Consultancy Services to Develop a Renewable Energy-based Off-grid Electrification Master Plan for Remote Islands of Vanuatu along the Example of Four Islands

(Project Number 81195891; GIZ Contract number: 13.9022.8-001.00)

Report 3: Renewable Energy Resources and Prioritized Renewable Energy Projects and Technologies for the Islands of Emae, Makira, Mataso and Aneityum

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Map of Vanuatu showing air transport links
Source: Vanuatu Agricultural Census, 2007

Acronyms and Abbreviations

A$	Australian dollars
ACP	African Caribbean and Pacific countries associated with the EU
CIF	Climate Investment Funds
CME	coco-methyl ester
CNO	Coconut oil
DoE	Department of Energy, Vanuatu
ESMAP	Energy Sector Management Assistance programme
EU	European Union
FAO	Food and Agriculture Organization
FDoE	Department of Energy, Fiji
GGGI	Global Green Growth Institute
GoV	Government of Vanuatu
IRENA	International Renewable Energy Agency
IUCN	International Union for Conservation of Nature
JICA	Japan International Cooperation Agency
KSEC	Kiribati Solar Energy Corporation
kW	Kilowatt (1,000 watts)
LED	Light Emitting Diode
NAMA	Nationally-Appropriate Mitigation Actions
NERM	National Energy Roadmap (original for 2013-2020; update for 2016-2030)
NZ	New Zealand
O&M	Operations and maintenance
PEEP2	Promoting Energy Efficiency in the Pacific (phase 2)
PIC	Pacific Island Country
PREFACE	Pacific Rural/Renewable Energy France & Australia Common Endeavour
PV	Photovoltaic(s)
RE	Renewable Energy
RESCO	Renewable Energy Service Company
RMI	Republic of the Marshall Islands
SHS	Solar Home System(s)
SOPAC	Pacific Islands Applied Geoscience Commission (now a division of SPC)
SPC	Secretariat of the Pacific Community
SPREP	Secretariat of the Pacific Regional Environment Programme
TOISEP	Tonga's Outer Island Solar Electrification Programme
TRR	Telecommunications and Radiocommunications Regulator
UNELCO	Union Electrique du Vanuatu Limited
UNIDO	United Nations Industrial Development Organization
US$	United States dollar
VARTC	Vanuatu Agriculture Research and Technical Centre
Vatu or vt	Vanuatu currency
VNSO	Vanuatu National Statistics Office
VREP	Vanuatu Rural Electrification Project
VUI	Vanuatu Utilities and Industries Ltd
W_p, kW_p	Peak watts; peak kilowatts (PV capacity)

Note on currency in May 2016: US$ 1.00 = about 105 vatu
€ 1.00 = about 122 vatu

1. Introduction

This report has been prepared for the Government of Vanuatu and the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH under "Consultancy Services to Develop a Renewable Energy-based Off-grid Electrification Master Plan for Remote Islands of Vanuatu along the Example of Four Islands" (GIZ project 81195891 of 2016). It is the third of the following series of reports being prepared for this project:

1	Inception Report	Completed 8 April 2016
2	Site Visits and Survey Report	Completed 12 June 2016
3	Renewable Energy Resources and Prioritized Renewable Energy Projects and Technologies for the Islands of Emae, Makira, Mataso and Aneityum	This report
4	Preliminary Technical Design of Potential Renewable Energy Projects for the Selected Islands	To be completed: mid-June
5	Financing Requirements & Mechanisms and Recommended Institutional Models	To be completed: mid-June
6	Renewable Energy Electrification Master Plan	Draft: by mid-June 2016 Final: by 30 June 2016

This report covers items 4.7-4.9 of the Scope of Work: a) an assessment of renewable energy resources and applicable technologies for the islands; b) determination of viable and least cost options which should be pursued and how they fit different business models and funding options with pros and cons; and c) an analysis of promising renewable energy options considering advantages and disadvantages, prioritized according to the guiding principles of Vanuatu's National Energy Road Map (NERM), including access and affordability targets.

2. Renewable Energy Resources for Vanuatu and the Selected Islands

2.1 Vanuatu's Renewable Energy Resources

There are very limited data on renewable energy resources overall for Vanuatu. Most data for rural areas are not detailed and have been averaged over a sizeable geographical area (e.g. satellite data for solar energy are typically averaged over an area one degree in longitude east to west and one degree of latitude north to south**,** an area that encompasses hundreds of square kilometers of surface that, in Vanuatu, often includes large components of both land an ocean surface). The data are broadly indicative of the resource and can be a reasonable basis for estimating the approximate energy available for projects. Even when long term, high quality data are available, the variability of most renewable energy resources is substantial and must be considered in the design process. Available data for renewable energy resources for Vanuatu overall are summarized below, followed by available data for the four selected islands.

Solar

The International Renewable Energy Agency (IRENA) is publishing a Global Atlas for Renewable Energy which includes broad, indicative data for horizontal solar insolation for Vanuatu based largely on the US National Aeronautics and Space Administration (NASA) satellite data that has been gathered over the past thirty years. IRENA's solar energy map for Vanuatu is shown in Figure 2.1 at the right. For a specific site, the useable solar energy depends on many variables such as cloud cover, shade patterns at the site and the geometry of the receiving surface. While there are predictable diurnal and seasonal variations, they are overlaid with largely unpredictable variations due to clouds, pollution, shade from new buildings and growing vegetation. However the data clearly show that Vanuatu generally has a good solar energy resource for all islands.

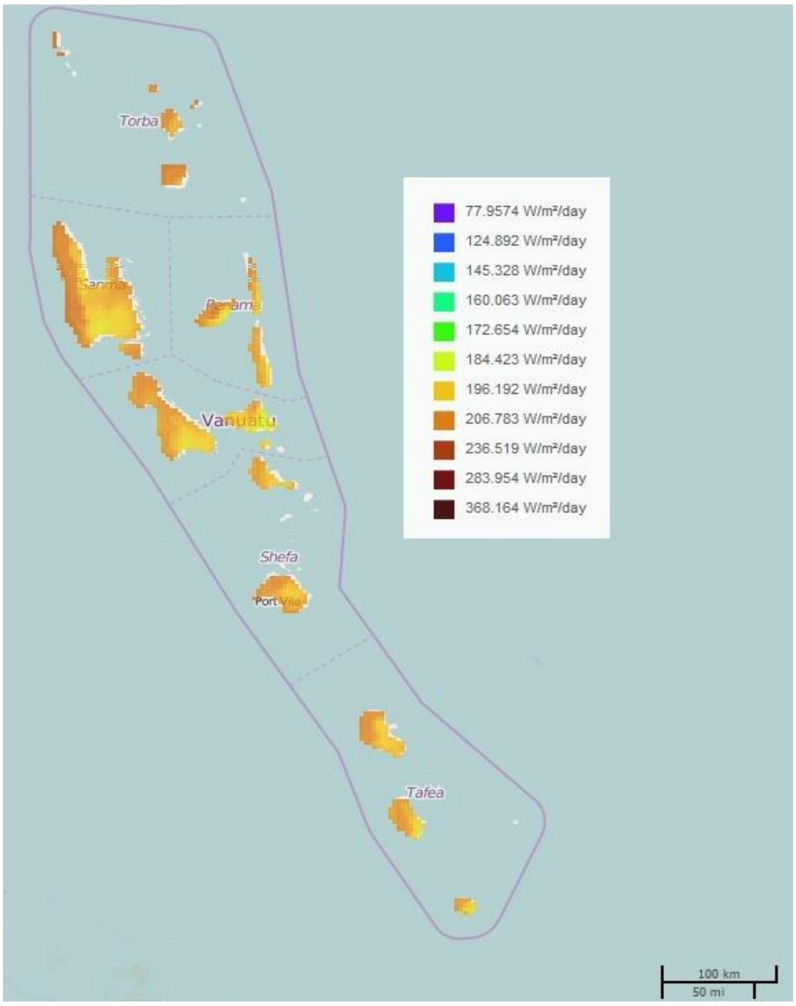

Figure 2.1: Indicative Solar Insolation for Vanuatu
Source: IRENA Global Atlas for Renewable Energy; http://irena.masdar.ac.ae/#

Vanuatu's Meteorological Services has collected solar insolation data at several sites for many years using high-quality pyranometers. However, the data is too limited in scope to do detailed designs for solar applications in most remote areas of the country, although it is useful for assessing the relevance of available satellite data at the specific sites measured and in general validates the use of satellite data as a reasonable design tool.

Wind

IRENA has also produced an indicative wind energy map for Vanuatu (Figure 2.2) which suggests that the resource is broadly favorable with average wind speeds of about 6 m/s in many locations. However, average speeds are not useful for project development and wind energy is very site specific. Since the available energy varies as the cube of wind speed, a 20% reduction in actual wind speed results in a 73% reduction in potential wind energy. The broad IRENA maps do suggest locations where detailed resource assessments might be warranted should energy development in those locations be proposed.

