

IUCN

Technical Assistance for the Tuvalu Photovoltaic Electricity Network Integration Project (TPVENIP)

G. Zieroth December 2008

FINAL REPORT



Technical Assistance for the Tuvalu Photovoltaic Electricity Network Integration Project (TPVENIP)

IUCN-Oceania in collaboration with the Tuvalu Government through the Tuvalu Electricity Corporation (TEC) and the Tuvalu Department of Energy has commissioned a consultancy for the Tuvalu Photovoltaic Electricity Network Integration Project (TPVENIP).

This Final Report describes the project together with major findings and recommendations. Tender documents for a competitive procurement of the equipment and related training of TEC staff are provided as an annex.

Author: Gerhard Zieroth
Contact: gzieroth@yahoo.de

ABBREVIATIONS AND ACRONYMS.....	5
ENERGY CONTENT AND CONVERSIONS	5
1. INTRODUCTION	6
1.1 Background	6
1.2 Objective	6
1.3 Scope of Assignment.....	6
1.4 The Report.....	7
1.5 Acknowledgements.....	7
2. COUNTRY PROFILE TUVALU	8
2.1 General Setting.....	8
2.2 Economy	9
2.3 Energy in Tuvalu.....	9
2.4 Tuvalu Electricity Corporation (TEC).....	11
3. THE VAITUPU POWER SYSTEM.....	13
3.1 General Setting.....	13
3.2 Existing Power Infrastructure	15
3.2 Load and Demand Forecast	17
3.3 Operating Cost Forecast.....	20
3.4 Investment Requirements	21
4. SOLAR ENERGY FOR VAITUPU.....	22
4.1 Solar Energy Experience in Tuvalu	22
4.2 System Design Options for Vaitupu	24
4.2 Solar System Location Vaitupu	29
4.3 Benefits	30
4.4 Capacity Building and Institutional Strengthening	32
5. OTHER OUTER ISLAND POWER SUPPLY.....	33
6. RECOMMENDATIONS	35
ANNEXES.....	36
Annex 1 Terms of Reference.....	37
Annex 2 Operating Cost Forecasts TEC Vaitupu.....	41
Annex 3 Load Data Fogafale Grid Connected System	42

Annex 4 Consultations	43
Annex 5: Concept Note Renewable Energy Electrification Outer Islands Tuvalu	45
Annex 6: Capacity Building RE Systems Tuvalu.....	49

Abbreviations and Acronyms

ADB	Asian Development Bank
AUD	Australian Dollars
NBT	National Bank of Tuvalu
DBU	Dispatchable Battery Unit
DSM	Demand Side Management
EDF	European Development Fund
EIB	European Investment Bank
EU	European Union
GDP	Gross Domestic Product
GoT	Government of Tuvalu
GWh	Gigawatt hour
kV	Kilo-Volts (thousands of volts)
kVA	Kilo-Volt-Amperes (Thousands of Volt Amperes of power)
kW	Kilo-Watt (Thousands of Watts of power)
kWh	Kilowatt Hour
LRP	Loss Reduction Program
MDG	Millennium Development Goals
MWh	Megawatt Hour
NGO	Non Government Organisations
NPV	Net Present Value
NZ\$	New Zealand Dollars
PIEPSAP	Pacific Islands Energy Policy and Strategic Action Planning
PIFS	Pacific Islands Forum Secretariat
PV	Photo-Voltaic
RFQ	Request for Quotation
ROI	Return on Investment
SFC	Specific Fuel Consumption
TCS	Tuvalu Co-operative Society
TEC	Tuvalu Electricity Corporation
TOR	Terms of Reference
TTF	Tuvalu Trust Fund
UN	United Nations
UNDP	United Nations Development Programme
US\$	US Dollar
WB	World Bank

Energy Content and Conversions

Fuel	Unit	Typical Density kg / litre	Typical Density l / tonne	Gross Energy MJ / kg	Gross Energy MJ / litre	Oil Equiv.: toe / unit (net)	Kg CO ₂ equivalent ^e	
							per GJ	per litre
Vegetable & Mineral Fuels:								
Crude oil	tonne			42.6		1.00		
Coconut oil	tonne	0.920	1,100	38.4		0.90		
LPG	tonne	0.510	1,960	49.6	25.5	1.17	59.4	1.6
Gasoline (super)	tonne	0.730	1,370	46.5	34.0	1.09	73.9	2.5
Gasoline (unleaded)	tonne	0.735	1,360	46.5	34.2	1.09	73.9	2.5
Aviation gasoline (Avgas)	tonne	0.695	1,440	47.5	33.0	1.12	69.5	2.3
Lighting Kerosene	tonne	0.790	1,270	46.4	36.6	1.09	77.4	2.8
Multi Purpose Kerosene	tonne	0.795	1,260	46.4	36.9	1.09	70.4	2.6
Automotive diesel (ADO)	tonne	0.840	1,190	46.0	38.6	1.08	70.4	2.7
High sulphur fuel oil (IFO)	tonne	0.980	1,020	42.9	42.0	1.01	81.5	3.4
Low sulphur fuel oil (IFO)	tonne	0.900	1,110	44.5	40.1	1.04	81.5	3.4

1. Introduction

1.1 Background

The Government of Tuvalu is placing a high priority to promotion of renewable energy as a means of cushioning its economy from increasing volatility in the international fuel markets. The massive energy cost increases experienced in the first half of 2008 had a devastating effect for Tuvalu: Energy cost increases were exacerbated by significant supply cost increases of all other imported products as well, including food, household equipment and building materials. The negative economic and social impacts are even more pronounced in the outer islands than on Funafuti creating hardship for their residents. At the same time renewable energy solutions are available to enhance energy security and reduce the economy's vulnerability towards external shocks.

Any actions aimed at reducing dependency on imported fossil fuel will also help decrease greenhouse gas (GHG) emissions, and put Tuvalu on the road of a sustainable and exemplary development, giving the nation a stronger bargaining position in international negotiations. TEC already operates a 40 kW grid connected PV system in Funafuti and the positive experiences to date encouraged the Government and TEC to pursue solar projects for outer islands as well.

1.2 Objective

Against this background described above, IUCN-Oceania in collaboration with the Tuvalu Government through the Tuvalu Electricity Corporation (TEC) and the Tuvalu Department of Energy has commissioned a consultancy for the Tuvalu Photovoltaic Electricity Network Integration Project (TPVENIP). The overall objective of TPVENIP is the promotion of the use of renewable energy resources through the implementation of cost effective, equitable, reliable, accessible, affordable, secure and environmentally sustainable energy systems. In this particular project, the implementation of a grid parallel Photovoltaic system was seen as a step towards achieving the above objective.

1.3 Scope of Assignment

The scope of work for the consultancy includes the following activities:

- Carry out a scoping mission to Vaitupu and accurately assess the actual current power demand and a 10 year projected demand for the Vaitupu grid;
- Estimate operating expenditure of the 10 year period;
- Estimate investment requirements to meet demand;
- Determine the technical feasibility or otherwise of the proposed PV integration system and future expansion;
- Recommend the most proven and appropriate option of PV system to match the Vaitupu grid characteristics base on the current and future demand;
- Estimate the replacement costs of the major components and anticipated fuel savings from the chosen PV system to match the Vaitupu grid characteristics and other proven PV systems.
- Identify the appropriate site/location for the installation of the PV system.

- Provide set of recommendations required for the sustainability of the project based on past experiences of PV system in the Pacific.
- Prepare tender documents for the design, supply and installation of the recommended PV system taken into consideration the tropical climate in Tuvalu.
- Liaise closely with the Contractor during the installation of the PV system;
- Liaise closely with the TEC Engineer designated to the project; and
- Ensure the TEC Engineer has full advantage of hands on experience available during the scoping mission and the installation of the PV system.
- Identify training areas required for the sustainability of the project and provide set of recommendations to strengthen the Institutional Capacity of the station.

A field trip to Vaitupu Island was organized using the Government vessel Manui as a charter. This was necessary as no regular ferry service was available at the time of the field mission. The boat charter however, provided TEC with an opportunity to supply 2000 litres of fuel to the island.

Mr Polu Tanei of TEC joint the consultant G. Zieroth and assisted during field work. Mr Mika Elisaia, manager of BP Tuvalu also participated in the field trip. The boat charter provided the opportunity for TEC to supply badly needed fuel to the island. During the field trip, TEC load sheets and power station records were analysed and TEC staff were interviewed. The TEC installations were examined and the mode of operation discussed with local TEC staff.

1.4 The Report

This report summarizes the consultant's data collection during the field mission and the findings and recommendations developed in consultation with the key stakeholders. The Final Report is based on an inception report a Debriefing Note and a Mission Report that were submitted to IUCN and TEC in October 2008 for scrutiny and comment. Suggestions and comments received after submission of the Field Report were integrated into this final version. The report presents a description of the project site and its power infrastructure, electricity demand forecasts and an assessment of the need for investment into Vaitupu's power infrastructure. Various options for PV based power generation are assessed and a system design for the identified solution is presented. Cost estimates are provided together with benefits that the system would generate. The findings and recommendations provided in the report are the basis for the tender document which is annexed to the report. The document will allow competitive procurement of the PV system.

1.5 Acknowledgements

This study has been realised in the framework of a regional energy initiative funded by the Italian Government through an agreement signed between the Government of Italy represented by the Ministry of Foreign Affairs and the Ministry of Environment, Lands and Sea and the Pacific SIDS Permanent Missions based at the United Nations in New York. The Government of Italy has in turn signed an agreement with IUCN to be the implementing agency for this programme. The author would like to express his gratitude to the donor. He would also like to acknowledge the guidance and support provided by Anare Matakeviti, IUCN-Oceania Energy Programme

Coordinator. The author would also like to thank Mafalu Lotulua, Polu Tanei Tealu Honolulu and Taaku Esekielu of TEC. Without their contributions, support and encouragement this study would not have been possible. We would also like to express our gratitude to the numerous residents of Vaitupu who have provided information and support in many ways and who have demonstrated a truly remarkable hospitality.

2. Country Profile Tuvalu

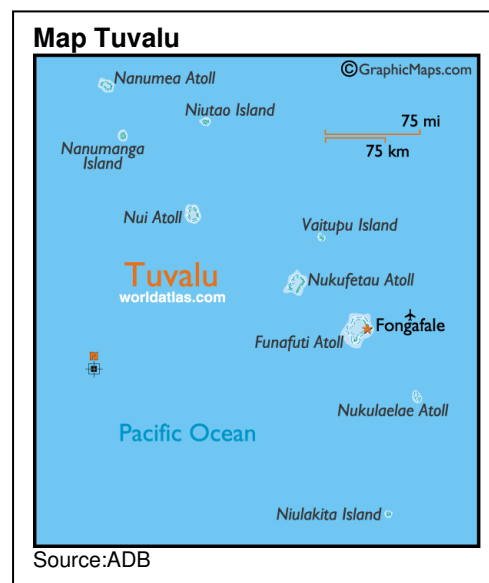
2.1 General Setting

Lying about 1100 km north of Fiji, the Tuvalu archipelago consists of six true atolls and three reef islands. The true atolls are Funafuti, Nanumea, Nui, Nukufetau, and Nukulaelae, while Nanumaga, Niulakita, and Niutao are single islands. Six atolls having a large lagoon enclosed by a reef and three raised coral islands having no large lagoon. The total land area is 26 km² and the EEZ is 900,000 km² in area. The islands are grouped in a southeast/northwest chain from 11° to 5°S Latitude clustered between 176° and 179° E Longitude. The largest island, Vaitupu, has a land area of about 5.6 km² while the smallest, Niulakita has about 0.42 km² of land. The climate is humid tropical, with no marked seasonal variations. Temperatures average about 28°C. The average annual rainfall varies from about 2,800 mm to 3,600 mm, depending on the island. Trade winds from the east moderate conditions for much of the year. The islands are occasionally affected by hurricanes, the hurricane season being from October to March.

Rising sea level has already resulted in increased saline intrusion into the groundwater, contaminating a part of the nation's very limited freshwater supplies, and in recent years, there has been increased flooding in parts of Funafuti during the high tides of February and September.

Tuvalu is one of the smallest sovereign countries in the world. The islands were declared a British protectorate in 1892, and administered as a colony jointly with the Gilbert Islands (now Kiribati) from 1915. Separate constitutions for the Ellice Islands, renamed Tuvalu, and the Gilbert Islands came into force in 1975, and in October 1978 Tuvalu became a fully independent nation.

Funafuti atoll has become the centre of government largely because of its large lagoon that has a deep water access to the sea for shipping and the airport that was constructed during World War II when Tuvalu was a staging area for the American assault on Japanese held islands to the north. Tuvalu's atolls are scattered across an exclusive economic zone. They are narrow and low-lying with Tuvalu's highest point being just three meters above sea level. Climate change and the potential rising sea levels displacing populations is of real concern to a low lying nation such as Tuvalu. Arrangements have already been made with the New Zealand Government concerning the evacuation of Tuvaluan residents if this event were to occur. The total population of Tuvalu is approx. 11,000 with about half the population living on Fongafale,



Funafuti. Population growth is estimated at 1.5% p.a. Vaitupu, the largest island of the group has a population of 1,600. With only 25.3 square kilometre of land surface, Tuvalu is a densely populated country. The nearly static population for the country as a whole is due mainly to migration to foreign countries, particularly Australia and New Zealand, rather than to a low rate of natural population growth. Although the outward migration has kept population pressures from increasing, the people migrating tend to have a higher level of education than the population on average and this has been a factor that has limited the ability of Government to locate qualified local staff to fill technical and administrative positions.

Each island (except tiny Niulakita) has several villages. Funafuti and Vaitupu each have nine villages although in many cases the villages are contiguous and boundaries are political rather than physical. On some islands, like most of Funafuti and Vaitupu, travel between villages is by road. In a few cases, villages are on different islets of the atoll and may only be accessed by boat from other villages.

2.2 Economy

Tuvalu is very small atoll economy with the prosperity of the economy hampered by limited natural resources, few industries, and limited export opportunities. Subsistence farming and fishing are the main economic activities. Commercial license fee earnings, remittances from overseas workers, official transfers, and income from Tuvalu Trust Fund (TTF) and the Falekaupule Trust Fund (FTF) have provided the country with the main sources of income. However, most recently the revenues from Internet domain name “.tv” and from telecommunication and fishing licensing fees have declined, causing fiscal and economic contraction. The economic growth rate has slowed down to 1-2% in the period 2005-2006 following an earlier period of public sector expansion. The GoT is the main employer in Tuvalu providing approximately 70% of salaried employment. The private sector is dominated by retailing companies and the largest trading company is the Tuvalu Cooperative Society.

Tuvalu is very dependent on external assistance with development aid amounting to over 33% of GDP. The public sector is still the dominant participant in the economy providing 70% of all employment, with the private sector playing only a limited role in the country's economic growth. Inflation has been low in the past five years, averaging 3.2% per annum and is projected to remain within the 2-3% range in the coming years. The private sector consists mainly of small shops and service providers on Funafuti plus agriculture for export to Funafuti on the outer islands. The high cost of access and limited development of tourist facilities has made tourism almost non-existent with most visitors arriving on business.

