy under normal operating conditions. At least one diesel generator set would be kept as stand-by.

In the following two options will be described: A limited application of battery storage that would fit into the project budget and a strategic solution that would supply Tokelau’s electricity from indigenous solar resources and would contribute to tackle the problems identified in Section 4.

5.3.2 Dispatchable Battery Unit (DBU)

A battery buffered hybrid system that supplies a major load of even one of the atolls would not fit into the project budget that is available now. Available funds would only allow the installation of a limited capacity, up to approx 10 KW solar capacity and sufficient battery storage that would enable to provide autonomy for selected essential consumers. The consultant identified such an application at the Fanuafala Hospital in Fakaofa. The case study is described below. TPS indicated, however, preferring to operate such a unit as general support to the Fakaofo system, in particular with the aim to manage peak loads.

Case Study Fanuafala Hospital

The case study discussed here refers to battery buffered PV installation at Fanuafala hospital in Fakaofo. The hospital is equipped with lights, sterilization equipment, refrigeration and office and communication equipment. Its current average electricity consumption is in the vicinity of 500 units per month or approx 17 KWh per day. Peak load is approx 3 KVA. It should be noted that the electricity demand of the hospital fluctuates considerably as a function of the services rendered to patients. Without inpatients daily demand can be as low as 5 KWh rising to 25 KWh on busy days. This characteristic is a limitation for the design of PV and battery capacity. The installation of a solar system should therefore go hand in hand with the establishment of a load management guideline.[23] In line with common practice the hospital used to have its own diesel generator (5 KVA Lister) that provided back up service in case of a failure in the village supply. The stand-by generator is no longer in working condition and in case of a loss of load in the village system the hospital has no power.

In order to make the hospital complex independent from village supply and at the same time provide the option of supplying surplus solar power back into the system the following design could be considered:

Solar Array nominal output:	10 KWpeak
Battery Efficiency:	95%
Inverter Efficiency:	90 %
Average daily output AC:	35 KWh
Average Supply to hospital:	17 KWh/d
Average Supply to system:	18 KWh/d
Battery Storage 3 day's autonomy	10 KWh/day[24]
Depth of Discharge (DOD):	40%
Design Battery Voltage:	110 V
Battery usable storage:	30 KWh
Battery Size:	800 Ah at 110 Volts
Interactive Sine wave Inverters:	3
Maximum demand per inverter	5 KVA
Surge Load per inverter	15 KVA
BoS components	

The above configuration would require a solar array area of approx 120 m2. This could be easily accommodated in a non-shaded area of the hospital compound. The location identified during the field visit could of course also be used to accommodate the fuel saving version of the PV generator described above. Grid connection would be through pillar boxes 14 or 20. The effective battery storage of 30 KWh could be selected smaller as the unit will be grid connected. In order to provide the hospital with tangible stand by

[23] It is suggested that the contractor who installs the equipment establishes a load management guideline together with the hospital staff
[24] The hospital would have to reduce electricity consumption to essential requirements in case of a power failure

power, autonomy of 3 days at reduced consumption of 10 KWh/d appears to be a reasonable compromise. The 3 days autonomy in case of power failures would be achieved by reducing non-essential electricity consumption in the hospital as soon as a power failure occurs. Also, a larger unit would provide higher surge load and grid support capability. In this case battery voltage is selected at 110 V in order to limit maximum load currents and to minimize resistive losses on the DC cabling side. Higher battery voltage is possible but 110 V seems to be a good compromise between limiting currents and safety.[25] It is however suggested to allow the hardware supplier/contractor to select the voltage of the battery bank in line with specific requirements for system optimisation.

In this configuration the solar unit would supply the full demand of the hospital and also supply an average of 18 KWh/day to the system. Two out of the three inverters would be able to handle the normal loads. The third unit would increase surge load capability of the system and also ensure the continuation of normal operations in case of one inverter failing. Again it should be left to the supplier to choose an inverter configuration that optimises redundancy, reliability, net electricity supply and cost.

In principle this configuration has all elements that a full solar supply would have. All that would be needed is adding array, battery and inverter capacities until full demand on the atolls can be met with solar power.

5.3.3 General Support to TPS System

TPS prefers to operate a battery buffered system as general support for their Fakaofo grid. There are two functions such a system could have. Firstly, a battery buffered system could take over nighttime loads and allow 24 hours supply without running the existing generators at low loads. Nighttime's supply using a battery bank and inverter would avoid noise pollution. In addition such a system would have the capability to support the system during daytime peak hours. The major design parameter for such a system would be the battery capacity. Based on the load forecasts provided in section 3.1.5 the battery capacity required to supply the system load from 11.00 p.m. until to 6.00 a.m. would be approx 108 KWh under the assumption that demand side measures are implemented as described in 3.1.5. The battery capacity alone would cost approx NZ$ 150.000 and thus leave no budget for other system components such as solar panels.

A 10 KW solar system as described in the case study above would, however, be able to support the daytime operation of TPS and could under certain circumstances help TPS to avoid using a second generator in Fakaofo. Operation had to be restricted within the design capacity parameters of the battery bank and the inverter. It is expected that a battery capacity of 30 KWh would be sufficient to keep generator loads below 35 KW for 3 - 4 peak hours.

5.3.4 Full Solar Supply

The difficulties to maintain a diesel-based electricity supply in Tokelau warrants an assessment of the options of a generation that is fully based on renewable energy. While outside the budget allocated for this project, supplying Tokelau completely with photovoltaic electricity could indeed become a long-term, strategic option. Tokelau would become the first country to go 100 % solar.

[25] Operators easily forget that batteries can hold voltages above save handling limits.

As there is a newly established efficient distribution system in place the supply would be through this grid. Individual solar home systems are not an attractive option for Tokelau because loads are quite high and each household would have to have an inverter and significant battery storage. In a centralized system at least one of the existing diesel generators would be retained as back-up, since it would be required to support the solar system during extended periods of cloudy weather. I.e. the supply would still be in a hybrid configuration, but with more than 90 % of the energy supplied by solar.

A sustainable solar supply would require co-operation from the consumers. Demand side management (DSM) would be a necessity in order to keep the massive capital investment in generation capacity and battery storage within reasonable limits. It is assumed here that DSM would keep the daily demand below 350 KWh and the peak load below 30 KW. This would be possible by a few simple measures such as:

- No use of electric kettles, frying pans and sandwich makers
- No use of incandescent lights
- Purchase of energy saving refrigeration equipment (4 star rating) when substituting old units
- Switching off lights and equipment that is not needed
- Well balanced loads in the distribution system

Assuming overall losses (battery, inverters, distribution) could be kept at 15 % such a demand could be met by 100 KWpeak solar generation and 40 KVA inverter capacity (sine wave inverter). Inverter capacity would be distributed over at least two – three units to provide some protection against unit failure. Battery capacity could be chosen between approx 300 and 1400 KWh effective storage capability. The later would provide 4 days solar autonomy and reduce diesel contribution to a level well below 5 %. The system would require approx 1000 m2 surface for the solar arrays and a building of 30 m2 to accommodate batteries and control equipment. Annual average solar production would be approx 128 MWh.

A project of this nature would cost approx NZ$ 18,000 per KW installed. I.e. the complete solar electrification of Tokelau would cost approx. 5.4 million NZ$. This price estimate is of course based on the assumption that the demand side would be managed as described earlier.

6 Project Economics

This section includes a financial analysis, a least cost analysis for the two project versions discussed in the previous sections and a broader economic benefit-cost analysis that aims at capturing the external effects of the various projects variants under considerations. In particular, environmental benefits have been included.

6.1 Financial Analysis

6.1.1 Assumptions

The financial and economic analyses are based on a set of assumptions that are outlined in the following. Clearly, only a competitive tender will yield the correct prices for equipment and installation. The cost assumed here are therefore indicative. Land costs are assumed to be zero. For all cases 3 generation scenarios (base, high and low) are tested to reflect the uncertainty with respect to insulation data.

Table 16 Cost Assumptions

Case		DTFS 6KW	DBU 10 KW
Specific Investment Cost (installed)		NZ$/KW	
Land		0	0
Pannels		13000	13000
Total Battery			50000
Inverter		2000	4000
Rack		1000	1000
BoS		1500	1500
Total per KW		17500	19500
Total per system		105000	245000
Discount Rate		6.00%	6.00%
Lifetime (in years)		15	15
Inflation		2%	2%
Other Cost Assumptions			
Depreciation Period		15	15
Depreciable share of capital		95%	95%
Salvage value		5%	5%
C Credits	t/MWh	0.32	0.32
C price	NZ$/t	40	40
O&M	NZ$/a	500	800
Insurance	NZ$/a	700	700
Other exp.	NZ$/a	0	0

6.1.2 Results

As already demonstrated by PB Power the financial performances of the project variants that are tested here are minor even under the best of assumptions. The required tariffs would not be achievable, and thus the project is not bankable. It can only be realised with considerable subsidies or donor contributions. Although this financial analysis does therefore not yield meaningful results, the simplified version that is supplied here demonstrates the required tariff for financial viability. The cases practically assume a private entrepreneur using equity finance to install the plants and sell electricity to TPS. In line with the ToR it is also assumed that the independent power generator would have a target FIRR of 6%. At the same time inflation adjusted carbon credits are paid to him over the lifetime of the facility. The environmental benefits of the project can be clearly demonstrated as diesel saving. Against the baseline of a (well run) diesel generator, solutions that are 100 % renewable energy based, the project could earn carbon credits of approx 350 kg of carbon per MWh generated. Unfortunately, the operation is so small that even assuming a generous carbon price of NZ$/Ton 40 (20 US$/Ton) a lifetime contribution would yield a maximum of NZ$ 1800. Obviously, this cannot change the financial characteristics of the projects.

The following table shows the results of the financial analysis for a 6 KW grid connected unit and the battery buffered 10 KW case study supplying back up at the Fakaofo hospital. Financial viability at 6 % interest would come within reach for real tariffs in the range of 2 NZ$/KWh. The DBU that sells a higher quality power to the grid would have to charge more than 3 NZ$/KWh to earn a 6 % return. A loss of 10 % average generation (due to an overestimated solar regime or through lower than expected performance of system components) would drop the FIRR to 3.47 % and 3.29% for the DTFS and the DBU units respectively. The high and low cases display generation/sales scenarios that deviate from the base case by 10 %. All results are significantly higher than the PB Power figures provided in their comparison of alternatives presented in 2000. It is however, not clear how their figures were calculated.

Table 17 Summary Results of Financial Analysis[26]

Case	Sales Price	FIRR	FNPV
Base	NZ$/KWh	%	NZ$
DTFS	2.00	6.00%	0
DBU	3.03	6.00%	0
Case	Sales Price	FIRR	FNPV
High	NZ$/KWh	%	NZ$
DTFS	2.00	8.33%	16935
DBU	3.03	8.48%	40494
Case	Sales Price	FIRR	FNPV
Low	NZ$/KWh	%	NZ$
DTFS	2.00	3.47%	-16935
DBU	3.03	3.29%	-40494

6.2 Economic Analysis

Economic performance of the projects is measured by calculating the Economic Internal Rate of Return (EIRR). The EIRR is a comparative measure of the economic worth of allocating resources to alternative projects, or to the same project under alternative

[26] The spreadsheets for financial and economic analysis are provided as Annex 5.

conditions. It is the discount rate, calculated from a comparison of the initial economic cost of a project to the stream of future economic benefits, at which the net present value of the project is zero. In the commercial environment that many power utilities operate in, an EIRR of a project of at least 8%-12% is usually required before investment in the project from national or utility resources is approved. The Asian Development Bank generally applies a 12% minimum rate of return rule to economic and social development projects before approving loan finance. In Tokelau, power supply is a heavily subsidized operation where the objective is not to recover cost, but to supply a remote community. The ToR for this study recognize this and request economic analysis be performed at a discount rate of 6 %.