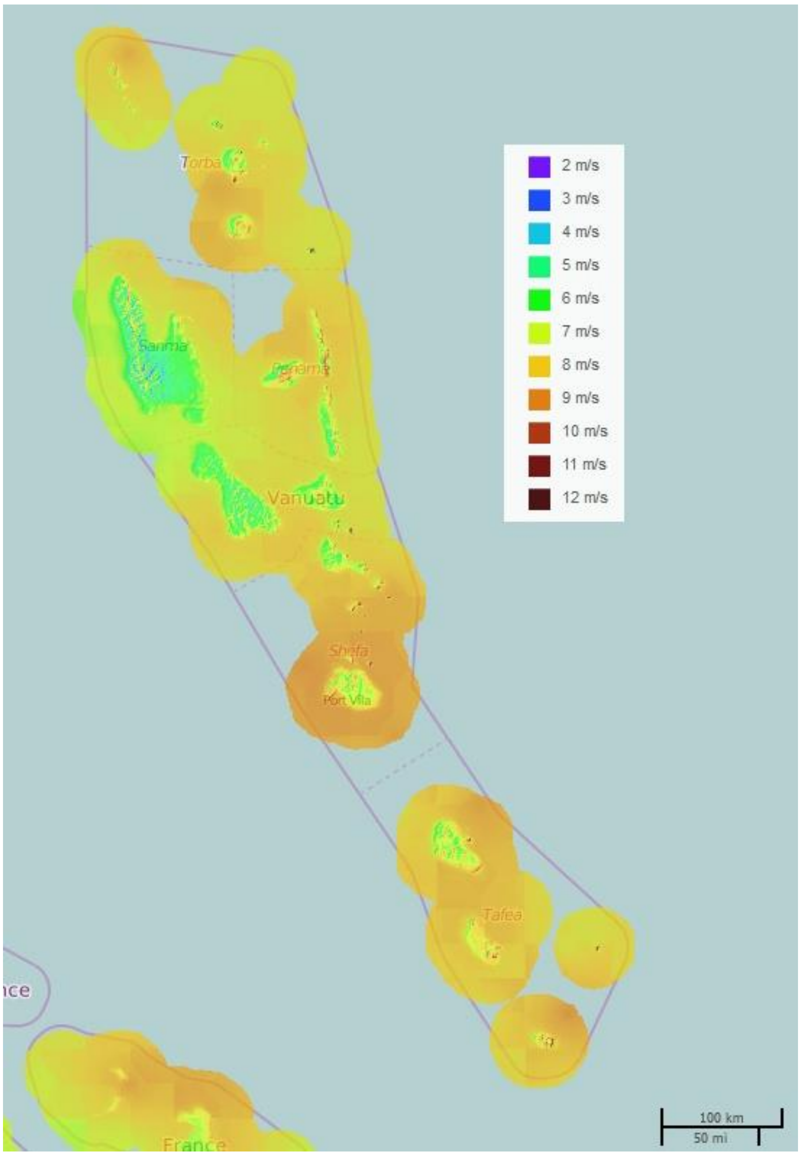

Figure 2.2: Indicative Wind Energy for Vanuatu
Source: IRENA Global Atlas for Renewable Energy

An earlier study (World Bank, 2009) suggests caution in using broad wind maps. Using various modelling techniques, and considering exposure, roughness of terrain and other factors, it concluded that "most low-lying coastal areas of Vanuatu have wind speeds ranging between 4.0 and 5.5 m/s [which is not particularly favorable]. Larger islands with especially good resources include Vanua Lava, Santa Maria, Maewo, Tann and Aneityum (Anatom). Higher wind speeds in these areas can be partially attributed to their proximity to the prevailing southeastern flow." The study stressed that the mean wind speed at any location may depart substantially from predicted values, especially where elevation, exposure, or surface roughness (such as tree cover) differ from assumed values. Mean speeds can be affected by surface roughness up to several kilometers away. The effect of a nearby stand of trees, a large outcropping of rock or even a building extends to twice the height of the obstacle and downwind for 10-20 times the obstacle height. This effect varies according to the direction of the wind – which tends to change seasonally – and explains why the available wind energy is so site specific and must be measured for a year or more close to the location where a wind system is proposed. A major result of this effect is that in areas with heavy vegetation cover – much of rural Vanuatu – wind turbines need to be on tall towers with turbine heights in excess of 50 meters, which tends to be practical only for the relatively large turbines that are used in high capacity wind farms such as at Devil's Point in Efate.

The Department of Energy (DoE) has installed wind-monitoring towers in each of Vanuatu's six provinces (at Vanua Lava, Pentecost, Santo, Malekula, Tongoa and Tanna) as shown in Figure 2.3. This was supported by the Secretariat of the Pacific Regional Environment Programme (SPREP) and the International Union for Conservation of Nature (IUCN) Oceania.

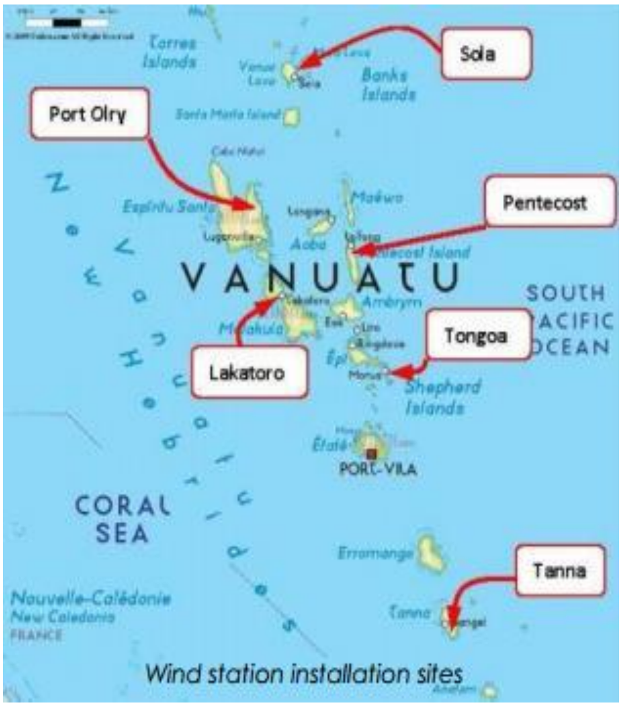

Figure 2.3: Wind Monitoring Stations in Vanuatu
https://www.sprep.org/piggarep-success-stories/

Recording began in March 2012 with data collection over 24 months (or more) completed by the end of 2014. The objective was to produce a wind atlas for Vanuatu and identify favorable sites for wind energy development (SPREP, 2013). Staff from Vanuatu and other Pacific Island Countries (PICs) had earlier been trained in the analysis of wind data (SPREP, 2010) using WAsP and WindPRO software. Unfortunately, the atlas was never completed, apparently due to financial constraints, and no reports of results are available.

Coconut-based Biofuel

Coconuts can be an excellent resource for producing biofuel and a potential source of rural employment and income. Information on land area under coconuts, and coconut production, in Vanuatu is outdated and available data are generally limited to provinces, not specific islands. About 75% of Vanuatu's total land area is covered in natural vegetation including lush forests, grassland and secondary growth, much of which is land unsuited to commercial coconut production. Many areas are deeply dissected by gullies and are virtually impenetrable. The most recent agricultural census (GoV, 2007), completed nearly nine years ago, indicated that under 10% of land area was under coconut trees.[1] There were 9.7 million trees (8.8 million bearing nuts) of which 2% were under 5 years, 22% were 5-19 years, 58% 20-49 years, and 18% 50 years and over. Copra was a key cash crop in Sanma, Penama, Malampa and Shefa provinces with 44% of all families selling some copra in the 12 months

[1] There were 119,384 hectares (1,194 km^2) of coconut trees and 12,190 km^2 of land area or 9.8% coconut coverage.

preceding the census. However in Shefa (which includes three of the four selected islands for this project) only 13% of all households produced copra and in Tafea (which includes the fourth selected island, Aneityum) the percentage was insignificant. 86% of copra sales were from Sanma and Malampa, with Shefa contributing only 4.4%. There is some limited data in the 2009 national census (GoV VNSO, 2011) which reported that 64% of rural ni-Vanuatu households were involved in copra production for cash, with Shefa the lowest at 23%. Although copra is a significant cash crop in much of Vanuatu, available data do not provide information on the amount of copra produced by island, the total resource which might be available for conversion to fuel, the resource which can be economically harvested, or the relative value of coconuts for fuel and for other purposes.

The value of coconut oil as an export crop is quite volatile, with the resource available locally for energy varying according to the export value of copra and oil, the import cost of petroleum products, and the cost of petroleum fuel at the proposed biofuel site. According to the Vanuatu National Statistics Office (VNSO homepage; http://www.vnso.gov.vu/, accessed 19 April 2016), in the fourth quarter of 2015, coconut oil exports dropped by 47% in quantity and 75% in value due to a 53% fall in the average coconut oil export price and the effects of category 5 Cyclone Pam earlier in the year. Coconut oil accounted for 12% of total domestic export value in the December quarter of 2015 and copra 8%. The amount of copra and coconut oil available for domestic fuel use depends in part on its fluctuating value relative to diesel fuel. As shown in Figure 2.4, coconut oil has been increasingly more valuable as an export commodity than as a diesel replacement in the past four years so the quantity that can be considered as a likely energy resource has declined.

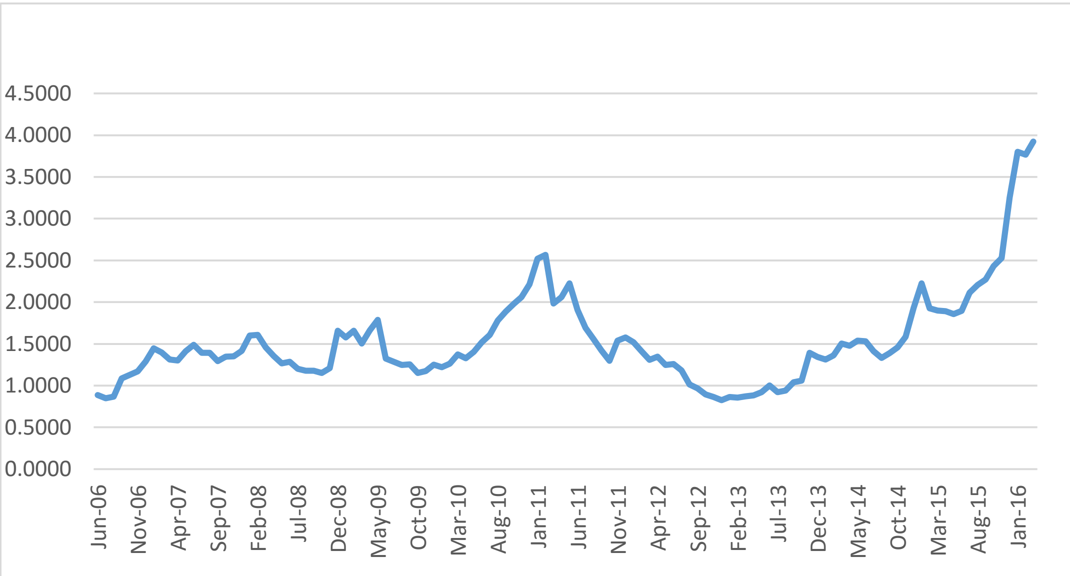

Figure 2.4: Ratio of coconut oil price to diesel fuel (US$/tonne)
Calculated from data in http://www.indexmundi.com/commodities/?commodity=coconut-oil&months=120&commodity=diesel&indicator=price-ratio

In Fiji, Department of Energy staff are concerned about reliance on a single resource (i.e. coconuts) for biofuel. Category 5+ Cyclone Winston in February 2016 destroyed 90% of the coconut trees in two of Fiji's nine islands with coconut-based biofuel systems and the DoE is currently reassessing the national biofuel program (discussed under Biofuel in Section 3.3) in part considering the expectation of further severe cyclones in the future.[2]

[2] Discussions with Fiji Department of Energy staff in Suva, Fiji (29 April 2016).