2.3 Energy in Tuvalu

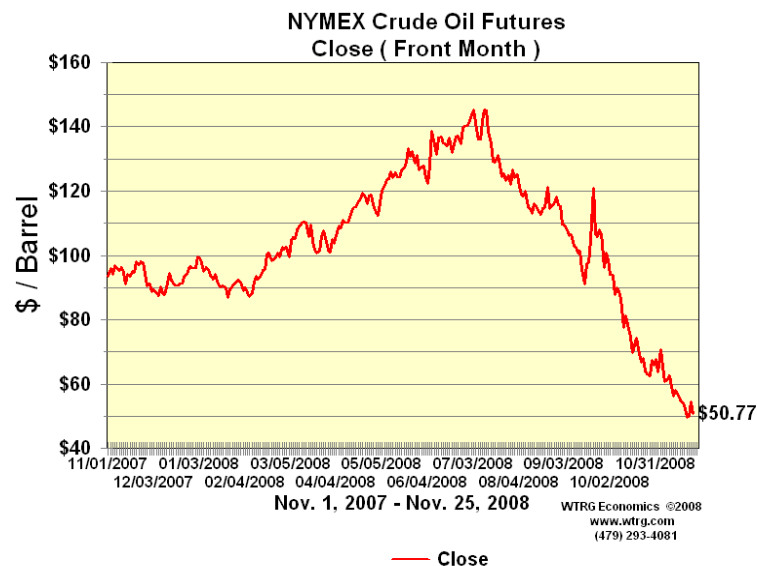
A comprehensive National Energy Policy Framework has been established by the Ministry of Works and Energy covering the next 15 years. Strategies have been put in place to ensure “adequate, secure and cost effective supply”, “efficient utilisation of energy” and “minimisation of negative impacts of energy production, conversion, utilisation and consumption upon the environment.” Tuvalu relies very heavily on imported fuels for commercial energy needs including 100% of transport and electricity generation (the chief uses), and a majority of household use including cooking, transport, refrigeration, and lighting. Some indigenous fuels such as biomass for cooking are used by households, but in Funafuti this use is minor.

At present energy services are provided by TEC (electricity), BP and Reef shipping (fuel) and Tuvalu Co-operative Society (TCS) (gas). It appears that BP intends to depart from Tuvalu which creates an opportunity for TEC to take a more significant role as an energy company and redeploy its significant staff resource. As TEC uses approximately 60% of imported fuels the corporation would be in a good position to expand and become a broader oriented energy provider along the model used in Marshall Islands where the local utility MEC provides services in electricity, gas, fuel and renewable energy.

Fuel imports through Fogafale harbor totalled 4 million liters in 2007 of which diesel accounted for 3 million litres, gasoline 0.7 million liters and multipurpose kerosene 0.3 million litres. Diesel is mainly consumed for power generation (1.7 million liters in 2007) and maritime transport. Over the last ten years there was little growth in fuel demand in Tuvalu reflecting slow growth in the economy and modest growth in population.

In the last two years, price volatility for petroleum has been high with a pronounced upward trend. International crude oil prices increased from US\$50/bbl in mid June 2005 to above US\$145/bbl in June 2008. Then - as a result of an international economic slow down - prices fell dramatically to 50 US\$ a barrel in November 2008 (Chart 1). Reasons for these price developments are complex and it is almost impossible to predict future developments with any degree of accuracy. It does appear, however, that the painful fuel price inflation experienced in the first half of 2008 is over.

Chart 1: Crude Oil Spot Prices



International fuel price changes are quite rapidly manifest in local fuel and electricity price changes. Fuel imports are a major component of Tuvalu's import bill. As affordable, stable and secure sources of energy are vital for the country's economic growth and prosperity, Government is actively seeking means to reduce dependence on imported fuels. Even if the Tuvalu will benefit from recent price drops development of world market prices will certainly remain out of the Government's control. Although energy price developments are notoriously difficult to predict, it is assumed for present purposes that prices below US\$100/ barrel of crude oil likely to in the medium term. Also it appears to be safe to assume that price volatility will continue, as the financial markets are extremely nervous and the political situation in the Middle East remains unstable. For fuel consumers such as TEC continued volatility

means that a large portion of their operating cost cannot be planned with accuracy. This uncertainty can be reduced through accelerated development of indigenous renewable energy.

As high reliance on imported fuel and exposure to price shocks will remain a serious problem for Tuvalu, affecting balance of payments, and growth prospects. Apart from supply side measures such as the development of renewable energy, there is significant potential for energy conservation and efficiency improvements in both the electricity and the liquid fuel sectors.

2.4 Tuvalu Electricity Corporation (TEC)

TEC is an incorporated entity under the Tuvalu Electricity Corporation Act with Mafalu Lotolua as its General Manager. Under this Act, TEC is authorised to generate and distribute electricity to all parts of Tuvalu. Presently, TEC supplies electricity to the eight largest islands. Under Tuvaluan law TEC has the “sole and exclusive right to supply electricity for sale within any supply area” Where TEC is unable to provide a reasonable supply of electricity (Section 6.2 of the Act) arrangements may be made for a licence to supply to be issued to a third party.

TEC’s installed capacity is in the order of 6 MW comprised solely of diesel generation on the eight largest islands (3x600 kW), and an older plant (2430kW) plus a 40 kW grid connected solar system on Funafuti. In the outer islands there are about 1,800 kW of relatively new (installed 1999/2000) plant. In 2007 peak load in the Fogafale system was 920 kW, with a load factor of 65%. The small outer island system typically have peak loads in the order of 30kW and load factors of 30 %. The larger system on Vaitupu has a peak load of 80 kW and a load factor of 47%.

Following a tariff review executed under the Pacific Island Energy Policy and Strategic Action Planning Project (PIEPSAP) in 2007 the Government of Tuvalu decided to adjust TEC’s tariffs to allow the corporation to regain a healthy financial position. Tariffs were increased and stand now at a level that is reflective of the operating cost of TEC. The new uniform tariff has an adjustable fuel component which currently stands at AUD 0.32 per unit. Fogafale customers are charged one cents more to cover for street lighting. For residential consumers, there is now an increasing block tariff as per table 1 below.

Table 1: TEC Tariffs October 2007

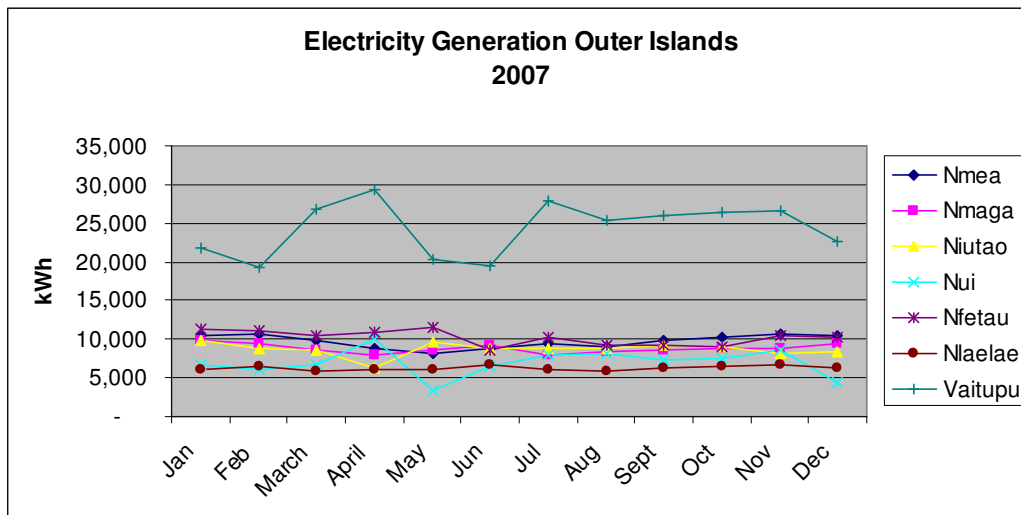
	Tariff		
	Block	Fogafale	Islands
Domestic	1-50 kWh	30	29
	51-100 kWh	39	38
	>100 kWh	56	55
Commercial		56	55
Government		56	55

Source: TEC

The 2002 census established that TEC supplied 73.5 % of Tuvalu’s households with power. Since 2000 the Government has undertaken an electrification program on Nui, Vaitupu and Nukulaelae aiming to achieve a high connection rate for the 400 unelectrified households on these islands. The island of Niulakita is now the only island where energy requirements for the approximately eight households are still being supplied by solar power. Consequently, electrification of residential households is now practically 100%.

In 2007 generation on all islands totalled at 747,000 kWh. During the same period, Fogafale power station generated 5.2 million kWh. Chart 2 shows monthly generation for 2007. The smaller islands have monthly generation of 10,000 kWh or less and show a fairly constant demand. Vaitupu's generation curve fluctuates between 20,000 and 30,000 kWh per month. These fluctuations can be explained by the school cycle of the Motofuoa Secondary School, by far the largest consumer on the island.

Chart 2 Outer Island Electricity Consumption 2007

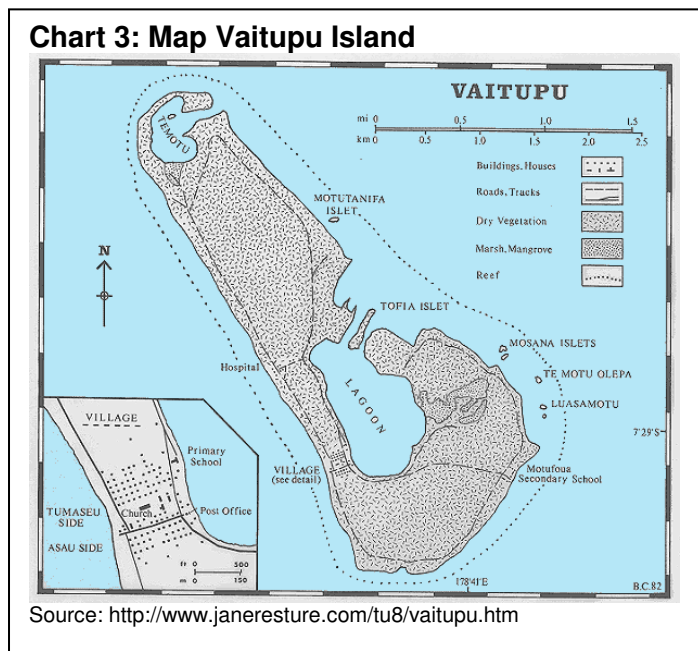


Source: TEC

3. The Vaitupu Power System

3.1 General Setting

Vaitupu is Tuvalu's largest outer island. It is located at 7.48 degrees south and 178.83 degrees west. Vaitupu consists of an oval shaped reef platform with a large central island and a number of smaller islets. They include (from south to north) the Lusamotu Islets, Te Motu Olepa, the Masana Islets and Motutanifa Islet. The outer reef is bordered by an extensive area of coral pavement which can be up to 700 m wide on the eastern side and averages around 200 m on the western side. At the southern end of the island two very small passages



(Tefuta and Alia Opeti Passages) cut across the coral pavement and connect to an interior lagoon. The passages do not allow entry by vessels larger than a traditional craft. With 1.6 km in length and 750 m across the lagoon is large enough to allow operation of seaplanes. A smaller lagoon is located at the far northern tip of the island (see chart 3).

With a total land area of 5 square kilometres and a population of 1600 Vaitupu has a low population density of 320 per square kilometre. This compares with 1600 on the main island of Fongafale. About half of the population lives scattered in the villages of Tumaseu and Asau (the main village); the balance lives at the Motufoua secondary school compound. There is a church, a primary school, one guesthouse, several trading stores and a post office. Water supply is usually through tanks that collect rainwater. Vaitupu has telecommunication facilities operated by Tuvalu Telecoms.

Harbor Facilities and Logistics

There is a small harbor facility on the Western site of the island directly at the located at Asau. The facility is protected from prevailing easterly winds and swells. The harbor has an entry that is approximately 25 meters wide. Its turning circle is approximately 30 meters and vessels above 25 meters in length cannot enter the harbor. The harbor is also quite shallow (see chart 4 for satellite image). Larger ferries have to unload onto lighters which then enter the harbor. Larger freight consignments can be brought into the harbor by barge. As there is no barge in Tuvalu, this means of transport requires barge charter from outside the country. Heavier goods such as vehicles are offloaded from the supply ships to provisory floating platforms that are build using several lighters tight together. A tractor and trailer is available on land to haul larger equipment such as generators to their destination on the island. There are also several 3 ton trucks which provide transport services on the island. Small motobikes are the main means of people transport.

Fuel supply for Vaitupu relies on 200 litre drums. Diesel is typically supplied from the main tanks of the ferries from which it is transferred to 200 litre drums which are then loaded onto lighters.

Chart 4 Asau Harbor and main Village



Source: Google Earth

Coconut Resources and Biofuel Potential

Vaitupu used to be a major copra producer. Coconut palms appear to be the dominant vegetation and the first impression with respect to Vaitupu is that it has abundant coconut resource. It even had its own oil extraction and soap manufacturing facility. However, the copra industry has essentially ceased to exist. At present coconuts are only harvested for household consumption. As coconut plantations still exist, and with some maintenance (cleaning of undergrowth, cutting of access) the plantations production could be re-established. Stratification of the resource is possible with a reasonable level of accuracy as even individual palms can be identified on available satellite images.

Coconut plantations are areas where the planting lines are visible in the satellite image. This type of coconut plantation covers an area of approximately 110 - 130 ha. Typical palm densities in the plantation areas are 120 trees per ha. Current productivity of the unmanaged plantations is difficult to estimate as the plantations have palms of different age. Palms in the understory are not visible in the satellite image, however, they can produce a significant amount of coconuts. Some stands may have reached senility and more detailed research would be required to determine the productive potential of Vaitupu's coconut plantations.

From experience in other similar locations, it is estimated that an annual production rate of 40 coconuts per palm can be achieved in Vaitupu. Total production would therefore be approximately 500,000 nuts per year. Assuming an average weight of 1.2 kg per nut and a copra content of 30%, total coconut oil production of Vaitupu would be in the order of 95,000 liters per annum. In other words, a biofuel project would be able to meet Vaitupu's diesel demand.

3.2 Existing Power Infrastructure

Vaitupu is currently supplied with power through a 11 KV 3 phase underground distribution network. The 11 kV distribution system was installed in 2002 and all its components seem to be in good condition. 9 step down substations provide 415 V power which is distributed mostly as single phase 240 V to 244 private 3 commercial and 23 institutional (government) consumers. All consumers are metered. Low voltage feeders are also underground and typically end with a pillar box from where the respective consumers are supplied.

Generation Assets

Power is generated at two locations: The main power house holds 2 Wilson P 100 (6 cylinder Perkins engine) each rated at 100 kW and one Wilson P 60 (4 cylinder Perkins engine) with a plate rating of 60 kW. All sets have logged approximately 20,000 operating hours and due to age and ambient temperatures they are de-rated to 100, 80 and 40 kW respectively. Table 2 provides a summary of the generation assets.

Table 3: TEC Generation assets Vaitupu

Generation Assets Vaitupu					
No	Genset	Plate Rating kW	Max Power kW	Operating Hours	Remarks
1	Wilson P 100	100	80	18330	Operational
2	Wilson P 60	60	40	16715	electrical fault
3	Wilson P 100	100	80	13843	under repair
4	Denyo	130	100	15045	operational

Source TEC 2007 Station Logistics Reports

The switchboard in the main power house allows automatic synchronization of the three generators. However at present only one of the P 100 sets is fully operational. The P 60 genset runs, but fails to communicate with the switchboard due to an electrical fault. One of the P 100 sets is under repair (starter motor problem).

TEC Generation Assets Vaitupu

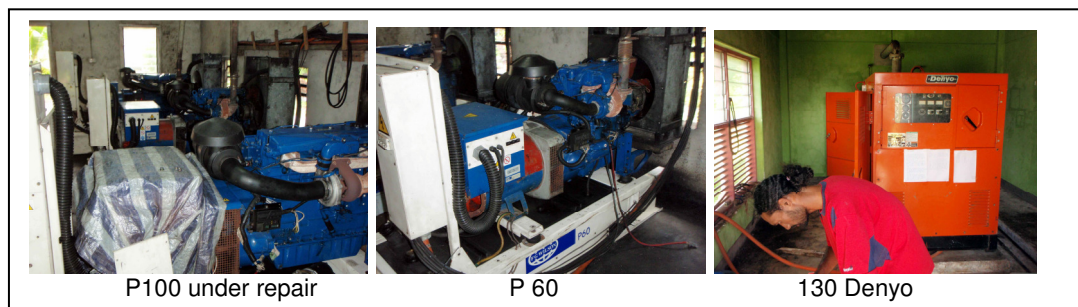


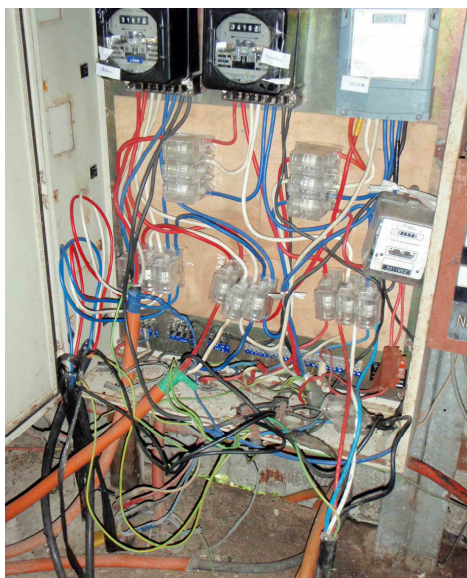
Photo: G. Zieroth

The second power source is located at the Motofua school complex. It is a 130 kW Denyo generator set located in a dedicated power house. This set has been provided under a Japanese funded upgrading of the secondary school. All sets have less than 20,000 operating hours and should have 5 – 8 years life left, provided that basic maintenance is performed.