6.2.1 Assumptions

Economic analysis is performed in 2003 NZ$, i.e. in real monetary terms.[27] As far as project cost are concerned the figures used in the Financial Analysis are used without any adjustment. As benefits the following have been assumed for one system.

Day Time Fuel Saving (DTFS)

- Diesel saving 8130 l/a
- Avoided cost of generation using the diesels (fuel, diesel capacity, O&M)
- Avoided distribution loss at 3 % of solar generation
- Avoided local environmental hazard (noise, fire danger, oil spills) valued at NZ$ 0.25 per liter of fuel substituted
- Global environmental benefits valued at NZ$ 40 per ton of carbon avoided

Dispatchable Battery Unit (DPU)/Hospital Back-up

- Diesel saving 12775 l/a
- Avoided cost of generation using the diesels (fuel, diesel capacity, O&M)
- Avoided distribution loss at 3 % of solar generation
- Avoided local environmental hazard (noise, fire danger, oil spills) valued at NZ$ 0.25 per litre of fuel substituted
- Global environmental benefits valued at NZ$ 40 per ton of carbon avoided
- Avoided capital cost for a back-up diesel engine (6KVA at 20,000 NZ$ installed)
- Capacity credit (surge load capability for up to 100 A) at 0.12 NZ$/KWh.

Most of the benefits assumed above are cost that are avoided to provide services at a quality that is similar to the solar option. The diesel savings are more significant in the second case as it is assumed that the battery bank is dispatched during the five peak hours, i.e. the Specific Fuel Saving penalty is lower compared to the first case. What could be considered as somehow arbitrary is the valuation of local environmental benefits at 1.0 NZ$/litre of fuel substituted. The exact economic measure for this benefit would be the avoided investment in save fuel storage and handling facilities, the sound proofing of the power houses, the save collection and disposal of waste oils, and the provision of fire fighting equipment. In total an investment of NZ$ 200,000 is assumed to be necessary per atoll to mitigate environmental risks. The annuity of this investment at 6 % and 10 years life is approx 1 NZ$ per litre of fuel used in a year.

[27] No provision for inflation is made

6.2.2 Results

The results of the EIRR calculation are displayed in table 18 below. Economic NPV values are displayed together with levelized economic energy production cost (LEPC). The DBU unit achieves the target EIRR of 6% in the base case. The DTFS unit shows significantly lower EIRR values and at the same time has lower LEPC. Although levelized economic energy production costs are significantly higher in the battery buffered case, the assumed benefits outweigh the increased cost. Firstly, there is the upfront benefit of an avoided diesel back-up unit. Secondly, environmental benefits related to avoiding the use of diesel are more significant as specific diesel savings are higher.

Table 18 Results Economic Analysis

Case	LEPC	EIRR	ENPV
Base	NZ$/KWh	%	NZ$
DTFS	1.48	1.6%	-26,148
DBU	2.28	5.99%	-198
Case	LEPC	EIRR	ENPV
High	NZ$/KWh	%	NZ$
DTFS	1.34	2.8%	-19430
DBU	2.07	6.88%	11853
Case	LEPC	EIRR	ENPV
Low	NZ$/KWh	%	NZ$
DTFS	1.64	0.4%	-32865
DBU	2.53	5.06%	-12249

Although the calculations demonstrate that battery capacity is a worthwhile investment, it is obvious that in reality, some of the benefits assumed for the DBU would only occur if a large quantity of diesel generation were replaced by solar. The local environmental benefits that are expressed in avoided cost for safe diesel handling facilities do only materialize in the full solar case.

The plant configuration preferred by TPS, i.e. a system that would provide general support to the grid and assist TPS to manage peak loads could not be credited with the benefits of providing a back-up for the hospital. (avoided investment approx NZ$ 20,000). Other benefits would be similar as described for the hospital back-up system and the EIRR for the base case would drop from 5.99% to 4%.[28]

6.2.3 The Stakeholder Perspective

There is of course another perspective to these computations. The major stakeholders i.e. the electricity consumers of Tokelau, their Government and TSP who will continue to receive significant subsidies or donor contributions particularly in terms of capital expenditures would be more interested in the operating cost of the systems. From their perspective, the highest return would be achieved with the lowest operating cost, assuming that capital expenditure and/or access to services would be subsidized in the future.

[28] Additional cost that will accrue due to the need to construct a battery house or some other form of battery enclosure will further reduce the EIRR

In order to reflect this perspective the financial calculations were also run using a heavy up-front capital subsidy of 95%. Under such a scenario, the DBU which can be used as a proxy for a full solar electrification in terms of specific investment cost would have to charge its customers a tariff in the order of 0.42 NZ$ to be financially viable. This is less than the operating cost expected from the diesel systems currently operating. At the same time, reliability of the system would be significantly enhanced and there would be no noise pollution. The major cost items over a 15 year period would be normal operating cost (staff, consumables etc) and the replacement of the battery bank after 10 years.

7 Risk

7.1 Solar Specific Risks

As already described in the UNESCO Project Proposal there are risks specific to the use of solar photovoltaic technology. The most significant risk is related to land issues. To be technically efficient and easy to supervise the systems have to be installed close to loads and/or close to the existing electrical system. This in turn would be locations that are close to existing settlements and therefore prime land. Distribution of the solar capacity over several roofs is technically possible but would complicate the issue of agreeing with the owners, investigate the structural strength of the roofs etc and certainly increase installation cost. The following table 19 summarizes solar specific risks:

Table 19 Risk Assessment

Risk	Risk Assessment	Risk In Control of the Project	Potential Killer
Environmental risks • DTFS • DBU	Environmental risks associated with panel installation (DTFS) very low as long as proper racks and mountings are used (hurricane proof) Battery use introduces a new risk dimension (H_2 explosion, acid, unsafe disposal) Refer to Part II - EIA	Yes, as far as specifications and insurance of proper construction is concerned. Not fully with respect to operational hazards related to battery use and disposal	No
Land/space not available, landowner disputes	This is probably the most significant risk. Space close to the settlements in Tokelau is a scarce resource and the negative experience with the new powerhouse in Fakaofo has shown that delays and/or unexpected cost can accrue.	Yes, Technically the panels can be mounted on roofs of public or private buildings. This will however, increase cost and require additional investigation in the structural strength of the roof construction. Also, optimal orientation (15 degree north facing, no shading) would not always be possible and output be reduced.	Possible Landowners can be compensated financially and the Government as a last resort could requisition land by warrant. This could, however, be politically not

Risk	Risk Assessment	Risk In Control of the Project	Potential Killer
		A better solution would be to seek a firm commitment and compensate landowners if necessary.	desirable
Vandalism and accidental damage	Possible	Partly through public awareness and consultation. Damage through cricket balls has affected the USP net installation on Atafu	No
Unreliable boat schedule.	Likely. Even this study was affected by restrictive boat schedule. Unreliable boat schedule due to weather and mechanical/structural problems have happened many times during the past years.	Yes, Most of the time there is the option to charter another boat (even though very expensive)	No. But it could increase project cost and delay installation and commissioning
PV systems fall short of assumed outputs	Possible.	Partially While weather is not controllable, the suppliers can be asked to provide warranties for their equipment.	No, but the project outputs will be sub-optimal.
Technical failure	Likely at some point	Partially Suppliers warrantees and sufficient training together with spare part management can reduce the exposure to risk, but as with all technical devices a rest risk remains	No, but life cycle cost can be substantially increased
Skilled operator not available on the three atolls	Possible	Partially. Initial training would be part of the project. tThe risk outward migration, however, can only be mitigated by trying to give the operator a higher social status	No, a solar system does not require a high level of attention. The systems used by Teletok have not seen much O&M since the last visit by the project engineer. I.e. in the worst-case scenario regular visits by an engineer had to compensate for lack of local staff.

7.2 Risks for TPS

TPS is currently in a phase of transition from an externally financed government department to a more modern form of corporate entity. The new General Manager's job description requires a review of tariff issues and the setting up of a management structure that ensures sustainability of the operation. A key here is to provide the market with the appropriate signals to keep electricity consumption within reasonable limits until a cost-covering tariff has been achieved.

There is a real risk that without consumer education and adequate price signals, the enhancements funded under the ongoing Power Project will be insufficient to cope with rapidly increasing electricity demand and as a consequence increasing losses of TPS. While external donor funding could be considered to fill the gaps, it would be much better to aim at least at a level of self-finance that covers operating cost. It appears that in line with past practice there is a high expectation that external assistance will be provided to fund the capital cost of this project[29] and perhaps even the full solar electrification. In the context of donor funding without commitment from the Government and TPS to raise tariffs the project could contribute to perseverance in aid orientation and lead to greater community dependency and expectations for external assistance.

7.3 Stakeholder Consultation

In order to enhance project ownership and to reduce risks related to lack of project support from the leaders, stakeholders such as the GM of TPS, the Faipule for Energy and the Director of the Office of the Council of Faipule have been engaged in discussions and participatory planning. The project parameters and possible options for the first phase of the project have been outlined together with the impacts of any solar-based generation, notably the necessity to find space to install the required technology. In general, the response of major stakeholders has been very positive, particularly with respect to the vision of a future where Tokelau owns a sustainable electricity supply based on renewable energies.

The plant configuration that the consultant considered optimal in terms of technical parameters such as proximity to load and economic benefits (providing a back-up system for the hospital in Fanuafale was, however, not accepted by TPS. TPS has instead specified a unit that will provide a general contribution to the grid and assist TPS in managing peak loads. At a later point, when 24 hours supply will be provided for Fakaofo, the unit is intended to be used as source for off peak power in stand alone mode. Given predicted load curve for Fakaofa in 24-hour mode, the unit will however only be able to supply nightime power for 2 – 3 hours.

[29] The Government of Tokelau has agreed that it would provide the land that is required for the project

8 Optimal System Configuration and Recommended Strategy

8.1 Recommended Project Design

The financial and economic analysis presented above has shown that solar electrification is currently not an investment from which a high performance should be expected. Not surprisingly, the DTFS shows significantly lower electricity production cost than the DBU unit. The economic analysis on the other hand shows a better performance of the DBU (EIRR 5.9 %) unit i.e. the project design that is considered as a proxy for full solar electrification could be justified at this rate. The performance of such a system would be even better, particularly if one adds the benefits associated with a lower loss of load probability that would also accrue in a solar electrification.[30] The EIRR for full solar electrification would also climb slightly as the specific investment cost for 100 KW units would be lower than in the DBU case described. In fact, a solar-based generation in conjunction with the high quality distribution system that is currently put in place might be a better match than the diesel generation that will continue to be plagued by operational problems inherent to the technology.

In other words the project considered here, has to be seen as a first step towards a renewable energy based electricity supply for Tokelau. If this route is not intended and Tokelau's electricity supply will remain essentially a diesel system, then additional funds would be better spend on improving the diesel systems by investing in safe fuel handling and storage facilities.[31] Under this premise the question is which project design would be the most effective first step towards the long-term objective of full solar electrification. Clearly, the DTFS solution produces more KWh per $ invested and the project budget would allow to install these units up to a size of approx 6 KW on all three atolls. The technology would be simple and all components could be later used when solar capacity is expanded together with the installation of battery banks and additional inverter capacity. If simple standardized string inverters were used for the DTFS unit, the expansion to 100 % solar would necessitate that these inverters would be kept directly connected to the grid, i.e. they would not be capable of managing the battery.

The DBU unit would consist of components that are fully compatible with an expansion of solar supply to any larger scale. The inverter unit would have to have battery management capability that is needed for the larger system. The approach to install a pilot plant on one atoll only would also facilitated logistics and reduces cost.

