Empower Consultants

Hybrid Photovoltaic/Coconut based Power Systems in Tokelau - Consultancy for the Feasibility, Environmental Impact Assessment, System Design and Specifications of Major Components and Financing Strategy

Report on Feasibility, Environmental Impact Assessment, Overall System Design and Specifications and Financing Strategy

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Contents

Executive Summary

Global attention is presently fixated on the price of oil and the growing body of evidence that global warming is a major threat to our collective ecosystem. Tokelau is almost 100% reliant on fossil fuels for its current power supplies (with the exception of some solar PV supply on Fakaofo to the University of the South Pacific, Teletok and some residences), but has recognised the need to reverse this situation and become 100% renewable energy based. This desire has been official policy for the Government of Tokelau since 2004, and is fully in line with the policy directions of the New Zealand Government as well.

There are no immediate technical reasons why Tokelau cannot place its electricity generation system fully onto solar photovoltaics and generators running on 100% indigenous coconut oil. Such a move would attract global media attention for a tiny nation to be leading the way, and could turn an energy budget problem into a 'green' marketing coup for both New Zealand and the Government of Tokelau. Such a move is in complete agreement with the 2 long term goals of the National Energy Policy and Strategic Action Plan (NEPSAP) which identifies improved energy quality and affordability, and the achievement of energy independence through the development of indigenous resources.

Technically, solar PV and inverter technologies are now fully mature and offer off the shelf components that are reliable, mass produced, simple to operate and maintain and include sophisticated online capabilities that allow remote diagnostics and adjustment, avoiding unnecessary service technician visits. While some minor variation in demand is present between the three atolls, essentially the same technical package can be deployed to all three atolls, using fully modular, scalable inverter and solar inverter technology. The approximate suggested system comprises 100 kWpk of solar PV per atoll, either centralised or dispersed around the low voltage network on each atoll and feeding power into the AC side via grid connected inverters. Large 3,000 AH battery bank strings are charged by the solar PV during the day, and then meet consumer demand at night, via 45 kW 3-phase inverter sets. In periods of bad weather of low solar PV input, or when consumer demand exceeds solar supply, the inverter set will automatically start a 100 kVA purpose built coconut oil generator set to meet the AC demand and recharge the battery bank, simultaneously.

The use of 100% coconut oil is a challenge. Incorrectly approached, the use of 100% coconut oil can reduce the operating life of generator sets. However, purpose built engines are available, and small scale oil process equipment is also accessible to enable the atolls of Tokelau to process their own oil. The process must be carefully approached, but it can be done.

From an environmental and social perspective, the overall impact is very positive. The atolls have an abundance of unused coconuts since copra production was discontinued around 30 years ago. There are no negative impacts of the project, but several advantages including a reduction in waste oil production and disposal issues. The presence of large lead acid battery banks do pose a potential environmental concern, however adequate training and planned recycling mechanisms will ensure that this risk is mitigated.

There is considerable scope to reduce demand for electricity through the implementation of an energy efficiency project, and possibly coupled with a mechanism to assist the population of Tokelau to afford better quality refrigeration, and better understand the need to turn off unused appliances. This could impact on the scale of the solar PV and coconut oil project, and it is recommended that an energy efficiency project be undertaken prior to the final renewable energy design being confirmed, as a significant reduction in scale is possible.

Financially the project has an estimated implementation cost of approximately NZD 6.4 million, for which there appears to be four possible options for funding. The most likely two options are either a grant from a donor entity or a commercial investor with revenues coming from the payment of power bills, underwritten by a reliable third party stakeholder. Discussion and agreement between stakeholders is clearly required, however sufficient potential appears to exist to form the basis for discussions to move forward on either option.

1. Introduction

The Tokelau Hybrid Photovoltaic / Coconut oil based power project is a major step towards energy independence for the 3 atolls of Tokelau. Located approximately 500 km north of Samoa, access to Tokelau is only by boat. The specific locations of Tokelau's atolls are:

Atafu:	8°33′6″S, 172°30′3″W
Nukunonu:	9°10′6″S, 171°48′35″W
Fakaofo:	9°21′55″S, 171°12′54″W

The population of Tokelau was assessed in the 2006 census at 1,466 persons, and is roughly evenly spread between the 3 atolls with 483 on Fakaofo, 426 on Nukunonu and 524 on Atafu.

The remote location, difficulty and expense of access have created a nexus of factors leading to expensive infrastructure and high energy prices. This has been recognised by Tokelau’s governing council, the Taupulega, and in response a policy of moving towards 100% renewable energy utilisation was endorsed in 2004. This policy, known as NEPSAP (National Energy Policy and Strategic Action Plan) is also completely in line with the low carbon, pro renewable energy aspirations of the New Zealand Government. This study including its recommendations will be fully in line with the intentions of NESAP.

To this end, the Tokelau Government, with support from the United Nations Development Program (UNDP), has undertaken a preparatory study to assess the resource, technical, socio-cultural, economic, financial and institutional/management feasibility of establishing renewable energy systems on each of the three atolls to meet electrical needs through a hybrid mix of 90% solar PV and 10% coconut oil based generation. The immediate beneficiaries of the project are the inhabitants of the Tokelau atolls, not through an improved power supply as the present a high standard of reliability and power quality exists, but being 100% based on fossil fuels, the cost to Tokelau is uncontrollable and increasing with the growing price for oil internationally.

This report details the findings of the study conducted, based on a field work study undertaken by Empower Consultants in September 2007. This report builds on the field work study, and provides detail on the topics outlined above in order to achieve the specific objectives of the study, as summarised below. Much of the detailed findings of the situation on the atolls has already been reported in the fieldwork study and hence this report is intended to be concise and to the point, and not simply a repetition of material already reported.

In addition, this study builds further on the renewable energy work already done on Tokelau, including the 10 kWpk grid connected solar PV array installed on the islet of Fenuafala, Fakaofo Atoll in January 2004, and the Verification Report done by Empower Consultants in November 2006 reviewing this installation.

The specific objectives of the study are as follows:

a) To determine for each of the three atolls the resource, technical, socio-cultural, economic, financial and institutional/management feasibility of a hybrid power system based on PV and coconut oil based biofuel;

b) To assess for each of the three atolls the Environmental Impact Assessment of the current power system and that of a future hybrid power system based on PV and coconut oil based bio-fuel;

c) To prepare for each of the three atolls system design and specifications for major components for a hybrid power system based on PV and coconut oil based bio-fuel; and,

d) To prepare a financing strategy (i.e. investment plan) for hybrid power systems based on PV and coconut oil based bio-fuel.

This report will address each of these topics in order, and where necessary, for individual atolls, in order to assess the feasibility in a coherent manner.

2. Tokelau Power Sector Structure

The energy sector in Tokelau is decentralised between the three atolls with direct responsibility under each Taupulega, but under the technical advice of an Energy Manager/Planner, Department of Energy based on the Atoll of Fakaofo. The Energy Manager/Planner (EMP) manages the operation of the Fakaofo power station and also oversees the technical operations on the atolls of Nukunonu and Atafu, via a power station managers on each atoll. The power station managers have direct control over the day to day operation and maintenance of the plant and equipment, necessarily so as the EMP cannot easily or regularly travel between atolls to undertake this function.

Governance on each atoll is the function of a council of elders, or Taupulega. Each Taupulega have the responsibility for making management decisions about the operation of the power station on their atoll, and this autonomy is reflected in the different prices charge for power between the three atolls. In general however, the Taupulega accept and implant the technical recommendations from the Energy Manager/Planner, Department of Energy. In addition, all three Taupulega accept the use of a common set of engineering standards.

All three Taupulega expressed concerns over the rising cost of diesel fuel, and also a desire to improve Tokelau's energy independence and ability to insulate itself from future energy shocks. It is widely recognised by Taupulega how dependent Tokelau has become on electricity, and the very serious impacts that would be felt should energy supplies become too expensive, or disrupted by another factor, such as the international closure of borders and transport links through an event such as a global pandemic. The development of indigenous energy resources is correctly seen as a pragmatic step towards avoiding the apparent inevitability of rising fossil fuel prices, and mitigating the impact of other global events on the population of Tokelau.

Operating budgets are set by each Taupulega, and the purchase of fuel supplies is not under the direct control of the Department of Energy but is managed by each Taupulega independently. To all intents and purposes, energy appears to be a non negotiable section of the budget for each Taupulega.

The planning, operation and management of the national power sector has benefited from the professional services of a qualified electrical engineer as Energy Manager/Planner, Department of Energy for the last 5 years, and the reliability and performance of the sector reflects this professional approach. Recent agreements with Samoa over the returning of waste materials will further allow incremental improvement in the power sector, particularly in the handling of used lubricants and components such as filters and starting batteries will be able to be returned to Samoa for safe recycling and/or disposal, rather than the simple dumping methods used in Tokelau to date.

The lack of hearing protection for operators in and around the generators was a concern however. It is recommended that additional sets be made available and staff be informed of the negative health impacts that will accompany their failure to use them.

The operation of the gensets is well managed, and duty units are rotated regularly to allow wear and tear to be evenly dispersed and scheduled maintenance activities to be undertaken. Loading on the gensets is light, but acceptable given the derating applied by the power sector managers to ensure that the units do not overheat. This does negatively impact on fuel efficiency, but has been acceptable in the past when fuel efficiency was an acceptable sacrifice compared to the risk of thermally overloading a generator set. This may need to be revised in the face of rising fuel costs. However, should the solar PV/bio-fuel project proceed then the inverter/charger technology expected to be deployed will allow much more precise loading of the gensets, as the generators, when started, will both meet the AC loads and simultaneously charge the battery bank. This is important both from an operating efficiency perspective but also from a biodiesel or coconut oil perspective where running an engine under load is the optimal condition.

3. Power demands and demand side management

Tariff Structure

The present tariff structure in Tokelau is subsidised and each Taupulega decides the rates chargeable by the consumer. Present rates per kWhr are NZ50 cents per kWhr on Fakaofo and Atafu, but only NZ30 cents per kWhr on Nukunonu. An indepth analysis of the true cost per kWhr, including depreciation, fuel and all operating expenses has not been undertaken, but the Energy Manager/Planner of the Department of Energy conservatively estimates the cost at around $1.20 per kWhr. Thus a significant subsidy is in place on all atolls.

There is considerable resistance to raising the tariff from the Taupulega's, due to the unpopularity of higher energy prices, and yet the price of energy has not yet reached a level where energy efficiency has become an entrenched and normal activity. Energy wastage and inefficient appliances are the norm, rather than the exception, and the high price of power should have provided an incentive to change consumer behaviour. The lack of change in behaviour suggests a need for consumer education, and access to a finance mechanism to allow consumers to purchase higher efficiency appliances, particularly refrigeration.

The calculation of a new tariff requires political agreement from the three Taupulega. At this point in time this does not appear to be supported; however there appeared to be surprise from some Taupulega members when the degree of subsidy present was discussed as some members were unaware that the losses per kWhr were so high. With an average power demand of 618 kWhrs per day, and an average loss of NZ$0.77 per kWhr[1], the cost of the electricity subsidy to the Tokelau Government is approximately NZ$475 per day. Or NZ$173,000 per annum, per atoll, or around NZ$ 500,000 per annum as at Sept 2007 diesel prices for all three atolls.

In addition there is an issue with unpaid power bills from consumers. The rules are clear, but enforcement is difficult in such small and close knit communities. A brief review of one atoll showed an annual unpaid power bill amount of NZ$22,000, but informal comments suggested that each Taupulega is carrying an accumulated unpaid consumer power bill debt

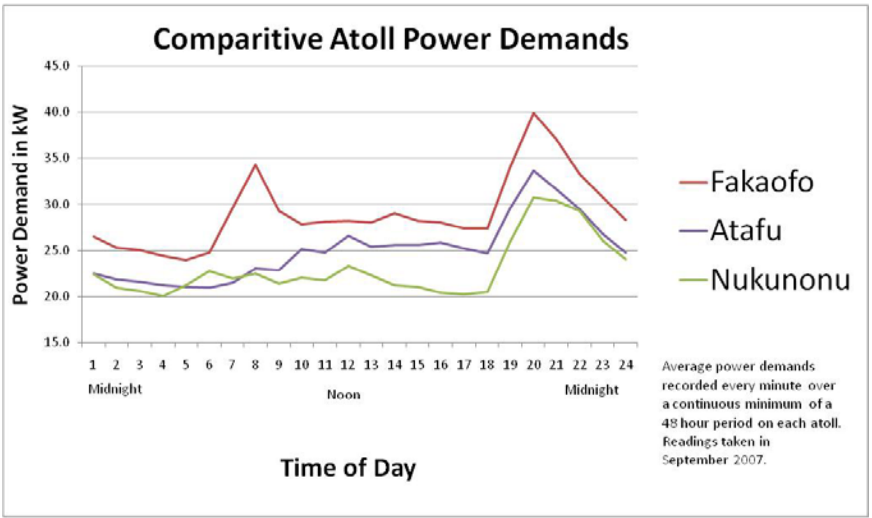
[1] Taking $1.20 and subtracting the average tariff of $0.43

of NZ$150,000 to NZ$200,000. This is significant and while tariff reform is outside of the scope of this project, clearly the issue of reducing power subsidy costs and improving the rate of bill payment needs to be addressed.

The introduction of hybrid solar PV and coconut oil systems will improve this situation, in part by fixing the cost of power to the cost of the capital items needed to construct the project. External influences, such as the cost of fuel, will be largely avoided and constrained to spare parts and expertise. This is more predictable and controllable than the price of oil.

Power demands on all three atolls are relatively consistent, as evidenced by the graphed data collected over the field visit. The September 2007 field study ascertained that the average demands over a 24 hour period totalled 29.1 kW, 23.0 kW and 25.0 kW for Fakaofo, Nukunonu and Atafu respectively. The maximum recorded loads on the three atolls were 51 kW, 37 kW and 38 kW during the field study period for Fakaofo, Nukunonu and Atafu respectively.

Table 1 below provide the data collected.



	Fakaofo	**Nukunonu**	**Atafu**	Unit
Total 24 hour average demand	**29.1**	**23.0**	**25.0**	kW
Maximum recorded demand	51.2	36.7	38.0	kW
Minimum recorded demand	22.2	16.3	18.2	kW
Average daily consumption	699	553	601	kWhrs
Consumption from 6pm to 6am	383	316	326	kWhrs
Consumption from 7am to 5pm	316	237	275	kWhrs
90% solar means delivering	629	498	541	kWhrs
and 10% from coconut oil	70	55	60	kWhrs
Litres fuel consumed per day	259	210	276	Litres
kWhrs produced per litre	2.7	2.6	2.2	kWhrs

There will be a natural growth in power demand, however at present there is so much scope to reduce demand through a reduction in wastage and inefficiency, that so long as a program of incremental efficiency improvement is adopted the total demand should stay flat for 5 years or more.

The study showed that the power demands are rather consistent throughout the day, with a clear spike during the evening hours as lighting, TV and some cooking loads come on line.

The relatively consistent load profiles between the daytime and nightime loads was explored in the Debrefing Note (attached in Annex 2) and is concluded mainly to be the the result of refrigeration, much of which is poorly maintained or not designed to cope with the high ambient temperatures present in Tokelau. A progressive program of replacing inefficient refrigeration devices with better insulated and more efficient friges and freezers is recommended and covered in the financial section.

The Tokelau strategy deployed to manage power demands is focused on not connecting large loads, and banning the use of loads such as cooking stoves and airconditioning. This has worked well to date however the use of cooking appliances other than stoves, such as electric frying pans and sandwich makers still presents a direct cooking related power demand spike as seen on the demand graph above. This spike is not entirely related to cooking loads, but the household surveys noted the presence of electric cooking appliances other than stoves and it is apparent that these are in use. Moving these onto gas will assist to reduce the peak demands.

Problem analysis

Technical

From a technical perspective, the current situation on each atoll is acceptable and no major operational issues were identified. The existing infrastructure is operating within limits and is well managed and controlled. The generators are operating well within limits, and may in fact be under-loaded rather than the reverse. There is a potential capacity problem to resolve if the existing commercial freezer facilities are refurbished and brought on line. Likewise the planned school and hospital reconstruction projects planned for each atoll include new facilities and features that will add additional loads to the existing network. Airconditioning, mortuary facilities and some climate controlled zones within the school and hospital can be included, but clearly need management and planning in the same way that new housing structures are required to build water storage as an integral part of the foundation. Solar PV can be planned into the roof structures in order to net out the energy footprint of the structure, particularly if airconditioning loads are planned.

Recommendation

Move to embed renewable energy generation into future construction projects as an integral part of the building plan, in the same manner that water storage is a compulsory part of building construction today. Move to make new structures energy neutral on the network.

Capacity

Human capacity is a present weakness in each of the three atolls. Specific technical and energy management skills are in short supply, and will be even more evident with the introduction of new technology in the form of batteries, inverter and PV technology. The Department is very dependent on the ongoing services of the present Energy Manager/Planner and the building of additional capacity in professional management and electrical engineering (including renewable energy technologies) is warranted. Retention of trained staff on Tokelau is an issue, as salaries are higher in NZ. Technical training of new staff, perhaps bonded to remain in Tokelau for a period following completion of studies, could be considered.

Environmental

The past disposal of waste oil and used parts and consumables has not been acceptable from an environmental perspective. The burial of waste oil in the porous sands of the atolls will result in leaching and groundwater contamination. The new agreement with Samoa will alleviate this situation but powerhouse staff need to be informed of new disposal procedures, particularly related to waste oil disposal.

Noise and air pollution from power generation are not presently a problem in Tokelau. Care was taken in the locating of the powerhouses for each atoll and environmental impacts of this nature are only expected if housing construction begins to encroach on land close to the powerhouses. The likelihood of impacts is further reduced if the planned hybrid solar and coconut oil project is implemented.

Financial

The power systems are operating well, and on the surface there are no obvious indicators of funding shortfalls, however this situation is largely due to the importance placed on the ongoing supply of reliable electricity supply by the Taupulega, and the willingness of the Taupulega to reduce investment in other aspects of Tokelau's infrastructure and services in order to ensure sufficient supplies of fuel and parts for the generators.

Improved energy efficiency could allow the Taupulega to reduce its losses on electricity generation while neither increasing tariffs or reducing services. The priority areas of consumption where efficiency can have an immediate and long term impacts are refrigeration and lighting. A key strategy should be to focus on education and awareness measures (failure to turn off unused appliances).

Improved payment regimes are recommended for the collection of power bills. A 25% non-collection rate is too high and would not be sustainable in a normal commercial operation. Existing models of 'pay or be disconnected' are in place in Tokelau for the use of telephone accounts with Teletok, and as a result Teletok bills are paid on time. A similar cause and effect mechanism is required for the power sector.

It is recognised and accepted that in small communities it is very difficult for a single person, or office to be seen to be responsible for disconnecting neighbours or even relatives, and hence a simple technical solution may be able to be deployed to alleviate this. Pay as you go meters/pre-paid meters, based on a token or scratch card purchased from the local shop could allow each house to take responsibility for having power on or off. No blame can be levelled at the Taupulega or the power station staff if the meter is not fed and automatic power disconnection occurs.

Recommendation

Consider prepay meters as a means of allowing the Taupulega to step back from direct responsibility for disconnecting non paying households.

Indigenous solar and coconut resources

The assessment of resources is an obvious first step. The field work study assessed that Tokelau has several realistic resources that can be developed, and scope for others are not yet mature enough to warrant further discussion. Under the realistic category we have listed wind, solar, coconut oil and energy efficiency. Under the 'possible, but not yet' category we have listed ocean thermal and wave power technologies.

Wind

This report is not tasked with investigating wind resources, however it is felt that sufficient potential exists to warrant keeping this technology on the agenda. A wind resource assessment is underway in Funafuti, Tuvalu, and preliminary discussions with SOPAC suggest that early results from the monitoring are cautiously optimistic. The NASA global meteorological database[2] indicates that an average wind speed of 4.87 m/s at a height of 50m is available. This is marginal in terms of a (mainland) normal commercial resource, but in the context of the very high energy costs in Tokelau it is still worth monitoring. Thus it is suggested that wind be kept as a possible viable option for now, and further, it is suggested that the meteorological station on Nukunonu be upgrade to include a taller wind monitoring tower and automated wind speed and direction recording instrumentation.