Next to the power house holding the No 4 set sits another powerhouse that still accommodates an old Caterpillar generator set which is not operational and probably beyond repair or re-building. The old power house also holds a makeshift

switchboard and three meters for the three circuits of the school labeled 'Motufoua, Japan and Local'.

Switchboard at Motufoua



Mode of Operation

Power supply typically starts between 7 and 8 a.m. The operator first isolates the main transformers and starts the No 1 generator. When stable running is achieved the main circuits are connected. According to TEC log sheets, which record hourly values for loads, the typical start up load is in the order of 40-50 kW. This load drops back by 10% in the second hour of operation which can be explained by the significant refrigeration load in the system. When power is supplied all fridges and freezers come on line to reach set temperature levels after being out of operation during the night hours.

System load remains stable around 45 kW during the day until the afternoon break, which is from 14.00 –16.00. At 16.00 the

No 1 set is brought back on line, typically with a start up load of 40 kW. Throughout the supply cycle the power factor of the systems remains quite stable at around 0.97 -0.99.

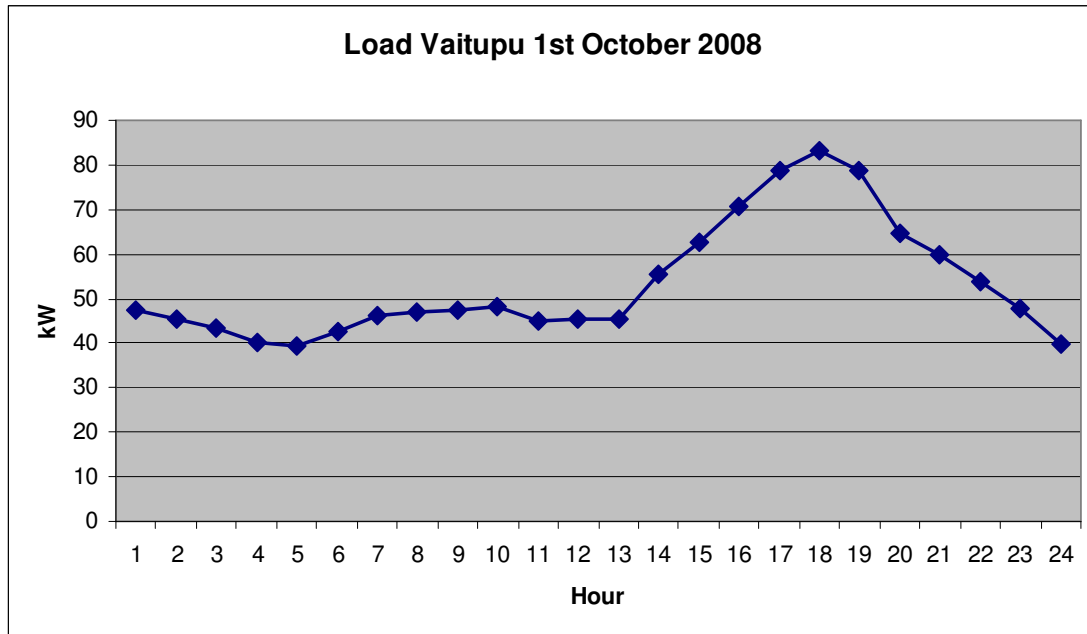
With an evening peak load in the order of 80 - 85 kW, the single P 100 set is unable to safely supply the peak. As a remedy, TEC isolates the school circuit - which is supplied through a 150 kVA transformer - typically at 5 p.m. and starts the 130 kW No 4 unit which then supplies the secondary school and the adjacent village in isolation from the rest of the grid. The switch from high voltage supply to the local generator is done at a make shift switchboard by pulling and inserting fuses (see picture above). This mode of operation does not allow TEC to supply the entire system from the 130 kW unit which would be capable of carrying the peak load.

Loads in the main system then fall to 35 – 40 kW while the school itself moves to its peak of 45 – 50 kW. Although the No 4 unit would provide enough output to meet the combined system demand this is currently not possible as the unit is connected to the low voltage circuit of the school. This leads to a sub-optimal operation of both the P 100 and the Denyo generator during the evening hours. Even during the evening peak which occurs around 6 – 8 p.m. both sets operate at less than 50 % of their output rating and therefore have a higher than necessary specific fuel consumption. This becomes more pronounced as the evening progresses and the system load falls back to 40 kW when both generators are switched off at midnight. TEC should therefore consider connecting the Denyo set to the 11 kV circuit. This would enhance system security, give the operator more flexibility and allow covering demand of the entire system by one generator.

It should be noted that the local TEC manager in Vaitupu has some discretion with regard to scheduling operating hours of the system. The major constraint is fuel supply which is currently not sufficient to cover a 24 hours supply. TEC has to control its operating cost and one way is to curtail fuel supply to its outer island operations. On certain occasions, however, 24 hours supply is provided. On 1 October 2008 (Independence Day) 24 hours supply was provided and the log sheets for such days

allow constructing a load curve for uninterrupted 24 h supply. On Independence Day the No 4 set was started at 16.00 with a start up load of 42 kW. Peak occurred at around 6.30 p.m. Chart 5 displays the Vaitupu 24 hour load curve for October 1st 2008.

Chart 5 Vaitupu Daily Load Curve



Source: TEC Vaitupu Log Sheets

3.2 Load and Demand Forecast

Historic Demand

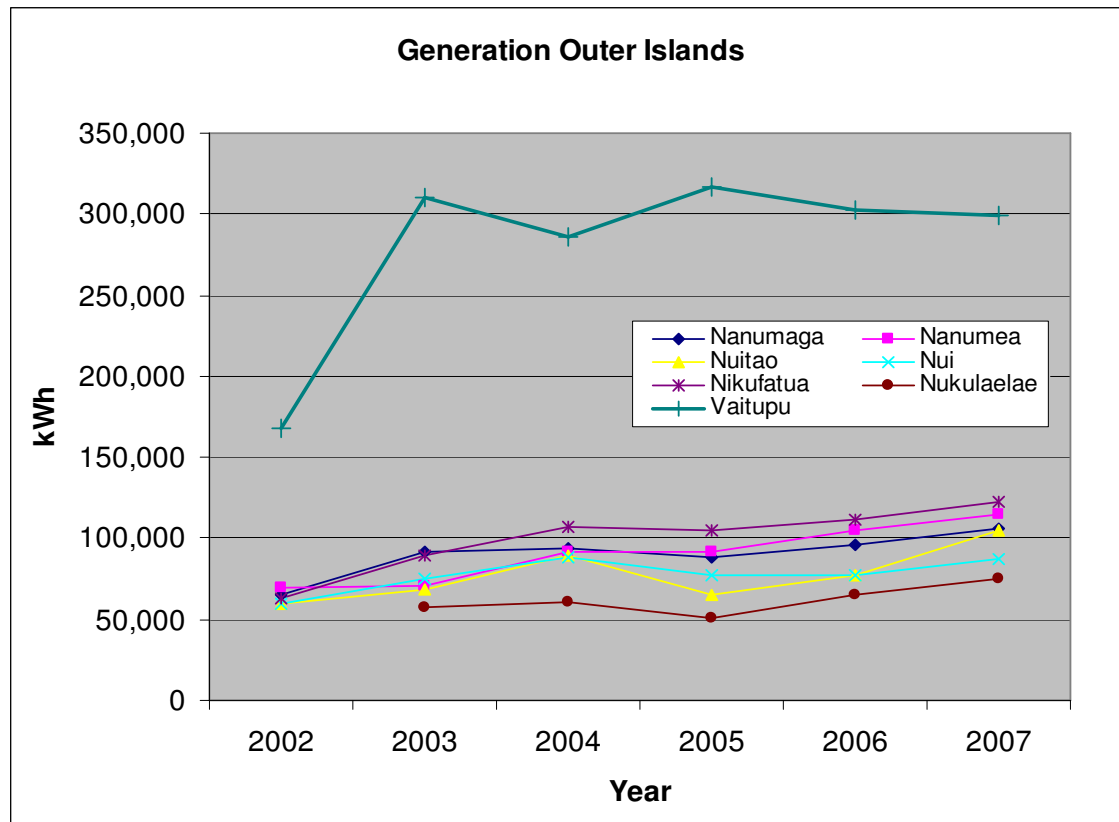
Statistics of aggregated outer Island energy demand are available from TEC from 2002 until 2007. This six year data series is sufficient to establish trends in energy demand development for individual islands and for the outer islands as a group. Total energy generated in all outer islands grew from 483,971 in 2002 to 909,629 kWh in 2007. This represents an impressive average growth rate of 13.5 %. It should be noted, however, that this demand growth has been achieved from a very low level.

On Vaitupu Island itself generation grew from 167, 307 to 299, 392 kWh in the same period, representing an average growth rate of 12%. A closer examination of these high growth rates reveals that they are not suitable to predict future demand growth. As the following chart shows, there are two major distortions in the starting year 2002. Firstly, the Island of Nukulaelae was not supplied at all in 2002. Secondly, and more significantly there was a major shift in demand on Vaitupu itself which lead to a demand increase by 143,000 kWh or 85% between 2002 and 2003. This was triggered by the inclusion of the Motufoua secondary school into the TEC system. In prior to 2002, the school was supplied as an isolated entity with a dedicated generator and powerhouse.

As the Chart 6 below shows, the growth rates stabilized from 2003 onwards and much better trends can be obtained through the elimination of 2002 from the analysis. This elimination results in an average growth for all outer islands of 4.4 % (764,166 - 907,799 kWh). Vaitupu itself shows a negative growth rate of -0.9% with generation decreasing from 310,733 kWh in 2003 to 299,697 kWh in 2007. In order to establish a more accurate picture on current demand in Vaitupu, the 2007 and

2008 billing data available for the island has been obtained for cross referencing generation data.

Chart 6 Demand Growth Outer Islands



Source: TEC

Comparing billing data and generation log sheets cannot be expected to always produce consistent results as the reporting period for generation is always strictly monthly whereas the billing data depends on the actual day of reading the individual meters. Nevertheless, such a comparison – when performed over a longer period such as a full year should provide a good check for data quality and should also provide a good indication of total system losses. Accordingly total losses in the Vaitupu system in 2007 were 9.4 % which is an acceptable value for this type of operation.

Table 4 Billing and Generation Records for Vaitupu 2007

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Generation	21,704	19,274	26,926	29,284	20,394	19,503	27,775	25,438	26,081	26,462	26,687	22,624	292,152
Billing	16,817	18,639	25,566	26,484	16,614	20,800	24,058	25,449	24,825	25,092	24,032	16,442	264,818

Source: TEC Monthly Reports

In terms of average daily consumption, the figures in Table 4 above indicate that Vaitupu requires a generation of 800 kWh to meet an average daily demand of 725 kWh. It is interesting to compare these values with the generation data for a 24 hour supply which was provided on October 1st. On this day generation was approximately 1280 kWh i.e. 55% higher than the average daily generation of 800 kWh. This cannot be deemed to indicate a sustained suppressed demand of 55% as the Independence Day was marked by a number of special events and celebrations which would have boosted power demand. Nevertheless, it is save to assume that a suppressed demand exists and that demand would increase if supply hours would increase.

Future Demand

For the purpose of this study a ten year horizon is used starting from 2007 as a base year as 2008 data are not yet available for the full year. Projections beyond 10 years are not considered to provide any useful guidance as parameters such as fuel supply cost, climate change impacts, technology development etc are difficult to predict even for a ten years period. Energy price developments on the world market are a case in point to underline the vagary with which even short term projections can be fraught.

In forecasting future loads, developments such as the construction of the new primary school and the planned expansion of the secondary school need to be considered. There is also a suppressed demand due to restricted supply hours as mentioned above. This demand will add to the current demand when supply hours for the secondary school may be extended through the solar system and extension of supply hours for the school complex. On the other hand, there is room for energy conservation and the implementation of the solar project described in this report should go hand in hand with an educational campaign promoting prudent use of energy. It should also be noted that TEC is in the position to control demand through variation of supply hours. In conclusion it is assumed that energy demand will be continued to be managed through supply hour restrictions. Residents of Vaitupu were interviewed in order to determine typical household electricity consumption and appliances utilisation. In addition, the consultant checked if there are ongoing or future projects that would have an impact on future power demand on the island.

This suggests that a moderate growth rate of approx 1.5 % p.a. can be considered as a base case scenario for both energy and peak load. This scenario would result in an energy demand of 339,000 kWh and a peak demand of 96 kW at the end of the projection period in 2017. A low case scenario would essentially project the past four years growth values into the future.

This scenario may eventuate if international oil prices bounce back rapidly from their low experienced in the past weeks and TEC is forced to constrain fuel supply and restrict operating hours. Generation would be 307,000 kWh and peak load only 87 kW in 2017. As high case scenario projects past average growth of all outer islands into the future at 4 % annual growth for both energy and peak. This scenario results in generation requirements of kWh 432,000 and a peak load of 123 kW in 2017.

Table 5 depicts the development of demand growth for both energy and peak demand until 2017 based on the three scenario assumption described above.

Table 5 Base Case Growth Projects Energy and Peak

		2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Base	Energy kWh	292,152	296,534	300,982	305,497	310,079	314,731	319,452	324,243	329,107	334,044	339,054
	Peak kW	83	84	86	87	88	89	91	92	93	95	96
High	Energy kWh	292,152	303,838	315,992	328,631	341,777	355,448	369,665	384,452	399,830	415,823	432,456
	Peak kW	83	86	90	93	97	101	105	109	114	118	123
Low	Energy kWh	292,152	293,613	295,081	296,556	298,039	299,529	301,027	302,532	304,045	305,565	307,093
	Peak kW	83	83	84	84	85	85	86	86	86	87	87

There is the possibility of a fourth's scenario which would lead to negative growth in the Vaitupu system. Failure of one of the operational generators would constrain supply significantly. In fact failure of the P100 in the main powerhouse at this point in time would result in TEC's inability to supply demand of the village and would restrict power supply to the Motufoua school complex only. Failure of the No 4 generator on the other hand would constrain supply to the school during the evening hours to a level significantly below their current peak demand. As it is assumed that TEC will

rehabilitate the No 2 and No 3 generators in due time, this scenario is not taken into consideration in this study.