One main motive for installing a DTFS unit on Atafu, Fakaofo and Nukunonu is the possibility to have pilot projects on all three atolls. I.e. on all three atolls the stakeholders and communities would already be involved in the first step of a solar electrification project. There would be a chance to learn about problems that need to be resolved and the consumer education/awareness program could start simultaneously.

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[30] It should be noted that cost of non-supply have not been included in any of the calculations, as there are no records of historic performance of the systems. Only anecdotal evidence exists that power supply in Tokelau has never been very reliable.

[31] The UNESCO project document which has been approved by all stakeholders explicitly states that the long term objective of the project is to contribute to a self sufficient and sustainable energy supply for Tokelau.

On balance it is thus recommended to initially implement the DBU unit on the Fakaofo atoll. The main stakeholders have accepted this approach that has also been endorsed by an expert reviewing the draft report. The unit would be located close to the new TPS powerhouse [32] and provide general support to the TPS system. Focussing initially on Fakaofo, where the GM of TPS resides provides the opportunity to acquire experience with the operation of the unit under controlled conditions. The facility could serve as a training ground for technical staff that would later operate systems on all three atolls.

8.2 Project Plan

In the following a project plan is developed that describes the implementation process for the project.

8.2.1 Commitments

Supply and installation of the plant would be tendered as a package. I.e. the supplier of the equipment would have the responsibility to transport the plant on site, cover all insurances and install the facility at the site defined by TPS on Fanuafala. Until final commissioning the contractor would be responsible for all components. The contractor would also be responsible to provide a detailed operation and fault-finding manual together with on the job training for a responsible local operators. This training is absolutely essential to ensure a sustainable operation of the facility and enable the responsible operator to perform the regular maintenance as well as fault finding and repairs/replacements.

The government of Tokelau would have to commit to allocate the necessary space close to the new powerhouse on Fanuafala. A surface area of approx 120 m2 would be needed. TPS would have to clear the selected site of all vegetation and level the site. In addition TPS would have to construct a battery house with a surface area of approx 8 m^2, which features a concrete slap floor, a lockable door, two windows equipped with shutters, a hurricane proof roofing and sufficient storm drainage to avoid flooding of the battery house in heavy rains. This battery house would accommodate the battery bank and the unit's power electronics.

Plant Ownership and Operation

The plant would be owned by the government of Tokelau[33] and operated by TPS under the responsibility of the General Manger. TPS has to formally accept this responsibility and commit to support the project implementation. TPS should nominate at least one staff member as responsible for the operation of the plant. Support for the contractor should include assistance with local labourer for the preparation of foundations and installation of the solar arrays and inverters.[34] TPS will also undertake maintenance as required to the battery the battery house and the solar arrays (cleaning).

Ideally, the person seconded to assist the contractor would be the operator of the facility. Through the installation process the close contact to the contractor provides an excellent

[32] The consultants recommendation to locate the unit within the hospital compound and operate it as a grid connected power back up system for the hospital was not accepted by TPS.
[33] The date of transfer of ownership will be decided upon by UNDP/UNESCO
[34] This has been agreed upon in the project document

practical training opportunity and would yield a good understanding of the facility's functions and components.

TPS should also commit to undertake training of technical personnel from the other atolls including operators from the Teletok and USPNet facilities (since these power systems are very identical to the one to be installed on Fakaofo). Further TPS should commit to run a campaign of consumer awareness building and education. As the installation is considered the first step in a full solar electrification of Tokelau, demand side management will be a necessity to avoid wasteful use of precious energy and to ensure sustainability of the supply concept.

The system will be equipped with a data logger that will collect and store essential data on system performance and solar irradiation. TPS has to commit to download this data regularly (monthly intervals), store the data and transfer them upon request from UNESCO/UNDP or other relevant organisations in the region (e.g. SOPAC if/when Tokelau becomes a member). Data should be analysed regularly and stored at at least two different locations, i.e. at TPS and UNESCO/UNDP or a regional organisation.

8.2.2 Time Schedule

In the following a time schedule is layed out for the implementation of the pilot project. It is assumed that implementation takes approx 20 weeks from presentation of the draft final report and other relevant documents until commissioning of the facility. The following time schedule also includes allocation of major responsibilities for the individual tasks. The key to the abbreviations is provided below the table.

Table 20: Indicative Time Schedule for Project Implementation

Week/Activity	Resp.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Tender Document	CO																				
Land allocation preparation	TG/TPS																				
Construction of battery house																					
Issue Tender	TC																				
Tender Period	CO																				
Tender Evaluation	CO TC																				
Award of Contract	TG																				
Mobilisation Contractor	CT																				
Shipping	CT GT																				
Site Installation	TPS TG CT																				
Training	CT TPS																				
Start of Operation	CT																				
Commissioning	UN																				

Responsibilities:
UN: UNDP/UNESCO, CO: Consultant, CT: Contractor, TC Tender Committee TG: Tokelau Government, TPS: Tokelau Power System

8.3 Capacity Building

Training and retaining skilled plant operators is absolutely essential to ensure efficient use of the equipment. The fact that there are already 4 sophisticated solar units operating in Tokelau without skilled technical PV operators around underlines the need to build capacity. Up until now visiting consultants have provided technical support for the existing stations. This is not considered a sustainable operation in the long term. On the consumer side, capacity to understand the concept of energy conservation needs to be developed.

8.3.1 Training Requirements

Training has to ensure that the responsible plant operator is able to consistently perform:

- Regular supervision and maintenance of the facility
- Dispatch/Switching in case manual switching is selected
- Fault-finding
- Repair/replacement of faulty equipment
- Reporting of faults and unusual conditions

These capabilities have to cover all components of the system, i.e. solar array, inverter/battery controller, battery and balance of system components such as wiring, switches, connections etc. It is not assumed that complex repairs of power electronics will take place on site in Tokelau. An operator is not expected to open an inverter unit that is diagnosed faulty. What is needed is the capability to diagnose the fault and replace the unit from a spare part stock. It is recommended to train the operator using a **plant specific maintenance and fault-finding manual** that is provided by the supplier. Training of operators should take place during and after installation of the facility. In principle training of operators will have to establish the following skills in relation to the system components:

Solar Array

- Regular cutting vegetation that shades the array
- Regular cleaning of modules
- Regular check for module damage, cracks peeling, delamination etc
- Regular checking of rack structure for mechanical faults and treatment of corrosion
- Regular check of wiring for loose connections and damage
- Regular electrical performance check by voltage measuring of array strings
- Identification of faulty modules/diodes
- Replacement of faulty modules

Inverter/Controller Unit

- Regular inspection and cleaning
- Regular check for insect invasion

- Regular check for loose connections
- Regular check of performance (Voltages and Currents)
- Resetting of tripped circuit breaker (caused by surge current or excessive load)
- Disconnection of unit and replacement from spare stock

Note: In case of any fault of an inverter/controller unit that is not obvious such as a loose connection, blown fuse or tripped circuit breaker, the unit should be disconnected, replaced from spare part stock and shipped to the supplier.

Battery Bank

- Regular inspection and cleaning of battery units and tray
- Regular check for loose connections
- Regular applications of Vaseline at connectors
- Regular check of cell and bank voltages
- Regular check for abnormalities (discoloration of electrolyte, leakage, sediment ect)
- Regular check of specific gravity of electrolyte and temperature (n/a for gel type)
- Regular topping of water

Overall System

- Regular check of grounding
- Regular check of all switches (battery, load and array disconnect etc)
- Regular check of all fuses
- Determination why fuses or circuit breakers have tripped
- Regular check of all connections
- Regular measurements of voltages and currents and comparison with specs

Recording and Reporting

- Maintaining a log book
- Follow checklists and trouble shooting guides
- Fill in maintenance charts
- Consistently report abnormalities to supervisor

Note: The check of logbooks by a supervisor (TPS manager) and the reporting of faulty conditions are essential for spare part management, warrantee claims and timely replacement of faulty system components.

It is assumed that operator training and instruction of the TPS supervisor takes place over the whole installation and commissioning process, i.e. over a period of approx 5 weeks.

8.3.2 Awareness Campaigns and Consumer Education

As mentioned earlier a campaign targeted to induce consumer awareness and propagate demand side management should go hand in hand with the implementation of the pilot solar facility. There is good information material for household and commercial sector DSM available which can serve as a basis for consumer education (The SOPAC Energy Conservation brochure for instance covers the subject well and is available free of charge). The following measures could contribute to building awareness and triggering energy conservation:

- Discussion of the subject at village meetings
- Handing out of information material during meter reading
- Discussion of electricity consumption and use of appliances during meter reading
- House visits by TPS representative manager to assist in planning DSM
- Introducing the subject in the science curriculum in school[35]

Clearly, the agents who interface with the consumers and students need to be trained in the subject first. These agents would be meter readers, TPS staff, schoolteachers and community leaders. This would be a task that could be performed on a regional level, as part of ongoing or forthcoming regional energy initiatives. Alternatively, the General Manager of TPS or external consultants could perform the training. It is not recommended to include this training into the supply and install contract for the facility as this is certainly not part of their regular business.

8.4 Financing "Tokelau Goes Solar"

8.4.1 Structuring Finance

As mentioned earlier, a full solar electrification (with diesel as stand-by) would cost approx NZ$ 5.4 million. It will not be easy to raise this amount of money on a grant basis, but the vision that a whole country (whose existence is threatened by the impacts of global warming and sea level rise) will attract substantial international interest if properly marketed. It has to be assumed that multi-source financing will be required for a project of this size. There are a number of renewable energy initiatives in the Pacific region that are ongoing or forthcoming (among others to be funded by ADB, EU, GEF, IBRD but eligibility of Tokelau has to be confirmed as far as these resources are concerned. Most of the programs however, follow their own rules of appraisal, procurement and implementation and international experience shows that multi-source financing needs a strong lead agency whose rules are accepted by all other contributors to become a realistic option. This lead agency could be UNDP/UNESCO. The appropriate mechanism would be a single purpose trust fund "Solar Electrification of Tokelau". On a global level a relevant trust fund is the recently established "UNDP Thematic Thrust Fund – Energy for Sustainable Development". It has the following Service Lines (which also are the corporate priority areas for UNDP with regard to energy): 1) strengthening national policy frameworks to support energy for poverty reduction and sustainable development; 2) promoting rural energy services to support growth and equity; 3) promoting clean energy technologies for sustainable development; and 4) increasing access to investment financing for sustainable energy. In the case of a

[35] This type of consumer education through school children has been implemented under the Pacific Regional Energy Program in Fiji and Tonga. A full set of training aids and text books has been developed and should be available at SOPAC, the Fiji DoE and the Tongan Energy Planning Unit.

"Tokelau Goes Solar"-project Service Line 3 in particular would be relevant, but also Service Line 4. In addition recently it also has been decided that on a country level Resident Representatives can approve trust funds, which are derived from and confirm to the criteria and conditions of the "parent" trust fund. Thus UNDP Samoa could in principle create and manage a Trust Fund for "Solar Electrification of Tokelau" as long as it is based on the "Thematic Thrust Fund – Energy for Sustainable Development".

Procurement rules would be international competitive bidding with external auditing of the financial part of the operation by international chartered accountants. In case of a UNDP trust fund there are already established policies, guidelines, etc. regarding procurement (international) and auditing (external).

Other resources include hardware manufacturers and suppliers who might be interested in having this type of pilot project on their reference and can tap into some JI or export credit finance. There are also a number of foundations and special purpose funds that support clean energy development in various forms. What would be important from the marketing point of view, is a tangible commitment from the Government of Tokelau's side in form of an early contribution to the fund. Non-expended project funds from this project could also be an early contribution, sufficient to finance the international marketing campaign. It is beyond the scope of this study to develop the details of such a fund but the consultant believes that there is realistic chance to implement this project.[36]

8.4.2 Carbon Credits and CDM

The Kyoto Protocol to the United Nations Framework Convention on Climate change specifies targets to reduce greenhouse gas emission in developed countries from their 1990 levels by an average of 5.2% in 2008–2012. Although the Kyoto Protocol is yet to be ratified[37], a market for emission credits has started to develop. The Protocol established a mechanism whereby Parties with emissions commitments may trade their emission allowances with other Parties.