[2] http://eosweb.larc.nasa.gov/cgi-bin/sse/grid.cgi?email=twoods@mpwr.co.nz&step=2&lat=-9.1&lon=171.5&num=352081&p=grid_id&p=swv_dwn&p=daylight&p=no_sun1&p=wspd50m&veg=17&hgt=+100&submit=Submit

Solar

Tokelau has a viable solar resource. Using the same NASA meteorological database, Tokelau has an average annual insulation of 5.24 kWhr/m^2/day, ranging between a low of 4.53 in July and a maximum of 5.79 in October. There is little month by month variation in demand patterns, hence no need to vary the array angle away from an optimal ten degrees. Calculations for the technical and financial sections of this report are based on the data obtained from this database. Hard copy of the data is included at annex 1 of this report.

The data also provides detail on solar design parameters such as the average number of 'black days' or effective days with no solar input. In a pure solar design, these parameters would be used to size the battery bank, to ensure the battery bank was of sufficient capacity to carry power demand through periods of low or no sun.

In this installation, recognising the abundance of coconut oil resources, and the financial cost and environmental risk associated with purchasing, transporting and recycling large amounts of lead acid batteries, a smaller battery bank is recommended than would normally be the case, and the primary energy storage medium is the coconut oil.

Coconut oil

None of the three atolls is constrained in terms of access to sufficient coconuts to produce the quantity of oil needed to meet the 10% generation as per the design brief for the project. In the scope of this report, power generation from coconut oil is only as a backstop to cover times of peak demand, or periods of extended bad weather, and in this context the volumes of oil are small, in the order of 20 to 30 litres per day, per atoll, or 150 to 220 coconuts per day per atoll. On each atoll, Taupulega were consulted on the availability of this approximate quantity of nuts, and the labour to collect and process them. An assurance was provided at each atoll that both were available, and visual inspection of the islets correlates this.

The social survey conducted ascertained that most households have ownership of land resources on the islets around the three atolls, but virtually all have been allowed to return to a wild state and are not systematically harvested or cultivated. Coconuts are collected informally by most households, but only in low quantities, with the bulk for pig feed.

The project requirements for coconut oil are modest and according to the Department of Energy and the local Taupulega's, are easily within the capacity of existing plantations. There are however two factors that will influence the collection of the coconuts available. Firstly the labour required to collect and process the nuts must be designated and directed by the Taupulega's. This was discussed at each Taupulega meeting, and at each an assurance obtained that labour could be coordinated, however it remains a critical factor in the future project. The agreement to provide unskilled labour for the collection and processing of raw, dried copra does however indicate a degree of community comfort and project 'buy in' which is encouraging.

The nature of the labour required is not specialised. Minimal training is required for the operation of the oil press and filtering equipment necessary to produce fuel grade oil but the existing power station staff is assessed as being able to undertake these tasks without difficulty.

Second is the age of the existing coconut stock. Copra has not been collected and sold in Tokelau for around 30 years, and the plantations have not been maintained. Given the low demand for coconut oil by this project, the aging population is not expected to be a problem however if demand grows in future there is an incentive to begin to replant elderly and unproductive trees.

Energy efficiency

There is considerable scope for energy efficiency activities on all three of Tokelau's atolls. So much so that it is felt necessary to include it here as a resource as it could significantly impact on the scope of the project under consideration. Refrigeration, lighting and public awareness for turning off unnecessary appliances could save a third or more of the present energy demand. This was discussed in more detail in the Debriefing Note and is concluded to be so significant that it should be addressed at the same time as the technical study. It offers firstly an opportunity to reduce demand and hence the upfront costs of meeting the demand, or an opportunity to progressively integrate energy efficient products and education in future to assist to keep demand within the limits of the system.

Recommendation

Undertake a separate activity specifically designed to identify and implement energy efficiency actions and activities, or include such an activity in the planned project. This would significantly impact on the cost of achieving a 100% renewables target in Tokelau.

4. Technical designs

Assess technology and project engineering for each island.

All three atolls have similar average demands, and hence require inverter and battery bank capacities that are likewise similar. For simplicity, and in the interests of ensuring a degree of redundant capacity to allow for component failure or growth in demand, it is recommended that battery and inverter sets be identical for all three atolls. To ensure that components are not operated at or near their design tolerances, a derating factor of 30% is applied to the recorded data.

Variation is possible in the size of the PV arrays deployed for the three atolls, as there is a 146 kWhr variation between the highest recorded daily consumption on Fakaofo of 699 kWhrs, and the lowest on Nukunonu of 553 kWhrs. In terms of solar PV capacity, this is considerable and thus variation in the PV array design is necessary to avoid over capacity on Nukunonu and Atafu.

The technical expectations for each power system on each atoll must therefore follow the following parameters.

		Fakaofo	Nukunonu	Atafu	
Number of households		82	66	83	Nos
Population		483	426	524	Nos
Power consumption per person		1.4	1.3	1.1	kWhrs
Power consumption per household		8.5	8.4	7.2	kWhrs
Total 24 hour average demand		**29.1**	**23.0**	**25.0**	kW
Maximum recorded demand		51.2	36.7	38.0	kW
Minimum recorded demand		22.2	16.3	18.2	kW
Average daily consumption		699	553	601	kWhrs
Consumption from 6pm to 6am		383	316	326	kWhrs
Consumption from 7am to 5pm		316	237	275	kWhrs
90% solar means delivering		629	498	541	kWhrs
and 10% from coconut oil		70	55	60	kWhrs
Litres fuel consumed per day at present		259	210	276	litres
kWhrs produced per litre		2.7	2.6	2.2	kWhrs
Litres coconut oil required		29	23	31	Litres
Coconuts per litre of oil		7	7	7	Nuts/litre
Number of coconuts per day		202	164	215	Nuts
Solar					
Combined Battery/inverter losses	15%				
Gross electrical energy required		723	572	622	kWhrs
Solar hours per day	6				
Approximate array size		120	95	104	kWpk
Battery 24 hours storage	**VDC**	**AH**	**AH**	**AH**	
VDC	48	15,062	11,922	12,961	
Depth of discharge	50%	30,124	23,845	25,922	
Cell size AH	3,000				
Number of strings at 48 VDC		10	8	9	
Cells per string		24	24	24	
Number of cells		240	240	240	

Proposed General Design

The scale of the arrays on each of the three atolls is large by off-grid standards. This poses some technical challenges. The proposed design configuration for each of the three atolls is a standard solar PV, battery, inverter/charger and backup generator design. The general principle is:

1. The solar PV provides sufficient charge to meet the day time demand while simultaneously allowing the recharging of the battery bank.
2. The battery bank is sized to provide 24 hours supply at a depth of discharge not greater than 50%, although this can be varied.
3. A charge control system is required to regulate the quantity of solar generated electricity fed into the network.
4. The inverter is required to monitor the battery state of charge and provide a charging current from the AC network whenever an AC input is available. It is required to automatically start and stop the generator whenever the state of charge falls below set parameters. The inverter is required to be able to place the generator under automatic control.
5. The generator is required to be of a design whereby the manufacturer has offered a warranty or guaranty for operation on coconut oil, or at the least 100% biodiesel.

An AC bus design is suggested for the solar charge control function. In this design the solar PV arrays are not connect to the battery bank via a solar charge controller. Instead, the solar PV output is inverted and passed directly into the AC network. The solar input is regulated by the inverter, which has overall control of the network. This allows the solar PV to be either located in one central location, or dispersed around the atoll. The system design for each atoll is required to meet the following minimum standards, as measured during the September 2007 field work.

	Fakaofo	**Nukunonu**	**Atafu**	Unit
Total 24 hour average demand	**29.1**	**23.0**	**25.0**	kW
Maximum recorded demand	51.2	36.7	38.0	kW
Minimum recorded demand	22.2	16.3	18.2	kW
Average daily consumption	699	553	601	kWhrs

The use of an AC bus configuration is a variation from traditional solar PV/battery bank designs, however the amount of power produced by the array makes an AC bus approach more manageable and expandable in future. It also allows the array to be dispersed, which is possibly critically important as the power demand grows in future. A configuration whereby the solar PV is connected directly to the battery bank via a solar charge controller, as is the case with the pilot system on Fenuafala, Fakaofo atoll. Such a design configuration requires the array and the batteries to be in close proximity, which is not always optimal or indeed possible.

Coconut oil production

Pure coconut oil can be used in diesel generators given careful preparation of the fuel and a engine system designed for the purpose. There is ample scope for failure in the use of 100% coconut oil in standard diesel engines over the medium to long term and many of the potential pitfalls are detailed in the SOPAC/EPC/UNDP CocoGen report, October 2005. Thus the engine specified must be either factory certified to operate on 100% coconut oil, or professionally modified to enable 100% coconut oil use. Modifications would include as a minimum a fuel pre-heater, to raise fuel to around 70 to 80 Deg C prior to entering the fuel pump system, and also the inclusion of additional fuel filtering.

Successful tests have been undertaken in other pacific islands on the blending of small amounts of pure coconut oil with normal diesel fuel. This can also be an intermediate step in Tokelau to demonstrate the collection and processing of raw nuts into oil for use.

The production of coconut oil is recommended to be kept simple and not over-complicated. The volumes of oil are relatively small and can be accomplished using standard, commercially available DME (Direct Micro Expeller) presses. The DME process requires the copra to be grated, dried and then pressed in a batch process. This produces a higher grade of oil than the more standard heating and expelling process.

Filtering of the oil is important, and the oil production package supplied to this project will include off the shelf filter equipment down to 1 micron prior to entering the engine fuel tank.

Power Supply Standards

The inverter and solar charge controller system is required to operate at a nominal 230 VAC and 50 Hz, with the ability of the operator to vary the output voltage slightly to allow for transmission losses, if appropriate. It is required to interface to, and provide power through an 11 kV transformer.

Supporting infrastructure

The infrastructure required to support the installation is as follows:

Fakaofo

Fakaofo is fortunate to have a large unused building in the immediate vicinity of the existing power house, as shown in the photo adjacent:

The building offers a roof area of 200 m^2, and is of the correct angle (10 deg) for the installation of solar PV directly onto the roof. Approximately 30 kW of solar PV can be installed on the roof of the existing building and ample battery and inverter space is present inside the building to accommodate the other components.

The additional space required to accommodate the other 90 kW is available in several possible areas. Firstly the vacant space in front of the building shown is available, and with some minor pruning of trees could accommodate all the solar PV and mounting frames.

The planned reconstruction of the school and hospital facilities also provides scope for inclusion of solar PV into the roof structures. Given the possible inclusion of airconditioning loads into the new school and hospital, this should be considered as more compulsory than optional.

A solar drying structure is required on all three atolls, to assist with the simple drying of copra prior to processing into oil for use in the generator. A frequent complaint from survey respondents was that the time taken to protect copra from rain showers by collecting and placing cut copra under cover when rain threatened was very significant. The construction of a perspex, or stout glass canopy over a simple manual conveyor belt would ensure that solar energy input is maximised, but exposure to rain is prevented. Clearly all infrastructure installed are required to be designed to survive cyclone strength wind speeds.

The oil press and filtering equipment is also able to be easily accommodated within the existing building structure. Storage facilities are required for the processed coconut oil, and at least 500 litres of oil is available at any one time, to allow for emergency periods where the collection of nuts and undertaking processing may not be possible. Oil storage must allow the tapping off of condensation or accumulated moisture from the base of the tank. Oil stocks must also be rotated, so with 30 litres of consumption per day, and 500 litres of storage, typically oil will be processed and used within 10 days.

Nukunonu

Nukunonu also has space available beside the existing powerhouse, however the existing powerhouse is already constrained for space and is in an exposed location and will be moved in the near term. Given that a new powerhouse is to be constructed, it would be prudent to construct a purpose built building with the solar PV and coconut oil facilities incorporated.

The new site is planned some 400m West from the current site, and will require considerable pruning or clearing of coconut trees to ensure unimpeded solar resources on the site. Given that this is possible the site should not pose a development problem from a technical perspective. As with Fakaofo, the use of decentralised solar inverter technologies allows the utilisation of present and planned construction such as the school and hospital, to turn vacant roof space into part of the solar collection area. This would reduce the amount of land required for the solar array around the new powerhouse.

Atafu

Atafu has sufficient land area in the immediate vicinity of the existing powerhouse to construct a small facility for the processing of the coconut oil, as well as the solar PV array. Pruning will be required to prevent shading, but it can be achieved.

Structural requirements for all three atolls

- In all three atolls the PV structures are required to be constructed to a standard demonstrably able to survive a pacific cyclone (up to 200 km/hr).
- Materials shall be hot dipped galvanised steel or marine grade aluminium.
- Fixtures shall be stainless steel.

Future Power Plant Organisation

There may be little requirement to change the labour structure of the Department of Energy in order to manage this new project and infrastructure. Retraining is required as staff will still be required to supervise and maintain plant operations, however less intensively than with the operation of the diesel gensets. The main adjustment required is with the village councils, at the atoll level, as it is these councils who manage the labour at a community level. The primary labour requirement is the collection of coconut and the processing of nuts into oil for consumption. New roles and responsibilities will be created, including the need to process the coconut oil and ensure the solar PV panels are maintained in a clean and efficient condition, while less time will be required to supervise the running of the diesel gensets.

Scheduled external technical assistance is recommended. 6 month visits by a qualified technician is necessary to identify any potential faults and rectify them early. However, given that local staff will be trained in the simple tasks required to swap out modular items of equipment, and that the entire inverter and solar charge controller system is monitored at least weekly by the same technician using an online IP based access system. This allows the technician full access to monitor and adjust all operating parameters such as temperature, voltage, current etc as well as the ability to detect error messages and isolate problems over the internet. Since each atoll has reliable internet access, it is envisaged that the ability to diagnose and monitor remotely, plus give online support, including video tutorials and instruction on specific issues, means that the necessity for external technicians to visit more regularly may be able to be mitigated, or at the least the response time for solving problems reduced significantly. To see an example of the front end of this online monitoring, please contact twoods@mpwr.co.nz

Components identified as problematic using this internet access system may be very simply withdrawn from the network and sent to Samoa, or back to NZ for maintenance as required without needing to shut down the whole system or require skilled staff to visit the site.

6. Budget and financial evaluation

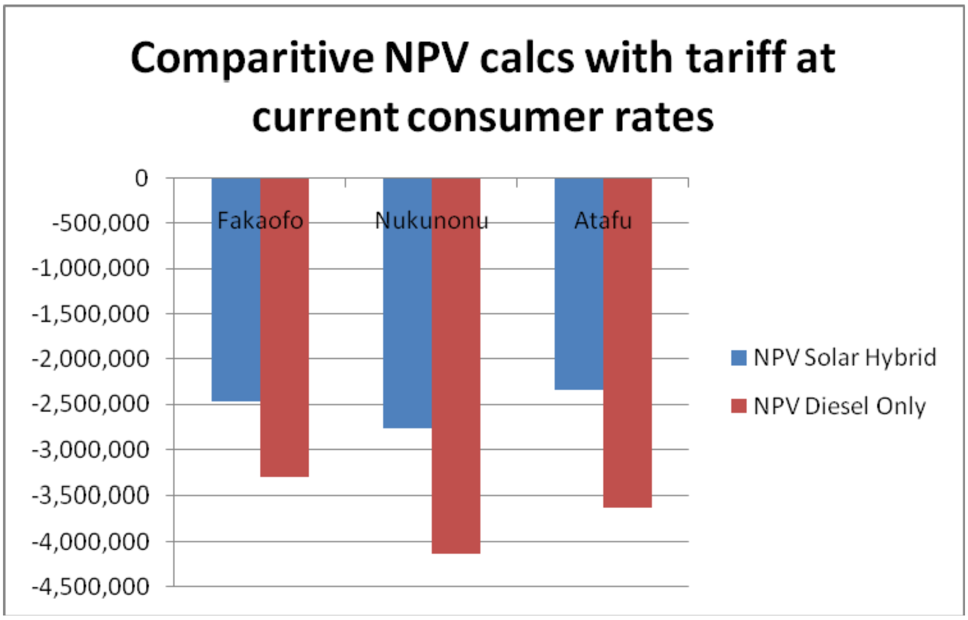
An indicative budget has been prepared, as per the table following. It must be noted that the variation in the USD, and volatile prices for copper and lead have made some components like batteries unpredictable in terms of pricing. An indicative budget follows:

			Fakaofo	Nukunonu	Atafu		
Number of households			82	66	83	Nos	
Population			483	426	524	Nos	
Power consumption per person			1.4	1.3	1.1	kWhrs	
Power consumption per household			8.5	8.4	7.2	kWhrs	
Total 24 hour average demand			**29.1**	**23.0**	**25.0**	kW	
Maximum recorded demand			51.2	36.7	38.0	kW	
Minimum recorded demand			22.2	16.3	18.2	kW	
Average daily consumption			699	553	601	kWhrs	
Consumption from 6pm to 6am			383	316	326	kWhrs	
Consumption from 7am to 5pm			316	237	275	kWhrs	
90% solar means delivering			629	498	541	kWhrs	
and 10% from coconut oil			70	55	60	kWhrs	
Litres fuel consumed per day at present			259	210	276	litres	
kWhrs produced per litre			2.7	2.6	2.2	kWhrs	
Litres coconut oil required			29	23	31	Litres	
Coconuts per litre of oil			7	7	7	Nuts/litre	
Number of coconuts per day			202	164	215	Nuts	
Solar							
Combined Battery/inverter losses		15%					
Gross electrical energy required from solar			723	572	622	kWhrs	
Solar hours per day		6					
Approximate array size			120	95	104	kWpk	NZD
Approximate cost			$ 1,084,472	$ 858,417	$ 933,188		**$ 2,876,077**
Battery 24 hours storage		**Volts DC**	**AH**	**AH**	**AH**		
VDC		48	15,062	12,961	12,961		
Depth of discharge	50%		30,124	25,922	25,922		
Cell size AH		3,000					
Number of strings at 48 VDC			12	9	9		
Cells per string			24	24	24		
Number of cells			288	216	216		
Cost per cell		$ 2,600	$ 748,800	$ 561,600	$ 561,600		**$ 1,872,000**
Charge controller and Inverter		allow	$ 200,000	$ 170,000	$ 175,000		**$ 545,000**
Replace existing diesel sets		allow	$ 50,000	$ 50,000	$ 50,000		**$ 150,000**
Coconut oil processing		allow	$ 50,000	$ 50,000	$ 50,000		**$ 150,000**
Solar dryer		allow	$ 20,000	$ 20,000	$ 20,000		**$ 60,000**
Installation and commissioning		allow	$ 150,000	$ 150,000	$ 150,000		**$ 450,000**
Transport, siteworks and misc		allow	$ 100,000	$ 100,000	$ 100,000		**$ 300,000**
							$ 6,403,077

The operating budget for the system will show very significant savings in fuel and generator operating costs, but is unlikely to show a reduction in labour costs (approximately NZ$80,000 per atoll per annum) as staff are expected to be retrained and redeployed into new roles, rather than being employed elsewhere within the government (as there is a full employment policy in place with the Tokelau Government).

The financial case for the project offers an improvement when evaluated against the status quo. The NPV for the diesel only case assumes the price of diesel increases at a very conservative rate of 10% pa. It is assumed for all cases that the rate of non-paying households is reduced to zero, and the cost of labour for each site is NZ$80,000 pa, and an additional NZ$20,000 in misc maintenance applied for each site pa. A discount rate of 6% is applied to all cases. This table is based on the tariff charged of NZ$0.50 per kWhr for Fakaofo and Atafu, and NZ$0.30 for Nukunonu. The calculation period is 15 years.