3.3 Operating Cost Forecast

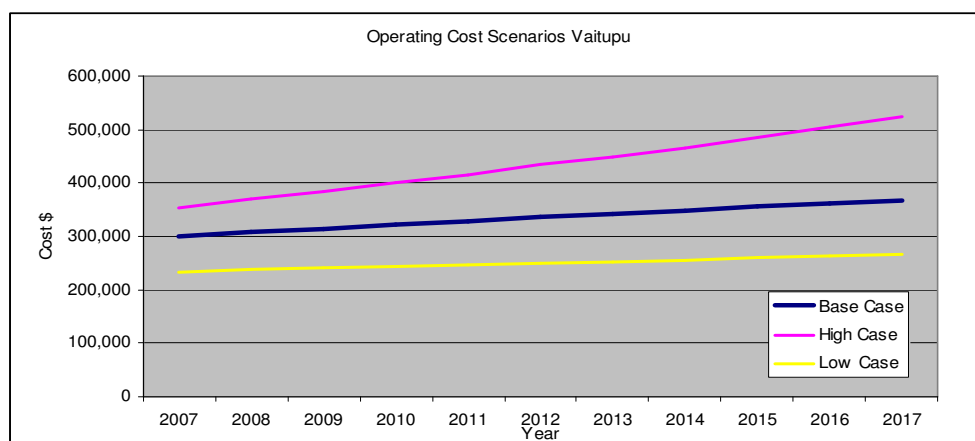
There are two types of operating cost: Variable operating costs are largely determined by cost of fuel, engine oil and regular replacements of minor parts such as fuel and oil filters. Fixed operating cost are essentially the salaries for TEC staff operating the equipment, reading meters and collecting revenues from the customers. Depreciation costs are also to be considered. A detailed analysis of operating cost has been recently performed in the framework of a tariff review for TEC (Ridgeway Capital Projects). This analysis included a forecast of operating expenditures which has been reviewed by the consultant and is used as the basis for the operating cost forecast in this study. Some updating has been made in order to reflect 2007 and 2008 data for fuel supply cost and specific fuel consumption. Also, operating cost forecasts have been made for all three scenarios mentioned above. A set of assumptions have been made with respect to forecasting operating expenditures for Vaitupu. These are summarised below for the three scenarios. Given the fuel price volatility experienced over the last years it does not make much sense to use a fuel price inflator such as the one used for projecting labour and non-fuel operating cost. Instead an average fuel price is assumed for each scenario. This allows constructing a band between low and high scenario that captures possible operating cost scenarios for Vaitupu. The assumptions underlying the three scenarios are listed in Table 6 below.

Table 6 Scenario Assumptions Operating Cost

Operating Expenditures Assumptions	Base Case	High Case	Low Case
Specific Fuel Consumption l/kWh	0.41	0.45	0.35
Fuel Supply Cost \$/l	1.8	2	1.5
Other Operating Cost Baseyear	23,000	20000	26000
Base Year Staff Cost	33,000	36000	30000
Inflation %	3.60%	4.50%	2.80%

The three scenarios shown in Chart 7 basically show the considerable uncertainty under which TEC has to plan its financial future (see also Annex 1). While the base case scenario can be considered the most likely outcome given the information available at this point in time, the high case scenario shows what operating expenditures TEC could incur if all parameters develop unfavourably.

Chart 7 Scenario Analysis Operating Cost



The low case scenario on the other hand assumes low inflation, reduction in staff numbers and a low average fuel price. At the end of the projection timeframe in 2007, the difference between high cost and low cost scenario is almost 100%, i.e. \$ 265,000 for the low case and \$523,000 for the high case assumptions. While it is impossible to accurately predict the future, the scenario analysis demonstrates that there is a strong case to be made for a reduction in uncertainty and this can clearly be achieved through the development of renewable energies.

3.4 Investment Requirements

In the absence of solar investment TEC would have to rely on a business as usual scenario for Vaitupu. The business as usual scenario consists of maintaining the distribution network and of replacing existing diesel generators with new equipment as they reach the end of their technical life and perhaps increasing conventional diesel capacity as required by demand growth. This has been the practice in the past in Tuvalu with the exception of the 40 kW grid connected solar project in Fongafale.

Under this option, attention should be paid to diesel technical efficiency, generator sizing, and specific fuel consumption under different load conditions. There are modern engine designs available now that employ computerized injection and combustion management. There is also “low load” generators, designed to have flat specific fuel consumption curves over a wide range of engine loads. Although these units are more costly, at high fuel supply cost their performance is worth the additional expense. This is especially true for outer island systems such as Vaitupu where a single generator set often carries the system over the daily load cycle. The specific fuel consumption figures for Vaitupu are a case in point. During the last 12 months the generators were never used in an optimal load range as described in section 3.1. For an operation such as Vaitupu, a specific fuel consumption of 0.33 - 0.35 l/kwh (3 kWh/l) is achievable if generators are operated in the vicinity of 80% of their rated output. The average fuel consumption in 2007 was 0.41 l/kWh (2.44 kWh/l) which means 24% more fuel than necessary was consumed. Assuming fuel supply cost remain \$2.00/litre and above and average fuel efficiency remains about 0.40 litres/kWh, the electricity supply cost in outer island grids will continue to be well above \$1.00/ kWh.

Over a ten year period, only moderate investments would be required. It is assumed that No 1 generator in the main powerhouse would have to be replaced in 2011 as it accumulates substantially more operating hours as the other two sets in the main powerhouse which are currently not operational. No 2 and No 3 require major overhaul or repairs which are likely to take place in 2009. A sensible investment would be to rearrange the No 4 generator connection to the grid as described before. This would require the purchase of a 150 KVA step up transformer and some minor re-wiring of the current set up. This project should be done as soon as possible and it is here assumed that it will take place in 2010. No 4 generator is assumed to undergo a major overhaul in 2012. Table 7 summarizes the assumed investment requirements

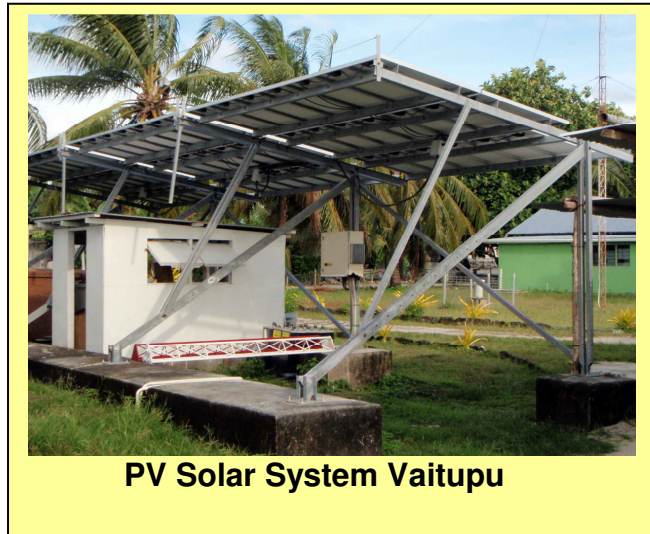
Table 7 Investment Requirements Vaitupu

Type of Investment	Year	Cost Estimate \$
Overhaul No 2 and No 3 Generators	2009	30,000
No 4 connected to high voltage	2010	50,000
Replace No 1 Generator	2011	150,000
Overhaul No 4 Generator	2012	25,000

4. Solar Energy for Vaitupu

4.1 Solar Energy Experience in Tuvalu

Tuvalu was one of the world's first countries making a serious attempt to use solar photovoltaics as a means of rural electrification. Over the period 1984-1994, approximately 450 solar home systems were installed on the outer islands reaching nearly 40% of all rural households. While the systems performed technically, institutional problems of the utility type organisation that was in charge of the solar electrification caused a collapse of the programme. In 2000, TEC started developing diesel powered grids on the outer islands and most of the solar systems were abandoned.



Only Niulakita and a few remote islets of Funafuti now use solar energy as their source of electrical supply. There are also several PV arrays on the outer islands that are operated by Tuvalu Telecom. These systems ensure an uninterrupted supply of the telecommunication facilities and are battery buffered. One of these systems is currently under rehabilitation in Vaitupu (see picture above). There are also solar powered street lights in Vaitupu, they are however not operational at the moment, apparently the batteries have failed some time ago and have not been replaced. As these street lights also provide a very valuable navigation aid for boats trying to enter the Vaitupu harbour at night, it would be highly desirable to replace the batteries and put the units back into operation.

As the Tuvalu Government pursues a National Energy Policy that aims at actively promoting renewable energy, the idea to supplement outer island grids with solar PV in order to save diesel fuel has been contemplated repeatedly over the last ten years. In response to these intentions, a study has been recently performed by a Japanese consultant who investigated the feasibility of a grid connected solar system for the island of Nukufetau¹. The island's 140 households have an average energy demand of 400 kWh per day with an evening peak of approximately 35 kW. The report assesses the feasibility of supplying the entire load of the island using a PV solar system and a battery bank and concludes that a peak PV capacity of 200 kW would be required together with a nominal battery capacity of 4300 kWh. The project cost is estimated to be AUD 2,000,000 and the consultant concludes that the project is not feasible. He also considers a grid connected system as not feasible, arguing that the minimum daytime load is only 20 kW, which is already low considering that the smallest generator has a nominal capacity of 60 kW.

¹ Dr. A. SHIOTA JICA Project Formulation Study 2, September 2008

Grid Connected PV Array Fogafale

In order gain experience with larger grid connected photovoltaic systems, the Tuvalu Government and TEC have in co-operation with the Government of Japan established a 40 kW grid connected solar system next to the Fogafale power station in Funafuti. The system has been commissioned in December 2007. The array is mounted on the grand stand of the Fogafale sports stadium and on three shipping containers one of which holds 3 inverters each connected to one of the phases of the circuit. The inverters are indoor versions and the container holding these units are insulated and air conditioned. The system is connected to the low voltage circuit that supplies power to the institutional buildings next to the power station (Substation No 9).

Solar System Fogafale



The Fogafale PV system provides an excellent reference for performance of PV arrays under real conditions in Tuvalu. It is equipped with a public display that shows real time output in kW and daily production. It is also equipped with a data logger which records solar radiation, wind speed, loads and energy output. On a sunny day, the system is capable of supplying the entire load of the substation 9 circuit as can be seen in Annex 2. No stability problems were encountered, although solar penetration must have approached 100% in the No 9 substation feeder on several occasions.

Net output data for seven month are shown in Table 8. So far, the system has performed beyond expectations and has delivered an average daily output of 4.2 kWh per kW_{peak} PV installed. This output figures include inverter and array losses, but exclude line losses between inverter house and connecting point.

Table 8 Performance of Fogafale Grid Connected PV System

Month	Expected Generation kWh/d	Actual Generation kWh/d	Expected Generation kWh/month	Actual Generation kWh/month	Number of Days
February	153	203	4,437	5,887	29
March	160	176	4,960	5,456	31
April	158	193	4,740	5,792	30
May	146	169	4,526	5,227	31
June	138	156	4,140	4,680	30
July	141	155	4,371	4,808	31
August	150	160	4,650	4,947	31
Total			31,824	36,797	213

Source: TEC

Although Vaitupu may receive a slightly higher solar radiation as Funafuti, it seems appropriate to use the data recorded in Funafuti as a cross reference for the design of the Vaitupu solar project.

4.2 System Design Options for Vaitupu

Grid Parallel System

The original project concept consisted of a grid connected (grid parallel) solar system in the order of 40 kW_{peak}. This concept had to be dropped as the load pattern of Vaitupu shows extended periods during the daytime when system loads in the order of 40 kW occur. During the period from June to September 2008 loads during the day even dropped below 40 kW occasionally. Under such conditions a small grid parallel PV system of 40 kW is clearly not feasible. Even reducing the system size to 20 kW would still risk instability and poor power quality in the system. Besides variability with time, other power quality parameters include:

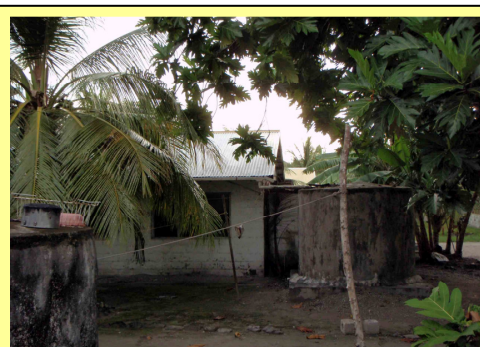
- Power factor
- Voltage fluctuations
- Harmonic distortion
- Frequency deviations.

The spiky load pattern which involves instantaneous switching of large loads in relation to the system load exacerbates the problem. Two 2 kW hot water kettles switching simultaneously represent 10 % of the daytime load of the system. If such events coincide with sudden changes in solar output (sudden cloud cover) system stability is seriously compromised.

The analysis of the data set provided by TEC, suggests that a first phase of a grid parallel solar project should not exceed 10-15kW_{peak}. A higher penetration of solar would involve a high risk of voltage fluctuations and system instability. Specific fuel consumption of the operating diesel generator would increase as the unit would be forced to operate at very low loads.

Quite obviously for any grid parallel solar system to operate efficiently the current mode of operation of the Vaitupu system had to be changed to a continuous supply during the day. With a two hour break during midday (as practiced now) approximately 25% - 30% of the benefits of the solar system would be lost.

Assuming that the output of the grid parallel system is reduced to say 15kW in order to ensure technical feasibility, there are two principal options for the solar system design: The PV array can be located in one central location and feed into the low voltage grid at a point where loads are high. A second option involves splitting the system into two or three decentralized arrays (say 5 kW each) and feed into the low voltage feeder where the particular part of the system is located. A third option is a variant of the second and would further distribute generation into small units of approximately 500 Watts which all would have their own inverter and which could be located on the roofs of private residences and institutional buildings. This embedded generation option, however, had to be discarded as all residential areas on Vaitupu are covered in dense



Residential Building Vaitupu

vegetation (mainly breadfruit and coconut palm, providing shade for the residential buildings. Residents appreciate the positive impact the shading has on the climate in the houses and any attempts to trim back vegetation to allow the installation of PV arrays is likely to meet severe resistance from residents.

In addition to the constraints described above, a grid parallel system would not be a step in the direction the Government wants to move with regard to outer island electrification. All officials contacted emphasized that the long term goal is to supply outer islands 100 % with renewable energy based electricity. It is therefore concluded that a grid parallel system is not an adequate solution for the TPVENIP.

Battery Buffered System

The problems described above can be overcome by a battery buffered solution which uses a lead acid battery bank to store energy and releases it as required. Although this solution is more costly than a grid parallel configuration, it allows operating the entire hybrid system more efficiently and maximizes benefits for TEC and the community of Vaitupu. As with a simple grid parallel system there are various options to realize a hybrid system within the financial budget allocated for Tuvalu under the TVENIP project.

A system could be configured to feed into TEC's general grid with relatively small battery storage to allow use of solar energy collected during the day for the evening peak. Such a configuration would also allow load shaving, i.e. it could be used to avoid the use of a second diesel generator in order to avoid operating two generators with both sets running at sub-optimal loads. The system could be split in several units which would have the advantage to avoid distribution losses. A logical split would be between a location in the main village and the Motufoua School.

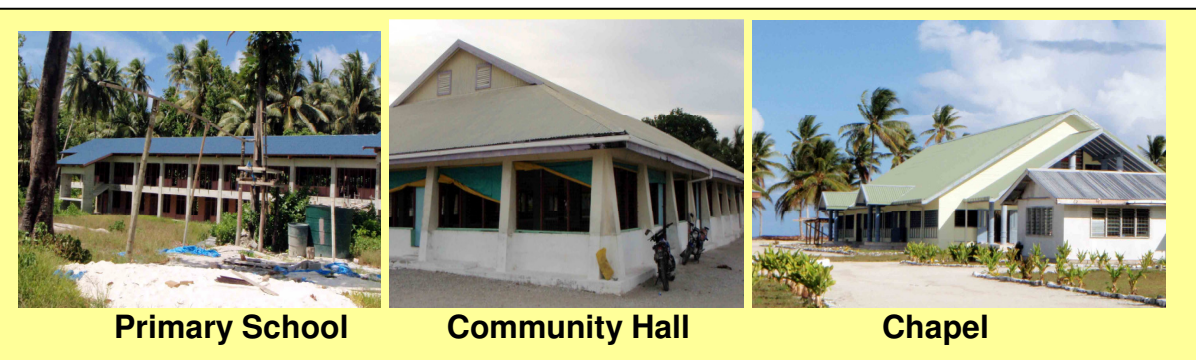
Location of Systems

All possible sites for a solar installation were examined during the field trip and checked against the following criteria:

- Proximity to existing electrical grid
- Undisturbed solar radiation
- Exposure to sea spray
- Security

The investigations included an inspection of existing roof surfaces with regard to structural integrity and capability to carry the load of a solar array (estimated mass 3,000 kg). Three possible roof mounted solutions were identified: The newly constructed Primary School, the Asau Community Hall and the new Chapel at the Motufoua School.