Small Hydro

Vanuatu has considerable technical potential for hydropower, but its porous geological structure makes it unsuitable for dam empounded storage ponds leaving the more seasonal run-of-the river type installations as the main option. Useable hydropower resources have been identified on many islands including Vanua Lava, Santo, Maewo, Malekula, Epi and Tanna. Although some resources have been identified, only a few sites have been assessed and only a few hydropower systems have been developed, the most significant and largest being the 1.2 MW Sarakata installation on Espiritu Santo. Studies suggest a technical potential on Efate (e.g. 1.2 MW at Teouma) but with prohibitively high development costs. The European Union has investigated micro-hydro potential for 13 sites on 6 islands with about 1,500 kW total of available power. Four sites are promising: Lowanau in Tanna, Mbe Tapren in Vanua Lava, Waterfall in Pentecost and Anivo in South Santo (UNIDO, 2013). The World Bank's Energy Sector Management Assistance Program (ESMAP, 2015) has agreed to support further investigation of sites with the potential to provide 100 kW to 5 MW of generation capacity and plan to visit at least twenty promising sites. ESMAP consultants will develop resource maps: "(i) to contribute to a detailed comprehensive assessment and to a geospatial planning framework for small hydro resources in Vanuatu; (ii) to verify the potential for the most promising sites; (iii) to prioritize sites and to facilitate development of new small hydropower projects and ideally to guide private investments into the sector; and (iv) to increase the awareness and knowledge of the Government of Vanuatu on renewable energy potential."

Small run-of-river systems may be economically attractive in several locations in Vanuatu, and one has been constructed on Maewo island, but costs are very site-specific and these systems are extremely vulnerable to damage or destruction during periods of very high water flow during cyclone passages (which can exceed a thousand times typical flows). Before the energy potential of a site, and the potential for flood damage, can be accurately determined, the resource must be measured for at least several years.

Biomass

According to the International Renewable Energy Agency (IRENA, 2015), around 43,600 toe of fuel wood is burned each year in Vanuatu for cooking and crop drying, although some estimates suggest as much as 67,000 toe[3] or roughly 160,000 tonnes of wood (at 5% moisture content). IRENA concludes that there is no evidence that this level of wood use is detrimental to Vanuatu's forests. Deforestation in Vanuatu appears to be tied mainly to agricultural expansion and logging. Although annual saw log yields in Vanuatu are currently around 10,000 cubic metres (m^3), the sustainable harvest level has been estimated by IRENA as 38,000-60,000 m^3 per year or higher, with the Forestry Department (GoV, 2013) estimating a higher sustainable cut of 68,000 m^3, roughly 48,000 tonnes,[4] which comes from the 20% of the land which is under accessible commercial forests such as the 800 ha of Caribbean Pine

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[3] A Global Green Growth Institute (GGGI, 2016) draft internal working paper which incorporates data from Vanuatu's 2013 urban household energy and appliance survey (PEEP2, 2014) and census data 67,000 toe of which 48 ktoe was for cooking and 19 ktoe for copra and cocoa drying, mostly copra.

[4] Tropical wood density is typically 0.5-0.8 t/m^3 (from Wood Density Variations of Tropical Wood Species; https://www.researchgate.net/publication/265533169_Wood_Density_Variations_of_Tropical_Wood_Species_Implications_to_the_Physical_Properties_of_Sawdust_as_Substrate_for_Mushroom_Cultivation). Assuming an average of 0.7 t/m^3, 68,000 m^3 is roughly 47,600 tonnes.

on Aneityum. It is possible, therefore, that substantial forest production waste could be used as feedstock for energy production in the future as forest plantations expand, mature and are harvested. This could be used for electricity generation both for powering the forest products facilities and providing electricity to nearby villages. The sustainable resource is only an estimate as there has not been a national forest sector study since 2000 (FAO, 2001), and this contains no disaggregated data by island. According to the Vanuatu Forestry Department, a key issue is land disputes in forest areas or areas with potential for development, which continue to hamper forest development. Disputes about ownership of land and forest resources disrupt forestry operations, cause financial losses for forestry investors and limit the establishment of development projects.

Geothermal

The geothermal resource potential of Vanuatu is moderate to high. A moderate level of geoscientific investigations have been undertaken by New Zealand (NZ govt, 2011), which concludes that geothermal power warrants further consideration. As shown in Figure 2.5, there are geothermal areas from the Banks islands in the north to Tanna in the south, with some potential near Emae. However, Efate is likely to be the only island in Vanuatu with a sufficiently large population to support geothermal power generation, and this is being actively considered with test drilling planned (though currently on hold). Geothermal energy is not considered further in this report as it is very expensive to develop and is unsuitable for small communities in remote islands.

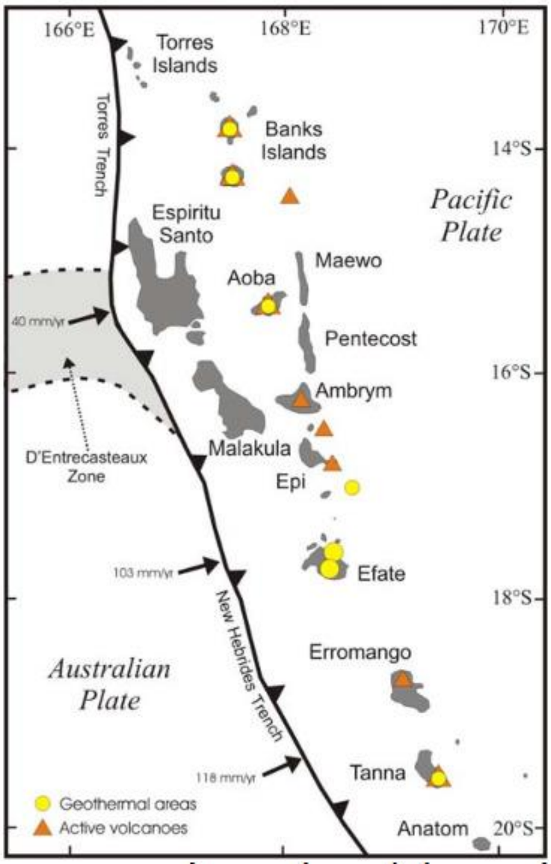

Figure 2.5: Vanuatu's Geothermal Energy Potential
Source: Geothermal Resources in the Pacific Islands, 2011

Other Renewable Energy Resources

There have been studies carried out some years ago (SPREP, 2005) by the SOPAC division of SPC of Vanuatu's seawave and ocean thermal energy (OTEC) potential. In the early 1990s, Oceanor of Norway monitored Vanuatu's sea wave potential. Data from buoys suggested an average of 14.4 kW per meter of wave front off Efate. Satellite data suggested 9-20 kW/m at various sites, although power output is not necessarily proportional to energy per meter. A more recent study (SPC, 2015), which indicates that sites with 7 kW/m or more may be technically feasible, measured about 11 kW/m for parts of Efate and 9 kW/m for Tanna. The study suggests that wave energy conversion could potentially be cost-effective, in at least some PICs, although not at a scale suitable for remote island electrification. Even if technically feasible, protecting the generation facilities from the ravages of cyclones could be a major problem.

There have apparently been no measurements of deep sea versus surface ocean temperatures to enable estimates of near-shore Ocean Thermal Energy Conversion (OTEC) potential. The ocean energy resource may be substantial but wave energy systems are still non-commercial. OTEC is many years away from commercial availability, is extremely high-tech, and, if ever developed, will be on a scale far beyond the demands of Vanuatu's remote islands. Neither is considered further in this report.

General comment on Vanuatu's Renewable Energy Resources

In general, the renewable energy resources suitable for small-scale rural electrification in Vanuatu are only broadly known. In the few locations where equipment has been installed to quantify the resource at specific sites, the measuring devices may not have always been properly calibrated or maintained (solar and wind energy), data based in part on aerial photographs are outdated (biomass), or detailed data collected over several years or more have not been well evaluated, resulting in a considerable amount of raw or semi-processed information (wind, hydro) that is insufficient for design purposes. Nonetheless, the solar resource is generally well understood as variability by region is relatively low across the country and existing satellite data has been confirmed as adequate for design purposes. For biofuel, there are records of copra production by island (those where production is at least 20 tonnes per year), providing some basis for quantifying the potential resource, although the resource may be unavailable (owners do not wish to process it), economically inaccessible (steep lands or too distant) or too expensive, as the varying value of copra as a commodity over time can quickly affect the amount available in practice as an energy source.

As a component of any new remote island electrification programme, *it is recommended that*:

- The large amount of wind energy data that has already been collected be located, assembled at DoE, professionally analyzed, maintained in a database and a report be produced on Vanuatu's practical wind energy potential with locations and gaps in coverage clearly shown. If there are sufficient data, a preliminary wind atlas could be produced.
- All pyranometers currently in use be cleaned and recalibrated if instruments are five or more years old and historical and current data placed on line, to allow a more accurate evaluation of Vanuatu's solar energy resource.

2.2 Renewable Energy Resources for the Four Selected Islands

The limited energy resource data available for Aneityum, Emae, Mataso and Makira are summarized below.

Aneityum

As shown in Figure 2.6 on the next page, Aneityum's population is scattered among a number of communities along the south and north coasts. The population resides in widely scattered communities along the north and south coasts without any road network to connect them, so any practical RE resource must be located close to those population centers.

- **Solar**. There are no solar insolation measurements for Aneityum but locations which are not shaded between about 9am and 3pm have an excellent potential for solar energy development.
- **Wind**. There may have been wind energy measurements during the study phase of an EU-ACP Energy Facility funded project "The Answer is Blowing in the Wind – Improving access to energy

services for the communities of Futuna and Aneityum Islands." The project was managed by a non-governmental organization, VANREPA, and began about 2008 but was later cancelled. There are references in EU Monitoring Reports to high wind speeds and several technical and a socio-economic project survey in 2008 but no reports or data can be found from either EU sources or the DOE.