	NPV Solar Hybrid	NPV Diesel Only
Fakaofo	-2,475,461	-3,300,602
Nukunonu	-2,770,253	-4,127,270
Atafu	-2,341,942	-3,626,394



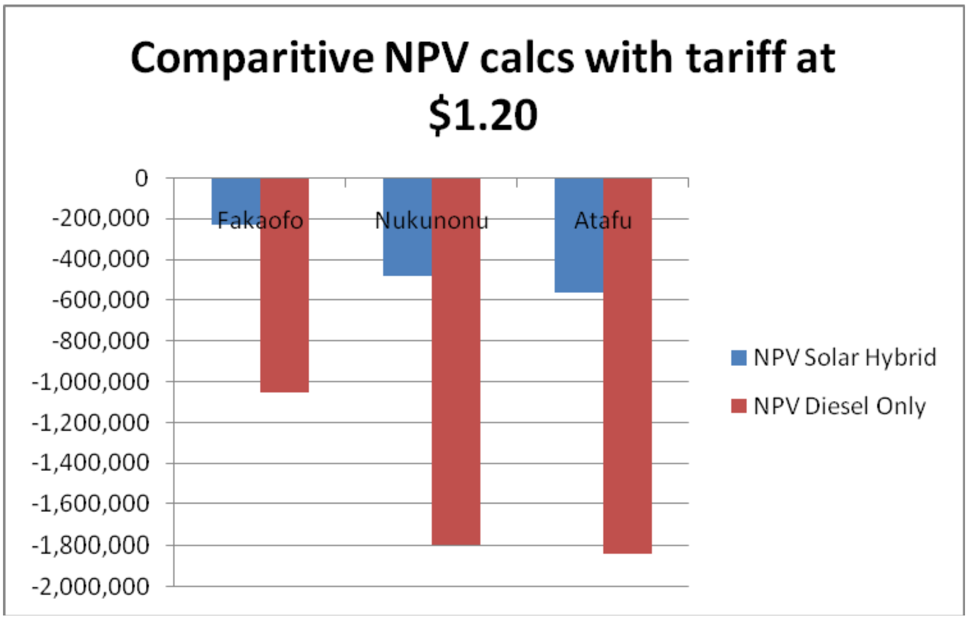
Thus it can be seen that while the NPV is still negative, the project case offers savings of more than NZ$1,000,000 on each atoll over a period of 15 years, in addition to the environmental and energy security advantages. It is assumed that the battery bank is completely replaced after 10 years with no scrap value.

Economic activity on the 3 atolls is not demonstrably constrained by a lack of energy at this point in time and thus the economic impacts will result from the manner in which the saved funds are redeployed or invested by the Taupulega. This is an unknown at this time.

The FIRR is negative in all cases evaluated.

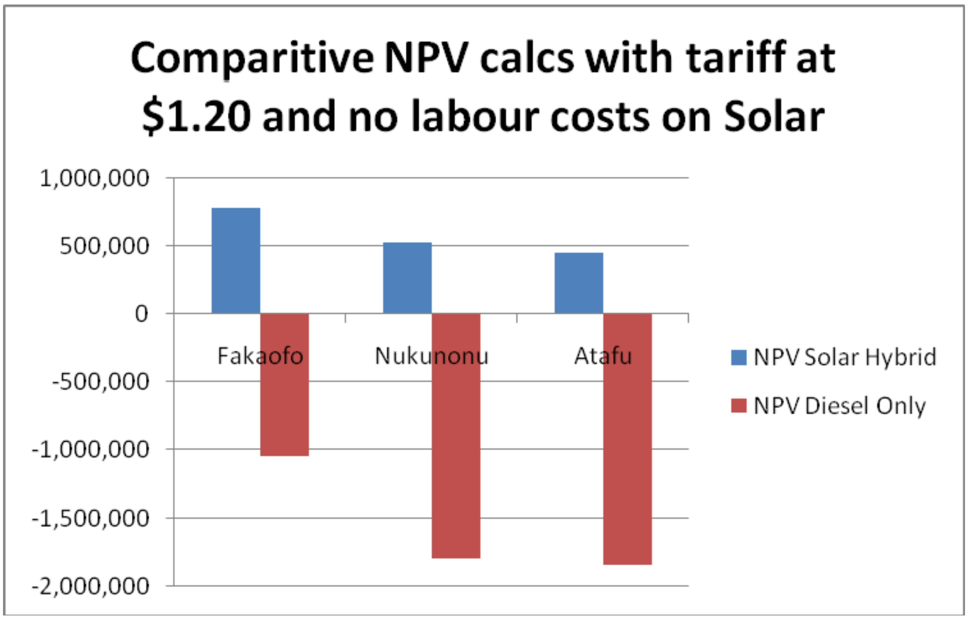
If the actual cost of power is applied at the real cost of NZ$1.20 per kWhr, and all other variables remain the same, then the situation changes as per the following table:

	NPV Solar Hybrid	NPV Diesel Only
Fakaofo	-228,879	-1,053,901
Nukunonu	-483,882	-1,792,914
Atafu	-563,654	-1,835,800



It can be seen from the above, that over a period of 15 years, and assuming no increase in power tariffs over this period, that the project activity offers a significant improvement, compared to the cost of not doing the project.

To make the project attractive to an investor, the financial rate of return cannot be negative. Given that the Tokelau Government has a policy of full employment, and that the labour costs of the staff involved will be paid no matter what, then it is suggested that the labour costs be born by the government and not included in the financial model for the installation. In this situation the investment case looks attractive, and if the risk of non-payment can be addressed then it is possible that a private sector partner can be located.



	NPV Solar Hybrid	NPV Diesel Only
Fakaofo	778,133	-1,053,901
Nukunonu	523,130	-1,792,914
Atafu	443,358	-1,835,800

The project FIRR in this situation is 3.3% on Atafu, 4.1% on Nukunonu and 4.9% on Fakaofo, for the solar hybrid project In this situation, the results look more encouraging, albeit with the somewhat unusual situation of removing the labour costs.

Environmental

The environmental case for the installation is robust. The current arrangement has made the best of a difficult situation but suffers from a number of key disadvantages. Specifically these are:

- The situation of 100% reliance on fossil fuels is recognized as being unsustainable by both the Governments of Tokelau and New Zealand, and is in conflict with the current policy directions of both administrations.
- The transport and storage of fuel and lubricants to Tokelau is difficult and handling of the drums is risky. Spillage and leaks of fuel oil into the lagoon and sea around the atolls is reportedly common.
- A reduction in the running time on the diesel gensets will also reduce the waste oils produced, and which were previously disposed of in an unsafe manner on all three atolls. This will be mitigated with the new waste disposal agreement signed between

Tokelau and Samoa, but nonetheless, a reduction in the need to consume and dispose of waste oil is positive.

- Noise and air pollution impacts will also be mitigated through the implementation of the project activity. No direct comment was noted in the household surveys for any complaint or impact of either noise or exhaust, however land is at a premium and houses will inevitably encroach on land closer to the powerhouses if population growth occurs. Noise and exhaust may therefore be a problem in the future, if not a problem now.

The collection and processing of coconut on a large scale could have potential negative impacts, however the volume of nuts required by the project is very minor and according to the Taupulega will not require the use of private lands and nor will it require the use of clearing of undergrowth to facilitate the collection of nuts. With the expectation that ground collected nuts is sufficient to meet the needs of the project, no negative impacts are anticipated whatsoever.

Concerns would be present if the coconut oil was to undergo further processing into biodiesel, involving an esterification process with sodium hydroxide and methanol, but it is understood that this will not be necessary owing to the high ambient temperatures found in Tokelau. In addition most likely cost-considerations would make such option un-realistic.

Therefore, the only potential negative impact likely to be experienced in the course of the project is related to the pruning and/or clearing of lands to accommodate the solar PV arrays, primarily on the atoll of Nukunonu, where an entirely new powerhouse is planned. On balance, this impact is minor and Taupulega expect this will be done with minimal impact.

The presence of lead acid batteries is one component, introduced by the project that will be new to Tokelau in terms of scale. Part of the project plan will need to be a detailed proposal for the safe handling and recycling of these cells at the end of their expected 10 year life. The value of the lead will ensure that this asset is not casually disposed of, however the acids will require handling by staff that have been trained, and possess the necessary material and tools to render the acids inert prior to transporting back to Samoa or NZ for recycling. This is not complicated, but will need to be addressed in the project plan.

Technical Planning

There are multiple configurations of solar PV and batteries that could be used to reach an optimal solution for the 3 atolls in Tokelau. In addition, an energy efficiency stage is strongly recommended prior to undertaking the final design as the scale of the installation could be significantly reduced if energy demands can be reduced without compromising convenience or quality. Thus, assuming that the energy efficiency stage is undertaken, the design information provided here will be found to be overstated.

However the key technical parameters assessed in this study are:

- The DC voltage for the inverters should be as high as possible, however it is noted that once voltages increase above 48 VDC the inverter models on offer become much less mainstream and more specialized, with greater difficulties in service and support. The problem with 48 VDC is that the currents being handled become very high at a relatively low voltage, and this can be inefficient and expensive. New modular inverter technology can be deployed to mitigate these issues. Single inverter blocks of 5 kW per unit can be linked in series, to provide up to 20 kW per phase in a 3 phase configuration, easily enough to cover the needs of the 3 atolls.

- The inverter shall be able to be fully interrogated and configured remotely, via an internet connection. This is to reduce the need for technical staff to visit the site to make minor adjustments of configuration changes, and also to identify when a physical repair needs to be done.

- It is recommended that the solar arrays for each atoll be deployed in blocks of 2.5 to 8 kWpk each. Each block has its own inverter and provides a charge directly to the AC network, under remote control by the main power inverters. The DC voltage of each array block will vary depending on the size of PV panel installed, but a DC voltage of 300 to 400 VDC would be typical, and recommended to reduce line losses. The array inverter will accept the 400 VDC input and invert to a 230 VAC 50 Hz output, and then automatically synchronise and feed power back to the network. Derating of the solar PV based on temperature and salt or dirt is to be allowed for by the bidder.

- The maximum charging current for the inverters is 120 A, with a continuous charging current rating of 100A. The maximum rated ambient temperature without derating is 50 deg C. The standby load presented by each inverter unit is to be not more than 30 watts.

- Each 15 kW inverter set (3 x 5 kW) will directly control its own battery string, thus if a 45 kW inverter capacity is required, then the inverter comprises 3 x 15 kW units, and thus includes 3 x 9,000 AH flooded lead acid cells (in 3 x 3,000 AH strings).

- The cells will be installed on ground mounted racks, and in strings of 24 cells @ a nominal 2 volts per cell. Each inverter set comprises one phase and is connected to its own set of battery strings.

- The lead acid cells will include ‘hydrocaps’ to dramatically reduce the loss of water to atmosphere, and further reduce maintenance costs and complexity. A design depth of discharge of not greater than 50% is recommended to maximize the effective operational life of the cells and ensure cost effective operation. This parameter can be further reduced depending on the availability of coconut oil. Should the labour be able to process more oil then it is recommended that the generator set be run more frequently to reduce cycling on the battery banks. This parameter is automated and placed under the direct control of the inverter. Furthermore these parameters should be able to be monitored and adjusted remotely if modern inverter technology is deployed.

The selection of the solar PV panel should be restricted to well recognized, international brands with a demonstrated track record of installation in marine environments. Both monocrystalline or polycrystalline panels would be suitable for this application, as the sites are not subject to shading or disrupted light, and the focus should be on survivability in a marine environment and in potential cyclone conditions, rather than specific module efficiencies. Module outputs must be specified and meet a given tender specification, such as the delivered power demanded for each atoll, as defined in this study.

The power demand patterns appear very consistent throughout the year, on a month by month basis. Thus there is no incentive or advantage in orientating the arrays to maximize one season or another, or a particular time of the day. A standard north facing, 9 degree array is recommended, however some variation may be necessary in order to take advantage of existing or future roof structures.

Panel mounting structures must be either hot dipped galvanized and either of an industry standard, pre-certified loading capacity, or a custom built structure with an engineers certificate specifying wind load capacity.

To minimize opportunity for corrosion, and to ensure correct polarity and diode blocking use, panels designed for grid connection situations are recommended, utilizing preformed male and female connector systems for panel interconnections.

Available technology

Off the shelf technology is available that meets the technical requirements of this project, for each of the three atolls. The general expectations of the inverter and solar charge controller are:

1. It is a humid, marine environment. Corrosion will be a factor and any design submitted must be suitable for long term operation in such conditions. Many solar PV panels are well proven in these situations but charge controller and inverter technologies are less so. Warranties on inverter and solar charge controller technology is to be not less than a standard period of 2 years, or extendable.

2. Design components must be a proven, robust and 'off the shelf' product.

3. Allowing for no reduction in loads through energy efficiency activities, the system must be capable of delivering a constant output of at least 40 kW to cover the measured loads of around 30 kW, and then auto-starting a back up generator to cover the evening periods. Output must be in a 3 phase, 230 VAC 50 Hz.

4. When the coconut oil generator is started by the inverter, the genset capacity must be sufficient to both meet the AC demands from the consumers, and also provide a charging current to the battery bank. The inverter array will be sophisticated enough to not overload the generator, and will reduce charge to the battery bank in order to allow AC demands to be met, surplus charge directed to the batteries and without overloading the genset.

5. AC loads from the consumer side average between 23 and 29 kW. The inverter charge capacity is 45 kW. Thus the minimum generator size required to meet the average demand and still recharge the generator is not less than 75 kW (allow 100 kVA).

6. Maximum recorded AC loads are between 40 and 51 kW. Thus the 100 kVA genset is able to fully meet current maximum loads as presented by the consumer side, and as the inverter will automatically vary the charge provided to the battery bank to ensure that the genset is not overloaded. It can achieve this without input from the inverter.

7. The design must allow for simple expansion of the PV capacity, and/or the inverter capacity in future. Hence a modular approach is recommended.

8. It is preferable for the design to allow a decentralised approach, where the inverters and batteries may be housed together, in close proximity to the transformer feeding the main network, but the solar PV may be located on roof space or other locations around the network and feed power in as required.

9. Adequate battery capacity is required to allow the system to operate in a smooth and uninterrupted fashion, however given the cost and complexity of transporting heavy

lead-acid cells to Tokelau, and then recycling at the end of their useable life, the primary energy storage medium in this design is taken to be coconut oil and not the battery bank.

10. No preference is specified between either monocrystalline or polycrystalline solar PV panels. A reputable manufacturer is required. A warranty of not less than 20 years is expected, both for power outputs and corrosion resistance for frames. MC plugs are preferred to ensure connections are solid and opportunity for terminal corrosion is minimised.

Thus the equipment to be deployed is to be robust, capable of withstanding a hot, salty and humid marine environment and function without a high level of service and support. Studies by the authors of this report have found suitable equipment is available off the shelf from major international brands that can meet all the design specifications recommended in this report, and used to construct a system that exhibits the high reliability and long service life envisaged.

Detailed Specifications for Key Components

Inverter Specifications (general specifications per 5,000 watt power module)

Output data	
Nominal AC voltage ($V_{AC, nom}$) (adjustable)	230 V (202 to 253 V)
Nominal frequency (f_{nom})	45 to 65 Hz
Continuous AC output (P_{nom}) at 25°C	5000 W
Continuous AC output (P_{nom}) at 45°C	4000 W
AC output for 30 min at 25°C	6500 W
AC output power for 5 min at 25°C	7200 W
AC output power for 1 min at 25 °C	8400 W
Nominal AC current ($I_{AC, nom}$)	21 A
Max. current (peak value) for 100 ms	100 A (100 ms)
Harmonic distortion of output voltage (K_{VAC})	< 3 %
Power Factor (cos ϕ)	–1 to +1
Standby power demand	25 watts or less
Device protection to include:	Over-temperature, short circuit and overload
Inbuilt datalogging function of historical operating parameters	60 days minimum
Minimum guarantee period	2 years
Operating temperature	-25 deg C to +50 deg C
Inverter must have CE Declaration of Conformity	YES
Protection category	IP40
Input data	
Input voltage ($V_{AC, ext}$) (adjustable)	230 V (172.5 to 250 V)
Input frequency (f_{ext}) (adjustable)	50 Hz (40 to 70 Hz)
Max. AC input current ($I_{AC, ext}$) (adjustable)	56 A (2 to 56 A)
Max. input power (P_{AC}, ext)	12.8 kW

General inverter characteristics suggested for tender

The inverters must reliably convert voltages ranging from 44VDC to 54VDC to a stable, utility quality sine wave source efficiently and with minimal maintenance. It will be expected to operate continuously in a marine, tropical environment that includes ambient temperatures from 25°C to 50°C, humidity approaching 100% and significant risk of salt laden air contact. Regular user intervention should not be expected for normal operation. Any programming or parameter adjustment should only be required at initial setup with all programming remembered even if DC input power is lost.

Required Specifications

Physical requirements: Inverter circuitry must be sealed against moisture and salt entry. Any cooling fans must be external to the housing containing the circuitry. Materials used in construction must not be affected adversely by the high temperatures, high humidity or high salt content air commonly present at the installation site.

Electrical requirements: Input power will be from lead-acid batteries operating at a nominal 48VDC (operating range 44-55V). Output power should be via single phase inverter units, stackable to form 3 phase operation with multiple units to improve overall system reliability. Nominal single phase AC output is to be in the range of 230VAC at 50 Hertz, with a pure sine wave output. Demonstrated overload capacity shall be as per the table on page 30. Waveform, voltage regulation and frequency regulation shall be within utility standards (as set by EPC) over the range of power output from 5 Watts to full rated capacity. Rapid response to motor starting surge current (as with freezers or refrigerators) is required. A sleep mode is not required. Electronic radiation should be minimal. No interference with AM radio, FM radio or television reception should be found at distances exceeding four (4) metres from the inverter.

Internal protection: No damage to the unit shall result from input voltage below the minimum specification, excessive output current flow or overheating.

International standards compliance: Units shall be designed and constructed in conformance with ISO/IEC Guide 22 and EN 45014.

Warranty: A full replacement or repair warranty shall be provided for a period of at least two (2) years. Additional warranties for longer periods are preferred.

Prequalification: The SMA Sunny Island SI5048 inverter with a multicluster box is considered pre-qualified for this application and a quotation for this unit is specifically requested as well as quotations on any competing units the vendor has to offer.

Minimum documentation to be provided with each quotation: Full manufacturer specifications for each size and type of unit quoted should be provided with quotations. That should include:

- Full electrical specifications including self consumption and waveform variation at various power output levels ranging from 5 Watts to 150% of rated continuous power.
- Physical specifications including dimensions, weight and mounting requirements.
- Programming and data logging capability and whether or not programming and/or data logs are lost if power is disconnected.
- Derating curves for ambient temperature in the range of 20°C to 40°C.
- Full warranty details including terms of replacement, or reimbursement, where to send warranty claims and the requirements for warranty claims.

- Photograph or detailed drawings.

55 kW inverter specification sheet for quotation

All power will be delivered to users at single phase 230VAC and 50 HZ. Loading is expected to consist primarily of lighting, entertainment appliances and freezers or refrigerators. Fans, small household appliances and small electric tools may also be used intermittently.

The inverter system will not be grid connected however a generator will be used for battery charging. No internal charger or grid connecting system is required. Peak three phase loads range between 51 kW on Fakaofo, 37 kW on Nukunonu and 38 kW on Atafu. Average demands range from 29 kW on Fakaofo, 23 kW on Nukunonu and 25 kW on Atafu. The three phase inverter sets will be required to cover all of these demand patterns while remaining comfortably inside their operating parameters and allowing for temperature derating.

Inverters must reliably convert voltages ranging from 44VDC to 54VDC to a stable, utility quality sine wave source efficiently and with minimal maintenance. Inverters must operate continuously in a marine, tropical environment that includes ambient temperatures from 25°C to 40°C, humidity approaching 100% and significant risk of salt laden air contact. User intervention should not be required at any point. Any programming or parameter adjustment should only be required at initial setup with all programming remembered even if DC input power is lost.

When maximum continuous inverter power outputs are attained, the inverter will automatically start the biodiesel generator and transfer load to the generator to prevent unnecessary loading and cycling of the battery during peak hours. This feature is generally referred to as 'load starting'. If the inverter does not offer this feature then a separate current based sensor must be deployed to start the generator under high load conditions.

The inverter will also automatically start the generator when battery DoD reaches a preset level, not lower than 50% of capacity. The inverter will then automatically shut down the generator once a minimum of 90% of full capacity is attained. Other user selectable parameters will include must run and quiet times for the generator, load start and voltage start options.

The inverter will offer other standard features including warm up time for the generator before applying load, as well as other user variable functions including all charging voltages, times, battery capacity and type and temperature compensated charging.

The inverter will contain sufficient onboard memory to retain 30 minute averaged operational data on main system conditions for at least one year.

The inverter system must also offer an online diagnostic system to allow remote monitoring and review of operating conditions and parameters. Usually via a dialup modem or permanently online IP address, remote service technicians will be able to call up the inverter, download stored operation data on the onboard memory, and alter any operational parameters as if the technician were onsite.