Possible Location for Roof Mounted Solar Arrays



Primary School

Community Hall

Chapel

Roof structures of all three buildings pictured above are sound and sufficient to take PV arrays of 200 – 300 m², the Motufoua chapel could even take up to 650 m² array surface equivalent to an installed PV capacity of approximately 750 kW. Using the roof of the newly constructed primary school would, however, only be suitable after trimming a substantial part of the vegetation surrounding the school, which in turn would create a significantly hotter climate inside the school building. It is therefore not considered a viable option.

Motufoua Secondary School System Design

The secondary school has a roll of approximately 600 students and a teaching staff of 50 and is a major educational asset for Tuvalu. The school uses modern teaching equipment such as internet and relies on a sound power supply. All stakeholders expressed a desire to locate the solar system at the Motufoua secondary school and consequently this option was analysed in detail.

The Principal of the Motufoua Secondary School Mr Mosese Halofaki, expressed concerns about the intermitted power supply received from the TEC system and emphasized the need to secure a minimum supply for the school in case of power supply interruptions from the grid or the No 4 generator. Improving security of supply for the school can only be achieved if a solar system is equipped with battery storage. This solution would allow a continued supply of power to the schools essential services in case of problems with supply by the diesel system.

The school is currently supplies by three individual circuits which are metered separately. They are labeled Motufoua School, Japanese and Local. The three circuits are metered separately and had a total consumption of 92,152 kWh in 2007. Table 9 displays the records obtained from TEC’s Billing section.

Table 9: 2007 Billing for Motufoua School Circuits

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Motufoua School	5,967	6,325	4,937	8,710	5,745	5,967	6,273	4,009	8,710	4,265	4,937	7,213	73,058
Local	3	10	5	10	8	3	5	5	10	11	7	9	86
Japan	1,356	1,504	2,034	1,234	1,502	1,356	1,403	1,193	1,403	1,875	2,034	2,113	19,007
Total	7,326	7,839	6,976	9,954	7,255	7,326	7,681	5,207	10,123	6,151	6,978	9,335	92,151

Source: TEC Billing Section

According to the billing Data the average daily consumption of the school is 250 kWh, which is a substantial load and represents 27% of the total consumption in the Vaitupu grid. There are however some inconsistencies in the billing records which do not match with generation records and in order to cross check consumption data, TEC has performed a dedicated metering of the school circuits for two week days and a weekend day.

Table 10 displays the results of these recordings and accordingly, the main circuits consumed an average of 87.5 for the circuit Japan and 149 kWh/day for the circuit Motufoua respectively. It appears that some loads have been shifted from the Motufoua circuit to the Japan circuit as the sum of both corresponds very well with the average daily consumption experienced in 2007.

Table 10: Metering of Motufoua School Circuits October 2008

Customer	Sat 11/10	Sun 12/10	Mon 13/10	Tue 14/10	Wed 15/10
Meter Japan	32192	32277	32368	32459	32542
kWh/day		85	91	91	83
Meter Motufoua	34996	35160	35327	35451	35592
kWh/day		164	167	124	141
Total kWh/day		249	258	215	224

Assuming a net average output to load figure of 3.5 kWh per kW_{peak} installed, a system supplying the total demand of the school could not be matched with the budget available for the project as the system would have to have at least a PV capacity of 70 kW_{peak} and an effective minimum battery capacity of 250 kWh. The issue was discussed with all stakeholders and it was agreed to aim at supplying the essential load of the school, i.e. the circuit labeled Motufoua School as a matter of priority and a first step towards a full solar supply.

Based on the values measured by TEC a design figure 160 kWh per day would allow the Motufoua school circuit to operate at a high level of independence. It would be prudent, however, for TEC to keep recording daily consumption of the school circuits for some time to provide some more empirical ground for these figures. The system would have to have an installed capacity of 46 – 50 kW and a battery capacity that allows operating on battery power for 24 – 36 hours. The battery should have a minimum battery voltage of 48 V. Inverter capacity would have to be 45 kW continuous in order to cope with all load situations in the Motufoua circuit.² A configuration of one 15 kW inverter per phase seems to be an adequate solution. It should be noted here that the system is not a complete stand alone system as there is grid power in the background that can be used in during prolonged periods of clouds or in cases of higher electricity demands. The system would therefore be equipped with a battery charger that feeds off the grid in order to provide more operational flexibility.

Effective Battery capacity of the system should be in the range of 200 kWh. This would allow operating the Motufoua circuit at least 24 hours independently and up to 48 hours in case a demand side management program is embarked upon when there is a failure of both the power house generators and the No 4 Motufoua generator. In fact with some prudent load management, all essential functions of the school could be maintained with this system even in case of longer power outages of the diesel generators.

In order to achieve this it is recommended that the school appoints a technician who will be in charge of load management. This technician should then participate in the PV training provided for TEC staff during installation of the PV system. Thus, the school's technician will obtain a first hand understanding of the system and its limitations.

Table 11 summarizes design and replacement cost assumptions for the system per kW.

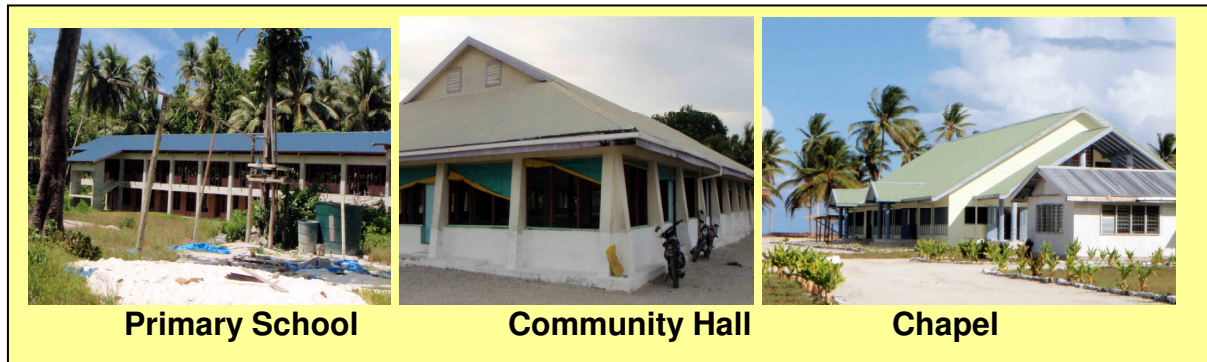
² Peak load of the combined circuits Motufoua and Japan is currently 40 kW, i.e. a 45 kW inverter would be sufficient to comfortably carrying the load of the Motufoua circuit and allow for load growth in the future

Table 11 Design Assumptions Battery System Motufoua

Assumptions Battery Buffered System		per kW installed solar	
Generation cost estimate based on annuity of capital cost plus maintenance			
5.8 Solar resource kWh/kW/day			
10%	Losses (Temperature, non max power point, dirt, aging)		
5.22	kWh Panel output/kW peak		
15%	Inverter losses		
5%	Line losses		
14%	Battery losses		
4%	Losses between load and battery		
33%	Total losses		
3.50	Net daily output to load (kWh)		
1277	Net annual output to load (kWh)		
14.6%	Capacity Factor		
5740	Solar Array \$/kW		
2500	Rack \$/kW		
1600	Inverter \$/kW installed PV		
200	Charge controller \$/kW installed		
6000	Battery \$/kW PV		
16040	Cost Supplied Funafuti (\$/kW peak)		
2000	Transport and Installation per kW PV		
18040	Total \$ per kW		
\$0.01	Maintenace cost per kWh	Interest	10%
(\$1.65)	Cost per kWh	Lifetime	20
829,840	Total Cost of system	System Size	46

4.2 Solar System Location Vaitupu

Within the school complex there are two options to install a solar array with a mass of approximately 3,000 kg: First, an existing roof surface could be used. The roof of the new Chapel was identified as large enough, structurally sound and north facing. However, using the roof of the recently build church would have negative aesthetic impacts and would require significant work on the roof structure. This in turn required permission of the Public Works Department.³



Other roof surfaces may be able to accommodate an array, but more detailed structural engineering investigations would be required as some of the buildings constructed under the Japanese up-grading project do not appear to be very well finished (see picture above).

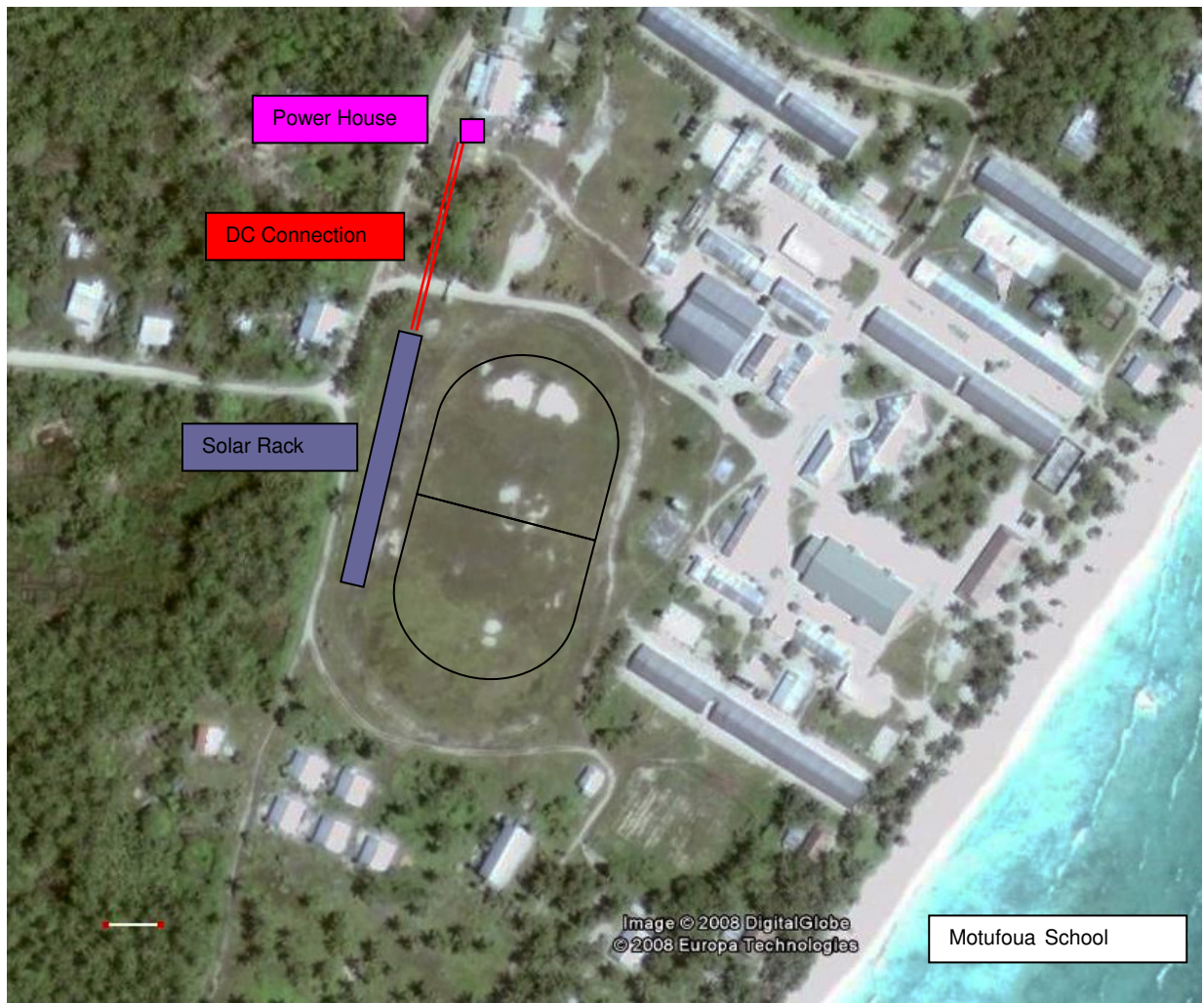
It appears therefore that a dedicated rack which holds the solar array would be the most suitable solution. Such a structure could double as a sports grand stand similar to the structure that accommodates the solar system in Funafuti. The solution was preferred by the school's Principal and would enhance the infrastructure of the school by providing additional utility to the sports ground.

This solution would have an additional advantage: The location of the unit on the western side of the sports ground would bring the installation within a distance of less than 70 meters from the old disused powerhouse which holds the switchboard mentioned above. This building is next to the powerhouse of the No 4 generator and adjacent to the 11kV/415V step down transformer. This distance allows to transport 48 or 96 V DC without too much line loss and would bring all power infrastructure of the school together in one dedicated area. The old powerhouse could be refurbished and extended to hold the battery bank, inverters and the switchboards required.

Locations of the Solar Array, Battery House and DC connection in relation to the sports ground are displayed on the satellite image below. The solar rack would have to hold a total panel area of approximately 90x4 meter equivalent to a surface area of approximately 360 m². For reasons of cost savings it is suggested not to equip the solar stand with any seats as this could be arranged later by the school. In order to allow comfortable use as a sport stand the height of the structure above ground should be no less than 3.5 meters.

³ Preliminary talks were held with the Public Works Department which also provided the design drawings for the chapel.

Chart 8 Recommended Location of the Solar System and Battery House



Source: Google Earth

4.3 Benefits

At given specific fuel consumption figures for Vaitupu of 2.44 kWh/l the solar unit would save approximately 66 liters of fuel per day. An additional benefit of such a system would be significant fuel savings that could be achieved through avoiding the operation of two generators during the evening peak. With the system supplying the load of the Motufoua circuit, either the P 100 or the Denyo generator could carry the load of the rest of the system. This would require re-arranging the connection of the No 4 generator and connecting this unit to the high voltage side of the grid via a step up transformer, a measure that is highly recommendable even without the implementation of the solar system.

The following Chart shows the effect of a 46 kW solar system on the Vaitupu system load curve under current operating conditions, i.e a 16 hours supply that starts at 7 a.m. takes a 2 hours break during midday and switches off at midnight.⁴ The chart

⁴ Normal operation of the station is 18hrs/day but lack due to fuel supply constraint operating hours are reduced

assumes that the load of the Motufoua circuit follows the pattern of the overall system load. The contribution of the solar system would allow operating the P60 generator comfortably during the daytime as the system load would be shaved to approximately 40 kW during day. The P 60 unit would operate in a good load range resulting in further fuel savings as the specific fuel consumption would drop in comparison to the P100 unit which is used to carry the daytime load now. It is difficult to quantify these additional savings with a high level of accuracy as they are highly dependent on the mode of operation of the various system components, hours of operation and switching.

Chart 9 Effect of Solar System on Vaitupu Load Curve

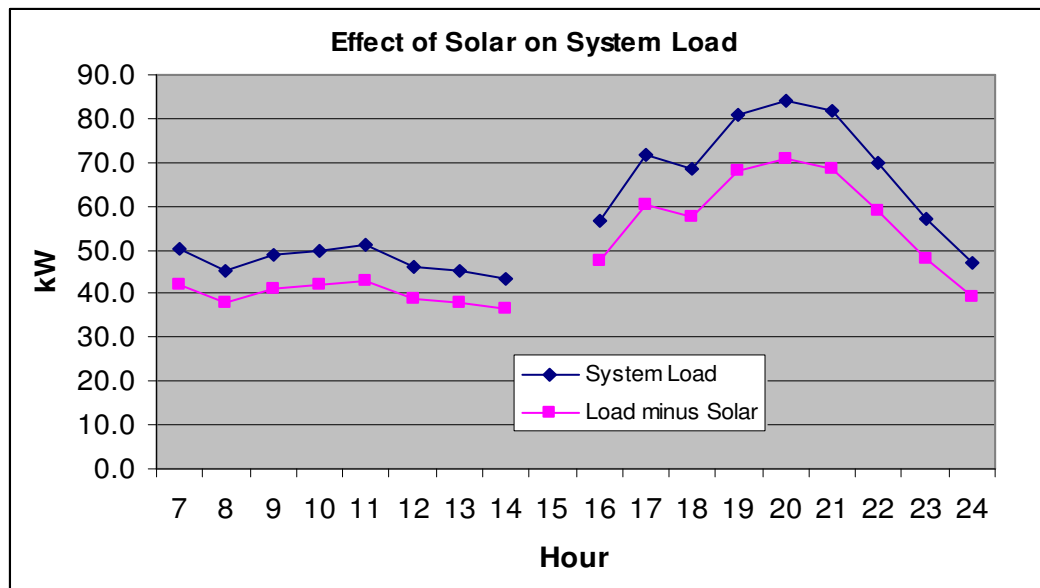


Table 12 below describes a scenario where both direct fuel savings through replacement of diesel generated kWh and savings through improved specific fuel consumptions are considered. The scenario is based on a daily generation of 1000 kWh for Vaitupu. Under business as usual conditions (BAU), specific fuel consumption would be 2.44 kWh/litre of fuel resulting in a daily fuel use of 410 liter. A net solar contribution of 160 kWh would save 66 liters of fuel a day. However, the solar system would allow operating the P60 unit during daytime and the P100 during the evening at good loads and an enhanced specific fuel consumption of 2.9 kWh/liter. This resulted in additional savings of 55 liters a day. Total annual savings would thus be in the order of 44,000 liters. This required, however, the rehabilitation of the P 60 unit by TEC.