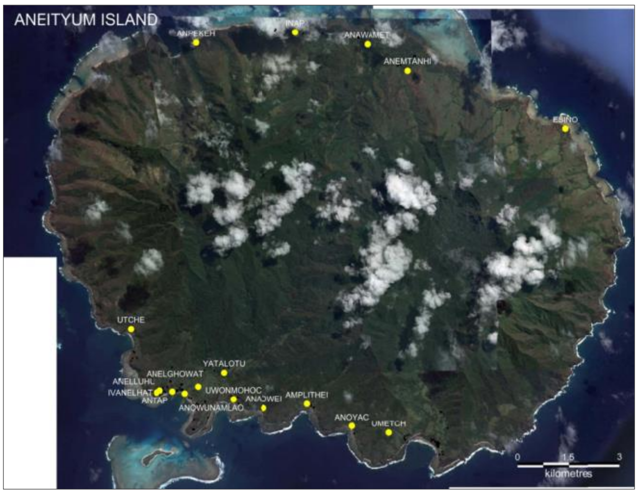

Figure 2.6: Map of Aneityum and Village Locations
Source: Google maps & VNSO

- **Biofuel**. There is a very limited coconut resource in Aneityum. Coconut cultivation in Vanuatu is generally confined to within twenty degrees of the equator, which puts the southern islands at the limit, and Aneityum slightly beyond. Some nuts have been sold for food in Tanna but there is no potential for coconut-based biofuel production on the island.
- **Biomass**. The Forestry Department (GoV, 2013) estimates an allowable sustainable cut of 2000 m^3 for Tanna and Aneityum combined, with Aneityum presumably accounting for considerably less than half of this. Aneityum "has only a small area of natural forest suitable for sustainable forest management. [It] has 800 ha of community-based pine plantation. [The] main focus [though 2023] will be community forestry and extension of plantation. [There are] future prospects for a small community sawmill, reforestation with high-value timber species and sandalwood plantations. [There is] little infrastructure, low population, a need for afforestation and special measures for erosion control." The potential for biomass-based electricity generation is very limited.
- **Hydropower**. As Figure 2.7 shows, there are numerous streams on Aneityum. However, the DOE reports that only two streams on the island have year-round flow which might be suitable for small-scale run-of-river hydro-power. One is near Anelghowat in the southwest which is believed to have the better technical characteristics, with a water drop reportedly over 60 meters. However the river (Figure 2.8), runs over flat land for some distance, with a suitable location for a power plant about 10-12 km (3 hours walk) from the community.

Figure 2.7: Streams on Aneityum
Source: Department of Energy files

Figure 2.8: Stream near Anelghowat, Aneityum
Photo: John Salong, April 2016

A second stream near Anawamet in the north may be easier to develop as the community has both customary and legal ownership of the river resource so land disputes, common in other communities, is not expected to be an issue. However, neither stream is located sufficiently close to a likely energy demand to allow economic power delivery from the site. There have been no assessments of flow (low, high, average) or of potential energy output for either source. The forthcoming World Bank ESMAP-funded assessment of the potential for small hydro (100 kW-5 MW) in Vanuatu is expected to begin during 2016. This does not currently include Aneityum, but the DOE says the island, and resources elsewhere below 100 kW, may be added to the list.

Emae, Makira and Mataso

Emae is the largest of the three islands of the Shepherd Group shown in Figure 2.9. The smaller island of Makira is to the southeast of Emae and Mataso is south of Makira. Village locations are shown in Figure 2.11.

Figure 2.9: Outline Map of Emae and the Shepherd Group

- **Solar**. There are no solar insolation measurements for these islands but locations that are not shaded by trees or hills have an excellent solar potential. Most of the island population of these islands are currently using small solar lanterns and/or larger solar lights successfully. Several permanent PV installations at school, government, and commercial facilities are also working satisfactorily.
- **Wind**. There is no information on the wind energy resource for these three islands, other than the broad national wind energy map.
- **Hydro**. None of the three islands have any rivers or streams. There is no hydro power opportunity.
- **Biomass**. The Forestry Department (GoV, 2013) provides no data on the biomass resource or sustainable annual yields for the three islands. The resource is quite small.
- **Biofuel**. Copra was the main source of cash income for the people of Emae Island for some years. However, the Department of Agriculture has not recorded copra production from the island since destruction of coconut trees from Cyclone Uma in 1985[5] and apparently there has been no significant planting since then, with 2016 production, according to the island chiefs, expected to be 15 tonnes or less.[6] Cyclone Pam in early 2015 seriously damaged the Shepherd Island's remaining coconut tree resource (GoV, 2015) with the main plantation on Emae (Sulua) damaged to such an extent that copra production and marketing is expected to be badly affected for another 7-8 years or more. There were some immature nuts seen on Makira and Emae but on

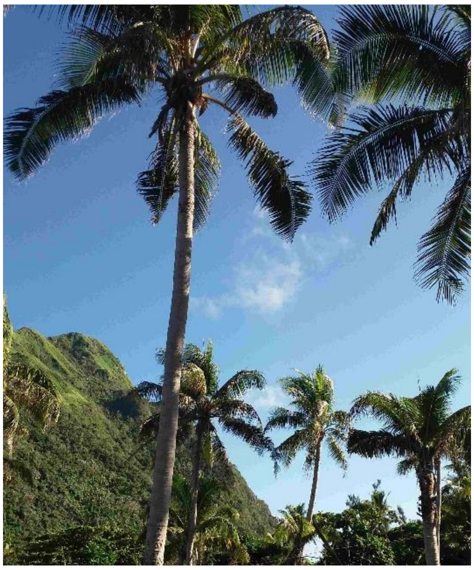

Figure 2:10
Coconut Trees, Mataso, with no nuts
Photo: John Salong, May 2016

[5] Source is Willy Iau, Principle Extension Officer, Shefa Province, Department of Agriculture (DOA). The DOA does not count any copra production from an island if it is under 20 tonnes per year

[6] Source is discussions with Emae Island chiefs on 20 May 2016. There was no copra production during the first half of 2016. Perhaps 5 tonnes might be produced in Q3 of 2016 and 10 tonnes in Q4.

Mataso (Figure 2.10) most trees had no nuts 14 months after the cyclone. The Cyclone Pam assessment team recommended that Emae and the nearby islands of Makira and Mataso be declared Disaster Zones. There appears to be little prospect for biofuel production in the next 7-10 years.

The practical renewable energy resource on these islands depends on the location and accessibility of the resource relative to centers of population. As shown in Figure 2.11, Emae has rough unpaved roads or walking paths (much damaged by Cyclone Pam) linking a number of small, dispersed communities. Makira and Mataso each have a single village and no roads.

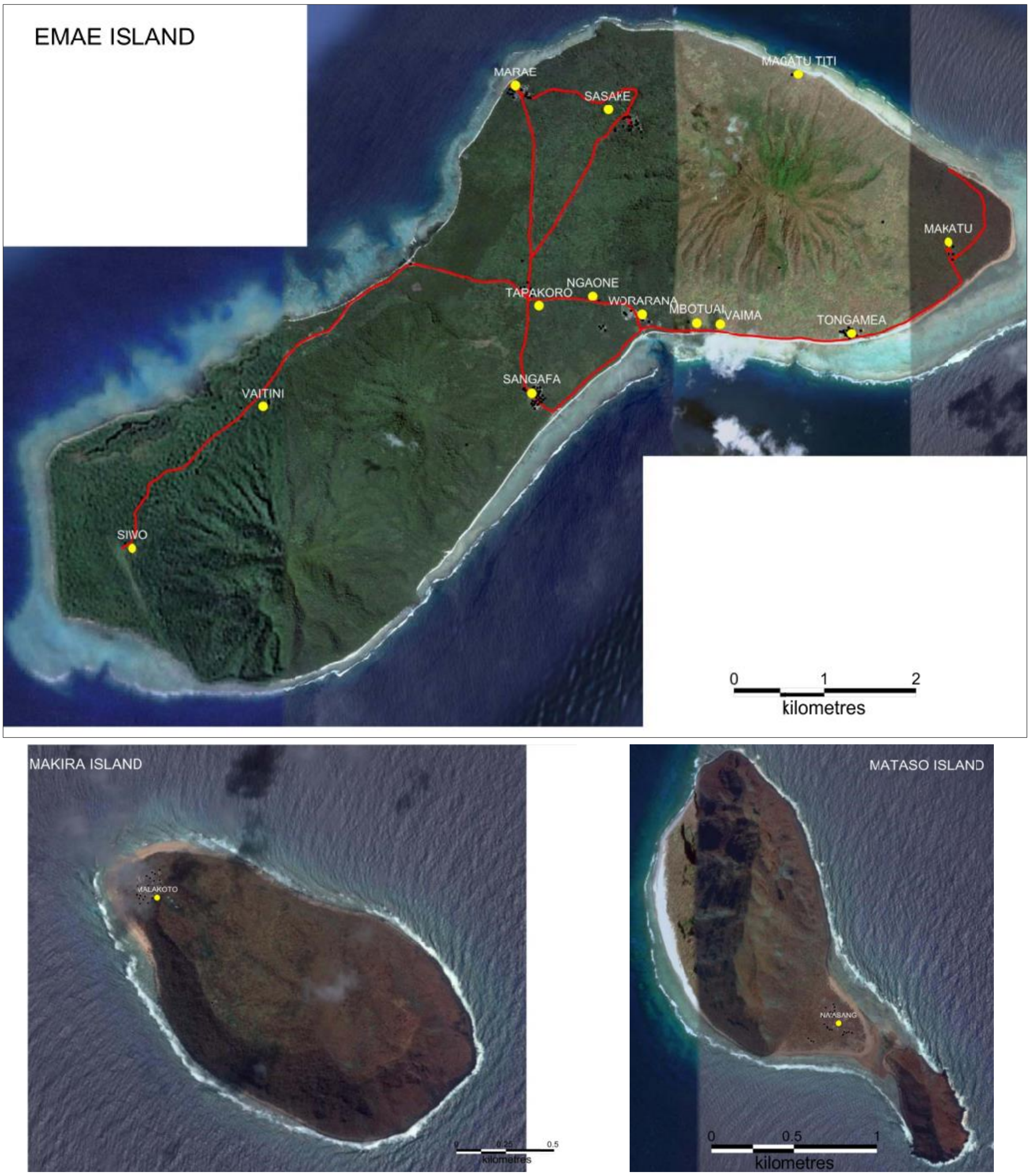

Figure 2.11: Emae, Makira & Mataso with Village Locations and Roads
Source: Google maps & VNSO

3. Applicable Renewable Energy Technologies for the Selected Islands

3.1 Applicable Rural Electrification Technologies for Rural Vanuatu

For rural Vanuatu in general, the potentially applicable renewable energy technologies at the village scale (roughly 10-50 kW) include coconut oil-based biofuel, solar photovoltaics (PV), hydropower, and possibly small wind turbines. The resource applicability will depend on the local resource actually available in practice, community size, housing density, the likely electricity demand, the initial capital cost, the operations and maintenance (O&M) costs and the ability of the community to pay for electricity services. Section 3.2 summarizes an earlier plan for rural electrification in Vanuatu, largely through small-scale renewable energy. Applicability of each technology is summarized in Table 3.1.