Battery specification sheet for quotation

Battery data	
Battery voltage (VBat, nom) (adjustable)	48 V (41 to 63 V)
Max. battery charging current (IBat, max)	120 A
Continuous charging current (IBat, nom)	100 A
Battery capacity	100 to 10 000 Ah
Battery charging temperature compensation	YES
Charge control	IUoU procedure with auto-matic full and equalization charge
Battery type	VRLA/FLA/NiCd

Battery Specifications (preferred)

Cell voltage (nominal)	2 VDC
AH capacity (nominal according to DIN 40736-1)	3,000 AH preferred
Minimum number of discharges to 80% DoD	1,500
Supplied with system interconnects and cables	YES
Battery type	Flooded lead acid
Condensation recombination caps (hydrocaps)	YES
Plate design	Tubular

Batteries will be of the lead-acid type and arranged in series connection to reach a nominal 48V level. The batteries will be operating in a tropical, marine environment subject to intermittent indirect salt spray, continuous exposure to high ambient temperature (25-40°C) and humidity approaching 100%. The system design provides for a 50% DOD per daily cycle under average solar and load conditions. A maximum DOD of 70% may occur.

Batteries will need to be transported by small boat through a reef passage and offloaded by hand at a small wharf at each of the three atolls. No mechanical offloading equipment are expected to be available but the installation of a small hoist at each location to lift lead acid batteries and other equipment off the boat and onto the wharf could be considered given that cell weights may be up to 250 kg per cell. During transport, batteries may be exposed to salt spray so they should be individually enclosed in plastic or other protective materials that can be easily removed on arrival at the small wharf for access to handles or other accessories provided for handling.

Three separate sets of batteries are required, as per the description provided for each atoll. The tenderer is not required to use 2 volt cell blocks, or any specific AH capacity, but must clearly demonstrate why in their view the combination they have selected is optimal for the conditions described.

Capacity and quantity: Separate quotations for price and delivery are requested for batteries with the following capacities and quantities. Note that parallel connected cells or batteries are not acceptable, all capacities must be for single cell ratings. Given the size of the battery bank, and the need for a long operational life, 2 volt flooded lead acid cells are expected to be the most suitable for the project.

Three sets of cells are required. Assuming 3,000 AH strings at a nominal 48 VDC, one set comprising 10 strings is required for Fakaofo, plus one of 9 strings on Nukunonu and one of 8 strings on Atafu.

The Cells are to be quoted at the C_{10} rate.

Required Specifications

Physical: Batteries may be provided as single 2V cells or a series connected combination of 2V cells up to a maximum of 48V. Single 2V cells are preferred for this application. A transparent or translucent case is required to allow easy determination of electrolyte level and examination of internal components. No maximum weight per battery unit is specified however tenders are advised that handling of battery cells on the atolls is largely manual, and consideration must be given to the realistic handling of cells in a largely manual unloading environment.

Preferred construction will include tubular positive plates and an open cell configuration. Sealed or “maintenance free” batteries will not be acceptable. Wet charged batteries are acceptable but shipment must be of batteries with a manufacturing date no earlier than two months before the time of shipment and should be charged fully immediately before transportation to the atoll. The battery must use electrolyte intended for tropical operation. Dry charged batteries are also acceptable however consideration must be given to the proper commissioning of the cells to full factory specifications on site.

For batteries with easily damaged external cases (e.g. those with breakable transparent plastic cases), spare cases representing a minimum of two (2) units and a maximum of 2% of shipped units will need to be included in quotations.

Flame retardant caps for cells are not required, however recombination caps to catch and recyle water vapour are essential. If a multi-cell battery is quoted, preference is for individual cell caps, not multiple caps combined into one cover assembly.

Life: A minimum design life of seven (7) years is required under daily cycling conditions averaging 50% DOD but sometimes reaching 70% DOD therefore “deep discharge” type batteries are required. This design life is to be achieved under the tropical conditions present at the site in Tokelau. Design life will be a major consideration and quotations will be evaluated on a cost-benefit basis.

Strengthening alloy: Pure lead cells are not acceptable due to their relative fragility and are not considered suitable for the type of service these batteries will provide in Tokelau. Up to 6% antimony as a plate strengthening alloy and for cycle life improvement is allowable. Calcium as a strengthening additive is not acceptable.

Self-discharge: Rated self-discharge of new cells should be less than 3% per month.

Connections: Connections shall be made by use of bolts into or through solid terminals. Clamp on type connections are not acceptable.

Efficiency: The battery shall have a Coulombic efficiency of at least 85% and an energy conversion efficiency of at least 75% when charged to a level greater than 50% of nominal capacity.

Electrolyte: Electrolyte shall be of purity appropriate to lead-acid battery use and should meet a recognized international specification for lead-acid battery electrolyte such as VDE S10. Specific gravity of the acid provided should be appropriate for tropical use and intended to minimize internal corrosion at high ambient temperatures. For dry charged batteries, sufficient electrolyte shall be provided to fill all cells plus 5% extra to provide for spills.

Warranty: A replacement warranty is expected against manufacturing defects that are evidenced by early failure for a period of at least two (2) years. A prorated warranty for a significant fraction of the rated life of the battery is expected. English language copies of the full warranty document must be provided for each battery model proposed.

Label: Each battery should have a unique serial number shown on the label along with the identification of the manufacturer and the battery model designation. The date of manufacture must be provided with batteries and is preferably also shown on the manufacturer's label.

Minimum documentation to be provided with each quotation: Full manufacturer specifications for each size and type of unit quoted should be provided with quotations. That should include:

- Cycle life curve for different average DOD from standby service to 50% average DOD.
- Capacity curve for rates of discharge from C_{10} to C_{100}.
- Physical characteristics including dimensions, case composition and design, electrolyte specific gravity vs. charge level curves, voltage vs. charge level curves.
- Photograph or detailed drawing of each battery proposed.
- Cell construction details (e.g. plate composition, connection type, type of plate construction, etc.).

- Warranty information including full warranty text in English and details as to procedures for obtaining warranty replacement or reimbursement.

Battery Charger

(may either charge batteries directly using a traditional MPPT charger, or via an AC bus architecture with solar panels distributed around the power network and power fed into the AC network via a grid interactive inverter such as the SMA Sunny Boy (preapproved for this application). Any solar PV inverter or solar charge controller able to perform this function will be considered so long as it meets the same environmental standards as the main system inverters for humidity, salty marine environments and high ambient temperature.

Output data	
Max input open circuit voltage	600 VDC at – 10 deg C
Input voltage, MPP range	224 V to 600 VDC
Maximum input current	12 A per 2,500 W module
DC plug connectors	YES
Over voltage protection	Thermally monitored varistors
Voltage ripple	Less than 10% of the input voltage
Ground fault monitoring	YES
Nominal AC current ($I_{AC, nom}$)	21 A
Max. current (peak value) for 100 ms	100 A (100 ms)
Harmonic distortion of output voltage (K_{VAC})	< 3 %
Power Factor (cos ϕ)	–1 to +1
Standby power demand	7 watts or less per 2,500 watt module
Reverse polarity protection	Short circuit diode
Operating range - grid voltage	198 – 260 VAC
Operating range - grid frequency	49.8 – 50.2 Hz
Overvoltage category	3
Protection category	IP65

Because of the constrained land area around the three atolls, a battery charging system is recommended on the AC network, rather than the traditional method of directing regulated DC current directly to the battery bank, thus requiring the solar PV to be located in relatively close proximity to the battery bank. Connection to the AC network will facilitate extensive use of distributed generation opportunities around each atoll, and utilise presently unused roof space on houses and public buildings.

Tenderer' s are requested to outline in detail how they propose to address the charge controller design.

Solar PV Specifications

Panel specification sheet for quotation

Individual panels are being sought of either single crystal silicon or polycrystalline silicon suitable for charging either 12V or 24V lead acid batteries. The panels will be connected together in a manner suitable for corrosive marine environments, and preference is given to push together interconnects such as the MC cable connections.

The panels will be operating in a tropical, marine environment subject to intermittent salt spray, continuous exposure to high ambient temperature and humidity approaching 100%. Exposure to winds in excess of 150 km/hr during tropical cyclone passage is likely.

Quantity: Tenders are expected to suggest their own size, number and type of panels for the project, noting that for Fakaofo, Nukunonu and Atafu, array sizes of 120 kWpk, 95 kWpk and 104 kWpk respectively have been allowed for.

Required specifications

Cell type: Photovoltaic cells shall be of a mono-crystalline or polycrystalline silicon type. Thin film or non-silicon based modules will not be accepted unless suitable MPPT matching is demonstrated to maximise the output for the array, and certification for a minimum warranty period of 25 years is provided. Preference will be given to established, modern manufacturers with demonstrated and proven product.

Cell number: As cells will be used in an MPPT charge controller, or MPPT solar inverter configuration, individual cell voltages are not a critical parameter. Of greater importance is the string voltages attained for multiple cells.

Rated power: Larger capacity panels are expected, to minimise interconnections and string numbers, while keeping voltages within operational limits. Tenderers are expected to put forward their own designs and justifications for their designs.

Construction: Module frames should be of marine grade stainless steel or anodised aluminium. Cover glass should be impact resistant. Construction should be of a type consistent with international manufacturer practices for high grade solar panels. Modules must comply with recognized international standards of manufacture and test such as IEC 61215 or ESTI 503 and certification that panels have passed compliance tests for the standard being used must be provided with the quotation.

Bypass diodes: Bypass diodes are not required to be installed internally in the panels but panels are acceptable if they are installed.

Connections: Push together connections, such as the MC type cables are required. Screw connections are not acceptable due to the high humidity and risk of corrosion. String connections must be enclosed in a weather tight junction box with cable feed through arrangements that can be sealed against entry of salt laden air and moisture. A single junction box containing both positive and negative terminals is preferred but separate positive and negative junction boxes are an acceptable option.

Label: The panel shall have affixed a label that at a minimum includes a unique serial number, manufacturer name, model of panel and rated Wp of panel. It is preferred that the Wp listed be the actual value measured at the factory test of the panel.

Warranties: The module construction type used must have an expected lifetime of at least 25 years and include at least a 20 year warranty against loss of capacity exceeding 15% of the rated value or obvious physical degradation such as delamination or internal corrosion. A copy of the full warranty document (in English) for the panels must be provided with the quotation.

Minimum documentation to be provided with each quotation:

- Full electrical specifications including at least Voc, Isc, Wp, Voltage at maximum power point (standard conditions), current at maximum power point (standard conditions), presence or absence of internal bypass diodes.
- Voltage-current curves for a range of insolation from 250-1000 Watts per square meter.
- Physical specifications including at least physical dimensions; weight; preferred mounting method; connection type and location; junction box characteristics and location; characteristics of glass, encapsulation material and backing material; characteristics of frame and edge sealing system.
- Photograph or detailed drawing of the top and bottom of panel.
- Full warranty details in English including terms of replacement, or reimbursement where to send warranty claims, requirements for warranty claims.

Coconut oil extraction and drying

Tenderers are requested to provide a written description and design for a system to process not less than 250 coconuts per day, in order to provide not less than 35 litres of dry pure coconut oil, filtered to 2 microns. It is envisaged that this will include dehusking, copra separation and drying (copra drying must be undertaken in a covered enclosure to allow for protection from rain).

Oil extraction and filtering processes to 2 microns will be for the tenderer to recommend, but close attention will be paid to the quality of the finished product. The oil is to be used as fuel, and must be filtered and dried to a high standard. Preference will be given to off the shelf, proven products.

Biodiesel Generator Specifications

Manufacturer letter confirming acceptability for use with up to B100 coconut oil	YES
Multi cylinder engine,	YES
Three phase, 230 VAC L-N, 50 Hz	YES
Power output to be not less than 80 kVA	YES
Pre-chamber design preferred.	YES
Air cooled preferred. Maximum nominal operating RPM 1,500	YES
Alternator rated for tropical environments, IP21 minimum, class H insulation	YES
Protection system including over temperature, low oil pressure, Over current, under/over voltage, under/over speed	YES
Automated control panel fitted with 2 wire start/stop capacity and auto, off and on settings	YES
Integrated fuel tank and level	YES
Additional fuel filtering including water block and 2 micron fuel filter	YES
Integrated battery charger	YES
Soundproof canopy preferred, but allowing easy access to all consumables and maintenance items	YES
Unit is skid mounted and with single lifting point. Vibration dampers on engine mounts	YES
Dial type fuel gauge, internal fuel tank and option for external tank	YES

General tender information for all equipment items

Price quotation: All prices shall be CIF Tokelau in NZ Dollars (NZD) or US Dollars (USD).

Shipping: Shipping will be by lowest cost means that allows an acceptable delivery time. Apia has direct surface shipping access to Australia, New Zealand and Fiji shipping services and, via American Samoa, access to USA shippers. The following shipping companies. Pacific Forum Line, Betham Brothers Ltd, Transam Samoa Ltd, Samoa Shipping Services Ltd, and Summit Cargo Samoa provide scheduled service to Samoa.

Direct air freight service is provided by Air New Zealand, Air Pacific and Polynesian Airlines. Indirect (via American Samoa) is provided by Hawaiian Airlines.

All equipment shipments will be insured fully up until the point of arrival at the project site.

Finance Options

Finance possibilities for the project are essentially narrowed to four options.

1. The Tokelau Government identify this as a national priority and allocate resources to undertake the project.
2. A donor entity contributes funds to undertake the project.
3. A commercial partner invests in the project.
4. A combination of 1 and 2.

The financial rate of return from the project is not attractive, based on the income from the current tariff structure. The income streams of approximately NZ$127,500 on Fakaofo, NZ$60,500 on Nukunonu and NZ$101,000 on Atafu reflect the variation in power demands, and also the NZ$0.50 tariff on Fakaofo and Atafu, and the NZ$0.30 tariff on Nukunonu.

With approximate operational expenses of NZ$120,000 per atoll, excluding fuel costs, it can be seen that even if the fuel cost is reduced to zero there is still insufficient income to cover operational expenses, and hence no income stream to offer a rate of return to an investor.

However, the true cost of power has been conservatively estimated by the Department of Energy at NZ$1.20 per kWhr. If the real cost of power is used, then the financial situation changes significantly as shown in the graphs depicted on pages 24 and 25 of this report.

The most realistic funding options are expected to be option 2 or 4 of the list identified above. Tokelau is seen as too remote by commercial entities to enable investment without some form of guarantee or security over the safety of the assets and/or certainty of payment of monthly power bills. This has been briefly explored with funders without encouraging feedback. Thus at this point in time, the most likely source of project funding is donor funding, and/or Government of Tokelau.

Meetings have been held with the French Embassy in Wellington, as well as with the New Zealand Agency for International Development and Ministry of Foreign Affairs and Trade in late January 2008. While no formal interest in funding was expressed, attitudes with all agencies remain interested in the introduction of the renewable energy system and view this as precisely the nature of project that warrants support. The European Union and Government of Australia is also active and should be approached as part of the financing plan.

In addition, finding support from institutional funders such as those described is greatly enhanced by reducing risk and addressing some of the key barriers to successful implementation as described in the body of this report. One suggested approach is to fund the project is stages. The stagewise approach will allow the three Taupulega to demonstrate that the primary funder concerns are able to be resolved. Where Taupulega are confident that issues such as the coordination of labour for the collection and processing of coconuts is not a problem, the stagewise approach will allow this to be demonstrated. Likewise, impacts of energy efficiency improvements and billing and payments performance, possibly via the pre-pay metering technology mentioned, may also be proven.

Thus a funding plan is envisaged whereby institutional support is sought from the Government of Tokelau and the other parties mentioned above, but the allocation of funds is tied to the achievement of specific, measurable milestones, such as energy efficiency targets, improved billings collections and demonstrated biodiesel collection and processing,

While no mention of tied aid has been noted during discussions, it is strongly recommended that the selection of equipment or a contractor not be influenced in this manner should it be attempted.

At the request of MFAT and NZAID, a short concept note was prepared to briefly describe the different stages that could comprise the project and guide the strategy used to implement the project. This is provided overleaf. Standard UNDP tendering and contracting terms are very suitable for the implementation stage of the project, and can use the technical brief prepared as the basis for a tender specification.

Tokelau Islands

Renewable Energy Development Initiative

Discussion Draft on Stagewise Approach

Empower Consultants. Tony Woods. 8th February 2008

A comprehensive feasibility study commissioned by the UNDP has been developed and a final draft expected to be tabled in the next two weeks. The project envisages the construction of a 90% coconut oil and 10% solar power generation plant on each atoll. This system would produce approximately 600 kWhrs per atoll per day, for domestic, light industry and Government consumption. This is an average demand of approximately 30 kW. The total capital cost for the raw project is in the order of $7 million.

The UNDP approach calls for suggested approaches and financing models. Discussions with NZAID and MFAT also suggest that a stagewise approach to the project might be considered. This has merits, as itemized in a suggested stagewise approach as below:

Stage One Energy Efficiency

There is considerable scope for utilizing the energy produced on each atoll more efficiency. The energy study conducted by Empower Consultants in September 2007 identified several main areas for reducing loads without sacrificing convenience or performance. These include refrigeration, lighting and education of energy efficiency practices.

The return on investment from energy efficiency activities in Tokelau is expected to be very high, given the very high cost of energy and that some of the actions required to generate a return are very inexpensive, such as raising public awareness on the need to not waste energy, and how to act. Enabling a financing mechanism to facilitate the purchase of more efficient refrigeration devices, and promoting energy efficient lighting could be a project in their own right, and also yield very positive economic returns

Lastly, the undertaking of an energy efficiency program as a preliminary step will have an impact on the required scale of investment needed to achieve the 90% solar and 10% biofuel target put forward by the Government of Tokelau as specified in the Tokelau National Energy Policy and Strategic Action Plan. A reduction in loads will allow the deployment of less solar and less battery storage without compromising performance. These are two of the most expensive assets required for the renewable energy project, should it proceed as discussed. Therefore the energy efficiency project should be a first step, preceding the final design and installation of the renewable energy installation, as it is likely to have a significant impact on cost and scale, not forgetting that the cost of energy on Tokelau is such that energy efficiency should be a priority in any case.

Stage Two Improvement of Billing and Collections Performance

Concerns have been expressed that in general, the Tokelau population take the supply of electricity for granted and as a public service, rather than as an energy source that households consume. Household billing and payment collection needs to be more strictly enforced, to give project stakeholders confidence that the investment will lead to genuine economic improvement.

Such models are already in place, such as the Teletok system. It is understood from discussions on the atolls that Teletok, being a commercial company, cannot permit extended on ongoing defaulters and disconnections for non payment are enforced. This appears to be understood and accepted by the community. The electricity supply system needs to engender its consumers with the same understanding.

The social difficulties in small communities with rigid billing and disconnection rules are widely understood, but technical solutions (such as pre-paid metering) and social programs (such as community meetings or simple messages from community and/or church leaders) designed to raise awareness and understanding that power bills need to be paid, can mitigate the difficulties involved.

Stage Three Demonstrated mechanisms for the collection of biofuel

The third stage is the demonstration for the collection and processing of biofuel. Small quantities of coconut oil can be blended with diesel without engine modification, and thus can be demonstrated in the current situation in Tokelau safely. The primary intention is to demonstrate the social mechanism for access to land, organisation of labour and payment (if any) for the coconuts collected.

Stages one two and three do not necessarily need to be done in sequence, but each provides a higher level of confidence in community preparation and readiness for the investment in solar and biofuel technology to follow.

Stage Four Review and Refine Technical Design, followed by implementation

Stage four can then proceed on a solid foundation and with the certainty provided by:

- A reduction in energy waste and the subsequent impact on system design and cost
- Demonstrated improvement in billing and payments for household power bills, including possible technology introduction for metering and control.
- Demonstrated mechanism for coconut collection, labour and payment issues.

With focus and support, these stages can be rapidly undertaken and do not need to impede the actual implementation stage at all, and may speed the implementation project by facilitating, at an early stage, community consultation and support and identify and remove non technical issues that could delay the implementation phase. In any case, the stage wise approach will significantly reduce cost and reduce project risk by linking progress on foundation steps to the deployment of the final project.

Socio-economic Context

Information in this section is based upon secondary data, in particular the 2006 Census, and on primary data gathered on the field trip undertaken by the renewable energy specialist in September-October 2007. This included meetings with the Taupulega on each atoll, key informant interviews with energy suppliers, teachers and health professionals, and sixteen household surveys. Of these, ten were on Fakaofo, four on Atafu and two on Nukunonu. Ten households surveyed were nuclear families, five were extended families. The surveys were directed at Heads of Household or their spouse. Six respondents were male, and ten female; 37.% and 62.% respectively. Average age of respondents was 35 years for males, and 26 years for females. The households surveyed were selected at random, and do not present a visibly different profile from national averages in any of the particulars covered in the 2006 census. The sample was remarkably homogeneous, representing little difference from atoll to atoll except with respect to distribution of incomes and subsidies, discussed below.