The aim is to improve the overall flexibility and economic efficiency of making emissions cuts. This Joint Implementation (JI) and Clean Development Mechanism (CDM)[38] procedures are now being used by both multilateral and carbon trading funds as well as by private investors. Large international players are the GEF (GEF operates the Conventions "financial mechanism" on an interim basis and funds developing country projects that have global climate change benefits) and the Prototype Carbon Fund. Bilateral funds have also emerged with the Dutch CERUPT[39] Program being one of the more successful initiatives.

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[36] If supported by the Government of Tokelau UNDP/UNESCO Apia initially are positive towards the concept idea of preparing a "Tokelau Goes Solar" project. Depending on the exact nature of request from the Government of Tokelau UNDP/UNESCO might be able to provide funds for technical assistance (e.g. for project design and "marketing'). In addition UNDP Samoa are in principle in a position to create a trust fund for this particular purpose.

[37] The Protocol will only enter into force after it has been ratified by at least 55 Parties to the Climate Change Convention, including industrialized countries representing at least 55% of this group's total 1990 carbon dioxide emissions

[38] The Kyoto Protocol Art 12 established the CDM to enable industrialized countries to finance emissions-avoiding projects in developing countries and receive credit for doing so.

[39] Certified Emission Reduction Unit Procurement Tender (Indonesia qualifies for this facility)

Eligibility under CDM

CDM normally require that the sponsor demonstrate that the project would not go ahead without carbon credits or GEF support. Projects that are financially and commercially viable cannot claim CDM contributions even if their environmental benefits can be clearly demonstrated. The Tokelau project would certainly qualify under this criteria. Reductions in emissions would have to be measured against a baseline representing the situation "without" the project i.e. diesel generation.

The output level of the baseline estimate is always dynamic and cannot be predicted exactly before the project's implementation. Other parameters that need to be considered when determining emission credits are the crediting times. Clearly, the longer the lifetime of a project the more credits can be claimed. Technical lifetime, commercial lifetime or pay back time of loans can be chosen to determine credits. Currently carbon credit prices are in the vicinity of 15 – 20 US$/ton carbon, i.e. for projects that substitute diesel these credits can make significant contributions to the cost of a project. Facilities such as the CDCF are able to put a premium on these rates if a project can demonstrate additional social and environmental benefits from the replacement of fossil fuels. Again, in the case of Tokelau this would probably be possible.

For carbon credits to be paid independent validation has to take place and the credit claim has to be certified. There are also penalties when a project falls short of its contracted renewable energy output. For this reason, it is important to work with conservative or at least very realistic generation estimates. Assuming full solar electrification on three atolls and a total replacement of the generation of approx 500 MWh annually by solar generation and DSM the carbon saving would be 3500 tons over 20 years lifetime. This could earn a carbon credit in the order of NZ$ 140,000.

Apart from credits under PCF or similar facilities the possibility of GEF contributions (provided Tokelau becomes eligible for GEF) for a project of this nature could cover additional costs, i.e. costs that are incremental to a baseline electrification investment without GEF contribution. Two types of subsidies that cover incremental cost are distinguished:

1. Subsidies that cover the higher costs shifting from current energy used to cleaner alternatives.
2. Incremental costs that serve to remove barriers to RE investment and dissemination. This includes capacity building, marketing etc.

Contributions under the latter heading could possibly be channelled through a second phase of PIREP where Tokelau is a member through funding from a UNDP Thematic Trust Fund for Sustainable Energy. The precise determination of eligibilities, procedures and sources is a complex task and needs to be tackled as a separate activity.

9 Hardware Specification

In this section the hardware is specified together with explanations why a certain design feature has been selected. Note that too narrow specifications will reduce not enable suppliers to optimise the system in a creative way. It would also inhibit competition. Therefore the specifications that are provided here are performance oriented and not targeted at any specific product.[40]

It is recommended in general to follow the guideline of Australian Standards for RAPS, i.e. AS 4509.1 (safety) and 4509.2 (system design) “Stand Alone Power Systems”. These standards are specifically developed for systems similar to the application in Tokelau. However, for components of the system no particular standard will be prescribed as this limits competition. Instead all system components have to comply with internationally accepted standards such as Australian Standards, New Zealand Standards or IEC or CEC standards. The international standards for system components have to be declared by the supplier.

9.1 System Configuration

The system consists of a solar array having an installed generation capacity of 10 KW. Effective battery storage would have to be approx 30 KWh to allow supporting peak-hour operation of one diesel generator set. At 30 KWh per day the unit would allow to keep the load on a single generator below 35 KW during approx six peaking hours. (Refer to chart number 1 “Load Curve Fakaofo 13-hours supply”). The unit should also be able to supply off-peak loads in 24-hour supply mode. Chart number 6 depicts the predicted load curve in 24-hours supply mode assuming that demand side management measures are put into place. In this case the battery bank could supply up to 30 KWh in the off-peak periods when demand is below 15 KW and no high surge loads are to be expected.

There are two possible configurations for such a system: A switched configuration or a parallel configuration. A system in series configuration is not an option for the project. This configuration is only suitable for very small isolated supplies where all generator output is fed through a battery charger first and all AC loads are exclusively supplied via the inverter.

In a switched system battery charging and inverter function would be separated. The configuration allows supply of AC either to the grid or to isolated local loads e.g. the hospital. Switching could be manual and/or automatic. Manual switching configurations are simpler than automatic switching but more vulnerable to operator mistake. The system has to have the capability to automatically prevent current flowing into the main grid when the gensets are not running. This configuration is appropriate for the 13 hours supply modality that is current practice. Stand-alone operation in off-peak mode must be possible by manually overriding this facility.

A parallel system on the other hand is characterized by an interactive inverter capacity that allows power flow both from the battery bank via inverter into the grid system and flow from the mains into the battery. In order to ensure optimal dispatch and operation of all system components the, the power electronics of the inverter unit would also have to

[40] Note that there have been complains from suppliers in the region that procurement of solar equipment in the past used specs that favoured certain suppliers.

have the capability to control the generators. The inverter would also manage the battery and ensure optimal feeding of surplus power into the grid. As in the switched configuration the system has to have to capability to avoid islanding, i.e. when mains power is off, no current is allowed to flow into the mains. As TPS intends to operate the unit also in stand alone mode the automatic disconnection facility must have a manual override switch.

It is recommended to leave the choice of inverter configuration and switching mode to the supplier and specify the systems capabilities instead. Refer to section 9.4.

9.2 PV Solar Array

The solar array consists of strings of PV modules that together produce a nominal output of 10 Volts. PV modules have to comply with IEC 61215 or have to be ESTI CEC 503 certified. The solar array will produce 10 KW under standard test conditions. This output has to be guaranteed within ±10% for a minimum of 15 years under tropical coastal conditions, which include exposure to high ambient temperature, high humidity, and high levels of atmospheric salt. As the system peaks in summer due to refrigeration load, the tilt angle should be 10 – 15 degrees. Lower tilt angles may yield slightly more energy but it is expected that this would be more than offset by the reduced self-cleaning capability.

Specifications:

Nominal output in line with IEC 61825/60904.1	> 10 KW
Real array output	approx 8-9 KW peak
Cell material:	mono or polycrystalline Si
By pass diodes:	integrated in modules
Blocking diodes minimum rating:	1.25 x I_{sc} of modules in the string
Frame:	anodised aluminium

9.3 Battery Bank

The lead acid type battery bank will be installed on racks in an enclosure provided by the TPS. The batteries must be of deep cycle heavy-duty design, with expected lifetime of 10 years. In order to avoid explosion hazards form H_2 accumulation good ventilation of the battery enclosure should be ensured. Catalytic vent caps help to reduce H_2 production by converting hydrogen into water that is recycled into the battery. The general specifications of the battery include:

Battery type:	lead acid positive tubular plate
H_2 Management:	Catalytic vent cap
Operating Temperature Range:	20 – 50 degree C
Containers:	Impact resistant plastic
Nominal Bank Voltage:	to be determined by supplier
Effective capacity at 40 % design DOD:	30 KWh
Nominal charge at C 20 approx:	90 KWh
Surge load capability:	20 KVA
Self-Discharge % per month at 20 degree C:	< 4%
Energy conversion efficiency:	>75%
Cycles at 40 % discharge:	> 2500
Battery Racks:	Corrosion protected

Transport/delivery:	dry charged
Supplier warranty:	>3 years
Battery enclosure/house:	Ventilated, sufficient to accommodate battery and power electronics

9.4 Inverters/Controllers

Inverter/controller Type:	Sine Wave
Preferred number of units for redundancy:	3
Combined max continuous output:	>15 KVA, supplying 3 phases, 415 V
Combined half hour rating:	>20 KVA
Combined surge rating:	>24 KVA
Full load conversion efficiency:	>90%
Demand start response time:	<1 sec
Inverter operation:	manually and/or automatic switching
Safety feature:	automatic disconnection of inverter in case of generator stoppage with manual overriding facility

Operation modes (minimum requirements):

1. Charging (controlled by voltage, high amperage charging)
    a. From mains - limited to a set Amax
    b. From solar array
    c. From both sources

2. Utility Interactive Mode
    a. Peak load shaving of at peak hours (6 KVA) manual and/or automatic switching
    b. Support for grid to cope with short time peaks up to 15 KVA up to 2 hours minutes (manual or automatic switching)
    c. Excess power from solar array fed directly into grid (automatic when generator is working)
    d. Excess power from battery (limited by voltage setting) fed into grid (automatic when generator is working)

3. Stand Alone Off-peak Mode (in case of 24 hours supply only)
    a. Off-peak supply up to 15 KVA for up to 2 hours with no generator back-up
    b. Excess power from solar array fed directly into grid

The inverters will be installed in an environment of high ambient temperature, high humidity, and high levels of atmospheric salt in the battery enclosure/house. At least one inverter/controller unit has to be provided as spare unit.

9.5 Rack

The material of the rack and the mounting of the solar arrays has to withstand a very corrosive maritime climate and hurricane force wind up to 200 Km/h. It must allow mounting of the panels at approx 10-15 degrees tilt angle facing north +/- 5 degrees.

Foundation:	Concrete
Material:	hot-dipped galvanising steel of at least 400g/m^2 of zinc or anodised aluminium, steel structure with additional white epoxy paint
Brackets and fasteners:	stainless steel or anodised aluminium.

9.6 Other Components/BoS

DC Junction Box

The DC junction box containing a control board will be located in the battery house. It will contain fuses, circuit breakers/switches in IP 65:

- DC circuit breaker to isolate the Battery Bank rating 150 A IP 65
- Isolating circuit breakers/fuses for DC inputs from any string of the solar array
- Isolating circuit breaker from Inverters/chargers
- Positive and negative buses for the termination of all DC loads

Cabling/Wiring

In general heavy-duty copper wiring of the UF type should be used for all DC wiring with all connections in watertight junction boxes and strain relief connectors.
Resistive losses Voltage Drop between array and battery less than 3%
Resistive losses between array and inverter less than 3 %
AC wiring and termination inverter – main grid including terminals/connectors

Earthing

Adequate earthing has to be provided for both DC and AC sides of the unit. Earthing protects against radio interference, lightning and electrical shock.