Table 3.1: Advantages and Disadvantages of RE Options for Small Remote Communities

Technology	Potential Advantages	Potential Disadvantages	Resource
Coconut oil biofuel (CNO)	• Similar to diesel so relatively simple to operate • Local employment & cash income • Continuous local supply of copra • Lower imports of diesel fuel • Relatively scalable • Reduced pollutants compared to diesel fuel	• Copra supply sensitive to price changes • More maintenance than diesel system • Requires skills in both oil production and electricity generation and distribution • Requires drying & milling infrastructure • Variable fuel quality depending on copra drying, milling, filtering • Restricted to communities where mini-grid is practical	• Widely available in Vanuatu, particularly in northern and central islands; less applicable in Torba Province
Solar PV	• Highly scalar/modular; suited to wide range of demand • Low maintenance • Suited to individual homes or buildings as well as mini-grids.	• Intermittent • Battery storage expensive • Battery life limited, especially if over-discharged • Requires shade free access to sunlight at least between 9am and 3pm • Substantial land area needed for community scale installations	• Energy input limited to daylight hours • Some seasonal variation • Generally good resource in unshaded locations throughout Vanuatu
Micro-hydro	• No fuel imports • Reliable; low maintenance • Continuous supply if flow is adequate	• Water flows are seasonal; may require backup • Not easily scalable • Site specific design required • Can be destroyed during extreme flows, highly susceptible to cyclone damage • High capital costs per kW • Usually restricted to communities where mini-grid is practical	• Flow monitoring required over several years
Wind	• Scalable • Can be suited to individual homes or buildings as well as mini-grids. • For one supplier, repair and maintenance are available from New Caledonia	• Intermittent, requiring battery storage or backup • Can be damaged/destroyed by high winds highly susceptible to cyclone damage • Limited local O&M skills • Expensive; unlike some RE technologies, prices are not dropping much • Little recent technical development at small scales • Few small machines designed for tropical, oceanic environments • Limited PIC experience with small systems (which has been poor)	• Very site specific • Considerable seasonal variation in wind speed and available energy

***** CME is similar but more complicated, requiring coconut oil processing

These are each discussed briefly below. Section 3.3 then describes Vanuatu experiences, and to a lesser extent the practical experience of other Pacific Island Countries, with renewable energy technologies at village scale.

Coconut oil

Coconut oil (CNO) appears to be technically feasible for community-level electricity generation in Vanuatu but, but as shown in the Port Orly system in Espiritu Santo (described in Section 3.3), a combination of technical, social and economic factors, may make it impractical for remote communities. Port Olry is in principle an ideal community for this technology: it is a large village, has long been a copra producer, is relatively affluent with a range of agricultural income and good tourism potential, is easily accessible by sealed road from Vanuatu's second largest urban center Luganville, is the health and education center for northeast Santo, has a functioning agricultural cooperative, and is relatively homogeneous as a Catholic village. For the short term, it demonstrated that electricity can be generated by burning 100% coconut oil in purpose-built generators in a village context. While the capital cost can be three to four times higher than conventional diesel, this can be offset by the ability to create local employment and use a locally produced fuel. Unfortunately after seven years of sporadic operation using locally produced coconut oil, the Port Orly project is now operating on 100% diesel fuel.

An alternative technology is coco-methyl ester (CME) which requires processing coconut oil through trans-esterification. CME has combustion properties similar to diesel fuel so conventional diesel generators can burn it without modification. The disadvantage is its substantially higher cost and the need to import, store, and handle methanol and lye which pose logistical challenges as well as health and safety risks and potentially negative environmental impacts.

Solar PV

Photovoltaic systems have been used for many years in Vanuatu, at household and community scale. Solar panels can be expected to last for 20 years or more, though special deep-discharge batteries often need replacement after 5-10 years depending on usage patterns, quality of the battery and maintenance. A disadvantage is that input is intermittent, being restricted to daylight hours, therefore requiring storage or a back-up energy source such as diesel to operate when the solar energy is not available. In a suitable location in Vanuatu, a 1 kW peak (1 kW_p) system can in practice deliver up to about 3 to 4 kWh/day to a load with actual kWh delivery varying depending on island topography, latitude, the type of installation, electricity use patterns and the quality of the components. Unfortunately many, if not most, of the rural solar electricity projects have failed largely due to a lack of funds to carry out proper maintenance, in particular to purchase proper replacement batteries when the original units come to the end of their life.

Hydropower

The only hydro system in Vanuatu providing electricity to communities (and the Luganville grid) is the 1.2 MW Sarakata run-of-river scheme on the island of Espiritu Santo. It demonstrates the technical viability of hydro in Vanuatu but is well beyond village scale and is not discussed further. A 75 kW system (described in Section 3.3) has been constructed in Maewo and there are reportedly a few very small privately-built systems (under 5 kW) in various parts of Vanuatu but no information was located on these, except a 3 kW Pelton system about to be commissioned in Pentecost (also described in Section 3.3). Clearly in some locations, micro-hydro is technically feasible in Vanuatu but the lack of good sites near population centers is a major economic barrier.

Wind turbines

The wind resource in Vanuatu is suitable for generating electricity in some locations but as noted earlier it is highly site-specific, with small changes in wind speed associated with large changes in energy availability. There are small-scale turbines commercially available and they are technically feasible where wind speeds are about 6 m/s although their maintenance requirements can be high. Considering the serious threat of cyclones, the preferred option is the use of hinged towers that can be lowered prior to passage of the cyclone by using a hand operated winch. In Vanuatu, the wind resource is seasonal, with trade winds generally during the dry season from May to October when the wind speed is highest. For village use, some battery storage will be required. Unlike solar PV, costs have not dropped significantly for small systems in recent years and wind systems are becoming expensive relative to solar PV. A major problem is finding a site for the turbine that is not seriously compromised due to wind resource reductions caused by the surrounding trees and local topography.

3.2 UNELCO Rural Electrification Plan Coverage of Renewable Energy (2006)

The power utility UNELCO is currently preparing a report on potential locations for diesel and renewable energy-based micro-grids for communities outside of the four electricity supply concession areas. This is expected to be completed during 2016 and should provide valuable information on technical options and approximate costs for electrifying various islands. For now, the most recent, and only, national study of technical options for rural electrification in Vanuatu was produced by UNELCO in 2006.[7] UNELCO considered "over 3,100 potential sites representing 21,000 households and a population of over 110,000." Based on experience in the islands of Santo, Malekula and Tanna, the population density of islands and existing economies and infrastructure, the criteria shown in Table 3.2 were considered by UNELCO as appropriate for the choice of generation technology.

Table 3.2: Criteria for Choice of Generation Technology (UNELCO, 2006)

Generation system	Suitable sites *	Number** of sites	Number** of households
Individual solar home systems	Very low-income hh in remote areas; basically provision of lighting by PV	2,500	9,500
Community PV or wind turbine	Villages of 10-30 hh with very little economic activities; battery storage; LV (230-400 v) network adaptable to 24 hr/7 day operations	530	9,000 (45,500 people)
10 kVA diesel or micro-hydro	Villages up to 60 hh with typically two lamps and average consumption of 5 kWh/hh/m, and maximum ≤ 10 kWh	90	3,615 (18,750 people)
Diesel or copra-based biofuel	Villages with average of 40 kWh/hh/m, permanent active centers, administration, businesses, schools, clinics or cooperatives	10	750 (4,200 people)

***** hh = household ** From 2000 census data

[7] Vanuatu Rural Electrification Plan (UNELCO, 2016), which is not available on-line. Many tables and maps are only in the French original.

At the time (2006), only 20% of the population had electricity, with rural electrification limited to small portions of Tanna and Malekula (from 2000 or 2001). Populations, incomes, technologies, and relative costs of options have of course changed in the past decade, although the technical suitability of various options may not have changed much. The average capacity of the coconut oil mills studied (100 tonnes/year/island) was said to be adequate for electricity production plus excess production for other uses. Considering at the time the expected increases in diesel fuel cost, on-site availability of copra and environmental issues, “the use of refined copra oil as a substitute fuel on the islands not only becomes the obvious choice[8] but would benefit the local agricultural economy as well.” Hydropower was considered an interesting option at selected sites but required in-depth assessment of each site and was beyond the scope of the 2006 study. Wind was barely mentioned as an option.

It was assumed that investment costs would be met by international funding organizations. Consumers would be required to contribute to re-equipment and operations costs. For solar home systems, there would be a fixed monthly lump sum charge. For thermal systems (diesel gensets and coconut oil) and mini-networks, there would be pre-payment meters and a kWh charge adapted to each site. Two options were considered for biofuel, “one using a processed fuel (coco-methyl ester)” and a “100% copra generator, which is designed to incorporate indirect injection diesel and is able to burn … crude copra oil without entailing costly processing.”