Table 12 Fuel Saving Benefits from 46 kW Solar Unit

	BAU	Savings Solar	Balance	Improved SFC	Savings SFC	Total Savings
kWh/day	1000	160	840.0	840.0	840	1000
kWh/l	2.44	2.44	2.44	2.9	2.9	2.9
l/day	410	66	344	290	55	120
l/year	149,590	23,934	125,656	105,724	19,932	43,866

There are other benefits of a solar system in Vaitupu that should be mentioned here. Besides diesel fuel savings there avoided cost of generation using the diesels (diesel capacity, O&M). Generating power close to the load of the school involves avoided distribution losses, at least during the day when the school would be supplied from the main power house. There are also avoided local environmental hazards such as noise, fire danger and oil spills which can be valued according to the quantity of fuel

saved. Avoided capital cost for a new diesel engine may also be valued as the solar system with battery provides firm capacity. In addition there are global environmental benefits which accrue both in a physical sense through reduced CO₂ emissions which can be valued at \$30 per ton of CO₂ avoided.

An additional benefit of the project could emerge from a community mobilization and education campaign which the GoT could launch in parallel to project implementation. There is a significant potential for energy consumption efficiency that should be realized urgently. Although fuel prices and electricity tariffs have been strong market signals, consumer response has been slow, because appliance stocks tend to remain fixed in the short term, high efficiency appliances tend to cost more than less efficient ones, and because of limited awareness of the potential of conservation to save costs without significantly reducing services. The implementation of a major renewable energy project such as the TPVENIP provides an excellent opportunity to address those issues is a joint campaign implemented by GoT and TEC.

4.4 Capacity Building and Institutional Strengthening

For the above benefits to materialize a program of capacity building and institutional strengthening is required. International and regional experience in the Pacific has shown that the performance of rural and remote area electrification is directly correlated with the understanding, skills and knowledge of system operators. This is true for both conventional (diesel) and renewable energy systems. However, adequate capacity of operational personnel becomes even more important when renewable energy systems are employed. This is due to their characteristics of high up-front investments and low operating cost. I.e. if operators are not capable to handle an expensive PV solar system in the appropriate way, the monetary damage is by far greater than inappropriate handling of a diesel system. In Tuvalu, hybrid style PV diesel systems will be implemented as a means to reduce operating costs of diesel systems currently employed. The systems are more complex than pure diesel or solar systems as an optimal outcome of the projects can only be achieved if the operators are capable of maintaining and operating the systems.

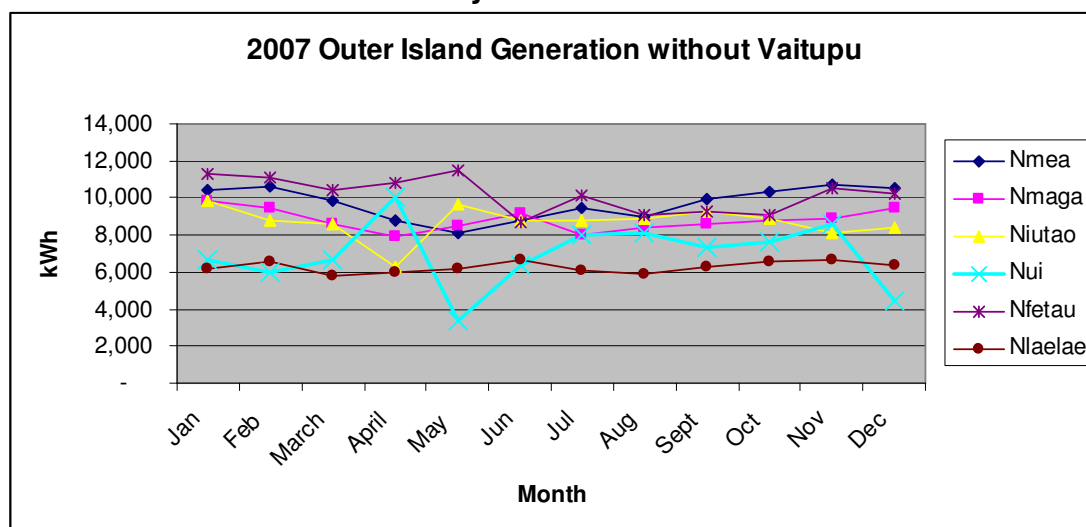
Capacity to operate and maintain hybrid renewable energy systems in an optimal way requires technical knowledge and technology specific skills. However, it is here proposed here that the objective to create adequate capacity is more than transferring skills to the operators. The capacity program must also acknowledge the experiences and latent capacities the candidates already have and at the same time provide opportunities and incentives for the operators to practice and extend the skills acquired. In other words, capacity building is seen as a long term process where initial training is provided during the installation and commissioning of the projects. Thereafter TEC management has to ensure that the operators are provided with incentives to practice and extend knowledge and skills acquired during the initial training. Capacity building should be an ongoing process of human resource development that encompasses the entire utility, refines processes and procedures and offers opportunities for staff to constantly improve.

Annex 6 provides the scope for a capacity building program that is recommended for all operators who will be in charge of operating and maintaining diesel hybrid systems. The training described therein should be integrated part of the supply contracts for Vaitupu and perhaps later for other outer islands that will receive hybrid systems. It is also recommended to create a special regional network of hybrid system users- There are now a sufficient large number of projects in the region that such a network group could exchange information, discuss experiences and lessons learnt and assist each other in case of difficulties with the systems.

5. Other Outer Island Power Supply

At the current cost of fuel and the capital and operating cost for the diesel generators supplying electricity to the small outer island power grids, the use of solar and/or wind power is a financially viable option for TEC as long as concessionary or grant financing can be identified for such projects. Chart 10 below shows that monthly consumptions are fairly steady throughout the year and even on a daily basis, there is not much variation in consumptions. All islands have the typical daily load curve of small rural systems which are dominated by household consumption (see Chart 9).

Chart 10 Outer Island Electricity Generation



Source:TEC

It is estimated that supply cost for diesel power is currently above \$1.80/ kWh for the small systems consuming less than 100,000 kWh per year. At generation cost of approximately \$1.65-1.80 per kWh from a solar or wind powered battery systems this technology becomes an option in particular if some diesel capacity is kept as a back up, allowing to reduce battery capacity to levels of 24 hours consumption. Surprisingly the Japanese study for the island of Nukufetau did not consider a hybrid configuration with a dispatchable battery unit (DBU) and only contemplated a grid parallel system and a full solar electrification.⁵ Both variants were considered not feasible, the grid parallel unit on grounds of stability problems the 100% solar option because of the large size of the battery bank required. However, in a hybrid configuration battery capacity can be reduced to 15-25% of the capacity that would be required for a 100% solar supply achieving diesel savings up to 60% depending on load pattern and mode of system operation.

As described earlier a DBU not only directly saves fuel by producing kWh that would otherwise have to be generated by burning diesel, the DBU also allows considerable operational flexibility and optimization of the operation of diesel sets. Specific fuel consumptions deteriorates substantially when a diesel unit is operated below 50 % of its nominal output, a situation that is quite common in the outer islands as the poor SFC performance of the system testifies.

⁵ Dr. A. SHIOTA JICA Project Formulation Study 2, September 2008

Table 13 below describes a scenario that combines a DSM program in conjunction with a solar powered DBUs based on the current generation and fuel use figures for the smaller outer islands.

The scenario assumes a reduction of power consumption by 20 % through educational campaigns and DSM measures such as substitution of incandescent light bulbs by CFLs and the reduction of use of heating devices such as water kettles, sandwich makers and electric frying pans. Although many households already use fluorescent tubes, there is still room to manage the demand side in the outer islands. A DSM program, however, can only produce tangible benefits from lower fuel consumption when it is implemented in conjunction with a DBU. I.e. reducing the demand would force the generators to operate even less efficiently than now. The DBU, however, would allow operating the diesel sets close to optimal loading. Either the DBU could supply power in low load situations without the diesel. In case the diesel is needed, charging of the DGU would help to operate the diesel sets close to their optimal operating point.

The DSM program would also involve government consumers. It should be noted that this scenario would not significantly impact on any quality of life for the islands residents. Solar powered DBUs would then supply 60% of each islands total demand. The required total solar capacity would range from 25 kW_{peak} on Nukulaelae to 41 kW_{peak} on Nukufetau. In total 201 kW would be required together with effective battery capacities of 1200 kWh. The DBUs together with operator training would improve specific fuel consumption to 2.8 l/kWh, a realistic figure that has been achieved in similar situations. (The value for Fogafale is currently 3.8 kWh/l).

Table 13 Solar-Diesel Hybrid and DSM

Island	Current Situation			Solar Hybrid+DSM						
	kWh	kWh/l	Liters	total kWh	Solar kWh	Solar kW	kWh/l	kWh from diesel	Liter Fuel Use	Liter Fuel Savings
Nanumaga	103,150	2.4	42,979	82,520	49,512	39	2.8	33,008	11,789	31,191
Nanumea	101,584	2.44	41,633	81,267	48,760	38	2.8	32,507	11,610	30,023
Nuitao	77,980	2.52	30,944	62,384	37,430	29	2.8	24,954	8,912	22,032
Nui	78,692	1.97	39,945	62,954	37,772	30	2.8	25,181	8,993	30,952
Nikufatua	108,251	2.55	42,451	86,601	51,960	41	2.8	34,640	12,372	30,080
Nukulaelae	66,401	2.12	31,321	53,121	31,872	25	2.8	21,248	7,589	23,733
Total	536,058		229,274	428,846	257,308	201		171,539	61,264	168,010

These measures combined would reduce outer island fuel consumption from 229,274 liters to 61,264 representing a saving of 168,010 liters per annum. It is estimated that the total investment required to convert the outer islands to hybrid systems is AUD 4,000,000. Such a program would also enable TEC to reduce installed diesel capacity by one generator per island. These units could possibly be sold off as recommended in the recent Tariff review study performed by Ridgway Capital Projects. It should be noted that the detailed design of such a program required on site analysis, in particular with respect to locating the solar arrays (a total surface of approx 16,000 m² would be required).

A detailed design of the systems would also require an analysis of daily load curves. As it is considered realistic to attract funding for such a program, TEC should start to record and store daily load curves for all the outer islands. A concept note for a national program of hybrid electrification is attached as Annex 5.

6. Recommendations

It is recommended to depart from the original concept of a grid parallel system and opt for a dispatchable battery unit powered by solar. This is considered the most appropriate solution which matches the characteristics of the Vaitupu grid and reflects current and future demand of the system. The size should be sufficient to supply the demand of the main circuit of the Motufoua School. It is suggested to avoid overly narrow specifications in the tender to give suppliers the opportunity to offer innovative solutions and optimize the configuration of the system.

The solar array should be mounted on a rack placed alongside the sports ground. The old power house should be refurbished and extended to hold the inverters, battery bank and switchboards. A surface area of approximately 60 – 70 m² would be required to house the equipment. The powerhouse would have to be well ventilated and its concrete base plate should be strong enough to safely accommodate the battery bank.

In case stakeholders agree with the presented concept, TEC in cooperation with GoT should seek the required permissions (Publics Works etc, Education) to implement the project.

The project would serve as a pilot for the implementation of a program to implement solar diesel hybrid systems in all outer islands as described in section 5 and in the separate concept note provided as Annex 5. It is recommended to commence dialoguing with relevant funding sources for an expansion of the Vaitupu system and the implementation of the outer island program on the basis of the concept note.

It is also recommended to include a comprehensive capacity building program into the pilot project. The supplier/contractor should train TEC staff in system installation, management and operation during the installation process. A capacity building program has been developed and is attached as Annex 6 to this report. The implementation of the training described therein should be made part of the contract.

Annex 7 contains the tender documents for the procurement of the required hardware, installation services and related training of TEC staff. It is recommended to procure the package through an open international tender. Widespread circulation of the tender and allowing for a tender period of 2 months will help to ensure that a sufficient number of competitive bids are going to be received.

Annexes

Annex 1 Terms of Reference

1. Introduction

IUCN-Oceania in collaboration with the Tuvalu Government through the Tuvalu Electricity Corporation (TEC) and the Tuvalu Department of Energy is commissioning a consultancy for the **Tuvalu Photovoltaic Electricity Network Integration Project (TPVENIP)**.

2. Objective

The overall objective of TPVNIP is the promotion of the use of renewable energy resources through the implementation of cost effective, equitable, reliable, accessible, affordable, secure and environmentally sustainable energy systems. In this particular project, the use of grid connected Photovoltaic system is seen as a step towards achieving the above objective.

3. Background

3.1 General Information

Tuvalu lies about 1100 km due north of the Fiji Islands and is centred at about 8° south latitude and 177° east longitude. The EEZ is 900,000 km² in area. The total land area of 26 km² is spread over 8 islands. The largest, Vaitupu, has an area of about 5.6 km² while the smallest, Niulakita, has only 0.42 km² of land.

Like any other atoll the soil is low in fertility and only a narrow range of food plants can be supported. The sea is the primary source of local food. The climate is tropical to equatorial. Rainfall averages 3500 mm per year with April – November lower than the rest of the year. Droughts do occur and maintaining a fresh water supply on the densely populated Funafuti the main business and political centre is increasingly a problem. The primary source is rainwater but there is a 65,000 litre per day desalination plant in use.

Tuvalu depends heavily on imported petroleum fuels. British Petroleum (BP) through a non-competitive agreement is currently supplying petroleum fuels to Tuvalu. However, supply to the outer islands is through the Tuvalu Cooperative Society and are transported in 200 litre drums. Liquid Petroleum Gas (LPG) is brought in containerised bulk tanks and this is through a private entrepreneur. Prices of petroleum fuels are determined by the suppliers in the absence of a price regulator. On the other hand the price of electricity for consumers is controlled by Government.

3.2 Government Priority

The Government of Tuvalu is placing high priority to promotion of renewable energy as a means of cushioning its economy from the ever increasing fuel price. The current global oil shock is having a devastating effect not only in the increase in cost of imported oil but also cost of all other imported products as well, including food, household equipment and building materials. These negative economic and social aspects are even more pronounced in the outer islands than on Funafuti.

It is clear that any actions aimed at reducing imported oil dependency will help decrease greenhouse gas (GHG) emissions, reduce Tuvalu's impact on global warming and put Tuvalu on the road of a sustainable and exemplary development, giving the nation a stronger bargaining position in international negotiations.