Array earthing (lightning):	copper coated steel earth stake 1.5 m into ground connected via 16 mm^2 cable
DC side earthing:	One side earthing with battery fuse for the other rail
AC side earthing:	Multiple earth neutral type

Data Logger with Solarimeter

Data on irradiation are sketchy. Data logging and analysis will allow a fine tuned design of the planned larger systems. Data logging also facilitates faultfinding. The system therefore has to be equipped with a data logger. Data logging capability of an interactive inverter is acceptable. Data logging has to have the following minimum capabilities:

Minimum Variables:
Solar irradiation
PV array current
Battery current charging and discharging
Currents to grid
Battery voltage
System frequency

System Voltage
Power Factor
Ambient temperature outside
Ambient temperature in Battery enclosure/house
Generator start/stop events
KWh supplied to grid

Minimum Features:
Power supply by DC/DC converter from Battery plus Lithium Battery back up
All variables 30 minute average recording
Min/Max values for 24 hour cycles
Storage capability 90 days
Communications Cable and software to download to PC and transfer via phone line

The data has to be retrieved by the Manager TPS or the operator, stored safely and transferred to UNDP/UNESCO or an appointed consultant upon request.

9.7 Spare Parts Tools and Documentation

9.7.1 Spare Parts

In order to respond to failures of essential components quickly, the following items have to be supplied as spares:

- Battery cells worth 5 % of the battery capacity installed (dry with acid in containers)
- 100 litres of deionised water
- 5 kg of Vaseline
- Solar modules worth 5 % of the installed solar array capacity
- 1 inverter unit
- 1 Control board terminal
- 1 each of any circuit breaker/switch used
- 5 each of any fuse used
- Assorted set of fixations, colson rings, sealing leads and wire

9.7.2 Tools

Tools have to be provided to perform all supervision, maintenance work and replacements of spare parts provided. As a minimum the following items will be required:

- 1 heavy duty plastic toolbox
- 1 professional clamp type multimeter
- 1 simple multimeter
- 1 DC Voltmeter
- 2 Hygrometer syringe type
- 2 Immersion thermometers
- 2 pairs of safety glasses
- 2 acid-resistant protective aprons
- 2 pairs of rubber gloves

- 2 pairs of safety boots
- 1 set of appropriate spanners
- 1 torque wrench with insulated handles
- 1 set of professional screw drivers
- 1 wire stripper
- 1 wire cutter
- 1 electrician knife

9.7.3 Documentation and Manuals

The documentation and manuals provided have to enable local staff to perform supervision and maintenance, find faults and replace faulty items. All items have to be provided in 5 copies. As a minimum the following will be required:

- Training Manual
- Fault Finding Guideline
- Operators poster laminated with essential features, functions and maintenance procedures
- Circuit diagram for entire system
- Wiring diagrams for assemblies of components
- Block or Connection diagram (AS 4509)
- Operations manual for data logger

The above specifications are the basis for the description of the plant provided in the tender document.

Annex 1 Contacts

During Field Mission to Tokelau

Mr. Falani I. Aukuso, Director, Office of the Council of Faipule
Hon Kolouei O'Brian, Faipule for Energy
Mr. Thomas Tafia, General Manager, Tokelau Power System, Fakaofo
Mr. Tom Twinning-Ward, UNDP Apia
Mr. Thomas Jensen, UNESCO/UNDP Apia
Mr. Russell Hortion, Electrician PB Power, Fakaofo
Mr. Tino Vitale, General Manager Teletok, Fakaofo
The Council of Elders Fakaofo

Other Contacts
Mr. Chris Lynch, PB Power, Wellington
Mr. Alexander Abbass, Total Energy Noumea
Mr John Hall, Solar Sales Australia
Mr Paul Sand, Reid Technology, New Zealand
Mr Oussama Chehab, Rosendahl- Energietechnik, Germany
Mr. Erich Hauck, SMART Energy Systems, Germany

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Annex 3 System Loads According to Household Survey by GM TPS

Atafu							
User		Units per		**13 Hours Supply**		**24 Hours Supply**	
Households	Watts	System	% Household	Hours/day	KWh/month	Hours/day	KWh/month
Incandescent Lights	60	13	15.48%	5	117	5	117
Fluorescent Lights	120	83	98.81%	7	2092	7	2092
Entertainment							
TV/VCR	120	46	54.76%	3	497	3	497
Stereo	40	18	21.43%	4	86	4	86
Fan	40	82	97.62%	6	590	6	590
Computer	50	10	11.90%	3	45	3	45
Printer	40	4	4.76%	3	14	3	14
Play Station	10	2	2.38%	5	3	5	3
El Guitar	50	1	1.19%	1	2	1	2
Aplifier	500	1	1.19%	1	15	1	15
Kitchen							
Fridge	130	20	23.81%	10	780	12	1076
Freezer	230	76	90.48%	10	5244	12	6872
Sandwitch Maker	700	16	19.05%	1	336	1	336
El Frying Pan	800	12	14.29%	2	576	2	576
Microwave	300	1	1.19%	2	18	2	18
Rice Cooker	500	2	2.38%	0.75	23	0.75	23
Stove	1000	3	3.57%	0.5	45	0.5	45
Iron	1350	8	9.52%	0.75	243	0.75	243
Washing maschine	80	53	63.10%	1	127	1	127
Water Cooler	200	4	4.76%	5	120	5	120
Kettle	2200	58	69.05%	0.5	1914	0.5	1914
Other					0		0
Batterie Charger	40	1	1.19%	1	1	1	1
Power Tool	150	74	88.10%	0.5	167	0.5	167
Total Households					**13055**		**14979**
Institutions							
Administration	500	1		3	45.00	3	45.00
School	850	1		8	204.00	8	204.00
Hospital	600	1		12	216.00	12	216.00
Teletok	400	1		5	60.00	5	60.00
Total Institutions	2.35				**525**		**525**
Total					**13580**		**15504**

	Fakaofo						
User		Units per	% Household	**13 Hours**		**24 Hours**	
Households	Watts	System		Hours/day	KWh/month	Hours/day	KWh/month
Incandescent Lights	60	4	14.29%	5	120	5	120
Fluorescent Lights	160	27	96.43%	7	3013	7	3013
Entertainment			0.00%		0		0
TV/VCR	120	11	39.29%	3	395	3	395
Stereo	40	10	35.71%	4	159	4	159
Fan	40	5	17.86%	6	120	6	120
Computer	50	5	17.86%	3	75	3	75
Printer	40	3	10.71%	3	36	3	36
Play Station	10	3	10.71%	5	15	5	15
El Guitar	50	1	3.57%	1	5	1	5
Aplifier	500	1	3.57%	1	50	1	50
Kitchen			0.00%				
Fridge	130	10	35.71%	10	1295	12	1554
Freezer	230	21	75.00%	10	4813	12	6875
Sandwitch Maker	700	6	21.43%	1	419	1	419
El Frying Pan	800	6	21.43%	2	957	2	957
Microwave	300	1	3.57%	2	60	2	60
Rice Cooker	500	10	35.71%	0.75	374	0.75	374
Stove	1000	2	7.14%	0.5	100	0.5	100
Iron	1350	6	21.43%	0.75	605	0.75	1312
Washing maschine	80	11	39.29%	1	88	1	88
Water Cooler	200	2	7.14%	5	199	5	199
Kettle	2200	9	32.14%	0.5	986	0.5	986
Other							0
Batterie Charger	40	0	0.00%	1	0	1	0
Power Tool	150	20	71.43%	0.5	149	0.5	149
Total Households					**14031**		**17059**
Institutions							
Administration	500	1		3	45.00	3	45.00
School	850	1		8	204.00	8	204.00
Hospital	600	1		12	216.00	12	216.00
Teletok	1400	1		5	210.00	5	210.00
Total Institutions					**675**		**675**
Total					**14706**		**17734**

Note:
No household survey has been performed for Nukononu yet. Consumption pattern can however be assumed to be similar to Atafu

Annex 4 Inception Note Tokelau PV Project

G. Zieroth
April 2003

Work under the Tokelau Sustainable Energy Consultancy comprises three distinguished investigations together with respective reporting:

4. Specification of hardware for Tokelau PV Project
5. EIA for Diesel and PV Project
6. Tender Management for Selected Hardware

The Consultant has fully understood the ToR for these three components. After reviewing available documents and background information, the following issues have been identified as critical and should be discussed at an inception meeting:

1. Specification of Hardware for Tokelau PV Project

The objective of this component is to find the most appropriate solution to support the three existing diesel mini-grids with PV power. The options to be investigated include the converting the stand-alone photovoltaic powered telecommunication facilities into grid-connected photovoltaic capacity and the installation of new and independent PV capacity. For the preferred option detailed specifications will have to be developed.

Integration of existing PV capacity

After reviewing specifications of existing equipment, background information and correspondence with stakeholders on the subject, the consultant believes that technically, the interconnection of both the Teletok and the USPNet stations can be integrated into the existing diesel systems. They would operate as embedded generators with the capability to deliver excess power to the grids and to draw power from the grids during times the units fall short of their own supply. As imbedded generators, the individual facilities would remain property of their operators, they would act under an IPP modality with an agreed price for energy sold to the grid. This modality would avoid the problem of unclear responsibilities raised by P. McQuarry.

While technically feasible and economically most probably the least cost solution, the solution has three major downsides: Firstly, it seems to be save to assume that a consensus with respect to integration will be difficult if not impossible to achieve with the projects' owners and major stakeholders. Secondly, the effect on diesel savings in the main grids would not amount to much as the stand-alone PV units have been designed to supply their own requirements plus a safety margin. This safety margin minus transmission losses between the interconnection point and the loads would theoretically be available as fuel saving input. This issue has to be analysed in detail using power consumption data of the telecoms facilities. Thirdly, integration, however technically achieved would increase complexity and thus introduce an additional risk component for the telecommunication facilities.

Consequently, the consultant suggests investigating the possibility of integration of Teletok and USPnet while focusing on the establishment of new capacity. It should be borne in mind here, that the option of full integration will always be there, whether realized under this project or not. I.e. adding new PV capacity now would not automatically rule out integration at a later stage.

System Design and Optimization

The ToR do not leave much room for system optimization. The preferred option is defined as PV arrays operating in fuel saving mode without battery capacity. In addition, there are severe budget restrictions that constrain total capacity to approx 15 – 20 KW peak. What is possible within the constraints is to find the optimal location and/or distribution of solar capacity.

The system design as stipulated in the UNESCO project document apparently meets considerable skepticism if not resistance from the power utilities General Manager, no doubt one of the key stakeholders of the project. (letter 1st February 2003). He considers the project not only as a high-risk investment but also as economically not viable. At current prices, a PV generated electricity has long run average cost in the order of 1.1 – 1.5 NZ$ per KWh. Cost data for diesel generation will need to be verified on site as there seems to be doubts about specific diesel consumption. Assuming that PB Power's appraisal figures are correct i.e. approx 0.9 NZ$ per KWh, overall average economic generation cost will indeed increase and it would be difficult to persuade Mr. Tafia on the basis of simple cost considerations. It will be necessary to convince Mr Tafia that the use of PV power in fuel saving mode is indeed beneficial for his operation. Benefits that would accrue include:

- Fuel is saved (approx 0.4 l per KWh)
- PV capacity could later be integrated in a larger battery buffered system (as recommended by him)
- Additional funding might be easier to mobilise if a successful pilot operation is already established
- Distributed benefits such as kVAR support, reduction of transmission losses, delay of transformer, circuit or conductor upgrading, increasing reliability etc
- Avoidance of thermal overload at line ends.

It is understandable that key stakeholders approach the project with a healthy dose of skepticism and a consequence; consensus building and consultation will be an important part of the consultancy.

2. EIA for Diesel and PV Project

The objective of this component is to provide the decision makers in Tokelau with an account of the environmental implications of the proposed PV Project and identify, describe and recommend feasible mitigation measures for minimizing, eliminating or offsetting unavoidable adverse effects from the existing Tokelau power facilities.