Geography and Climate

Tokelau comprises three atolls in the South Pacific Ocean between 171° and 173° W longitude and 8° and 10° S latitude, approximately midway between Hawaii and New Zealand. They lie about 500 km (311 mi) north of Samoa. The islands are Atafu, at one time known as the Duke of York Group, Nukunonu, also the Duke of Clarence Group, and Fakaofo, once Bowditch Island. Between them they comprise a land area of 10.8 km². There are no ports or harbours. Tokelau is tropical and lies in the Pacific typhoon belt, and has essentially no high ground, with most of the land mass not more than 2m above sea level.

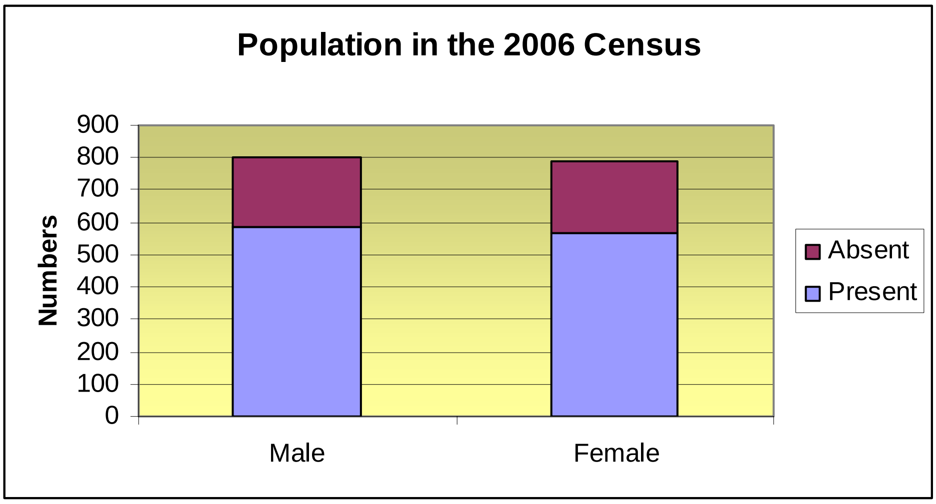
Structure of Local Administration

Tokelau is a self administering territory of New Zealand. It has no national capital. The formal chief of state is Queen ELIZABETH II and is represented by the Governor General of New Zealand. The head of government is a- position rotated annually among the three Faipule (village leaders). The Government Cabinet is the Council for the Ongoing Government of Tokelau, consisting of three Faipule (village leaders) and three Pulenuku (village mayors). There are no elections and the monarch is hereditary. The administrator is appointed by the Minister of Foreign Affairs and Trade in New Zealand and the head of government is chosen from the Council of Faipule and serves a one-year term.

Population structure and density

The *de jure* population of Tokelau on Census night 2006 was 1,466[3]. Of these, 442 were absent on census night. The residents-plus-visitors figure, 1,151, is probably realistic as an indicative basis for planning provision of services, since Tokelauans travel frequently and are often absent for quite long periods of time working, studying, holidaying or receiving medical treatment; 32% of the population surveyed had lived overseas for six months or more[4]. The population resident on census night had declined by 20% compared with the 2001 census figures. Almost the same percentage was not in Tokelau five years ago[5]. The population counted in 2006 distributed by sex and location on census night is shown in the graph below.

Figure 1: Population normally resident by status on Census Night 2006



Data source: 2006 Census Tables 1.1.2 and 1.1.3

As an aid to planning, the population distribution by age across the three atolls is shown below. There is a sharp decline in population on all atolls from the economically active age onwards. Age distribution of absentees is similar, and does not suggest that a reflux of any particular age group is likely to affect planning parameters.

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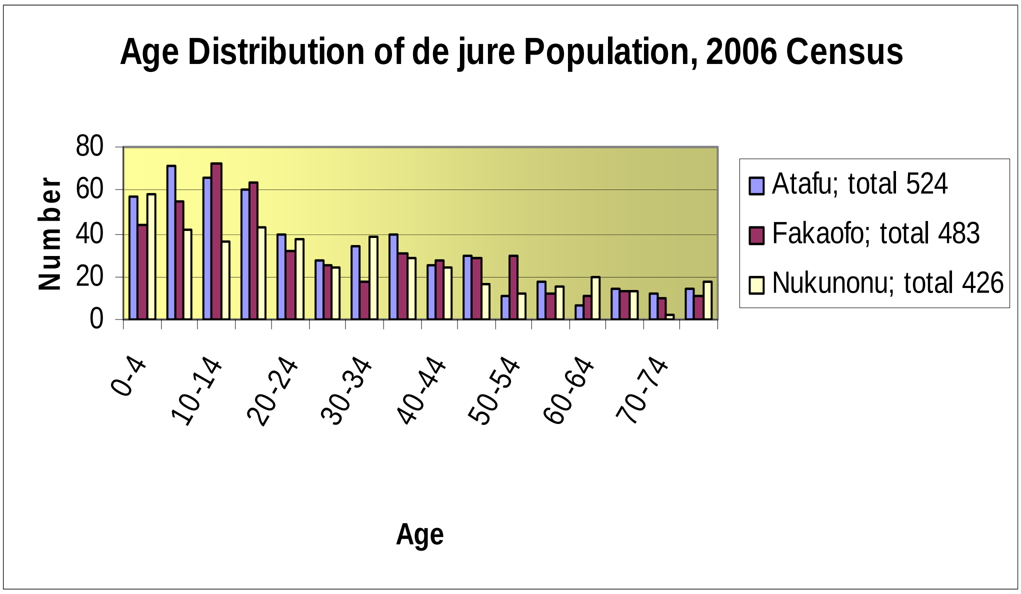
[3] 2006 Census, accessed October 2007 at http://www.spc.int/prism/NSO-news/TK/2006%20Census%20Tabular%20Report%20-%20Final.pdf, Tables 2.8 and 2.9

[4] 2006 Census Table 3.3

[5] See 2006 Census, Table 3.6

Figure 2: Age Distribution of the Population



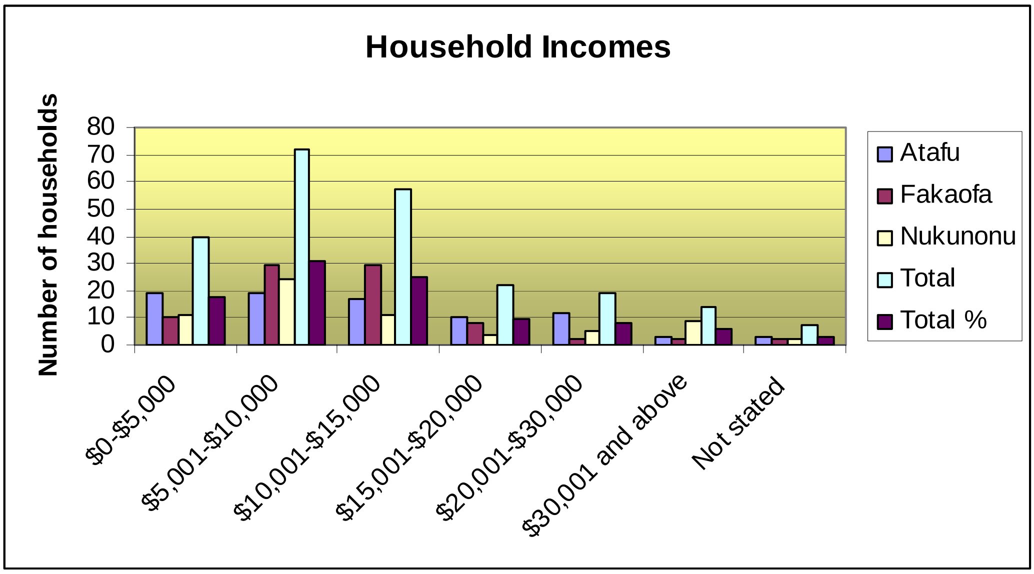
Data source: 2006 Census Table 1.2.1

The area of the atolls in Tokelau is 10 square kilometres, giving a population density of around 147 persons per square kilometre. However, most of the population is closely agglomerated into residential settlements. The households surveyed own around five acres of land each, but this is in the main situated away from residences.

Distribution of Occupations and Incomes

Of 375 occupations reported in the census, 54% are contract workers for the Village Council. A further 39% are salaried members of the Taupulega. Of the remaining 7% less than 2% are self employed. Only 5% of those seeking paid employment stated that they had looked for work in the week preceding the census, but 85% of the population had performed some unpaid work. A third of the work residents perform on their own behalf is in gardens, 20% on making cloth or sewing, and 20% on building or repairs of dwellings or boats. Cash incomes are graphed below.

Figure 3: Distribution of household income by levels



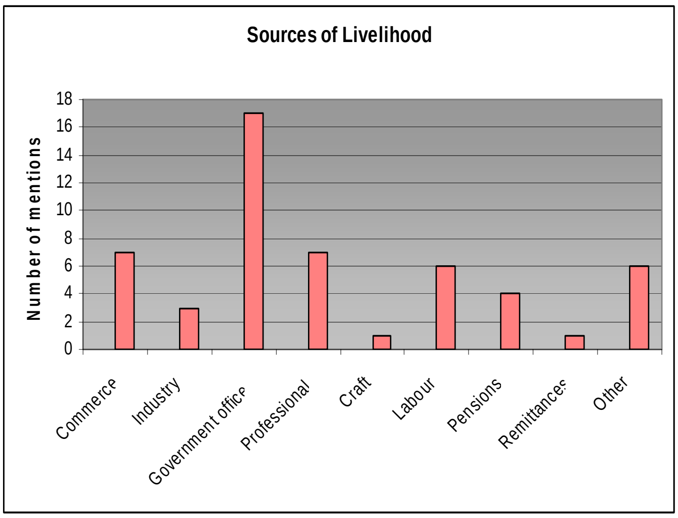
Data source: 2006 Census Table 6.16

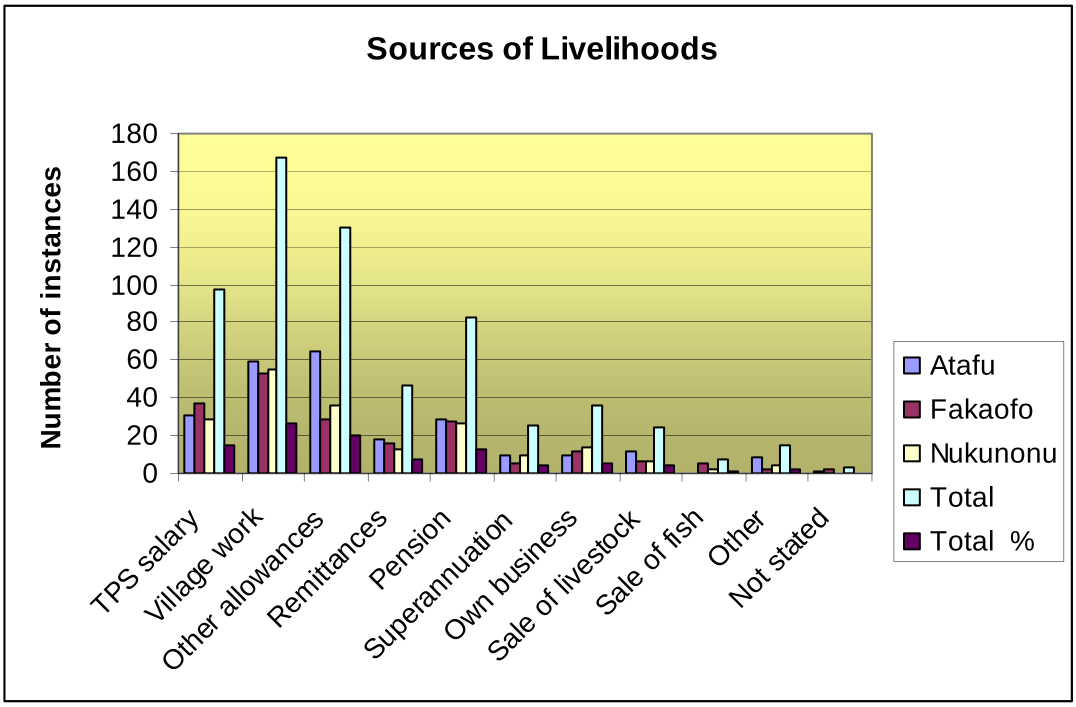
A third of households have an income between NZ$5,000 and NZ$10,000. Fifty-six per cent earn between NZ$5,000 and NZ$15,000. This analysis does not include the value of subsistence activities.

The fourteen surveyed households that were willing to answer this question had incomes averaging NZ$13,100 per annum with a range from NZ$28,580 to NZ$7,920. Average per capita incomes within surveyed households ranged from NZ$3,176 to NZ$706. Though small, the sample thus appears valid for this criterion.

The graph below shows reported sources of livelihoods reported in the 2006 Census. It does not reflect the value of each source, but instead is a commentary on prevalence of particular livelihoods activities. Tokelau Public Service (TPS) salaried work and village contract labour are numerically the most significant activities. Other allowances and pensions are significant sources of livelihood, reflecting relative poverty of opportunity for productive work.

Figure 4: Livelihoods in Tokelau





Data source: 2006 Census Table 6.15

In the surveyed households, 41 sources of livelihood were mentioned, an average of almost 3 sources per household that responded to this question. In the figure below, the sources are graphed. "Other" includes allowances paid to housewives and children on Atafu. Almost every household has at least one TPS salary or pension. The almost total absence of remittance income in this highly family-responsive society indicates that the majority of absent Tokelauans in the families surveyed assess standards of living at home to be comfortable. Comparison with national Census figures confirm that this is a general trend; allowances and pensions are much more significant than remittances in both data sets.

Figure 5: Livelihoods in the Household Survey, October 2007

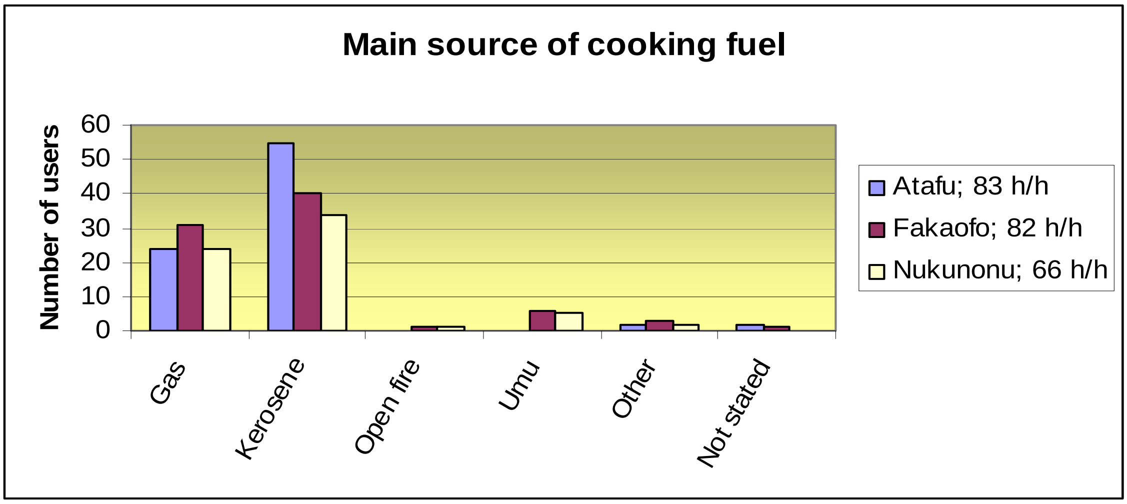
Economic Growth and Potential

Tokelau's economy is constrained by its remote location, and this suggests that economic activity could focus on small volume, high value activities or services. Access is difficult, but for example, some sectors of the tourism market this is an attraction, and signifies exclusivity rather than a reason not to go. However investment is required to provide a consummate level of service, and is unlikely to be attempted on a 'build it and they will come' approach.

Energy Use and Expenditure

Cooking fuel use revealed in the census is graphed below. The Census form does not list electricity as an option as this is quite explicitly discouraged due to constrained supply.

Figure 6: Cooking fuel sources in Tokelau



Data source: 2006 Census Table 6.10

On all atolls gas and kerosene combined account for in excess of 86% of main cooking fuels included in the census. On Atafu, more than 95% comes from these sources, with a measurably higher proportion (66%) represented by kerosene than on the other two main atolls. Firewood is little used, and *umus* are used mainly for ceremonial occasions.

In the household surveys questions about fuel use were asked as an open question related to function. Responses are tabulated below.

Table 1: Fuel Functions and Use in the Household Survey October 2007

Fuel/Function	**Electricity**		**Kerosene**		**Gas**		**Petrol**	
	No	%	No	%	No	%	No	%
Lighting	16	100						
Cooking	3	18.75	9	56.25	11	68.75		
Water heating	5	31.25	1	6.25				
Crop processing	1	6.25						
Transport							15	93.75

Most surveyed households use coconut husk or fuelwood as a cooking fuel on an occasional basis for ceremonial *umu* but the pattern of response was too tentative to be statistically reliable; suffice it to say that there is abundant supply at no cost other than labour.

Table 2: Average Monthly Household Expenditure on Fuels

in the Household Survey October 2007

Fuel	**Number**	**Average $/mth**
Electricity	16	72
Kerosene	11	16.45
Gas	12	45.90
Batteries	12	6.08
Petrol	15	55.20
Total		**195.63**

If a household used all the above fuels, a hypothetical average monthly bill might be almost NZ$200. However, no household did in fact report using the full range of commonly used commercial energy sources. Average household energy costs including transport fuels were NZ$177 per month. Excluding transport fuels, this dropped to an average of NZ$122. In the thirteen households for which both credible income and energy expenditure could be compared, energy costs averaged 17% of individual household income, with a range between 5% and 29%. Excluding transport fuel, costs averaged 11% of individual household income, with a range from 5% to 27%.

Willingness and Ability to Pay

Assessment of willingness and ability to pay was based on census data, key informant information and household surveys.

Prima facie, Tokelauans are relatively comfortable financially. Only forty households in the 2006 Census have an annual cash income of NZ$5000 or less. The vast majority own their own home. Poverty surrogates such as quality of housing, access to water and sanitation indicate relatively good standards of living. Ownership of consumer durables and other assets is quite high; over 80% have access to media and entertainment, 90% have freezers, often more than one, 75% have a boat and an outboard motor, the local equivalent of the family motor car. More than 80% of households own pigs, on average around 20 per household. About 40% own around 20 chickens. Half the population over the age of fifteen smokes regularly.

All Fakaofo households in the survey take credit from the local trade store, where they run up monthly accounts so as not to have to carry cash. All said they could meet their debt obligations. None reported taking a loan that increased household income; that is, credit is a convenient interest-free facility to cover daily expenses rather than an investment to improve income or livelihoods. This practice is known, but less prevalent on Atafu and Nukunonu. All surveyed households reported savings for education, travel, retirement, house or boat improvements, gifts or the proverbial rainy day.

On average households surveyed spend 11% of their reported cash incomes on energy excluding transport costs, and 17% if transport is included. This is considerably lower than for many remote area and developing countries, where 20-25% of cash income is typically spent on household energy excluding transport. All energy costs plus all other regular household cash expenditure on essentials including food, education, medical costs, donations, savings and outward remittances account in the surveyed households for an average of 67% of cash income, with a range from 35% to 89%. The shopping list did not include clothing or housing expenses which are more difficult to quantify on a monthly basis.