3.3 Tuvalu Electricity Corporation

(1) The government owned Tuvalu Electricity Corporation (TEC) manages all grid-based electrification on all islands. There is no formal regulation of the TEC although setting tariffs does require a cabinet decision. The TEC regulates others through their imposition of Australian standards for wiring and safety in electricity system installation and servicing. The 2007 review⁶ of the TEC base tariff reveals that TEC requires an average of AUD0.80/kWh (before allowance for capital expenditure, depreciation and government subsidy) which is almost twice the current average tariff of AUD0.44/kWh. The review further stated that due to the monopoly fuel supplier the fuel costs in generation alone is AUD0.40/kWh, which leaves AUD0.04/kWh from the AUD0.44/kWh tariff to fund all of TEC's operating costs. Tuvalu is experiencing high diesel power generation cost of about US\$0.50/kWh at present due to the continuous escalating crude oil price.

(2) On the other islands, combinations of diesel generation plants purchased in 2000 together with low voltage line (and 11kV in Vaitupu) supply the seven islands. A summary of the existing supply and demand situation is provided in the table below:

Summary of TEC Generation and Sales Data (2006)									
	Generation Capability & Production				Sales and Network Losses				
	New Units	kVa Available	kWh	kWh /l	PK kW	LF	kWh in 2006	Growth 2004-6	Losses
Fogafale	3x600 kW	3230	5,255,601	3.76	920	65%	4,484,329	7%	14%
Nanumaga	P60, P60, P100	220	96,591	2.40	36	31%	103,150	9%	-8%
Nanumea	P60, P60, P100	220	104,909	2.44	34	35%	101,584	13%	2%
Nuitao	P60, P60, P100	220	77,481	2.52	28	32%	77,980	4%	-2%
Nui	P60, P60, P100	220	76,762	1.97	29	30%	78,692	4%	-4%
Nikufatua	P60, P60, P100	220	111,317	2.55	37	34%	108,251	4%	2%
Nukulaele	P60, P60, P60	180	65,418	2.12	26	29%	66,401	9%	-3%
Vaitupu	P100, P60, P100	260	302,450	2.54	74	47%	275,131	11%	8%

Note

Outstation peak demand mainly occurred at night time compared to Fogafale during day time.

⁶ Conducted by Ridgeway Capital Projects Ltd of New Zealand, and funded by the SOPAC Pacific Islands Energy Policy and Strategic Action Planning (PIEPSAP) project in October 2007.

TEC is facing three major challenges that need to be overcome if the organisation is to have a commercially sound future. The first challenge is how TEC is going to reduce its fuel usage and thereby the country's reliance, on expensive imported diesel fuel. The second hurdle is how TEC will reduce its base operating cost by rationalising the use of its surplus generation plant, and the final concern is how TEC can better monitor and manage its technical and commercial losses to bring them down from an estimated 16% to an industry standard of about 7%.

4. Scope of Work

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

- Carry out a scoping mission to Vaitupu and accurately assess the actual current power demand and a 10 year projected demand for the Vaitupu grid;
- Estimate operating expenditure of the 10 year period;
- Estimate investment requirements to meet demand;
- Determine the technical feasibility or otherwise of the proposed PV integration system and future expansion;
- Recommend the most proven and appropriate option of PV system to match the Vaitupu grid characteristics base on the current and future demand;
- Estimate the replacement costs per kWh of the major components and anticipated fuel savings from the chosen PV system to match the Vaitupu grid characteristics and other proven PV systems.
- Identify the appropriate site/location for the installation of the PV system.
- Provide set of recommendations required for the sustainability of the project based on past experiences of PV system in the Pacific.
- Prepare tender documents for the design, supply and installation of the recommended PV system taken into consideration the tropical climate in Tuvalu;
- Liaise closely with the Contractor during the installation of the PV system;
- Liaise closely with the TEC Engineer designated to the project; and
- Ensure the TEC Engineer has full advantage of hands on experience available during the scoping mission and the installation of the PV system.
- Identify training areas required for the sustainability of the project and provide set of recommendations to strengthen the Institutional Capacity of the station.

5. Outputs

The following are the expected outputs:

- Inception Note

Write-up an inception note comprising the Consultant’s understanding of the consultancy and associated tasks; identification of issues crucial to the successful completion of the consultancy; and comments on this TOR. Subsequently, if required and approved by IUCN and TEC the activities can be elaborated, modified, etc.

- Debriefing Note

- Prepare debriefing note, based on the desk study, preliminary findings, conclusions and recommendations from the scoping mission; and

- Discuss the debriefing note with the General Manager and staff of TEC, the Energy Unit and, task force, and if appropriate, with the Board of Directors of the TEC.

- A scoping mission report
- A final report covering all the tasks highlighted above

6. Reporting Requirements

Deliverables	Deadline
1. Inception Note	Before start of mission to Tuvalu
2. De-briefing Note	Before departure from Tuvalu
3. Scoping Mission Report	<i>October 2008</i>
4. Final Evaluation Report	Third week November

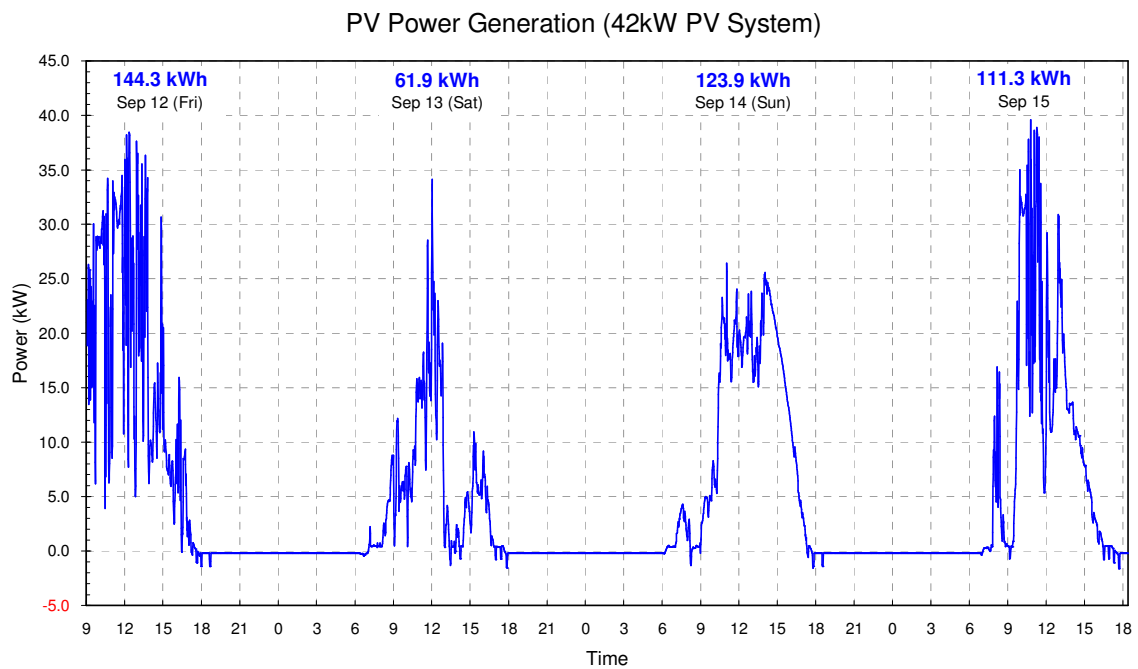
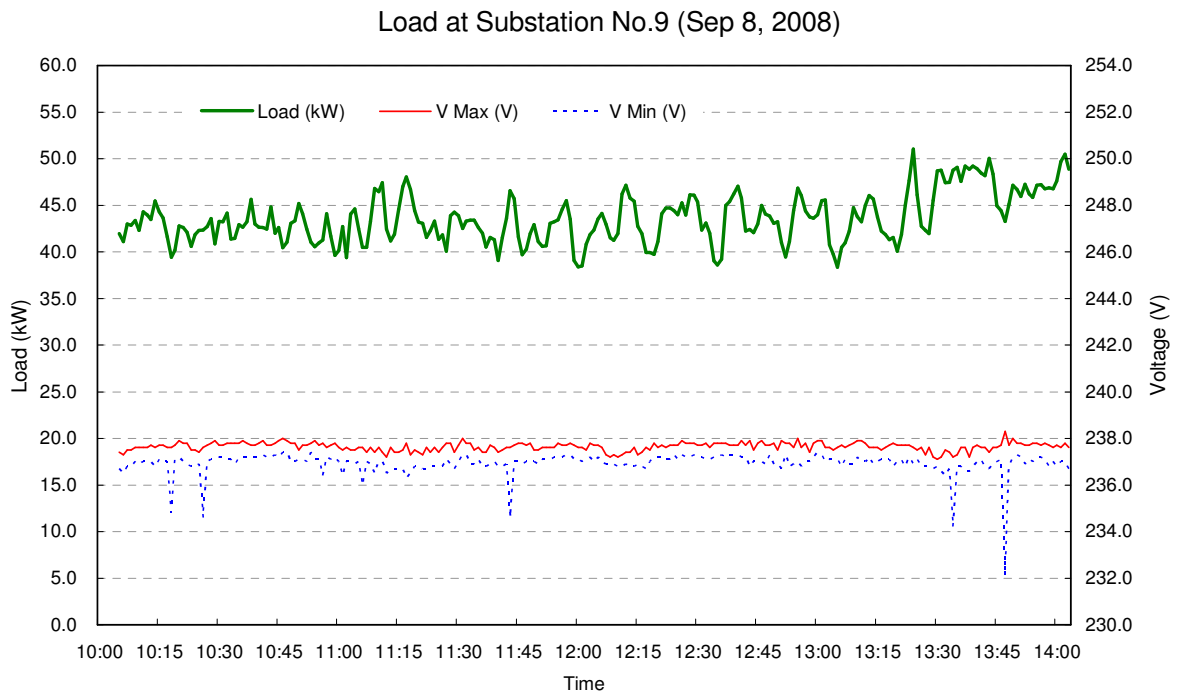
7. Consultant

The consultancy shall require the services of qualified power utility practitioners with skills in distribution and generation and preferably with experience in solar PV technologies.

Annex 2 Operating Cost Forecasts TEC Vaitupu

Base Case	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Fuel Use	119,782	121,579	123,403	125,254	127,133	129,040	130,975	132,940	134,934	136,958	139,012
Fuel Cost	215,608	218,842	222,125	225,457	228,839	232,271	235,755	239,292	242,881	246,524	250,222
Staff Cost	33,000	34,188	35,419	36,694	38,015	39,383	40,801	42,270	43,792	45,368	47,001
Other O&M Cost	23,000	23,828	24,686	25,574	26,495	27,449	28,437	29,461	30,522	31,620	32,759
Depreciation	29,100	32,100	32,100	34,100	34,100	36,100	36,100	35,922	37,922	38,017	38,114
Total Cost	300,708	308,958	314,329	321,825	327,449	335,203	341,094	346,944	355,116	361,529	368,096
High Case											
Fuel Use	131,468	136,727	142,196	147,884	153,799	159,951	166,349	173,003	179,924	187,121	194,605
Fuel Cost	262,937	273,454	284,392	295,768	307,599	319,903	332,699	346,007	359,847	374,241	389,211
Staff Cost	36,000	37,620	39,313	41,082	42,931	44,863	46,881	48,991	51,196	53,499	55,907
Other O&M Cost	26,000	27,170	28,393	29,670	31,005	32,401	33,859	35,382	36,975	38,638	40,377
Depreciation	29,100	32,100	32,100	34,100	34,100	36,100	36,100	35,922	37,922	38,017	38,114
Total Cost	354,037	370,344	384,198	400,620	415,635	433,266	449,539	466,302	485,939	504,396	523,609
Low Case											
Fuel Use	102,253	102,764	103,278	103,795	104,314	104,835	105,359	105,886	106,416	106,948	107,482
Fuel Cost	153,380	154,147	154,917	155,692	156,470	157,253	158,039	158,829	159,623	160,422	161,224
Staff Cost	30,000	30,840	31,704	32,591	33,504	34,442	35,406	36,398	37,417	38,464	39,541
Other O&M Cost	20,000	20,560	21,136	21,727	22,336	22,961	23,604	24,265	24,945	25,643	26,361
Depreciation	29,100	32,100	32,100	34,100	34,100	36,100	36,100	35,922	37,922	38,017	38,114
Total Cost	232,480	237,647	239,857	244,111	246,410	250,756	253,149	255,414	259,907	262,546	265,240

Annex 3 Load Data Fogafale Grid Connected System



Source: Dr. A. SHIOTA JICA Project Formulation Study 2, September 2008

Annex 4 Consultations

The following stakeholders have been consulted during the mission:

Contact	Designation	Subjects Discussed
Mr. Anare Matakeviti	Manager IUCN	All aspects of project appraisal and design, project budget, timing of implementation, co-ordination with other stakeholders and donors, compatibility with national energy policy and donor expectations.
Mr. Taholo Kami –	IUCN- Oceania Regional Director	Briefing on project mission methodology and time frame, IUCN policy
Mr. Taukelina Finikaso	Hon Minister for Works and Energy	General briefing, government policy on outer island electrification, project design, limitations for grid parallel systems, timeframe and possibility to expand project concept to other outer islands. The Hon Minister emphasised that the Tuvalu Government is committed to convert outer islands' power supply to 100 % renewable energy. Thus, the Vaitupu solar project is seen by the Cabinet as a first step in this direction.
Mr. Mafalu Lotulua	General Manager TEC	All aspects of project appraisal and design, project logistics, experience with PV in Fogafale, inconsistencies in billing and generation data, timing of project, co-ordination of mission with other stakeholders
Mr Nielu Mesisake and Mr. Timaio Auega	Energy Department GoT	All aspects of project appraisal and design, budget restrictions, compatibility with GoT policy, need to include community mobilization and energy conservation campaign by Energy Department, project, co-ordination of mission with other stakeholders
Mr. Mr Taaku Esekielu.	TEC Engineer Outer Islands	Data acquisition on outer island power supply, technical design of systems, institutional aspects
Mr Polu Tanei	TEC Technician	Counterpart during mission and field work. All aspects of project appraisal and design, project logistics, inconsistencies in billing and generation data, timing of project, co-ordination of mission with other stakeholders
Mr Mosese Halofaki	Principal Motofoua secondary School	Energy needs of school, problems with supply constraints (TEC operating hours), location of solar unit, design considerations, implementation schedule, support from school staff, security of project, time frame.

Mr. Malcolm Ponton	EU Delegation Suva	Compatibility of project with EU Country Strategy for Tuvalu, Possibility of financing additional renewable energy projects under EDF 10 and possibly 2 nd call under EU Energy facility
Mr. Paul Fairbairn	Manger SOPAC	Explanation of project, coordination
Mr. James Conway	Advisor to National Authorizing Officer EU	Possibility of financing additional renewable energy projects under EDF 10 and possibly 2 nd call for proposals under EU Energy facility, general co-ordination
Mr. Mika Elisaia	General Manager BP Tuvalu	Fuel supply and transport logistics to Vaitupu, future of fuel supply for Tuvalu (possible withdrawal of BP from Tuvalu) prospects for renewable energies in outer island energy supply.
Mr. Tealu Honolulu	Chief Operator TEC Vaitupu	All aspects of project appraisal and design, current mode of operation (operating hours) of Vaitupu system, fuel supply logistics, energy conservation, billing and meter reading, payment and revenue collection, timing of project, transport logistics for equipment.
Mr. Steve Boland	Advisor Ministry of Finance	General Briefing on project, budget and potential savings
Mr. Eti Esela	Alpha Pacific Navigation	Transport logistics and cost, availability of maritime transport, off-loading capabilities in Vaitupu, general project support services and availability of local labour for installation of system.