Ex post EIA Diesel Power

The review of background material did not show any evidence of acute environmental problems with the refurbished power systems. The installations have been made in line with New Zealand standards and appear to be environmentally sound. The consultant will, nevertheless, provide an independent account of impacts from both construction and operation of the facilities. It is however, suggested, to focus here on developing guidelines and recommendations on how to maintain environmental safety of the existing facilities. Emphasis will be given to fuel and lube oil handling, noise pollution and electrical systems safety.

Ex ante EIA PV Systems

Although PV systems – in particular those without lead acid batteries typically rarely show negative environmental impacts, the unique situation in Tokelau merits a careful look at aspects such as land requirement (obviously in very short supply), hazards in connection with hurricanes and islanding of grid connected PV arrays in case of a shut down of the main generators. The consultant suggests to focus on these points.

3. Tender Management for Selected Hardware

The objective of this component is to manage the procurement of the needed equipment its transport, installation and on-site training in operation and maintenance. The consultant sees the main challenge in creating a competitive environment with at least 2-3 serious bidders. This will not be easy to achieve. For a comparatively small project, suppliers who sign a turnkey contract will be confronted with substantial risk and difficult logistics.

The question is how to ensure sufficient competition to ensure cost effective procurement. It is suggested to request proposals from a shortlist of a maximum of 5 pre-selected bidders. A separate evaluation of technical proposal and price is suggested. Logical candidates for such a shortlist are the companies who have already implemented similar projects at locations with similar characteristics. A general procurement notice circulated in the Australasian region would be sufficient to generate a shortlist according to the following criteria:

1. Years in operation in the PV field
2. PV reference projects in the Pacific region
3. Grid connected reference projects.

It is also suggested to refrain from requesting bid bonds or other bid security as this has proven to be a deterrent for suppliers bidding on small projects.

Annex 5: Debriefing Notes PV Project Tokelau

G. Zieroth April 2003

Work under the Tokelau Sustainable Energy Consultancy comprises three distinguished investigations together with respective reporting:

1. Specification of hardware for Tokelau PV Project
2. EIA for Diesel and PV Project
3. Tender Management for Selected Hardware

After reviewing available documents and background information and conducting site investigations on Fakaofo from 16 – 18 April 2003[1], the following issues and options have been identified:

1. Current Problems and Project Design

The main problems in Tokelau's current diesel based power systems can be summarized as follows:

The fuel supply chain (i.e. fuel procurement, shipment, handling, on site storage and utilization) involves risks of supply interruptions, environmental damage and fire. Should MV Tokelau be unable to sail according to fuel supply schedule, stocks will be exhausted quickly and power supply will have to be shut down. Fuel handling and storage does not comply with safety standards (no holding facility in case of spillage at depot, no emergency procedures) and accidents are likely to involve pollution and potentially fire. Dependence on fuel makes the power supply vulnerable to price fluctuations and can threaten financial viability of the corporate utility that is being established.

Although all three systems have been equipped with some back-up capacity, the supply will continue to be vulnerable to lack of proper maintenance, mechanical break downs, and lack of spare parts. The fact that four different types of generator sets are being employed on the three atolls aggravates the problem of spare part management and maintenance. Supply interruptions are likely to occur in the future, particularly when the system load reaches a point that requires dispatch of two generator sets to meet peak demand. In this case there will be no back up available to cope with a second generator failing and load has to be disconnected. Numerous mechanical devices that have fallen into disrepair and litter the islands witness the problem of maintenance and repair of technical equipment.

The lack of demand management and consumer education together with a highly subsidized tariff has led to a rapid growth in use of a large variety of electrical appliances. As a consequence system operation faces difficulties to maintain balanced loads and cope with sudden peaks. There is also uncertainty as regards future load of the systems. It is unclear weather the communal fish freezing facilities which would impose a substantial loads on the system will ever take up a regular operation.

[1] Visits to Atafu and Nukonouno were not possible becasue of unexpected change in MV Tokelau's sailing schedule

2. Possible Interventions

Assuming that funds in the order of US$ 220,000 can be made available to improve sustainability of the current project a number of options have been identified. The intended connection of the existing Teletok and USP facilities as generators has to be discarded. These facilities are net consumers of village power, i.e. there is no surplus solar energy that could be fed into the grid. This leaves three different approaches that could be taken to reduce the vulnerability of the systems and of the environment on Tokelau's atolls:

Improving the existing diesel system. Although it is not entirely clear what is included in the scope of the ongoing project executed by PB power on behalf of NZaid, it appears that there are no funds available to enhance safety of the fuel supply chain. Measures to be taken here include the construction of proper fuel depots/and or bulk storage facilities at MV Tokelau's landing point and the powerhouses, establishment of response procedures for oil spills and fire and operator training with focus on fuel handling and emergencies.

Fuel saving through grid connected PV generators. Technically, the connection of up to 6 – 8 KW[2] of PV capacity is possible and will pose little problems. The system design would allow power injection at any of the pillar-boxes' 16 mm^2 cable termination. The issue to be resolved here is finding approx 60 – 80 m^2 of un-shaded North-facing space that could accommodate the solar panels. On Fakaofo two possible sites have been identified, one close to the new powerhouse, the second -preferred one - at the hospital. Although this option would gradually reduce dependence on diesel (savings of approx 5000 – 7000 liters per year, the main problems described above would certainly remain. In addition, the complexity of the system would increase, i.e. operators had to be familiarized with the solar components and their maintenance and supervision requirements. Before preceding to procurement of any equipment the sites for installing PV equipment would have to be confirmed by the Government of Tokelau.

First step into a full solar powered electricity supply. This concept would see this project only as an initial step to convert the power supply systems in Tokelau to 100 % renewable energy. Assuming that consumer education and demand side management could restrict daily consumption to approx 400 KWh per system and per day (the current consumption without fish freezer), a solar capacity of approx 100 KW_{peak} with approx 1200 KWh battery storage would be required on each island. Total cost would be in the range of 2 million NZ $ per island and surface requirements would be approx 30x40 meter. This solution would result in a low maintenance power supply involving very low operating cost. It would also be breaking ground, as Tokelau would become the first nation to supply its electricity needs 100 % from renewable sources.

3. Discussion

Obviously, the originally intended solution ii) of connecting a limited PV capacity to the grid would not hinder the longer-term option of Tokelau going fully solar as described in solution iii). The principal difference would be to include a fundraising campaign in the project and perhaps concentrating the first step installations on one atoll. This would facilitate logistics and reduce cost. Solution iii) would also require a strong commitment of the Government of Tokelau. Space had to be allocated and the consumers had to make a commitment to demand side management.

[2] KW peak

Annex 6 Terms of Reference

TERMS OF REFERENCE

SPECIFICATIONS OF HARDWARE FOR THE TOKELAU PV PROJECT [1]

1. BACKGROUND

In 1999/2000 an ex post feasibility study for different power supply options in Tokelau – all diesel, all photovoltaic (centralised and decentralised) and hybrid diesel/photovoltaic systems (with and without batteries) - was undertaken. The study recommended the all diesel option and thus confirmed the electrification project already in progress. Subsequent it was decided to utilise the significant solar energy resource to *supplement* the current diesel system. I.e. in the future hybrid diesel/photovoltaic system, the diesel gensets will be the *main source* of power. In year 2001 the preferred PV supply options was assessed and the option recommended was to install PV to the existing diesel system *with no batteries*. Then in June 2002 it was decided that in addition it was appropriate to investigate the feasibility of converting the existing stand-alone PV telecommunication capacity into grid-connected capacity.

2. OBJECTIVES

(a) To determine the feasibility of converting the stand-alone photovoltaic powered telecommunication facilities into grid-connected photovoltaic capacity.

(b) To determine whether the preferred grid-connected photovoltaic supply option either is to convert the stand-alone photovoltaic powered telecommunication facilities into grid-connected photovoltaic capacity or to install grid-connected photovoltaic capacity independent of the telecommunications facilities.

(c) To prepare detailed specifications for the preferred grid-connected photovoltaic supply option chosen.[2]

3. OUTPUTS [3] [4]

(a) An inception note.

(b) A debriefing note and minutes from the debriefing meeting(s).

(c) A feasibility study report.

(d) A document on the most optimal photovoltaic supply option.

(e) A hardware specification report.

4. ACTIVITIES

[1] These Terms of Reference has been prepared by UNESCO/UNDP-Apia with significant input from a rural energy expert. In addition *Hybrid Energy Systems – Resource Book*, Renewable Energy Centre, Brisbane Institute of Technical and Further Education (TAFE), Australia has been consulted extensively. UNESCO/UNDP-Apia would like to thank very much the rural energy expert for providing input and the Renewable Energy Centre for forwarding relevant chapters of the Resource Book.

[2] Please note that the specification will not include size and type of diesel gensets. The existing gensets in Tokelau will be utilised in the future hybrid diesel/photovoltaic system.

[3] All outputs from the consultancy are solely the property of UNESCO. E.g. UNESCO can distribute as widely as it finds appropriate.

[4] If appropriate the consultant may with the prior consent of UNESCO-Apia decide to include output b, c, d and e in one report.

The scope of work for the consultancy will include, but not necessarily be limited to, the following activities:

<u>REGARDING OUTPUT A – INCEPTION NOTE:</u>

(a) Study and review relevant background material.

(b) Identify key project stakeholders.

(c) Write-up inception note, comprising the consultant's understanding of the project and tasks; identification of issues crucial to the project viability; and comments to this TOR.

<u>REGARDING OUTPUT B - A DEBRIEFING NOTE AND MINUTES FROM THE DEBRIEFING MEETING(S):</u>

(a) Prepare debriefing note, based on preliminary findings, conclusions and recommendations.

(b) Discuss debriefing note with the Government of Tokelau, the General Manager and/or other representatives from the Tokelau Power System (e.g. electrical and mechanical staff on each atoll) and other relevant local stakeholders such as TeleTok and USPNet and UNDP/UNESCO-Apia before departure. Prepare minutes of the meeting(s).

<u>REGARDING OUTPUT C - A FEASIBILITY STUDY REPORT:</u>

In general:

Describe and assess the technical, economical and institutional feasibility of converting the four (4) stand-alone photovoltaic powered telecommunication facilities in Tokelau into grid-connected photovoltaic capacity. A basic premise for the feasibility study is that the reliability of the power supply for the telecommunication facilities should not be decreased significantly. The telecommunication facilities should not be put in a less optimal situation regarding reliability compared to the situation today.

In particular:

(a) Undertake problem analysis. The analysis might include but not necessarily be limited to the following; 1) the present power supply situation; 2) problems to be addressed (legislative, institutional, human resource, technical, environmental, financial, security of supply, etc.); and 3) present and potential demand for power services. A key here will be the load structure including peak and minimum power requirements, daily load curves and their variability, and forecasts of these parameters for the next 5-10 years. A survey of existing appliances being used in households and their daily use times and the inventory of other loads on the islands should be considered (since it may well turn out that the most appropriate design for supplying power on the islands is to separate the domestic and non-domestic loads, running the domestic load from PV and the non-domestic from diesel).

(b) Undertake technical feasibility. The *first part* of the technical assessment will answer the following questions: (1) what are the technical problems that would be faced and is the conversion technically reasonable; and (2) would the existing systems have the capacity necessary to provide the needed power and if not what would have to be added. The *second part* of the technical assessment will be dependent on the results of the first part; (1) if the conversion is not technically feasible, no further work shall be done; or (2) if the capacity of the conversion would not be sufficient but the conversion seems technically reasonable, the required added capacity to the telecom conversion should be assessed and described. The feasibility study should continue on this basis including assessing in detail, technology and project engineering. This assessment might include but not necessarily be limited to the following; 1) present and forecast needed power supply capacities and characteristics; 2) proposed standards of power supply; 3) power plant technology options and choice of technology/process including merits of technology; 4) power supply network technology options and choice of technology; 5) infrastructure (e.g. site, wharf, access roads, etc; 6) plant lay out; 7) overall building, machinery and equipment specifications; 8) procurement and construction supervision model (foreign – local supplies); and 9) operation and maintenance engineering requirements (e.g. spare parts and after sales services).