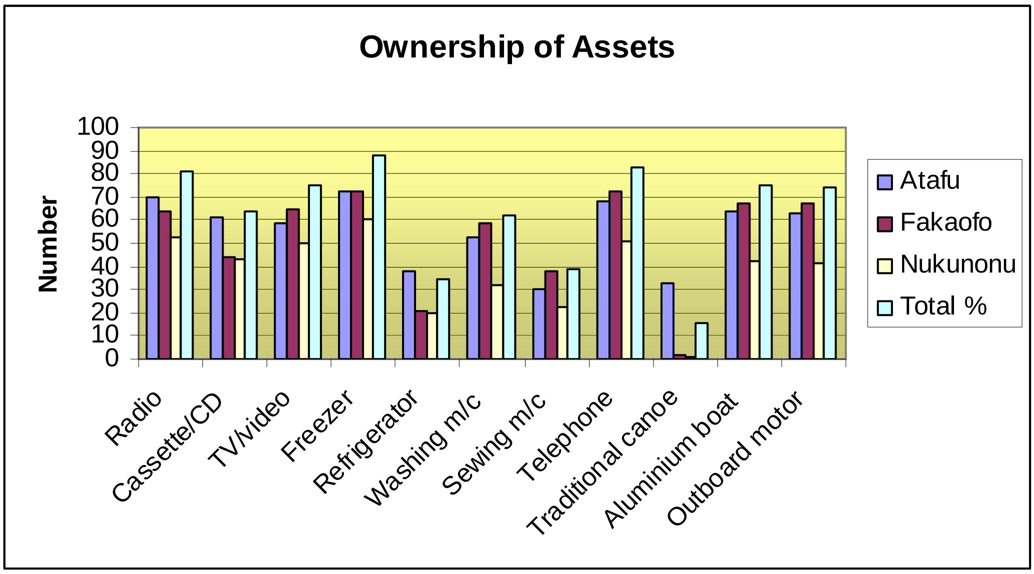
Household energy at present levels should thus impose no hardship in the Tokelauan context, especially as reasonably easy access to subsistence goods has the potential to reduce the relative significance of the cash component of incomes as a poverty indicator.

However, willingness to pay in the surveyed households is low. Asked what would be a reasonable electricity bill for their household, respondents stated willingness to pay at 41% on average of their present monthly bill, which is already subsidised by around 150%. Only one (1) consumer declared himself willing to pay 100%. At worst, the respondent was willing to pay only 10%. Taken together with current consumer behaviour where only around 75% of bills by subsidised value are collected, this indicates very serious sustainability issues will emerge unless there is a major change in consumer attitudes and behaviour.

Ownership of Assets

Poverty surrogates suggest that the problem of non-payment is more attitudinal than financial. The graph below shows national patterns of ownership of the items surveyed in the 2006 census. In all, 231 households were surveyed. The graph does not reflect ownership of multiple units, e.g. more than one TV or freezer per household. This table includes all articles tabulated in the census except wooden boats, of which there was no recorded ownership.

Figure 7: Household Asset Ownership, Tokelau



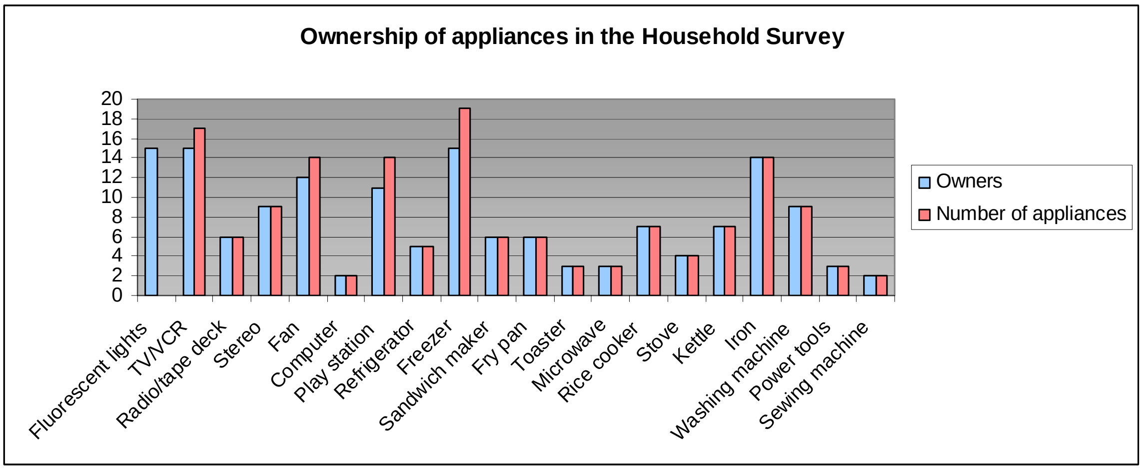
Data Source: 2006 Census Table 6.12

In the household survey, emphasis was placed upon revealing present or planned ownership of electrical appliances, especially those that consume relatively large amounts of power.

Surveyed households were invited to state what appliances they now own or would like to purchase. The list of wants was very minor and is not shown in the graph below, since it would be statistically irrelevant. Kitchen appliances dominated – two frypans, a microwave, a rice cooker, a refrigerator. Washing machines (2), along with a play station, a fan, a stereo and a set of Christmas lights.

The graph below shows current ownership of appliances. The number of fluorescent tubes was omitted to avoid distorting the graph, but averaged a little over three per household. Three respondents own power tools, and two a sewing machine. These were the only obvious potentially productive uses of power mentioned other than freezers, which could possibly be used for commercial applications. Multiple ownership of items also reflects the values Tokelauans place on items that offer entertainment or confer comfort and convenience, TV sets and play stations on the one hand, fans and freezers on the other.

Figure 8: Ownership of Electrical Appliances in the Household Survey, October 2007



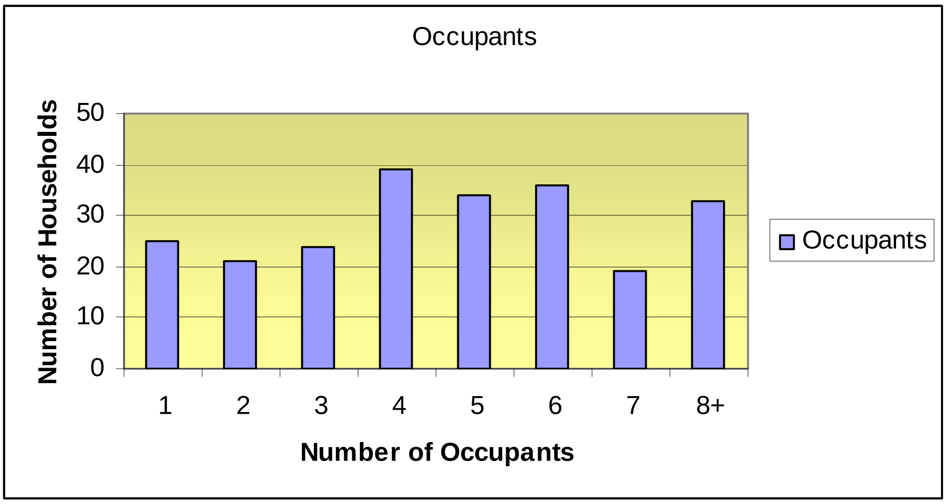
Other poverty surrogates convey a picture of reasonable comfort in the surveyed households. All those surveyed own land, though some could not say how much. For those who knew, the average is 5 acres. All but one own their own home. All homes are of permanent construction materials. All have their own water catchment; 90% have inside flush lavatories, and some have more than one; only one respondent has only an outdoor privy. 15 of the 16 own pigs, on average 14 in number, and four also own an average of 15 chickens. Almost all take credit, and state they can easily pay back their loans. 90% have savings. The same phenomena were examined at national level to guide assessment of future energy demand.

Forecast Energy Demand

Two hundred and thirty-one households feature in the 2006 national census. Ninety per cent are "palangi-style," i.e. of permanent construction materials; the balance is mixed or unstated. Most are of modest size; 70% have two rooms and only 14% have more than three rooms. The vast majority have flush lavatories (many outside, as a matter of cultural preference), their own rain water catchment tank, and a shower for personal hygiene. Observation suggests that none is so flimsy as to be unsafe for connection and use of electricity.

Household size averages 6.3 occupants. This compares with the October 2007 sample household survey average household size of 6.38.

Figure 9: Distribution of household sizes in Tokelau



The number of residents and households has declined by some 20% since the 2001 census, but energy demand overall is constrained by supply. Electricity consumers are not permitted to use electric ovens or cooktops due to constrained supply. Kerosene is rationed to five litres per household per fortnight, and petrol to 20 litres per household per fortnight.

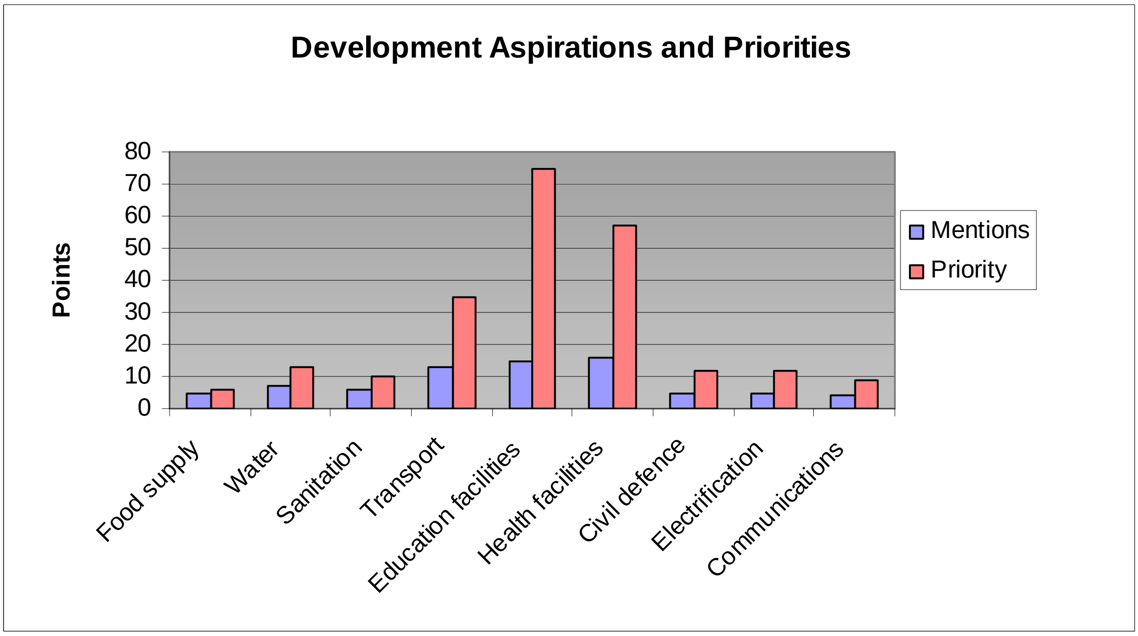
It is not probable that the number of households or residents will increase appreciably. Based on the very low response in the household survey to the question regarding aspirations for appliance ownership, patterns of household consumption may rise little. Use of more energy efficient appliances, in particular refrigerators and freezers, but also lights could contain demand for some time into the future.

Electrification has not thus far given rise to productive uses with high power demand.

Development Priorities

The household surveys reveal near-unanimity that the highest development priorities are education and health. Respondents were invited to select their five highest aspirations. Most named five; a small percentage ranked fewer. The graph below shows the goals that were selected by respondents, the number of times that they were mentioned, and the weighting given, where the highest priority was tabulated as five points, and the lowest one point. There was a small variation from atoll to atoll; civil defence was more often, and higher ranked on Atafu and Nukunonu, where on Fakaofo only one respondent mentioned this as of concern. Priorities were otherwise very similar.

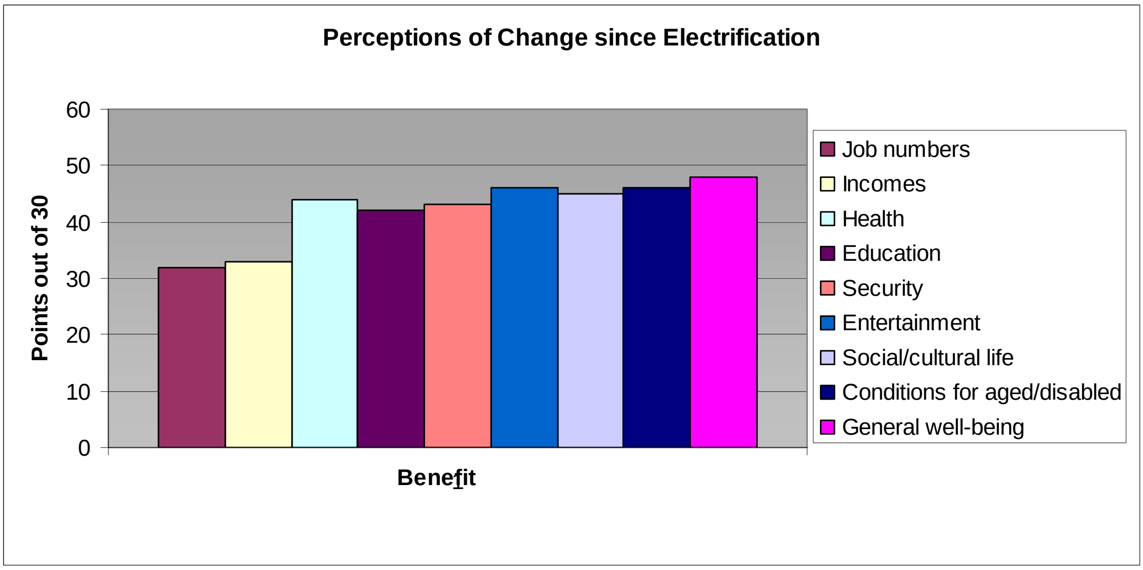
Figure 10: Development aspirations of the surveyed households



Consumer satisfaction

Feedback from the household surveys on change since electrification indicates a satisfied body of consumers. Electrification features low on the list of development priorities in the graph above. Few consumers have outstanding ambitions for ownership of electrical appliances. There may have been an element of self-censorship in demand for electric ovens which masks suppressed demand. Assessment of change since electrification is at worst neutral, and is generally positive for all the criteria on which comment was invited. No respondent mentioned anything in the "other" category invited in the survey. It is of concern that no respondent found that electrification had any positive impact on employment or incomes.

Figure 11: Impacts of Electrification



Comments on impacts did not reveal any dissatisfaction with the present quality or quantity of electricity supply. There was a small variation in the pattern of response between the atolls; for example, Atafu residents ranked security (specifically safety to walk the streets at night, drunken behaviour or theft) as having not changed because there was never any concern about it before, whereas Fakaofo residents almost all remarked that improved security was a big benefit of electrification.

Positive comments centred on better light and entertainment, facilities for reading and study, security and convenience. Negative comments mentioned that people are less sociable than before, eat more frozen food, exercise less, are more obese and less fit. However, the consensus about general wellbeing was overwhelmingly positive.

Key informant comment reinforced householders' opinions about impacts. A teacher stated that electrification has up and downsides in education; though students are more informed and aware through access to media, there has been no impact on levels of achievement. A Health Officer drew attention to the deterioration in diet and exercise, and the increased incidence of diabetes with heavy consumption of sweet carbonated drinks. A Planning Officer stated that the top householder development priorities of education and health are receiving planning attention at present.

Annex 1

NASA Solar data for Tokelau

NASA Surface meteorology and Solar Energy - Available Tables

At Latitude **-9.1** and Longitude **171.5**

Geometry Information

Average elevation: **0** meters

Northern boundary
-9

Western boundary
171

Center
Latitude **-9.5**
Longitude **171.5**

Eastern boundary
172

Southern boundary
-10

Parameters for Sizing and Pointing of Solar Panels and for Solar Thermal Applications:

Monthly Averaged Insolation Incident On A Horizontal Surface (kWh/m^2/day)

Lat -9.1 Lon 171.5	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
10-year Average	5.74	5.07	5.34	5.29	4.75	4.54	4.53	5.12	5.54	5.79	5.71	5.56	5.24

Minimum And Maximum Difference From Monthly Averaged Insolation (%)												
Lat -9.1 Lon 171.5	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Minimum	-12	-22	-19	-14	-10	-13	-20	-12	-19	-22	-8	-14
Maximum	13	18	13	13	14	13	17	13	16	18	11	27

Solar Geometry:

Monthly Averaged Daylight (hours)												
Lat -9.1 Lon 171.5	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average	12.5	12.3	12.1	11.9	11.7	11.6	11.6	11.8	12.0	12.3	12.5	12.6

Parameters for Sizing Battery or other Energy-storage Systems:

Equivalent Number Of NO-SUN Or BLACK Days (days)												
Lat -9.1 Lon 171.5	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1 day	0.95	0.94	0.92	0.94	0.96	0.95	0.95	0.96	0.96	0.96	0.96	0.94
3 day	2.74	2.31	2.20	2.30	2.31	1.75	2.03	2.03	2.12	2.20	2.30	2.20
7 day	4.05	3.45	4.41	5.22	3.37	1.89	3.74	3.10	3.00	3.89	2.57	3.67
14 day	3.83	5.73	5.92	6.28	4.55	2.28	5.55	4.43	4.31	6.98	2.89	4.87
21 day	3.79	5.34	6.71	5.84	3.45	3.08	7.10	5.38	3.37	8.29	4.19	5.89
Month	3.72	6.29	5.74	4.31	3.19	3.96	6.29	3.81	5.68	6.74	2.52	4.23

Meteorology (Wind):

Monthly Averaged Wind Speed At 50 m Above The Surface Of The Earth (m/s)													
Lat -9.1 Lon 171.5	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
10-year Average	4.61	5.18	4.73	4.23	4.55	5.20	5.69	5.85	5.33	4.41	3.91	4.84	4.87

Minimum And Maximum Difference From Monthly Averaged Wind Speed At 50 m (%)													
Lat -9.1 Lon 171.5	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
Minimum	-27	-30	-37	-26	-25	-30	-19	-24	-22	-18	-17	-26	-25
Maximum	21	43	43	33	30	33	20	35	35	21	27	30	31

It is recommended that users of these wind data review the SSE Methodology, Section 7. The user may wish to correct for biases as well as local effects within the selected grid region.	***All height measurements are from the soil, water, or ice/snow surface instead of "effective" surface, which is usually taken to be near the tops of vegetated canopies.***

Annex 2 References

The following materials were reviewed and used in the compilation of this report:

- The Apolima Photovoltaic System Design and Specifications for Preparing Requests for Quotation of Major Components. Prepared by Herb Wade, 31 May 2005
- The National Energy Policy and Strategic Action Plan (NEPSAP) for Tokelau, 2005
- Biomass Energy Potential in Tuvalu. Sarah Hemstock, Sept 2005
- Biofuel from Coconut Resources in Rotuma, Leba Gaunavinaka, Gerhard Zieroth and Wolf Forstreuter, September 2007
- Tokelau Pacific Islands Renewable Energy Project report, GEF - 2005
- The Project Works Installation and Verification Study (Fakaofo solar PV), Empower Consultants Ltd, Nov 2006
- Mission Report CocoGen II Inception Visit, Jan Cloin, SOPAC, December 2006
- Bio-energy systems at the community level in the South Pacific: impacts and monitoring, Jeremy Woods, Sarah Hemstock and William Burnyeat, May 2005
- Documentation pertaining to the feasibility study, EIA and technical specifications developed as part of the trial system in Fakaofo, NEPSAP, 2004

Annex 3 Fieldwork Report. September 2007

Empower Consultants

Hybrid Photovoltaic/Coconut based Power Systems in Tokelau - Consultancy for the Feasibility, Environmental Impact Assessment, System Design and Specifications of Major Components and Financing Strategy

Debriefing Note – Final Version

Field visit to Fakaofo, Nukunonu and Atafu Atolls

9th to 29th September 2007

Contents

Executive Summary

The United Nations Development Program (UNDP) Samoa office is assisting the Government of Tokelau to investigate the possibility of fulfilling the national policy of 100% renewable energy utilisation for power generation on each of the three atolls. Empower Consultants was contracted to undertake a consultancy for the feasibility, Environmental Impact Assessment (EIA), system design and specifications of major components and financing strategy for hybrid Photovoltaic (PV)/Coconut based power systems in Tokelau**.** This de-briefing note summaries the preliminary general findings of the field research conducted during the period 9-29 Sept 2007 and will be followed by a detailed report that covers the full project ToR. The detailed report will include the feasibility study report, the environmental impact assessment and the financing strategy report. A separate report will be provided including specifications for the major technical components.

Preliminary findings are that such a project is technically viable. It is possible to develop the power system on each of the three atolls to operate on the basis of 90% of the power coming from solar PV and 10% coming from coconut oil.

The fieldwork has also determined that a viable wind resource may also be present, and it is recommended that this resource be studied further to ascertain the extent of its availability. This study may involve the installation of wind monitoring equipment on at least one of the atolls and/or reviewing data from the wind monitoring equipment installed in Tuvalu in mid-May 2007 by support from UNDP. Tuvalu and Tokelau are both atoll nations and on similar latitudes and hence are likely to share similar wind regimes.