Annex 5: Concept Note Renewable Energy Electrification Outer Islands Tuvalu

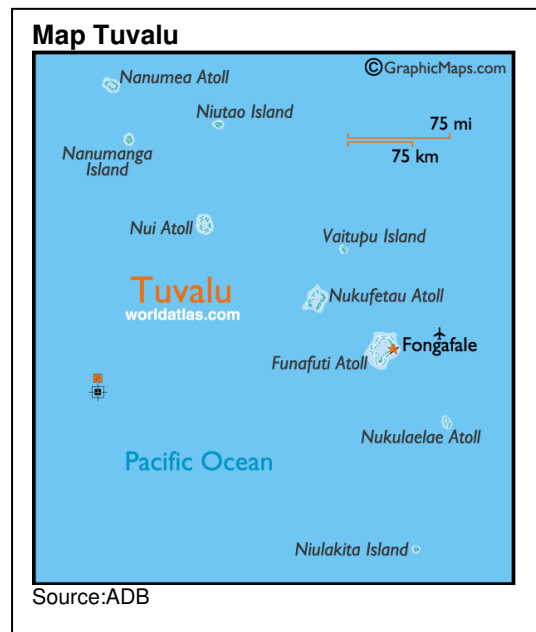
Introduction

This concept note briefly describes a project proposal to enhance the sustainability of outer island power supply in Tuvalu through the use of solar energy. The proposed project aims to implement solar – diesel hybrid systems that would allow to conserve approximately 80% of the diesel fuel currently used in the outer islands.

Background

The Government of Tuvalu is placing a high priority to promotion of renewable energy as a means of cushioning its economy from increasing volatility in the international fuel markets. The massive energy cost increases experienced in the first half of 2008 had a devastating effect for Tuvalu: Energy cost increases were exacerbated by significant supply cost increases of all other imported products as well, including food, household equipment and building materials.

The negative economic and social impacts are even more pronounced in the outer islands than on Funafuti creating hardship for their residents. At the same time renewable energy solutions are available to enhance energy security and reduce the economy's vulnerability towards external shocks.



Any actions aimed at reducing dependency on imported fossil fuel will also help decrease greenhouse gas (GHG) emissions, and put Tuvalu on the road of a sustainable and exemplary development, giving the nation a stronger bargaining position in international negotiations. TEC already operates a 40 kW grid connected PV system in Funafuti and is in the process of implementing a pilot project on the outer island of Vaitupu. This pilot project is intended to demonstrate the viability of solar-diesel hybrid systems in the outer islands.

Objective

Against this background described above, the Tuvalu Government through the Tuvalu Electricity Corporation (TEC) and the Tuvalu Department of Energy seeks support for a project to use environmentally friendly solar PV technology to improve energy security in the outer islands. The positive experiences to date with the grid parallel solar system on the main island of Fongafale encouraged the Government and TEC to pursue solar projects for outer islands as well. Considering difficult supply logistics and high supply costs for fuels, PV – diesel hybrid systems are considered an optimal solution for the outer islands.

The overall objective of the project is the promotion of the use of renewable energy resources through the implementation of cost effective, equitable, reliable, accessible, affordable, secure and environmentally sustainable energy systems. The project will integrate renewable energy supply with improved management of the existing diesel generation equipment and at the same time promote demand side management and energy conservation in the outer islands.

Experience with Solar Energy in Tuvalu

The Tuvalu Government through its the Ministry of Works and Energy has established a comprehensive National Energy Policy Framework covering the next 15 years. Strategies have been put in place to ensure “adequate, secure and cost effective supply”, “efficient utilization of energy” and “minimization of negative impacts of energy production, conversion, utilization and consumption upon the environment.” Tuvalu relies very heavily on imported fuels for commercial energy needs including 100% of transport and electricity generation (the chief uses), and a majority of household use including cooking, transport, refrigeration, and lighting. On the other hand the Tuvalu Government has promoted the use of indigenous renewable energy resources in cooperation with its development partners since the 80ies. The country was one of the first to promote stand alone solar home systems for outer island electrification. More recently with the assistance of the Japanese Government a 40 kW grid connected solar unit has been established on the main island of Fogafale.

The Fogafale PV unit has shown an encouraging performance saving a considerable quantity of diesel fuel every month. Its operational data are recorded for research purposes and allow predicting the performance of PV solar systems under the conditions in Tuvalu. Accordingly a PV solar system can be expected to provide an average of 3.5 kWh per day and kW_{peak} installed capacity. At current installation cost for solar equipment this translates into generation cost of approximately Australian \$ 1.65 per kWh. At the current cost of fuel and the capital and operating cost for the diesel generators supplying electricity to the small outer island power grids, the use of solar and/or wind power is a financially viable option for TEC as long as concessionary or grant financing can be identified for such projects.

Diesel – PV Hybrid Systems for Outer Islands

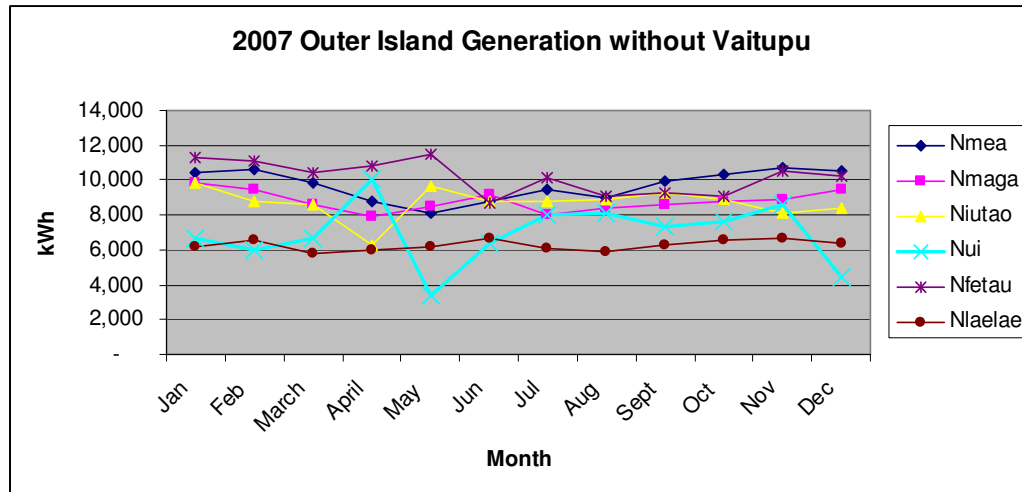
At present a pilot PV – Diesel hybrid project is being implemented with support from the Italian and Austrian Governments on the largest outer island of Vaitupu. The reason for selecting a hybrid configuration is that Diesel generators already operate in all outer islands. They can be used to back-up the solar installations thus allowing smaller solar generation and battery capacities and lower overall project cost.

In a hybrid configuration battery capacity can be reduced to 15-25% of the capacity that would be required for a 100% solar supply achieving diesel savings up to 60% depending on load pattern and mode of system operation.

The Chart below shows that monthly consumptions are fairly steady throughout the year and even on a daily basis, there is not much variation in consumptions. All islands have the typical daily load curve of small rural systems which are dominated by household consumption.

A solar charged battery unit not only directly saves fuel by producing kWh that would otherwise have to be generated by burning diesel, the battery also allows considerable operational flexibility and optimization of the operation of diesel sets. Specific fuel consumptions deteriorate substantially when a diesel unit is operated below 50 % of its nominal output, a situation that is quite common in the outer islands.

Outer Island Electricity Generation



Source:TEC

The table below describes a scenario that combines a Demand Site Management program in conjunction with a solar powered battery units based on the current generation and fuel use figures for the smaller outer islands.

The scenario assumes a reduction of power consumption by 20 % through educational campaigns and DSM measures such as substitution of incandescent light bulbs by CFLs and the reduction of use of heating devices such as water kettles, sandwich makers and electric frying pans. Although many households already use fluorescent tubes, there is still room to manage the demand side in the outer islands. A DSM program, however, can only produce tangible benefits from lower fuel consumption when it is implemented in conjunction with a DBU. I.e. reducing the demand would force the generators to operate even less efficiently than now. The DBU, however, would allow operating the diesel sets close to optimal loading. Either the DBU could supply power in low load situations without the diesel. In case the diesel is needed, charging of the DGU would help to operate the diesel sets close to their optimal operating point.

The DSM program would also involve government consumers. It is expected that the DSM scenario would not significantly impact on any quality of life for the islands residents. Only very minor changes in consumer behavior would required and the savings in power consumption would benefit the consumers financially through a lower power bill.

Solar power would supply approximately 60% of each islands total demand. The required total solar capacity would range from 25 kW_{peak} on Nukulaelae to 41 kW_{peak} on Nukufetau. The following table summarizes the key figures of the projects for each island. In total 201 kW would be required together with effective battery capacities of 1200 kWh. Installation of PV solar systems and battery unit together with operator training would improve specific fuel consumption to 2.8 l/kWh, a realistic figure that has been achieved in similar situations. (The value for Fogafale is currently 3.8 kWh/l).

Table Solar-Diesel Hybrid and DSM

Island	Current Situation			Solar Hybrid+DSM						
	kWh	kWh/l	Liters	total kWh	Solar kWh	Solar kW	kWh/l	kWh from diesel	Liter Fuel Use	Liter Fuel Savings
Nanumaga	103,150	2.4	42,979	82,520	49,512	39	2.8	33,008	11,789	31,191
Nanumea	101,584	2.44	41,633	81,267	48,760	38	2.8	32,507	11,610	30,023
Nuitao	77,980	2.52	30,944	62,384	37,430	29	2.8	24,954	8,912	22,032
Nui	78,692	1.97	39,945	62,954	37,772	30	2.8	25,181	8,993	30,952
Nikufatua	108,251	2.55	42,451	86,601	51,960	41	2.8	34,640	12,372	30,080
Nukulaelae	66,401	2.12	31,321	53,121	31,872	25	2.8	21,248	7,589	23,733
Total	536,058		229,274	428,846	257,308	201		171,539	61,264	168,010

These measures combined would reduce outer island fuel consumption from 229,274 liters to 61,264 representing a saving of 168,010 liters per annum. It is estimated that the total investment required to convert the outer islands to hybrid systems is AUD 4,000,000. Such a program would also enable TEC to reduce installed diesel capacity by one generator per island. It should be noted that the detailed design of such a program required on-site analysis, in particular with respect to locating the solar arrays (a total surface of approx 16,000 m² would be required).

A detailed design of the systems would also require an analysis of daily load curves. TEC is currently gathering load data for outer islands in preparation of the solar-diesel hybrid projects.

Annex 6: Capacity Building RE Systems Tuvalu

A. Introduction

International and regional experience in the Pacific has shown that the performance of rural and remote area electrification is directly correlated with the understanding, skills and knowledge of system operators. This is true for both conventional (diesel) and renewable energy systems. However, adequate capacity of operational personnel becomes even more important when renewable energy systems are employed. This is due to their characteristics of high up-front investments and low operating cost. I.e. if operators are not capable to handle an expensive PV solar system in the appropriate way, the monetary damage is by far greater than inappropriate handling of a diesel system. In Tuvalu, hybrid style PV diesel systems will be implemented as a means to reduce operating costs of diesel systems currently employed. The systems are more complex than pure diesel or solar systems as an optimal outcome of the projects can only be achieved if the operators are capable of maintaining and operating the systems.

B. Objectives of Capacity Building

Capacity to operate and maintain hybrid renewable energy systems in an optimal way requires technical knowledge and technology specific skills. However, it is here proposed here that the objective to create adequate capacity is more than transferring skills to the operators. The capacity program must also acknowledge the experiences and latent capacities the candidates already have and at the same time provide opportunities and incentives for the operators to practice and extend the skills acquired. In other words, capacity building is seen as a long term process where initial training is provided during the installation and commissioning of the projects. Thereafter TEC management has to ensure that the operators are provided with incentives to practice and extend knowledge and skills acquired during the initial training. Capacity building should be an ongoing process of human resource development that encompasses the entire utility, refines processes and procedures and offers opportunities for staff to constantly improve.

C. Scope of Initial Training

It is assumed that existing operators in islands that receive PV hybrid systems will be trained to operate and maintain the systems. It is further assumed that this training is part of the supply-install contracts for the equipment. Responsibility for the initial training will rest with the contractor. It is recommended that the operators/trainees are involved in the actual installation, testing and commissioning of the projects as much as practicable. The following steps are recommended for the initial training:

1. Review of Knowledge and Skills

Based on dossiers prepared by TEC, the contractor will review and record education, experience and skills of the candidates. This step will establish if there is a need to deepen basic understanding of electrical systems. In case potential trainees lack this basic understanding they should be referred back to the utility where basics are best acquired.

2. Introduction into PV

This step will familiarize the candidates with the general characteristics of PV systems, their performance parameters and principles. The training will include:

- Introduction to Photovoltaics (PV), Overview and Technology Context
- Solar Resource (daily and seasonal variations)
- Solar modules, panels and arrays, components
- Performance, module design and specifications

- Interconnections
- Diodes and grounding
- Shading, dirt and damage
- Safety issues
- Racks, purpose, materials, design, mountings
- Controllers (purpose, functions, electrical characteristics, adjustments, meters)
- Batteries (storage options, types, designs, characteristics, performance specifications)
- Battery safety issues (acid handling, H₂ production, need for ventilation, battery disposal issues)
- Inverter Types Functions and applications
- Inverter Capacity and Efficiency, secondary (additional) Inverter capabilities
- Specifics of the inverter type used in installation, safety and protection
- PV wiring differences: conventional vs. PV
- Wiring types, sizes and sizing, ratings, losses, colors
- Wiring schemes, terminations, connections, safety, fuses and grounding
- Protections, safety disconnects, over current protection, lightning and surge protection.

3. Hybrid Systems

This module will transfer knowledge specific to hybrid systems. It will focus on the system design to be implemented in Tuvalu and provide the trainees with an understanding of the operating principles. The training will include:

- Load characteristics of rural systems, base load-peak load, minimum load
- Operational characteristics of diesel generators, specific fuel consumption over load range, consequences of low load operations (higher fuel consumption, higher maintenance, lower life time)
- Reasons for hybrid configurations, optimization of storage capacity, economics, stand-by capability, security
- Examples of hybrid configurations (PV, Wind, Diesel)
- Options for diesel systems operated on biofuel
- Interfaces between PV arrays, battery and diesel, operating modes of hybrid system (Diesel alone, diesel charging battery and supplying load, battery alone)

4. System Installation

- Design considerations, site selection, site assessment and installation planning
- Safety review and construction safety requirements
- Quantity survey and quality checks of materials and components
- Tools and equipment
- Practical installation exercise (Racks, arrays, wiring, controller, batteries, inverters)
- System testing and performance checks
- Commissioning requirements, final checks

5. System Operation and Maintenance

- Review of diesel maintenance requirements, need to keep all system components in good operating conditions
- Review of expected load curves and contribution of solar to system energy requirements

- Specific fuel consumption characteristics of diesel generators and means to operate in optimal SFC range (generator dispatch)
- Operational planning, anticipation of system demand, daily, weekly and seasonal fluctuations
- Weather observations, anticipation of solar contribution, seasonal aspects
- Design operating modes, automation, time of operation, switching needs
- System parameters, meters, displays, data loggers
- Monitoring, recording and logging of operational data
- Optimal operation of diesel unit
- Operational limits for battery storage, effect of deep discharge
- Safety issues, 'islanding' emergency disconnect
- Environmental hazards, health and safety, fire hazards, fuel and acid spillage
- Maintenance schedule, maintenance planning
- Maintenance procedures for arrays, wiring, electronics
- Maintenance requirements for batteries, electrolyte testing, safety issues
- Fault finding, trouble shooting, operator discretion and communication with head office
- Replacement of system components, spare part management
- Reporting and event logging

6. Demand Side Management

Operators have to understand how demand influences system operation and have to work with consumers to create a sustainable electricity supply. Their role will be expanded from power systems operator to energy system managers. The following training points are essential:

- Survey of appliances used in community and consumption characteristics of popular appliances (loads, frequency and duration of use)
- Relationship between supply and demand, influencing consumer behavior, load curve shape and specific fuel consumption
- Avoiding spiky demand curves: Consumer education and time of use arrangements
- Energy conservation and energy efficient appliances (compact fluorescent bulbs, low energy fridges and freezers), impact of heating devices on load (electric frying pans, water kettles, sandwich makers)
- Monetary savings through energy efficiency and prudent consumer practice
- Alternatives to electricity use: LPG, kerosene and biomass as heat sources
- Advantages of 24 hour power supply and need for consumer cooperation
- Load levellers such as water pumps and battery charging
- Consumer education and awareness campaigns
- Productive use of electricity (education, crafts, small businesses)
- Common interests of TEC and consumers: A sustainable power supply.