(c) Describe possible future project/plant organisation. The description might include but not necessarily be limited to the following; 1) project preparation organisation (e.g. involved parties, possible technical support and their roles and responsibilities); 2) project implementing organisation (e.g. implementing agency, other involved parties, their roles and responsibilities including construction and installation supervision), 3) power supply entity organisation (e.g. existing (if an add-on project), after project implementation and roles and responsibilities); 4) job positions to be filled (e.g. recruitment needs, availability of relevant workforce within reasonable distance from the project); and 5) training needs.

(d) Briefly outline training and technical assistance programme. The outline might include but not necessarily be limited to the following; 1) specification of staff/positions to be trained and the training subjects; 2) training programme (e.g. content and duration of courses, participants, on-the-job or classroom; local regional or overseas); 3) technical assistance programme (e.g. specification of expertise needed, time schedule for inputs, placing and role of expert(s) in the project/plant organisation).

(e) Outline budget for converting the stand-alone photovoltaic powered telecommunication facilities in Tokelau into grid-connected photovoltaic capacity. The outline might include but not necessarily be limited to the following: 1) investment budget; and 2) operation budget.

(f) Undertake economic comparison between stand-alone diesels, stand alone PV and hybrid PV/Diesel. A 15-year term and 6% discount rate (when inflation is not considered) should be applied.

(g) Undertake assumptions and risks analysis.

REGARDING OUTPUT D - A DOCUMENT ON THE MOST OPTIMAL PHOTOVOLTAIC SUPPLY OPTION

(a) Briefly compare the two overall photovoltaic power supply options based on technical, economical and institutional issues. Basis for the comparison will be the outputs from the feasibility study mentioned above (regarding converting the existing stand-alone photovoltaic powered telecommunication facilities to grid-connected capacities), preliminary data concerning the option of installing new grid-connected PV capacity and other relevant information.

(b) Briefly justify the preferred photovoltaic gird-connected supply option with regard to technical, economical and institutional issues.

(c) Select the preferred photovoltaic gird-connected supply option in agreement with the Government of Tokelau and relevant local stakeholders such as the Tokelau Power System, TeleTok and USPNet and in consultation with UNESCO- and UNDP-Apia.

REGARDING OUTPUT E - A DETAILED HARDWARE SPECIFICATION REPORT:

In general:

(a) Specify the most optimal system components and configuration of the photovoltaic component of the future diesel/photovoltaic hybrid system. On an overall level the design concept should be applicable to the power system on all three atolls, but their slightly different load patterns and diesel engine types should be taken into consideration. In addition the design should reflect the extreme remoteness of the atolls hindering day-to-day specialist operational and maintenance support. Finally the design specifications should not cut out competition unnecessarily during the subsequent tender for hardware (i.e. it should be as generic in nature as possible).

(b) During the design process; 1) establish design criteria; 2) assess end-use services, energy demand for each, and energy source to task matching; 3) assess solar resource and select site(s); 4) survey available equipment and costs; 5) undertake system sizing and determine components; 6) determine balance-of system (BOS) sizing; 7) assess and determine most optimal control system and control strategies; and; 8) optimise system specifications and match budget.

(c) Prepare system specification documentation. This will be undertaken with the subsequent tender process and management in mind.

(d) During the whole design process, consult with relevant local stakeholders such as the Government of Tokelau, Tokelau Power System, TeleTok and USPNet and the community at large (women in particular).

In particular:[5]

(a) Determine system design criteria such as; 1) simplicity; 2) least life cycle costs; 3) high output; 4) high efficiency; 5) system must operate safely; 6) high reliability (redundancy and fault tolerance); 7) low maintenance; 8) flexibility for expansion; 9) minimum environmental effects; 10) consideration of availability of spare parts; and 11) consideration of aesthetics in consultation the Government of Tokelau and relevant local stakeholders such as the Tokelau Power System, TeleTok and USPNet. A predetermined design criterion is available capital for investment (as specified in the budget of the UNDP Project Document). This puts clear limitations on the design. In addition the specifications must meet relevant agreed upon standards for electrical systems, buildings, etc. (NZ standards is the most likely outcome).

(b) Assess the solar energy resources available based on pre-existing weather data from Tokelau and Samoa plus data from the stand-alone photovoltaic facilities and other relevant sources. Include shading analysis regarding natural and man-made obstacles if needed.

(c) Select preferred technology type (e.g. crystalline, amorphous, etc), number and size/power ratings for the photovoltaic arrays taken into consideration available solar energy resources and daily and seasonal load profiles. The assessment might include information about; 1) appropriate standards; 2) panel, sub-array, array wiring; 3) array DC voltage; 4) bypass

[5] Please note that activity (a) to (m) below is based on the scenario that the chosen photovoltaic grid-connected supply option will be to install grid-connected photovoltaic capacity independent of the telecommunications facilities If it is chosen to convert the stand-alone photovoltaic powered telecommunication facilities in Tokelau into grid-connected photovoltaic capacity the activities overall will be the same.

diode locations and sizes; 5) module performance; and 6) predicted array output. In addition compare the technical and economic characteristics of a single massive array (with a single large inverter) and distributing the PV system in several independent modest sized modules (with several small inverters) among others space utilisation, system reliability, and spare part availability taken into consideration. Finally determine tilt angle and orientation of the modules.

(d) Select the number and size of suitable balance-of-system components for the hybrid diesel/photovoltaic systems, including system control/monitoring and inverter(s). The following factors among others should be considered in the selection of type of *inverters* such as static or rotary; 1) standards; 2) maximum demand that is required from the inverter; 3) surge demand that is required from the inverter; 4) future load growth; 5) whether the inverter is for a series, switched or parallel system design; 6) power efficiency at different load levels from 10% to 100% of rated capacity; 7) earthing arrangements; 8) no-load and stand-by power consumption; 9) DC operating voltage range; 10) voltage and frequency regulation; 11) power factor handling range; 12) performance with "problem loads" (e.g. half wave loads or other loads which draw large harmonic interferences); 13) electromagnetic interference; 14) soft start capability; 15) control of operating parameters; 16) protection (thermal, electrical) and weather-proofing; and 17) load profile.

(e) Optimise and finalise the system specifications based on a mix of design criteria such as cost, availability, reliability, maintenance, environmental factors, convenience, etc. When *optimise* the system specification the following can be included; 1) vary the size of the PV arrays; 2) vary control strategies; and 3) change system configuration. When *finalise* the system specifications the following can be included; 1) budget matching; 2) life cycle cost minimisation; 3) check that all agreed upon design criteria have been met; and 4) balance conflicting client(s) requirements.

(f) Determine and map the exact location of the PV arrays and balance-of-system components on each of the three atolls. The assessment might include but not necessarily be limited to the following; 1) power quality; 2) accessibility, 3) exposure to corrosion; 4) exposure to storms/hurricanes; 5) exposure to lightning, 6) costs; 7) possible negative effects on water catchments if installed on roofs; 8) land availability, and 9) community awareness and involvement.

(g) Determine utility interconnection. This assessment might include but not necessarily be limited to the following; 1) appropriate standards; and 2) location point of connection to the utility grid.

(h) Specify control system (e.g. manual, automatic, degree of sophistication, etc.) and control strategies. In determining the control strategy the following among others will be taken into consideration; 1) what individual items need to be controlled; 2) how much control these items will need; and 3) what control the system operators (e.g. Tokelau Power System, TeleTok and USPNet) want, e.g. generator running hours. Ensure that the control strategies meet the agreed design criteria. Subsequently, determine the optimal values for each of the control parameters.

(i) Calculate and estimate system performance parameters given load data, resource data, equipment specifications, configuration and control strategy including final estimates of; 1) the load fraction contribution from the photovoltaic and the genset components respectively; 2) genset run time; 3) fuel usage; 4) power production costs; 5) diesel fuel savings, 6) diesel cost savings; and 7) CO_2 reductions.

(j) Specify the electrical components. The electrical specifications might include but not necessarily be limited to the following; 1) DC wiring type; 2) DC wiring size; 3) acceptable voltage loses; 4) AC wiring type; 5) AC wiring size; 6) wiring terminations; 7) overcurrent and over temperature protection; 8) disconnect locations and hardware; 9) grounding of conductors; grounding of metal non-conductors; 10) bypass diodes; 11) blocking diodes; 12) surge and lightning protection; 13) instrumentation; and 14) junction box locations and ratings.

(k) Specify mechanical components. The mechanical specifications might include but not necessarily be limited to the following; 1) array mounting design; 2) mechanical strength and compatibility with local code requirements; 3) environmentally compatible materials; 4) mounting hardware compatibility; 5) weather sealing materials and approach; 6) accessibility for array maintenance; 7) safety; and 8) aesthetics.

(l) Specify the operation and maintenance requirements for the photovoltaic components of the hybrid power system and the operation requirements of the future diesel/photovoltaic hybrid system.

(m) Undertake assumptions and risks analysis.

5. DOCUMENTARY SOURCES

The following documents among others will be made available:

(a) The UNDP Project Document for the Tokelau PV Project.

(b) The Project Proposal for the Tokelau PV Project prepared by UNESCO-Apia as part of the Tokelau Power Supply SPPD Project.

(c) Relevant Quarterly Reports and other relevant documents prepared to NZAID as part of the Tokelau Power Project.

(d) Relevant Quarterly Reports and other documents prepared to NZAID as part of the Tokelau Telecommunication Network project.

(e) Relevant design and performance documents from the USPNet station on Atafu.

6. REPORTING

(a) Draft feasibility study report in electronic format submitted to the Government of Tokelau and relevant local stakeholders such as the Tokelau Power System, TeleTok and USPNet and UNESCO/UNDP-Apia for input.

(b) Final feasibility study report in electronic format submitted to UNESCO-Apia.

(c) Draft report in electronic format on the most optimal photovoltaic supply option submitted to Government of Tokelau and relevant local stakeholders such as the Tokelau Power System, TeleTok and USPNet and UNESCO/UNDP-Apia for input.

(d) Final report in electronic format on the most optimal photovoltaic supply option submitted to UNESCO-Apia.

(e) Draft report in electronic format of the hardware design submitted to Government of Tokelau and relevant local stakeholders such as the Tokelau Power System, TeleTok and USPNet and UNESCO/UNDP-Apia for input.

(f) Final report in electronic format submitted to UNESCO-Apia.

All reports should be in Microsoft Word or Adobe Acrobat format, with no restriction in access.

7. INPUT [6]

Organisation	Input
Government of Tokelau	a) Provide relevant background information to the consultant regarding the government of Tokelau and its objectives, strategies, policies, programmes, plans, activities, etc. for the power sector; b) Assist with logistics concerning the field visit to Tokelau; c) Provide hourly load data for the power systems on each atoll as well as peak and minimum loads; d) assist in locating resource data; and e) Provide input on the draft reports.
UNESCO/UNDP-Apia	a) Organise the consultancy for the detailed design of hardware; b) Fund the consultancy for detailed design of hardware; c) Provide consultant with copies of documentary sources; d) Provide relevant background information to the consultant regarding UNDP/UNESCO (Apia) and its objectives, strategies, policies, programmes, plans, activities, etc.; e) If possible participate in the field visit to Tokelau; and f) Provide input on the draft reports.
NZAID	a) Provide copies of relevant Quarterly Reports and other relevant documents prepared to NZAID as part of the Tokelau Power Project and the Telecommunication Network project, and b) Assist the consultant in locating solar resource data at the NZ Weather office

[6] Please note that the input specifications in addition apply for the TOR for the EIA (appendix B) and Tender Management (appendix C).