The undertaking of an energy efficiency education and awareness raising program is strongly advocated. This will assist in reducing the loads and reducing energy wastage. In addition, a financing mechanism to assist the replacement of out of date and inappropriate appliances, particularly refrigeration and lighting is also recommended as this is a major source of energy loss. Once this is complete it is recommended to repeat the energy demand monitoring undertaken during the field visit in Sept 2007 to ensure that the basis for design of the solar PV system is still valid. In this regard the design and costings provided could be regarded as a worst case scenario as the basis for design used will reduce in cost with a reduction in demand.

There appear to be sufficient land resources and coconut resources to undertake the project (i.e. hybrid Photovoltaic/coconut based power systems in Tokelau**)** and politically the governing councils, known as Taupulega, on each atoll are all in agreement that reduced dependency on imported fuels for their energy needs is a direction that they want to proceed in. In addition, with the present impetus in Tokelau towards greater self determination, and the recent New Zealand political announcements of movements towards carbon neutrality, the movement of Tokelau, a dependency of New Zealand, away from 100% dependence on fossil fuels and towards near independence recommends itself. For New Zealand to assist

Tokelau to achieve this target would be a major international milestone, perhaps the first in the world for a self administering territory.

The social and environmental survey work has likewise found no compelling reason not to continue with the project. The environmental reasons for undertaking the project are clear and offer benefits from reduced air, noise and marine pollution. No negative changes in land use are expected. Other downsides are not direct impacts, but the *potential* for negative impacts from the use and future disposal of items such as lead-acid storage batteries. The recent signing of a waste disposal agreement with Samoa will mitigate these concerns, however the risk of an impact is still present. On balance it is evident that the environmental positives greatly exceed the negatives for the project.

In terms of social acceptability, respondents to the survey were generally positive about the prospects of a continued reliable power supply, and felt that the presence of electricity was a positive aspect in their lives. Some negative impacts were noted, particularly on the changes in diet facilitated through the widespread use of freezers allowing the importation of cheap foodstuffs from abroad, and altered sleeping patterns for children in the open room format of Tokelau style housing, once late night TV and lighting is introduced.

Social Findings

Taupulega Meetings

The Taupulega on all three atolls were consulted and engaged in open discussion on the general scope of the project, what would be involved and what the anticipated outcomes would be. Taupulega members on all three atolls did not simply accept the project outright and some well directed questions were raised on issues including land requirements, labour demands and impact on power costs and reliability. These were preliminarily responded to and in each case the Taupulega were left with the understanding that these were issues that needed further consultation, but conceptually they were all in agreement that the issues could and would be managed and resolved if the project moves forward.

Key points from discussions include:

- No labour shortage exists and no problems are anticipated with the collection and processing of coconuts into copra and copra oil, given access to the correct equipment.
- Assuming a requirement of 200 to 400 nuts per day, the Taupulega's forsee no shortage of access to sufficient coconuts, primarily from council lands on Fakaofo and Nukunonu, but on Atafu council owned lands are minimal and the collection, and possibly payment for nuts on private land is possible.
- Salient points raised by several individual council members included the need for Tokelau to be able to sustain itself during times of isolation, such as extended periods of bad weather or during international pandemic events such as a possible bird flu event requiring the closure of international borders.

Thus it seems that there are few, if any political impediments to the project from the Tokelau side. In fact given the current referendum on greater autonomy for Tokelau, the reduction in energy dependency paid from New Zealand and supplied via Samoa appears well timed.

Household survey results

Households were surveyed on all three atolls. The analysis of results will be presented in the final feasibility study report.

Labour requirements

Labour for each atoll is organized and directed by the Taupulega. There is no unemployment in Tokelau and every adult is employed in some role by the council. While the exact labour requirements are not yet determined, it appears likely that 200 to 300 coconuts would be required to be collected and processed each day on each atoll.

The older members of the communities recall that one of the most time consuming aspects of processing copra (the white flesh of the coconut) was the effort to spread it in the sun to dry and then gather it quickly when rain threatened, only to then spread it out again later. To avoid this a solar drying facility is planned. This simple structure (essentially a glasshouse with a fan installed) will significantly reduce the time and effort required to process the copra.

The process required is:

1. Collect the nuts from under the trees
2. Remove the external fibre layer (husk) in situ and leave the resides in the field
3. Split the nut into two halves and drain the coconut milk
4. Transport the nut halves to the solar dryer
5. Dry for 2 or 3 days
6. Remove the white flesh from the nut, ready for oil extraction
7. The dry coconut meat is chopped, heated and the oil crushed out using simple and widely available agricultural processing equipment
8. The oil is then filtered and stored ready for use in the generator
9. Residual meal is used as pig fodder
10. The husk may be burned as fuel
11. In some countries the fibre is processed into saleable products such as coir mats for domestic use, or on an industrial scale as geo-matting for stabilisation of slopes disturbed by earthworks or natural slips.

Studies by the SOPAC/UNDP/Government of Denmark Pacific Island Energy Policy and Strategic Action Planning (PIEPSAP) project for a coconut oil initiative in Rotuma, Fiji indicate that a single person with average training can collect and dehusk 80 coconuts per hour. Taking that a maximum of 300 nuts is required per day, one person should be able to undertake the bulk of the collection and dehusking activities in 3 to 4 hours a day. Allowing another 4 hours per day for removal of copra and processing into oil results in the equivalent of one person working 8 hours a day to meet the maximum demand for coconut oil for power generation for each atoll. This could be taken as a best case scenario but even so, the labour involvement is manageable.

Impacts of electricity

The survey results show that the impacts of electrification are generally regarded as positive and well received. However, during the course of the fieldwork the following were also noted:

Health implications

In general survey respondents found the availability of electricity to be a positive thing, primarily due to the presence of lighting and refrigeration. Both physical and mental health were noted to have improved as a result of electrification however other aspects were also visible as follows:

- The use of freezers has altered the diet and lifestyle patterns significantly. Prior to the arrival of electricity and refrigeration, households would catch fish on a daily basis as storage was not possible. Now households fish less frequently and store the fish for future use.
- The storage of foods is safer now due to refrigeration, however the type and nature of appliances used is such that at times the correct temperatures for safe storage of frozen foods are not attained as the ambient temperatures are too high and the freezer units are used as refrigeration units or coolers for all manner of products including drinks and fruit. This has the other impact of very frequent opening and closing of the door to extract food items (like milk and beer).
- Freezers have allowed the importation and consumption of meat and vegetable products that were not previously available. In the case of vegetables this is positive, but in the case of turkey tails, mutton flaps and other low quality cuts the impact is regarded as negative given the increase in obesity, diabetes and other health issues present. Few residents now cultivate any fresh fruit or vegetables, other than pandana, breadfruit and bananas on an informal basis.

Lighting of households is also very much improved, however the combination of lighting and television and sleeping layouts where the bulk of the family sleep together in a single open living room, mean that whereas before electrification, children would drift off to sleep in a mainly quiet and darkened room, they are now routinely up and awake until 10pm to midnight as the living room is now brightly lit and noisy from television and stereo appliances. It is possible that future building designs may need to find a way to segregate living and sleeping areas in a more western format, without compromising the open and highly valued traditional design that allows such free movement of air.

Household ownership of playstations is very high; one household of three members owned five, and all households surveyed owned at least one.

Environmental

Summary

No negative impacts from the development of this project were able to be determined. The Environment Officer on Fakaofa stated that there would be no negative impacts from collection of coconuts to produce copra and coconut oil (CNO), as he believes ground would not be cleared, and would continue to be left largely undisturbed as is the present practice. Primary concerns of land use change, or the clearing of lands to facilitate collection of coconuts were found to be unfounded, and the disposal of waste oils and old lead acid batteries will be accomplished via the recently signed agreement with Samoa allowing the return of wastes for safe disposal or recycling in Apia. Should Apia not be able to cope with the wastes generated from the project, (such as the old battery cells) then on shipping to NZ or Australia can be considered. An alternative arrangement that may be possible is to utilise the scheduled maintenance visits to New Zealand by the transport ship MV Tokelau every 5 or 6 years as an opportunity to transport old batteries to NZ for recycling.

The use of a bio-oil such as coconut oil will reduce the danger from oil spills and leakage experienced from the current method of transporting drums from the ships from Apia. In addition, the solar energy produced will significantly reduce the running time of the diesel gensets, thus reducing noise and air pollution and also reduce the quantity of waste lubricating oils required.

Waste disposal

The disposal of wastes in Tokelau has been undertaken in the past through a simple burial process. Essentially any and all waste products have been discarded in this manner, including waste oil from the generators, batteries, appliances etc. Given the highly porous nature of the coral and sand, there is effectively no ability for the pits to retain these wastes and eventually they will leech. In most cases it would be expected that this has already occurred.

Organic wastes are in most cases collected at each house and fed to pigs on a daily basis. In Tokelau pigs are kept contained and in specific locations which resulted in a cleaner living environment around the houses. The banning of dogs from all three atolls was also noted and welcomed. Chickens were the only livestock that roam freely, along with domestic cats.

Tokelau has very recently (August 2007) signed an agreement with Samoa to allow the transporting of wastes back to Apia aboard the regular transport boats. While this was not yet observed to have started, the presence of this agreement will ensure that in future, waste lubrication oils and in particular, lead acid storage batteries can be returned to Apia for recycling or safe disposal.

Land use

The majority of Tokelau's atolls are uninhabited with wild coconut covered islets. Land is owned by both private households and the Taupulega. Control over access is exercised by individual land owners, but since households in most cases do not live on their traditional lands there is little formal control over who goes where. This may only become an issue if land was being disturbed or product, such as coconuts being taken regularly for profit or private use. In practical terms this is unlikely to pose any problem to the project. The households surveyed at random by Mr Woods during the field work in Sept 2007on Fakaofa each own around six acres of land, irrespective of household size. There is very little household use of lands with the vast majority of foods coming from the atoll shops (and thus imported) rather than being grown on the plots of land belonging to individual households. Households report only visiting their lands every few months at the most, thus most lands are in a 'wild' state comprising mature coconut trees and underbrush. Some planting and tending of banana plants is recorded but only in a somewhat casual manner.

In Nukunonu and Fakaofo the Taupulega own significant plots of public land, also in a wild state, and Taupulega expects that the quantities of coconuts discussed can be fully obtained from public lands without needing to access privately held lands. On Atafu however the Taupulega own a very small amount of land and a different collection and payment mechanism may be required if public lands are unable to produce sufficient nuts to meet the demand.

In all cases the Taupulega felt that no clearance of underbrush would be needed and that nuts could easily be collected from the grounds around the trees in the same way that they are presently gathered for pig feed (albeit on a very limited basis).

Expected impacts

The only potentially negative impacts of the project are expected to come from the installation of the large photovoltaic arrays expected to produce 90% of the electricity for the atolls, and the deployment of large scale lead acid battery banks.

The PV arrays will require around 700 m^2 (approx ¼ acre) area to install, along with the space required for the housing of the batteries and inverter equipment. In all three atolls sufficient land was noted to be available for this purpose, however shading of this area will be a resulting impact, albeit not necessarily negative owing to the value placed on shaded areas for other uses.

Tree pruning around the array will also be needed in all sites to ensure the maximum output and solar exposure is achieved by the PV arrays however given the limited pruning required, and that the trees will not be cut down completely, the impacts are assessed to be minimal.

In no cases are domestic properties in the close proximity to the project sites as the noise from the generators is unwelcome and hence the powerhouses on each atoll were situated well away from most residences. The PV arrays can be installed either on or beside the existing powerhouses and will not affect any residences from shading, light reflection or the tree pruning.

Technical findings

The field work yielded no obvious technical no-go barriers to a large scale coconut oil and solar PV project on each of the three atolls. Land, solar and coconut resources are available on each, and the technical requirements to construct a high quality, reliable power system are available off the shelf. There are no records of the age or productivity of the coconut palms. As productivity declines with age, it may be necessary to plan for systematic replanting if demand for coconuts increases significantly. With the present demand for coconut being so low, even low productivity trees will be able to sustain the supply.

There is clearly a need to undertake an energy efficiency audit and public awareness program prior to, or in parallel with, the project proceeding as power demands could be significantly reduced with investment in energy efficient appliances – notably refrigeration, and education on the impacts and advantages of energy efficiency. Significant in the household surveys was the quite high percentage of respondents who stated that they are somewhat afraid of electricity. This indicates a need for education in consumer safety, as well as economy.

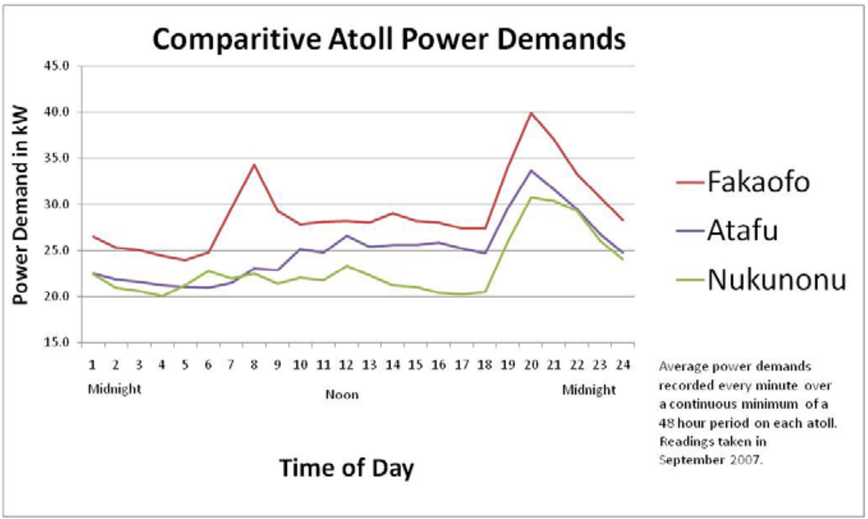
In addition, a wind monitoring exercise is strongly recommended to assess the presence of a useable wind resource. SOPAC (Secretariat for the Pacific Islands Applied Geoscience Commission) and UNDP (Samoa) as part of the PIEPSAP project have installed a wind monitoring station in Tuvalu in mid-May 2007 to measure wind speeds there. When contacted, SOPAC indicated that preliminary results from the station indicated that a viable wind resource was present, and given that Tuvalu is on the same latitude as Tokelau and both are atoll nations, very similar if not identical wind resources may exist there also. Given the high costs of generation on Tokelau, it is likely that if a technically viable resource exists then it will also be financially viable.

Preliminary technical findings and recommendations are:

1. The copra oil and PV project is technically viable. Given the apparent abundance of coconut resources, the relative contributions to power supply from each resource bears re-thinking in the interests of financial sustainability.
2. Considerable savings in energy, and hence capital costs for the project are possible given improved energy efficiency and demand side management.
3. A combined energy efficiency and wind monitoring program be undertaken as soon as possible to reduce loads and offer a third cost effective option to the present diesel based generation.

Power demand patterns

An analysis of power demands on the three atolls is represented as below. Data was collected at the powerhouse on each atoll for a minimum of 2 complete days at each atoll using a Fluke 1735 three- phase power analyser. Installed into the main distribution cabinet at each atoll, data was collected for up to 3 days, using a one minute average value for demand over the recorded period.



	Fakaofo	**Nukunonu**	**Atafu**	Unit
Total 24 hour average demand	**29.1**	**23.0**	**25.0**	kW
Maximum recorded demand	51.2	36.7	38.0	kW
Minimum recorded demand	22.2	16.3	18.2	kW
Average daily consumption	699	553	601	kWhrs
Consumption from 6pm to 6am	383	316	326	kWhrs
Consumption from 7am to 5pm	316	237	275	kWhrs
90% solar means delivering	629	498	541	kWhrs
and 10% from coconut oil	70	55	60	kWhrs
Litres fuel consumed per day	259	210	276	Litres
kWhrs produced per litre	2.7	2.6	2.2	kWhrs

The graph and table speaks for itself in terms of power consumption and comparison, however the interesting points to note are:

- Only Fakaofo seems to have a demand spike around breakfast time. This may be due to the presence of an electric bakery unit in Fakaofo however research indicated that it was not operational over this period. If not operating then there are other loads, most likely cooking related, that are used in Fakaofo but not elsewhere.
- Off peak loads are very consistent across all three atolls. Street lighting will account for some of this but only around 2 kW per atoll. It is suspected that domestic refrigeration, mostly freezers, accounts for a considerable amount of the off peak demands.
- Conspicuous energy inefficiency and wastage was noted in all three atolls. There is little effort to turn off unused computers, lights or fans when not in use. Light fixtures are mostly 2 foot or 4 foot fluorescent types and no incandescent bulbs were noted. Refrigeration appliances were noted to be a considerable percentage of the demand, as per the investigation following.

Given the prohibition on electric ovens (though small electric cooking devices such as sandwich makers are still in relatively common use), future demand patterns appear relatively flat from a domestic perspective, but potentially large increases in demand are possible from the school and hospital construction planning planned on each atoll. There is discussion on the inclusion of air conditioning in various parts of the new buildings, including computer labs, libraries and office areas, as well as intensive care units and the operating theatre for the hospitals. Mortuary facilities are also planned in each atoll. A two body refrigeration unit is planned for both Atafu and Fakaofo, and a two body unit for Nukunonu, where the main hospital facility is planned. As most deaths are expected in Nukunonu where the primary intensive care facility is planned, bodies will need to be stored until transport is available to take them back to their home atoll.

The airconditioning loads need carefully planning and were discussed with each Taupulega. It is suggested that the power capacity needed to operate these airconditioners can be built into the roof of each new building and used in a grid tied capacity, without batteries, but still able to allow the building to shoulder most of its own electrical demand from solar PV embedded in its own roof at the time of construction. A useful precedent is already in place in Tokelau, where every new building constructed is required to have water storage integrated into the design of the building.

Energy efficiency

It is highly recommended that energy efficient practices and energy efficient appliances be the focus of a short study prior to, or in parallel with, the development and implementation of the solar PV and coconut oil project. Considerable reductions in load *may* be possible with consumer education and incentivisation of economy.

The power tariff is already sufficiently high (50 cents per kWhr on Fakaofo and Atafu and 30 cents on Nukunonu) to expect a degree of energy efficiency to be manifesting itself. The absence of efficiency practices and appliances indicates therefore:

- The population are unaware of the impacts and potential savings, or
- The general population is aware but don't care as they don't pay the penalty for inefficiency, or
- The population is aware but lacks either access to, and/or the financial means needed to purchase energy efficient appliances.

During the field time in Tokelau it was concluded that all three factors are present. Therefore it is suggested:

- An energy audit is conducted to identify areas of improvement. The two most visible are refrigeration and turning off appliances when not needed.
- A public awareness campaign is initiated, possibly in conjunction with the schools, to educate on the advantages of efficiency

- A financing mechanism is investigated to facilitate the purchase of energy efficient appliances, primarily freezers and refrigerators. Excellent European designs are available that consume around $^{1}/_{3}$ of the power of standard New Zealand units, have better insulation and compressors and will perform more efficiently in Tokelau's warm ambient climate, compared to designs more suited to New Zealand's colder climate.