The UNELCO study considered two of the islands covered in this study, Emae and Aneityum. For Emae, UNELCO suggested a hybrid diesel/biofuel system for 30 households at Marae, with coconut oil not produced locally but supplied from an oil mill on the larger nearby island of Epi. The capital cost was estimated as 5 million vatu (about $50,000) with an electricity cost of 95 vatu/kWh. For Aneityum, biofuel could be provided from oil mills in the northern islands, with solar or limited wind generation at some particular sites. It was estimated at the time that a diesel/biofuel hybrid system for Anelgowat (46 households) would cost about 2.6 million vatu supplying electricity at 100 vatu/kWh. For both Emae and Aneityum, these electricity charges assumed that no capital costs were included in the tariff.

In 2006, UNELCO had not yet implemented any rural electrification schemes based on renewable energy, although soon afterwards pilot projects were developed for coconut oil-based biofuel for Port Olry in the north of Espiritu Santo and solar PV for the island of Nguna, off North Efate. Nonetheless it provides useful background on the sorts of technical options that might be appropriate for rural communities of different sizes and with varying electricity demands.

3.3 NAMA Proposals for Solar Micro-Grids (2015)

In 2015 the *Nationally-Appropriate Mitigation Action Design Document: Rural Electrification in Vanuatu* (NAMA; Gov/NAB, 2015) was prepared for the GoV. The NAMA proposed several interventions[9] including five solar PV ‘micro-grids’ (which we call mini-grids in these reports) for six

[8] At the time, there were no gensets using coconut oil as a fuel in Vanuatu but the study assumed it would be “a very profitable technical solution for the for the population affected, including producers and users” and is a technology which is “easily adaptable in the field … with a direct and immediate impact on the economy of the communities involved.”

[9] The NAMA proposals for an appropriate institutional structure are discussed in report 5 *Financing Requirements & Mechanisms and Recommended Business & Institutional Models* (June 2016)

villages on four islands. These are summarized in Table 3.3 below, adapted from Table 18 of the NAMA report. The NAMA apparently did not consider any renewable energy technology other than solar.

Table 3.3: Summary of NAMA proposal for Five PV Micro-Grids for Six Villages

Province	Tafea	Tafea	Malampa	Penama	Tafea	Total
Island	Tanna	Tanna	Malekula	Pentecost	Aniwa	
Area Council	Whitesands	Whitesands	Northwest Malekula	Central Pentecost	South Aniwa	
Village	Ipikel	Ipkangien	Unmet & Uri	Loltong	Ikaukau	
Population	358	127	662	237	125	1,509
Households	61	27	130	51	29	298
Potential income-generating activities	coastal fishing, tourism, handicrafts agricultural produce (peanuts, coffee, cocoa)	coastal fishing, tourism, handicrafts agricultural produce (peanuts, coffee, cocoa)	coastal fishing, tourism, agricultural produce (kava, copra, logging)	coastal fishing, tourism, women handicrafts, agricultural produce (kava, copra, logging)	coastal fishing, tourism, handicrafts, agricultural produce (orange juice)	
Other facilities to be connected	health centre, dispensaries, church, schools, shops, cooperatives, private enterprises	health centre, dispensaries, church, schools, shops, cooperatives, private enterprises	health centre, dispensaries, church, schools, shops, cooperatives, private enterprises	health centre, dispensaries, church, schools, shops, cooperatives, private enterprises	dispensaries, church, schools, shops, cooperatives, private enterprises	
Energy source	Solar PV	Solar PV	Solar PV	Solar PV	Solar PV	
Backup system	Battery &/or diesel	Battery &/or diesel	Battery &/or diesel	Battery &/or diesel	Battery &/or diesel	
Installed capacity (kW peak)	34.5	22.2	62.1	28.5	26.7	174
Consumption (Mwh/year)	49	31	88	40	38	246
Investment cost (US$ thousands)	362.5	233.4	652.5	298.7	280.1	1,827

Source: NAMA Design Document: Rural Electrification in Vanuatu (GoV/NAB, 2015)
Note: Installed capacity & annual consumption based on calculation model provided by Grue + Hornstrup.

The NAMA cost estimates are based on *Scaling Up Renewable Energy in Low Income Countries – Investment Plan for Vanuatu* (CIF, 2014) which estimated an average capital cost of US$10,500 per installed kW of solar PV for remote sites in Vanuatu. On this basis, the five solar grid systems would cost about US$1.8 million for 174 kW_p and diesel or battery backup, providing for 298 households, 5 health centers, 5 schools and 1500 people. The capital cost was about US$ 6,100/household. Overall installed PV capacity would be about 115 watts/capita. Overall consumption averages 69 kWh/household/month *including the schools and health centres* (but under 26 kWh/m for households alone).

The 2015 NAMA report does not provide preliminary designs but the grids were based on a 24 hour/day 230 volt alternating current (230 VAC) distribution network, with at least 75% of energy from solar PV. The initial costs and O&M costs per kWh, and thus user fees, would be considerably higher than a SHS or pico-solar lighting unit.

For households, consumption calculations were based on lighting (2 x 11w compact fluorescent lights), a radio or music player (35w each) and a cell phone charger 5w) plus provision for a community center, tourist bungalows, and facilities such as health centres, churches and schools. A sample calculation for one community estimates household demand alone as 0.85 kWh/hh/day. This is quite close to our estimates (Section 4 of this report) of about 1 kWh/hh/day.

3.4 Vanuatu and Fiji Experience with Renewables-based Rural Electrification

Solar Photovoltaics

Institutional PV systems. Between 1992 and 2002 Vanuatu had a very active small scale rural solar PV program (SPREP, 2005; BizClim/EU, 2012) with support from various donor agencies and the government's Sarakata Fund (using savings from a Japanese-funded hydro project in Santo). PV was installed in health centers, schools and staff houses at about 120 sites. The Ministries of Education and Health agreed to pay VT 36,000[10] per annum for every 150 W_p of installed capacity into a special government account to cover O&M costs but payments tended to be delinquent, maintenance was often poor and the systems eventually failed.

In 2009, IUCN Oceania (IUCN, 2009 and DoE files) agreed to rehabilitate a number of school and health center PV systems in Malekula (11 schools and 5 health centers), Santo (10 schools and 9 health centers) and Malo (3 schools and 1 health center) that were installed in 2001. Some were still producing electricity until August 2007 but, at the time of an assessment in late 2009, most had not operated since 2004 (i.e. failed within 3 years) due to battery and/or regulator failure. In general the PV panels remained functional. The institutional arrangements for O&M did not work well and the Energy Unit decided to adopt a management mechanism based on that of the French/Australia funded PREFACE project in Torba province that had reportedly been more effective.[11] DoE staff say that 'most' of the rehabilitated systems continue to function in May 2016.

In 2010, the Energy Unit (predecessor of the Department of Energy) carried out a review of the experiences and lessons learned from the school and health center PV programme, and this is attached as Annex 2. Although many issues for institutional PV systems differ from those of rural community PV, and the findings are incomplete, they are broadly relevant for technical designs and institutional mechanisms for the management of new remote island rural electrification, whether based on PV or other renewable technologies. These include the need to:

- standardize system designs for schools, health centers & staff housing with specified high-quality components such as batteries and regulators;

[10] When the SPREP PIREP report was written (March 2004) US$1.00 = vt 110 but the exchange rate was highly variable at the time.

[11] The Torba project demonstrated PV in 12 schools and 8 health centers, plus 40 staff houses, in 6 of the remote Banks and Torres islands. According to an independent evaluation (SPC, 2002), for health centers and schools, the ministries agreed to pay a specified fee into a special government account. For staff, a user fee of vt 1,500 per month (roughly US$15) was automatically deducted from their salaries. It is not known how long the payment system functioned.

- Standardize the lights to be used (e.g. 12v DC 7w compact fluorescent lights (CFLs), except 35w for maternity units, rather than seven or eight light types of varying voltages. (Today these might be light emitting diode (LED) lights rather than, or additional to CFLs);
- Establish institutional mechanisms for improved O&M and longer sustainability including maintenance checklists and timetables;
- Install batteries and regulators in safe, well-protected locations; and
- Train village PV technicians rather than government staff for O&M as officials are frequently transferred to other locations

The National Bank of Vanuatu has a PV system at Anelcauhat in Aneityum (Figure 3.1) primarily to power a satellite dish for bank transactions. We have not had the opportunity or time to assess the system but according to island residents, it is underpowered with insufficient hours of electricity available. A newer, smaller more energy-efficient satellite dish might be an option for the bank to consider.

Figure 3.1: PV-powered Satellite Communications, National Bank of Vanuatu, Aneityum
Photo: Peter Johnston, May 2016

At least 25 'Computer Lab & Internet Community Centres' are being established at schools, most with electricity from PV systems, through the Universal Access Policy (TRR, 2016) of the Telecommunications and Radiocommunications Regulator (TRR; www.trr.vu), with support from Digicel, TVL and Telsat. Schoolchildren are being supplied with tablet-type computers and high quality PV installations that provide reliable 240V AC power are being installed at the schools to charge tablets and phones and provide power for offices and classrooms. Reportedly schools are responsible for internal wiring and O&M but there is no O&M mechanism or any funding from the ministries for technical support. Some schools are reported to be adding additional computers, some of which are energy inefficient desktops, and high energy use laser printers, which appear beyond the PV system's design capacity, reducing hours of daily power availability and stressing the batteries.

About 14 PV systems are being installed in 2016 at new community facilities in Tanna through a cyclone relief effort coordinated by the Office of the Prime Minister. At least one of these, a new health center at the village of Irarap integrates a very small vertical axis wind system with solar PV. It is understood that local institutions are responsible for operations and maintenance, with no user fees to be charged.[12]

Figure 3.2:
JICA-funded Solar home System, Vanuatu
Source, SPREP, 2005

Solar home systems. Between 1995 and 2001, 310 solar home systems (SHS) of typically 100 kW_p

[12] Source is discussions in Tanna with a local person associated with the project

capacity were installed in 8 villages. The biggest single project was 220 SHS provided by the Government of Japan (JICA), installed between 1999-2001 in five communities on four islands (Figure 3.2). Each household was required to pay VT 9,000 (about US$90) upfront for installation plus VT 1,500 (about US$15) per month to the Energy Unit until they repaid VT 81,000 (e.g. over 4.5 years) but no proper accounting system was established for payments, the amount of money collected is unclear and many systems failed within a few years. There were problems with pre-payment meters. The systems in Efate operated longer but by 2004 about 20% of the systems had been disconnected by the Energy Unit for non-payment, which led to village chiefs refusing to allow Energy Unit staff to enter the villages. Primarily because of poor payments and issues between the energy officials and chiefs, the programme was discontinued and no government village SHS have been implemented in the past 15 years. The DoE estimates that 20 or fewer village SHS remain operational.