APPENDIX B

TERMS OF REFERENCE

ENVIRONMENTAL IMPACT ASSESMENT (EIA) OF THE PV PROJECT AND THE TOKELAU POWER PROJECT

1. BACKGROUND

It has been decided to undertake an Environmental Impact Assessment (EIA) of the PV Project and the already implemented Tokelau Power Project (refurbishment of the diesel electricity generation capacity as well as the distribution network).

The EIA (as minimum) is guided by two publications from the South Pacific Regional Environment Programme (SPREP) and Asian Development Bank (ADB) respectively. The former delineating the overall EIA approach applicable in a Pacific Island Country context and the latter specifying the EIA procedures applicable for (thermal) power projects in a developing country context.

2. OBJECTIVE

To provide the decision makers in Tokelau with an account of the environmental implications of the proposed PV Project and identify, describe and recommend feasible mitigation measures for minimising, eliminating or offsetting unavoidable adverse effects from the Tokelau Power Project.

3. OUTPUTS [1]

(a) An inception note.

(b) A debriefing note and minutes from debriefing meeting.

(c) An EIA study report.

4. ACTIVITIES

The scope of work for the consultancy will include, but not necessarily be limited to, the following activities:

REGARDING OUTPUT A – AN INCEPTION NOTE:

(a) Study and review relevant background material.

(b) Write-up inception note, comprising the consultant's understanding of the project and tasks; identification of issues crucial to the project viability and comments to this TOR.

REGARDING OUTPUT B – A DEBRIEFING NOTE AND MINUTES FROM THE DEBRIEFING MEETING:

(a) Prepare debriefing note, based on preliminary findings, conclusions and recommendations.

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(b) Discuss debriefing note with relevant departments from the Government of Tokelau, the General Manager and/or other representatives from the Tokelau Power System and other relevant local stakeholders such as TeleTok and USPNet and UNDP/UNESCO-Apia before departure. Prepare minutes of the meeting(s).

REGARDING OUTPUT C – AN EIA STUDY REPORT:

In general:

(a) Conduct ex ante EIA of the PV Project and ex post EIA of the Tokelau Power Project.

(b) Conduct a study sufficient; 1) to make an assessment which delineates the significant environmental effects of the projects; 2) to describe and quantify the effects; 3) to describe feasible mitigation measures for minimising, eliminating, or offsetting unavoidable adverse effects; and 4) to recommend the most appropriate mitigation and/or enhancement measures.

(c) During the whole process consult with relevant local stakeholders such as the Government of Tokelau, Tokelau Power System, TeleTok and USPNet and UNESCO/UNDP-Apia.

In particular:

(a) Undertake Ex Post EIA of the Tokelau Power Project with a particular focus on identifying, describing and recommending feasible mitigation measures for minimising, eliminating, or offsetting unavoidable adverse effects concerning the refurbished diesel power supply system (e.g. with regard to noise and exhaust levels, handling and storage of diesel oil drums and waste oil, etc.). The study might include but not necessarily be limited to the following; 1) environmental problems due to project location (e.g. disruption of hydrology, resettlement, encroachment on precious ecology, encroachment on historical/cultural values, cooling water obstruction (excessive), flooding hazards, waste emissions related to site location, etc.; 2) environmental problems due to design (e.g. cooling water, pollution, equipment selection, environmental pollution control operations (surface water, groundwater, air quality, noise, bottom sludges, etc), impact on adjacent land economic uses including recreation/tourism, occupational health and safety hazardous spills/fires/explosions etc.),; 3) environmental problems during construction stage (e.g. silt runoff during construction, continuing erosion of unprotected areas, other construction hazards, monitoring during construction, etc.); 4) environmental problems relating to inadequate operations (e.g. inadequate O&M due to poor management, occupational health and safety programs, including accidents, nuisances from handling/transport of fuel, surface runoff from plant yard, operations monitoring, etc.; 5) realisation of feasible enhancement measures; 6) impacts from power transmission facilities (encroachment on precious ecology, depreciation of environmental aesthetics, , continuing erosion/silt runoff from uncovered exposed areas, etc.); and 6) overall critical review criteria (use of precious irreplaceable resources, accelerated resources for short-term gains, hazards to endangered species, increase in affluent/poor income gap, etc.).

(b) Undertake ex ante EIA of the PV Project. The study might include but not necessarily be limited to the following; 1) environmental problems due to project location; 2) environmental problems due to design; 3) environmental problems during construction stage; 4) environmental problems relating to inadequate operations; 5) realisation of feasible enhancement measures; and 8) overall critical review criteria.

5. DOCUMENTARY SOURCES

In addition to the documents specified in Appendix A;

(a) Environmental Guidelines for Selected Industrial and Power Development Projects, Office of the Environment, Asian Development Bank (ADB), 1993

(b) A Guide to Environmental Impact Assessment in the South Pacific, South Pacific Regional Environment Programme (SPREP), 1993

6. REPORTING

(a) Draft EIA report in electronic format submitted to the Government of Tokelau and relevant local stakeholders such as the Tokelau Power System, TeleTok and USPNet and UNESCO/UNDP-Apia for input.

(b) Final report in electronic format submitted to UNESCO-Apia.

All reports should be in Microsoft Word or Adobe Acrobat format, with no restriction in access.

APPENDIX C

TERMS OF REFERENCE

TENDER MANAGMENT FOR THE PV PROJECT

1. BACKGROUND

THE PROCUREMENT OF THE NEEDED CAPITAL EQUIPMENT AND ACCESSORIES (INCLUDING ON-SITE TRAINING IN OPERATION AND MAINTENANCE) ASSOCIATED WITH THE PV PROJECT WILL BE GUIDED BY THE GENERAL PRINCIPLES, GUIDELINES, POLICIES, AND PRACTICES OF THE UNITED NATIONS DEVELOPMENT PROGRAM (UNDP). UNDP'S GENERAL PROCUREMENT PRINCIPLES ARE AS FOLLOWS: A) BEST VALUE FOR MONEY, B) FAIRNESS, C) COMPETITION, AND D) INTEGRITY.

2. OBJECTIVE

To manage the procurement of the needed capital equipment and accessories (including on-site training in operation and maintenance) associated with the PV Project.

3. OUTPUTS 2

(a) An inception note.

(b) Solicitation documents.

(c) Evaluation report.

(d) A final contract (ready for signature). .

4. ACTIVITIES

The scope of work for the consultancy will include, but not necessarily be limited to, the following activities:

REGARDING OUTPUT A – AN INCEPTION NOTE:

(a) Study and review relevant background material.

(b) Write-up inception note, comprising the consultant's understanding of the project and tasks; identification of issues crucial to the project viability and comments to this TOR.

REGARDING OUTPUT B – SOLICITATION DOCUMENTS:

In general:

(a) Prepare solicitation documents. The documents should include but not necessarily be limited to the following; 1) an invitation to offer; 2) instructions to the Offerors; 3) form of the Offer requested (bid, proposal or quotation); 4) form of the proposed contract; 5) conditions of contract – both general and specific; 6) technical design requirements based on the outcome of the specification of hardware (please refer to Appendix A); 7) evaluation criteria; and 8) minimum qualification requirements.

(b) During the whole tender process, consult with relevant local stakeholders such as the Government of Tokelau, Tokelau Power System, TeleTok and USPNet and UNESCO/UNDP-Apia.

In particular:

(a) Determine procurement modality, e.g. Request for Quotation, Invitation to Bid, or Request for Proposal.

(b) Determine type of competition, e.g. Open International Competition or Limited International Competition (e.g. via Pre-qualification or Expression of Interest).

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(c) Prepare solicitation documents including information about; 1) alternate proposals (e.g. suppliers should be informed of whether alternative proposals will be considered or not); 2) modifications to bids/proposals (e.g. the supplier should be informed that, if he has delivered, posted or dispatched the offer prior to the formal submission date, he has the right to modify or make corrections to it); 3) currencies and payments; 4) bid/proposal security (if appropriate); 5) performance security (if appropriate); and 6) methods for offerors' queries (e.g. correspondence method or pre-bid/proposal conference method).

(d) Prepare instructions to the Offerors. The instructions might include but not necessarily be limited to the following; 1) the language of the offer; 2) the number of copies of the offer that are required; 3) validity of the offer; 4) a document other than those issued as part of the solicitation document which the supplier must include with his offer (e.g. technical description or drawings, quality control, environmental impact, etc.), 5) procedures for issuing addenda to the solicitation documents; 6) procedures for dealing with queries raised by suppliers; 7) instructions for packing, labelling and addressing the offer; and 7) circumstances under which alternative offers may be submitted; 8) arrangements for opening of tenders; 9) procedures for dealing with arithmetic errors found in offers during evaluation; 10) evaluation criteria; and 11) rules relating to disqualification/rejection of offers (e.g. late arrivals, altered figures, incomplete submissions and deviations).

REGARDING OUTPUT C – AN EVALUATION REPORT:

In general:

(a) Provide receipt of Offers and undertake Opening of Bids (if appropriate)

(b) Undertake evaluation of offers.

(c) Undertake award in consultation with the Government of Tokelau and relevant local stakeholders such as the Tokelau Power System, TeleTok and USPNet and UNESCO/UNDP-Apia for input. A Contract Committee with representatives of the before mentioned stakeholders possibly will have to be established. Among others the objective would be to review the procurement process to ensure that it is fair, competitive, transparent and provides the best value for money.

In particular:

(a) Undertake evaluation of offers. The evaluation criteria and basis of award of offers will differ depending on the chosen procurement modality i.e. Request for Quotation, Invitation to Bid or Request for Proposals. In the case of *Evaluation of Quotations* the evaluation should be based on the following factors among others; 1) conformity to specifications/TOR; 2) product quality, i.e. conformity to national/international product standards; 3) promised delivery time; 4) complying with UNDP General Terms and conditions; 5) in-country after-sales maintenance facilities; and 6) landed price. In the case of *Bid Evaluation* the evaluation should be based on the following factors among others; 1) conformity to specifications; 2) product quality, i.e. conformity to national/international standards; 3) delivery time; 4) complying with the UNDP General Terms and Conditions; 5) after-sales services; 6) spare parts availability; 7) technical and financial capacity of the supplier; and 8) landed price. In the case of *Evaluation of Proposals* the evaluation must follow the process and criteria indicated in the Request for Proposal. Some/all relevant local stakeholders such as the Government of Tokelau, Tokelau Power System, TeleTok and USPNet and UNESCO/UNDP-Apia will be involved in the selection process.

<u>REGARDING OUTPUT D – A FINAL CONTRACT (READY FOR SIGNATURE):</u>

In general:

Prepare contract. The contract should include but not necessarily be limited to the following; 1) the detailed specifications of the goods, works and services to be supplied; 2) rights, obligations, functions, authority, etc. of the UNDP, the supplier and other relevant actors; 3) payment terms; and 4) shipping and insurance.

5. DOCUMENTARY SOURCES

In addition to relevant documents specified in Appendix A;

(a) UNDP Procurement Manual, Bureau of Management, Office of Legal and Procurement Support, February 2002.

6. REPORTING

(a) Draft solicitation documents in electronic format submitted to the Government of Tokelau and relevant local stakeholders such as the Tokelau Power System, TeleTok and USPNet and UNESCO/UNDP-Apia for input.

(b) Final solicitation documents in electronic format submitted to UNESCO-Apia.

(c) Draft evaluation report forwarded to the Government of Tokelau and relevant local stakeholders such as the Tokelau Power System, TeleTok and USPNet and UNESCO/UNDP-Apia for input.

(d) Final evaluation report forwarded to UNESCO-Apia.

(e) Draft contract in electronic format submitted to the Government of Tokelau and relevant local stakeholders such as the Tokelau Power System, TeleTok and USPNet and UNESCO/UNDP-Apia for input.

(f) Final contract forwarded to UNESCO-Apia.

All reports should be in Microsoft Word or Adobe Acrobat format, with no restriction in access.