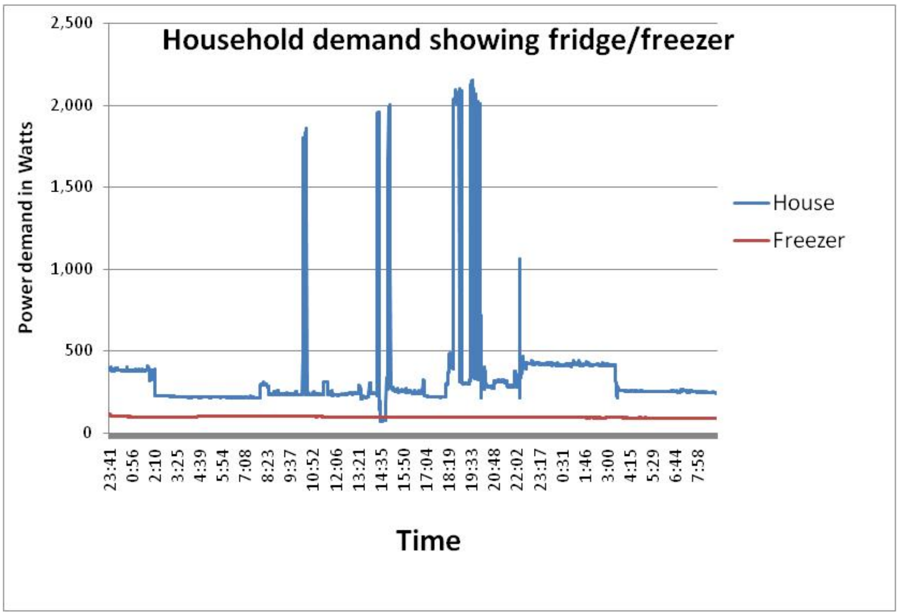
Refrigeration

Most houses were noted as containing one or two freezers, and some also with a separate refrigerator. The use of fridges and freezers has a clear impact on lifestyle with the two main impacts being:

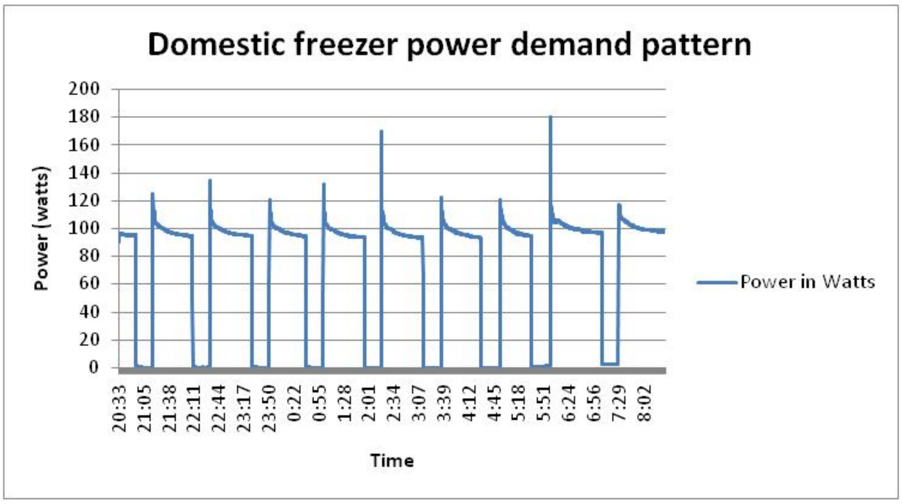
- The ability to purchase and store imported meat and dairy products as well as green vegetables
- A reduction in the need to fish every day. Households can now go once or twice a week and theoretically store fish safely.

But the impact on power demands is clear.

- Domestic fridges and freezers are widespread and generally appear old and not in good condition. Degraded or sometimes missing door seals are evident.
- The glaring spikes are from the use of appliances such as electric frying pans and sandwich makers. Electric ovens are banned from all three atolls however fry pans are not uncommon and present a significant 2 kW load on connection.



Note that the compressor in the above mentioned household ran continuously the entire period. It is apparent that the freezer never reached its correct operating temperature and hence calls into doubt the quality of its food storage quality, as well as the drain on energy supply. Note also that the recording time was done overnight when ambient temperatures were lower.



This example was taken in a different house, and in this case the compressor is cycling as expected, indicating that the freezer is able to attain and maintain its correct temperature, but the compressor is required to stay on for 71% of the time to achieve this. This recording was also done overnight during low ambient temperatures and no opening of the cabinet and so represents a best case scenario.

A standard late model New Zealand made chest freezer is designed to operate on 542 kWhrs per annum. Using a 210 watt compressor, the unit would have to run 29% of the time to stay at its operating temperature under typical operating conditions. It can be seen that the unit above is operating at 71/29 = 2.5 times the energy demand.

In financial terms, in New Zealand with a kilowatt of electricity costing 15 cents, a freezer would cost approximately \$0.15 x 542 kWhrs = NZ\$81 per annum. The same freezer operating in Tokelau will cost \$1.50 x (542 x 2.5) = NZ\$2,030, using an estimated actual tariff of 41.50 per kWhr. Even at the subsidised tariff of \$0.50 the cost to operate a freezer in Tokelau is around \$0.50 x (542 x 2.5) = \$680.

Clearly these costs suggest that energy efficient freezer units can make a significant saving in terms of the variable cost to Taupulega for operating the power system, and then secondly to funders of the large scale project as the overall scale of the PV and other costs can be reduced as the base load is reduced.

Demand side management

The Taupulega are in a difficult position. Living in the community they are intimately involved with their relatives, neighbours and colleagues and find it difficult to take affirmative action against defaulters who cannot, or refuse to, pay their power bills.

The lack of a downside to nonpayment of power bills breaks the cause and effect relationship and acts as a deterrent to other households paying their bills, or the purchase of energy efficient appliances, of energy conservation. The cost of the nonpayment of a $100 power bill is the same as the nonpayment of a $50 power bill.

To alleviate this situation it is suggested that the onus of disconnection for nonpayment be removed from the Taupulega, or the Taupulega be one step removed from the disconnection process. This could be achieved in several ways, however the most likely are:

- Deduction of household power bills directly from salary cheques paid by Taupulega.
- The use of pre-paid power meters.

Both of these measures could be used to recover the costs of investments in greater energy efficient appliances, and both will directly reward households for improvements in efficiency.

Resource assessment

Tokelau appears to have abundant solar and coconut reserves and potentially wind resources as well. This combination is very workable as it offers a useable resource in clear weather, bad weather as well as an easily stored natural liquid fuel for covering peak demand periods, maintenance periods or other events when wind and solar resources may be offline.

Ambient air temperatures are high with an annual average temperature of 27 deg C, and reported to never go below the low twenties so there are therefore apparently no expected difficulties with maintaining the oil in a liquid state. This needs confirmation.

No apparent technical barriers or lack of resources was noted during the field work. In fact the opposite was the case.

Solar

All three atolls have clear, and once pruned, unobstructed solar access. At latitudes of approximately 10 degrees, a north facing array is expected to achieve an average of 5.4 hours of solar input per day, based on NASA global solar data achieves. Greater analysis of this is to be conducted in the feasibility study report.

Wind

Interestingly, the name Tokelau is a Polynesian word for North Wind. The installation of a wind monitoring tower in at least one of the three atolls is strongly recommended. While a visual assessment over three weeks is not empirical and can only be regarded as at best indicative, in the experience of the engineer present a useable resource was available. More research is required to confirm this however if available, this would be a most useful compliment to the planned renewable energy system as it will provide power over night and also during periods of bad weather when solar resources will be reduced. Global wind speed data published by NASA give an average wind speed of 4.1 m/s at a height of 10m, which would correlate to an approximate wind speed of 5 m/s at a height of 40m. This could be considered viable, if the NASA estimates are accurate.

It is worth noting that due to the very high costs of power generation in Tokelau, even low wind speeds that would normally be discarded as nonviable in regions where the power generation costs are comparatively low (such as New Zealand, USA, Europe etc) are likely to be viable in Tokelau.

SOPAC has recently installed a wind monitoring tower set in Tuvalu and data from the tower has been requested as it is likely to be comparable with wind speeds in Tokelau. If useable wind resources are confirmed in Tuvalu then it is recommended that a wind monitoring tower be installed in at least one of Tokelau's atolls. A short meteorological tower is already installed in Nukunonu however it is too short and affected by nearby buildings to give accurate data for the purposes of power generation. In addition, wind speeds are only manually recorded at periodic intervals and are insufficiently detailed enough to allow a viability assessment for the purposes of power generation. A 50m tower with automatic 10 minute averaged wind direction and wind speed equipment should be included.

Coconut

Tokelau's islets are mostly unused and uninhabited and are covered with coconut palm. Given the low numbers of nuts required it is apparent that there are easily sufficient nuts available to meet the demands of the project. Having said that, a formal assessment will be conducted in the course of this project review.

Research from Rotuma, Fiji identified that approximately 9 coconuts were required to produce one litre of coconut oil. To cover any variation in nut size, etc a figure of 7 nuts per litre has been used in this assessment. On that basis, between 150 and 220 coconuts are required per day to provide between 20 to 30 litres of oil a day per atoll. Given that access to sufficient coconuts is no barrier, the risk is not in the availability of the resource but the collection and processing of it. This is covered under labour needs on page five of this report.

Local capacity

Tokelau has only a single properly qualified power station manager and engineer, thus training and capacity building will certainly be required to ensure the future safe and reliable long term operation of the current power systems as well as future power systems based on PV/CNO. Technical training in New Zealand would be advantageous for at least one, and preferably two electrical staff for each atoll, and possibly backed up with regular scheduled maintenance visits by an external expert until sufficient capacity is developed on the atolls. Candidates could be bonded to ensure that skills acquired do not immediately leak. This has proven to be a problem on other projects in the Pacific.

A strategy used on previous community electrification projects has been to require all trainees to attend the installation and commissioning at the other atolls, and thus gain greater experience and exposure to the technologies used, and also familiarity with the practices and processes used on other atolls.

Financial findings

Present situation

Electricity is regarded as a public service and is subsidised by Taupulega on each atoll. Tariffs do not cover the true costs of generation and significant debts are accrued by each Taupulega in order to keep the systems operational. According to preliminary information received, the operational costs of the system covering fuel, labour and spare parts amount to approximately NZ$220,000 per annum per atoll. Revenues collected on Fakaofo however were only around NZ$70,000.

Fuel consumption

Fuel consumption figures were obtained from the MV Tokelau which keeps accurate records for fuel deliveries made to each atoll. Based on this data, Fakaofo uses an average of 260 litres per day, Nukunonu an average of 210 litres and Atafu 276 litres per day. Out of these amounts must be subtracted the consumption of the diesel trucks however this is not expected to be significant at perhaps 10 litres per day maximum. Outboard motor fuel is excluded from these figures and only diesel consumption is covered here. These figures assume that the stocks of fuel held at the start of the monitoring period were the same as the stocks held at the end of the monitoring period, and hence should be taken as indicative only.

Tariff study

Tariffs are set by Taupulega on each atoll. Nukunonu set the tariff at 30 cents per kWhr while Fakaofo and Atafu set theirs at 50 cents. Interestingly the lower tariff does not show higher rates of consumption as Nukunonu has the lowest rate of consumption of all the three atolls.

Tariffs are not staggered and there is no ‘break-point’ at which tariff rates increase. A split tariff is considered however for future luxury items, should these ever be introduced, such as airconditioners.

Collected revenues are consistently lower than the amount of power sold as Taupulega rarely take action against defaulters (except in the case of telephone use where disconnections are performed for non payers, perhaps due to the billing and account oversight of external agencies such as the telecom provider).

Public offices such as the school, offices and hospital are large consumers, operate with low awareness of energy efficiency practices and perhaps also do not pay their power bills as an internal accounting transfer process within each Taupulega’s set of accounts.

Exact financial records for the power utility are not easy to locate, as there is no central point of storage for the expenses and revenues for all three atolls, and some costs (such as fuel) are held by other entities such as the three stores. Thus a simple printout of revenues and expenses is not readily available.

General comments from the community indicated that non payment of power bills is common, however some households default on payments for a period, and then catch up in one larger payment when additional funds become available from remittances or other income. It was commented by several people that the majority of households owe between NZ$1,500 to NZ$2,000 in unpaid power bills and this correlates with other comments that each of the three Taupulega holds around NZ$200,000 in debts from unpaid power bills. Willingness to pay as evidenced in the household surveys averages is low; an average bill is NZ$76, and respondents state on average that they consider NZ$29 a reasonable bill for their household. However, ownership of luxury consumer durables is widespread, and most have savings.

Further comments indicated that because Taupulega are so closely entwined with the communities that they live in enforce payments of bills for electricity becomes very difficult. This is reinforced by the prevailing attitude that electricity is a public service. However this contrasts with the situation for telephone services, where houses are disconnected for failure to pay their bills. No instances of disconnection were noted during the household interviews conducted. Also, no households counted the debt to the Taupulega for power as existing debt when answering this question.

Thus the financial aspects of the power operations on each atoll are not healthy from a strictly financial perspective. Costs are high, revenues are low and each of the atolls is in significant debt from the operation of its power system. This aspect will need to be tackled in the main feasibility report as donors may wish to see tighter financial control applied to the management of the significant asset investment planned for this project.

Recommendations preliminary would include:

- Hold discussions with Taupulega to better understand the need for household billing to be stricter. Perhaps an off atoll control point could be considered to remove the need for Taupulega to make unpopular local decisions, or the use of pre-paid meters considered for long term defaulters, with the costs of the meters recovered from the consumers over time through a higher tariff. Consumers should be required to replace their own meter in event of damage, however thus far all current meters appear to be in good condition and not tampered.
- An asset management plan is needed for each atoll to plan for depreciation and maintenance as well as develop forward plans for the various planned expansions such as the hospital and schools at each atoll.

Preliminary assessment of costs

A preliminary budget estimate of NZ$6.5 million is estimated to construct the hybrid/coconut power systems on the three atolls. This figure requires considerable study and refinement however for the purposes of a ballpark estimate this figure may be used.

This estimate contains very preliminary estimates of costs and ignores any possible benefits that may result from a reduction in loads from energy efficiency training, awareness raising or investment in better quality appliances. Thus it defaults to the high side. The feasibility report following will provide greater detail and breakdown.

Annex A Trip Diary

Sept 7th	Arrive in Samoa. Inception meeting with UNDP Samoa and General Manager, Department of Energy, Government of Tokelau
Sept 9th	Departed Apia on MV Lady Naomi
Sept 10th	Arrived Fakaofo in early evening
Sept 11th to Sept 20th	Interview households, visited power house and installed datalogger system, meet with Taupulega and key informants
Sept 21st	MV Tokelau to Nukunonu
Sept 22nd	Install datalogger at powerhouse. Inspect new power station site, visit hospital
Sept 23rd	Review Fakaofo data, discuss fuel consumption and power revenue data
Sept 24th	Meeting with Taupulega, Interview households and move to Atafu
Sept 25th	Install datalogger, review powerhouse records
Sept 26th	Meeting with Taupulega. Discuss power revenue records and fuel consumption
Sept 27th	meet with teacher and doctor, inspect school and hospital, undertake household surveys
Sept 28th	Move to Nukunonu
Sept 29th	Move to Fakaofo and on to Apia
Sept 30th	Arrive in Apia. De-briefing meeting with UNDP Samoa

Annex B Brief information paper provided to Taupulega

Tokelau Copra Oil / Solar PV project

1. **This information paper is to advise the council of a study that is underway under the guidance of the Department of Energy, and to discuss any issues that may arise resulting from the study. No formal approval is being sought from the council at this stage, it is only to advise and discuss the study in general.**

2. **The Terms of Reference for the study are to:**

    a. Study the overall power system and ascertain what is required for a successful project

    b. Technical. Undertake a design exercise to scope out the technical design parameters necessary to achieve the 90% solar PV and 10% coconut oil design.

    c. Financial. On the basis of the design mapped out above, assess an expected construction cost and prepare a financial viability plan and proposed model for funding the project.

    d. Report on the project activities and results.

3. **Next Steps**

The study will prepare a detailed feasibility report for proceeding with the implementation of a solar PV and coconut oil project. The report will form the basis of discussions with potential donors or funders of the project.

4. **Financial implications**

The study will detail the expected financial implications of the project, however given that it will result in the elimination of the need to purchase diesel for power generation, this financial burden will be removed from Taupulega. The terms of financing, if any, may introduce some new financial demands however these will be known and predictable, as compared to the unknown and unpredictable costs of imported diesel.

5. **Recommendations**

    a. Council to recognize this paper

    b. Recommend energy efficiency study

    c. Recommend a wind resources study

    d. Recommend council support moves to reduce dependency on diesel

6. Introduction

Diesel oil is rising in cost and uses a significant part of Tokelau's annual budget. Each atoll uses around 200 litres of fuel per day, or 600 litres in total, at a cost to Tokelau of around $800 per day. To date this has been managed out of the annual budget for each atoll, but oil costs globally are rising, and in future this cost may eventually become unmanageable. Currently the Tokelau Government protects the people from these high costs by subsidizing the price of electricity, but in the long term this will not be able to be continued. A new mechanism is required.

To reduce Tokelau's exposure to this variable and uncontrollable international fuel cost, Tokelau has wisely adopted a policy of 100% renewable energy resource utilisation. However, making a policy is only the first step. Making it happen is the next.

This current project is intended to assess the viability of reducing diesel consumption to zero, and installing a solar and coconut oil power system. Donor support would be sought to construct the three systems, estimated to cost up to $1.5 million per atoll.

Key advantages to Tokelau would include:

- Independence from international energy prices
- Perhaps the first nation in the world to be fully renewable energy based for electricity
- Ability to withstand external shocks such as biosecurity scares closing down borders etc
- Reduced expenditure of Taupulega budget on fuel, freeing up funds for use on other priorities such as housing, health and education.

Resources.

Tokelau has several renewable energy resources that can be harnessed. Primarily these are the sun, the wind and the ocean. For practical terms of complexity and cost, ocean based technologies are not considered in this study as they are essentially unproven at this point in time. Sun and wind however are proven and viable. Using a power system that does not use diesel oil does not mean any real changes for the consumer. Power is delivered and consumed by each user in the same way it is now. Education in the advantages in energy efficiency is also highly recommended. A financial mechanism to assist families to avoid purchasing low cost but inefficient domestic appliances, particularly freezers and refrigerators, is also recommended to accompany the education process.

Solar technology.

Solar PV systems, such as utilised by Teletok, are proven and workable. Energy from the sun is converted to electricity and provided for household consumption as per normal, or stored into large scale batteries for use over night. The plan for Tokelau is to provide 90% of the energy demanded for each atoll through solar technology. A large solar array is expected to be built on open land, or preferably onto the roof of the powerhouse. It is a good idea to keep the solar system in one place to ensure that safety and security is maintained, and to keep the general public safe.

But solar power will struggle to meet the energy needs of each atoll alone. Something else is also required to help meet high demand times in the morning and evening. One answer is to use coconut oil.

Coconut oil

The coconut is essentially stored solar energy, as the sun's energy goes into the plant. Copra is about 60% oil and around ten coconuts will produce 1 litre of coconut oil. In a warm climate like Tokelau, coconut oil can be used as a direct substitute for diesel. Some designs of diesel engines are better suited to burning coconut oil than others. Having said that, the very original diesel engines were designed to run on peanut oil, so this concept is not new at all.

Using coconut oil, the generators can start and operate whenever the weather is too cloudy for the solar array to run normally, or during the morning and evening times when the demand for electricity is high. If 90% of the electricity each day is provided by the solar system, then only 10% would need to be provided by the coconut oil. Since around 200 litres of coconut oil is used per day now this would equate to around 20 litres of coconut oil per day, or around 200 coconuts.

Labour needs

Labour is required to collect and process these nuts, and could be done on a weekly or monthly basis, and paid for out of the 100% reduction in diesel fuel purchases. Each Taupulega would be required to allocate labour resources to collect and process the nuts into oil. Equipment would be required to help process the raw coconuts into copra, and then dry and extract the oil ready for use.

Wind Resources

Tokelau may have useable wind resources, but these are not clear at this time. Some data is available on Tuvalu that indicates that a viable wind resource may exist. If this is the same for Tokelau then a hybrid system including solar / coconut oil and wind power may be preferable. More research into the wind resources is required, and ideally a proper 40m tall wind monitoring tower installed at each atoll to verify the actual wind resources.

The advantage of wind turbines would be that power may be able to be generated 24 hours a day and help reduce the need to store solar power overnight. Thus depending on the resource, the battery bank and amount of solar PV installed may both be reduced.

Cyclones are of course a concern for using wind turbines in the Pacific however designs are available that are either able to withstand very high wind speeds (up to 215 km per hr), or can be lowered to the ground in advance, or both. Both may be options for Tokelau but the research and data gathering needs to be done.

Energy Efficiency

It is strongly recommended that an energy efficiency audit is conducted prior to investing in the solar/coconut oil project. Considerable energy wastage appears to be occurring on all three atolls, resulting from poor consumer education and understanding of low quality appliances, particularly freezers, and leaving appliances running over night, such as fans, lights and computers. This wastes a lot of Taupulega money. It is recommended that a consumer education program be developed and undertaken, possibly in conjunction with a program to assist households with the purchase of better efficiency fridges and freezers that cost more to buy but cost much less to run. Other energy efficiency measures relate primarily to education, such as turning off appliances when not in use.

Technology

The technology may look similar to this equipment, used in the Marshall Islands to extract copra oil and operate a standard Chinese made 30 kW genset without modifications.

Copra is chopped into small pieces, heated in a drum heater, then the oil is pressed out

The raw copra oil is then filtered and used in a standard 30 kW generatorCopra oil can even be used in crude but workable diesel outboard motors