The UNELCO solar home system at Fareavau village at Nguna Island in North Efate was implemented in 2007 and is the most recent community PV system in Vanuatu. Each home had a PV panel and two lights, and customers were required to purchase pre-paid cards for the lights to operate. Most families were reportedly unable or unwilling to pay the fee so the program soon collapsed.

Solar lanterns and pico-solar systems. From 2010-2014, AusAID (Australian aid, now part of the Department of Foreign Affairs and Trade, DFAT) provided 38 million vatu (about US$0.38 million) to the Energy Unit of the GoV (now the Department of Energy) to subsidize the sales of at least 24,000 solar lanterns (typically with a tiny PV capacity of less than 1.5 watts), through two NGOs: ACTIV (Alternative Communities Trade in Vanuatu) and VANREPA (Vanuatu Renewable Energy & Power Association). An evaluation in 2014 (Kelly, 2014), which surveyed over 1,400 households in 193 villages on 19 islands, concluded that over 55,000 solar lanterns of various quality and models had been distributed between 2010 and 2013, although poor monitoring undermined the possibility of accurate estimates. Different types of lanterns retailed for 1,300-5,000 vatu and lasted 'up to four years depending on quality.' Solar lanterns (Figure 3.3) typically saved households 10,000-15,000 vatu per year each (about US$100-150) in expenditures for kerosene or dry batteries. Respondents were generally satisfied with even 3-4 hours per night of light. The efforts of ACTIV and VANREPA to provide replacement batteries or repair or recycle old lanterns largely failed. The majority of older or broken solar lanterns remained unfixed in homes, apparently with no safe disposal of batteries taking place.

Figure 3.3:
Solar Lantern Being Charged
Source: Kelly, 2014

The International Energy Agency (EIA, 2012) describes pico-solar as PV systems with a panel capacity as small as 0.3 W_p up to 10 W_p or more, usually including highly-efficient LED lights. "They are equipped with a rechargeable battery and a charge controller, and provide either light only (solar lanterns) or also additional electrical services. These services include: power for a radio, a music player, and charging a mobile phone." The Vanuatu Rural Electrification Project (VREP phase 1), funded by the New Zealand Government through the Pacific Region Infrastructure Facility (PRIF), was approved in 2014 (World Bank, 2014) and provides US$4.7 million to the GoV through the Department of Energy.

The objective is to provide access to basic electricity services through the subsidized[13] supply of pico-solar systems. The targeted beneficiaries are rural households, aid posts and community halls. According to the World Bank (2014), "Initially, the Project will focus on solar PV systems of between 5 to 30 Watts peak capacity that are of "plug and play" type, installed easily by the consumer and require little to no maintenance other than replacing batteries. These systems (Figure 3.4) can provide lighting and phone charging capabilities, with some systems capable of supporting other uses such as radios and small televisions." VREP phase 1 (2016-2019) began selling systems in February 2016. Based on total sales of 20,000 systems (17,500 households; 1,500 community), it needs to average 400 sales per month. About a hundred systems had been sold by late May 2016, so sales must average 476 per month from now on to attain the targets.

The World Bank characterizes the systems as follows (CIF, 2014), "While pico solar is relatively cheap, the life of these solar lanterns is short and services provided by them limited. As such, they are seen as a 'stepping stone' to more permanent solutions for households." The model used by VREP for pico-solar systems is not suitable for a widespread rural electrification program. There is no service provided to buyers after the warranty period, and spare batteries are generally unavailable or hard to obtain and expensive.

Figure 3.4: Example of VREP Pico-Solar-System
Source: VREP brochure; Dept of Energy

Biofuel

Port Olry. At Port Olry, about 65 km from Luganville on Santo (Bizclim/EU, 2012; PPA, 2010; UNDP, 2010), a prototype renewable energy system using coconut oil to fuel a 40 kW generator (Figure 3.5) was designed by UNELCO as "an economical solution that is adapted to the development of villages that are far removed from urban centers and to ensure the sustainability of the infrastructures by involving local people in the economics of the project and in creation of jobs." It was proposed in late 2006, approved in 2007 and implemented in 2008, funded by the EU, UNELCO and the GoV, to serve about a thousand people in 260 households. The cost was about 15 million vatu (US$150,000 or US$3,750/kW) for the energy system, excluding power transmission and connection costs of about 8.5 million vatu. Land was provided by the Catholic Church and management was through a community association, with UNELCO technical support until


Figure 3.5
40kW Biofuel Generator, Port Olry
Source: Port Olry case study (PPA, 2010)

[13] There is a 50% subsidy during the initial year, dropping to 40% in the second year, 30% in the third year, etc.

2010. According to a 2010 evaluation (PPA, 2010; UNDP, 2010) initially the system ran relatively well for 9 hours daily and 15 hours on Sundays. However fuel efficiency was quite low[14] as fewer households connected than expected and demand per household was far lower. The user charge of 150 vatu/kWh[15] (about US$1.5 per kWh[16]) was set by the community association apparently based on approximate O&M costs.

By mid-2010, most of the community's copra was being sold outside Port Olry (due to a new tar-sealed road and a copra price of 30,000 vatu/tonne in Port Olry and 37,500 in Luganville) so coconut oil was imported from Luganville, not produced locally. The system also suffered from other operational problems including failure of STAR© pre-paid three-phase meters (replaced by single-phase models), failure of the community association (replaced by a Parish committee), a broken oil press, and poor handling (storing and drying) of copra leading to excessive moisture, and thus poor quality oil and management difficulties. In some homes, wiring standards were poor. Nonetheless a 2010 survey indicated that people were generally pleased with the system (as it provided regular electricity), there was some increased economic activity (welding and tire repair), and less kerosene and dry battery use. There was also less socializing (due to television), more noise, and higher cash expenditures for electricity.

The cooperative arrangement was problematic and responsibility shifted to the community from 2011-2014 but there were operational difficulties and poor record keeping. The system ceased operations for a time. Responsibility for O&M shifted to the Santo electricity concessionaire Vanuatu Utilities and Industries Ltd (VUI) in late 2015 under a temporary contract, with the systems currently (June 2016) operating on 100% diesel fuel (no coconut oil at all) for 24 hours daily except 12 hours on Sundays.[17] As consumers had at some stage wired around the (new) meters, there is no metering and users are charged a nominal flat monthly fee, which is far below O&M costs. The Utilities Regulatory Agency (URA) is reviewing actual costs and will determine (with DoE) an appropriate new tariff later in 2016.

Early Fiji experience. There were two earlier trials of community-based coconut oil biofuel for three communities in the islands of Vanua Balavu (installed in 2000) and Welagi village in Taveuni (2001) in Fiji. Both used Deutz engines (as in Port Olry) modified for coconut oil. The smaller system was 40 kW to supply 48 households; the larger was 74 kW for 200 households plus schools, churches, a hospital and a police post. The capital costs (in 2000, about seven years earlier than the Port Olry system) were about US$1,840/kW for the larger system and US$2,300/kW for the smaller system.

The engines started on diesel fuel but switched to coconut oil (CNO) when the engines reached operating temperature, then switched back to diesel briefly before shutdown. An evaluation by SOPAC

[14] 1.37 kWh/liter of coconut oil compared to 2.4-3.5 kWh/l for diesel fuel for the same engine at the same loads, ranging from 14-29% (with 75% being optimal). A well-run engine of that size using coconut oil would expect to produce 2.0-2.5 kWh/litre.

[15] For a similar project (see Recent Vanuatu biofuel experience below), the user charge was estimated by UNELCO in late 2006 as 86 vatu/kWh (at the time €0.36), of which 50 vatu was for O&M and the rest for insurance, technical back up services & other charges. Source: UNELCO, 2006a

[16] In June-July 2010, US$1.00 was at or very close to vatu 100; http://www.exchangerate.com/past_rates.html?letter=V&continent=&cid=239-USD&currency=245&last30=&date_from=05-01-2010&date_to=07-30-2010&action=Generate+Chart

[17] Source: Peter Allen, President of Pernix Pacific (and General Manager of VUI in Santo), April 2016.

(SOPAC, 2006) concluded that both projects "successfully demonstrated the technical possibility to use coconut oil as a fuel for rural electrification. They have not however resulted in the expected socio-economic development." In both sites, generation by diesel fuel was found to be the most appropriate and lowest-cost option, despite thorough technical and socio-economic feasibility studies carried out before implementation. The tariffs were set too low for sustainable operations and neither system was operating on coconut oil at the time of the evaluation.

For both systems, there was inadequate consideration of coconut industry operations, variations in coconut oil quality and pricing, and alternative uses of the oil which provided a better return than burning it as fuel. The supply of copra was variable and insufficient. For the smaller system, minor technical difficulties caused deterioration of the copra dryer and oil mill. In addition, the screw press for crushing copra used more energy than the *entire* community demand leading to dissatisfaction and a preference for a 100% diesel system. After 6 months of operation on CNO, operation switched to 100% diesel.

For the larger system, the coconut oil mill ceased operation (before the engine was installed) and the electricity system had not operated since 2005, as the cost of importing coconut oil was prohibitive. Despite "a very large" willingness to pay, problems were exacerbated by weak cooperation among the three villages.

Recent Vanuatu biofuel experience. Following the apparent early success of the Port Olry project, the EU agreed to provide a grant of €2.44 million to Vanuatu through the 2007-2012 EU Energy Facility program towards the costs of three further biofuel projects for the islands of Torba, Penama and Malampa, based on the Port Olry design. Approved by the EU in 2007 and scheduled for completion by mid-2010, there have been long delays, threats by the EU of cancellation due to political disputes over the siting of plants, reportedly mismanagement of funds by provinces and poor reporting, difficulties in establishing community communities responsible for O&M, and for a time, failure of the GoV to provide its share of costs. In 2014, the GoV contributed 218 million vatu (about €1.8 million), the problems were resolved and the systems are being commissioned (April/May 2016), initially to be operated by UNELCO. There are five micro-grids, each with 2x30 kVA CNO-fueled gensets, and one coconut oil mill (100 kg/hour capacity) per island as follows:

- Ambae, Pelampa Province. 2x30 kVA generators each for the villages of Lolowai, Longana and Saratamata (provincial capital). The EU contribution was €585,460.
- Vanua Lava, Torba Province. 2x30 kVA generators each for the villages of Mosine and Sola (provincial capital). The EU contribution was €388,300.
- Malekula, Malampa Province. Originally planned for the villages of Lavalsal Fotinweiu, Vao, Orap and Wala, there is now one oil mill to supply UNELCO generation at Lakatoro with 26 km of grid extension connecting about 3500 people in the villages to the 5500 V transmission line. The EU contribution was €853,600.

Exchange rates have fluctuated considerably since the equipment was ordered in 2012. The total cost was about €4.24 million for ten 30 kVA systems or €14,000 per kW including reticulation.

An EU-funded study (BizClim/EU, 2012) concluded that "there are a considerable number of barriers to the further development of coconut (or palm) oil as a biofuel replacement for diesel. These barriers[18] include":

- Copra supply infrastructure. Considerable investment is needed to secure a steady supply of quality copra.
- Copra supply outlook. Many existing plantations in Vanuatu are nearing the end of their useful life and without significant new investment there will not be sufficient copra to provide fuel for generation beyond the short to medium term.
- Quality control issues. The oil has to be thoroughly cleaned before it can be used in the generators or it rapidly clogs the filters and generation must be interrupted for maintenance.
- Generator technical issues. Only specific diesel generators (e.g. Deutz) can successfully cope with 100% coconut oil fuel. Replacing older generators is only economic when they reach the end of their useful lives.
- Copra price. Diesel and copra prices tend to be reasonably highly correlated over time, with no clear comparative advantage to the use of coconut oil as a fuel.
- Lost tax and export earning revenue. A major barrier is the loss of government tax income from reduced diesel sales, with 40% of the price of fuel consisting of taxes. The underlying issue is the lack of a consistent government view: one department wishes to encourage the use of renewable energy including coconut oil while another wants revenue gains from copra exports.

Figure 3.6: Copra Processing for Biofuel, Koro Fiji
Source: Hales 2011

Recent Fiji biofuel experience. Since 2010, Fiji has invested F$5.4 million[19] (about US$2.7 million or VT 280 million, all from the national budget with no donor support) in nine coconut-based biofuel projects in nine remote islands (Figure 3.6) including two constructed but not (April 2016) yet commissioned. The mills each have a capacity of 170,000 litres of oil per year. These were initially planned to use an 80% diesel fuel/20% CNO blend but have been retrofit for 100% CNO. Although details are not available, there has generally been poor performance, a significant government investment with minimal return, poor coordination among stakeholders, an inconsistent supply of copra for biofuel production, and very low coconut oil production, about 1% of mill capacity. The Fiji DoE feels that to be economically viable, the mills must have capacity excess to needs for power generation, and a market for the excess production.

[18] Paraphrased for brevity and clarity.

[19] Source is Fiji Department of Energy, April 2016. This excludes F$1.9 million for accredited biofuel testing facilities at the University of the South Pacific and copra moisture testers (about US$3,400 each) but includes about US$120,000 for 40 dual-fuel conversion kits.

The Fiji government plans to undertake a comprehensive review of the program during the latter part of 2016 and is considering turning over management to private companies, as community management has not been effective. The review findings and lessons are likely to be valuable for future biofuel programs in Vanuatu as well as in Fiji.

Micro hydropower

The Talise scheme. As noted in Section 2.1, Vanuatu's geology restricts development to run-of-river schemes. A 75 kW system has been constructed near Talise in Maewo. Sixteen years after initial studies, it has been completed and is operational but transmission of the energy to three villages is still some months away. Each hydropower site differs; the costs for systems with similar capacity (kW) and output (kWh) can differ very substantially. Nonetheless, Talise might provide order-of-magnitude costs for other small hydro projects in Vanuatu.

Hydro development at Talise on the island of Maewo was advocated by SOPAC (now a division of SPC) about 2000. In 2002 a feasibility study on a community-based run-of-river micro hydropower at the Talise River was undertaken by Appropriate Technology for Community and Environment (APACE), an Australian-based Non-Governmental Organization (NGO). APACE proposed a 75 kW system to supply electricity to three villages (Talise, Nasawa, and Narovorovo) of about 1,300 people. The study concluded that it was technically viable but did not consider other electrification options or provide a detailed economic analysis.

Subsequently the Pacific Islands Greenhouse Gas Abatement through Renewable Energy Project (PIGGAREP) at the Secretariat of the Pacific Regional Environment Programme (SPREP) agreed to review and update the APACE study through a new feasibility study (GHD, 2010) including an environmental impact assessment, preparation of tender documents, a business plan and guidance for construction and operation. GHD confirmed the choice of a Pelton turbine as suitable for high pressure (100+m drop) at low flow (136-600 litres/second during measurements from Dec 2000 – March 2003 and 210 l/s in March 2009) but there were uncertainties regarding the technique and quality of measurements and insufficient flow data for accurate estimates of expected long-term output.[20] The project is summarized in Table 3.4 below.

Table 3.4: Communities to be Electrified by Talise Hydro and Initial Power & Energy Demand

Village	Households (kW)	Government (kW)	Community (kW)	Commercial (kW)	Total kW (initial demand)
Talise	11.36	1.95	0.66	0.72	14.69
Norovorovo	8.86	5.84	1.10	0.22	16.04
Nasawa	16.37	3.58	1.78	0.48	22.22
Total	36.59	11.37	3.54	1.42	52.95
% of supply	69%	21%	7%	3%	100%

Source: GHD feasibility study, 2010 and Department of Energy, April 2010
Notes: Projected demand by 2020 of 76 kW; Average willingness to pay: US$ 1.02/kWh or VT 315 / week

[20] Ongoing flow measurements were to be made after the 2002 study and a rain gauge was installed to measure rainfall and stream height but no data were collected and the data logger was not function in 2009 as the battery had long failed.

The community populations don't appear to have grown much but in 2002 APACE calculated an initial coincident demand of 34.1 kW and 50,300 kWh/year whereas GHD calculated 53 kW and 87,400 kWh, all assuming 10% losses. This is relevant to future project designs as assumptions about appliance uptake and use, number and hours of streetlights, commercial activity, etc. can make a large difference in the size (and cost) of the system specified. The project was expected to provide electricity to 1,300 people in the three villages and 366 buildings (260 households, 16 public and commercial establishments).

GHD estimated annual increases in energy consumption for the first five years as 7% for households, 4% by government facilities, 2% by community facilities and 5% by commercial users (mainly small shops), declining slightly afterwards. This results in an assumed generation requirement of 230 MWh and a power requirement of 105 kW after 20 years.

The project was approved with construction of civil works and installation of electromechanical works by Pelena Energy of Australia funded by the International Union for the Conservation of Nature (IUCN Oceania). Work on the generation system began in early 2011, was completed by early 2014, and was commissioned in July 2014 with power available for 24 hours daily at the powerhouse. Funding for transmission to the villages and service to the buildings was still being finalized in mid-2016. Technical aspects of the project are summarized in Table 3.5 below.

Table 3.5: Design Features of Talise Hydropower Project

Catchment area	1.5 km^2 at intake
Designed Discharge	120 litres per second (lps)
Gross Head; net head	107.3 m; 93.5 m
Design Capacity	75 kW
Weir/Intake	Concrete weir and side intake, Orifice type of opening of 0.65*0.2m
Headrace/Length	69 m stone masonry open canal (0.5m*0.75m) including 25 cm freeboard
Forebay	5.9m long, 1.9m wide and 1.1m high (Stone masonry 1:4 c/s)
Penstock Pipe	665 m long, 250 mm dia PVC for the upper part & steel for the lower part
Powerhouse	Brick masonry 4 m x 4 m x 3m (Inside dimension) and 12m tailrace
Turbine Type	Pelton turbine double jet
Driving system	Direct coupling
Generator Type	105 KVA, 3 Phases, Synchronous
Control system	ELC (digital type)
Transformers	One 100 kVA step up transformer (400V/20kV), two 25 kVA and one 50 kVA distribution transformers at Nasawa
Lighting arrestors	At every 1000 m of HT and 500m of LT lines
Trans. /Dist. Network	11 km

Sources: As in Table 3.4 above

GHD estimated that the initial capital/construction costs would be on the order of US$400,000 (weir, penstock, and powerhouse) excluding various administrative and technical assistance costs, and about US$16,000 per year for Operations and Maintenance (O&M). More detailed estimates are shown in Table 3.6.

Table 3.6: Assumed Talise Project Costs (from feasibility study)

Description	Cost US$	Cost A$	Remarks
Civil works	292,250	365,330	A$ = Australian dollars. Based on construction works contracted locally with local engineers designing and supervising. The cost of a resident international hydropower expert is not included in the report. The cost of training local operators is not included. Import duties and VAT were not included.
Electromechanical equipment	80,250	100,300	
Transmission line	162,900	203,650	
Administration, supervision and technical assistance	95,250	119,050	
Contingencies	59,100	73,850	
Total	689,750	862,180	

Operations and Maintenance (O&M) were expected to cost US$ 10,000/year for two operators and two managers) plus US$ 5,700 for maintenance of civil and other components. This excluded replacement of major parts like the turbine and generator.

It has not been possible to determine actual costs. However, discussions with IUCN and the DoE indicate that costs – excluding transmission and house connections – were lower than estimated in Table 3, about A$362,000 (possibly due in part to the extensive use of community labor). There have been several bids for the transmission and house wiring initially varying from A$1.3 million to A$3 million. One vendor reduced the price to A$690,000 based on the provision of a significant amount of labor by the three communities. This is based on 22 kV 3-phase transmission with transformers and HV switchgear, 240v LV reticulation and connections to about 360 households, halls, clinics and schools. The hydro capital costs were incurred when the A$ was nearly on par with the US$ but now A$1.00 = about US$ 0.74. If the entire system were built today, the cost would probably be about US$0.9 million[21] or about US$12,000 per kW.

Construction of a small hydro system is a major undertaking as illustrated (Figure 3.7) by the following photos of Talise under construction.

Pelton wheel housing

Intake

[21] The hydro system itself about US$350,000 plus transmission etc. at US$480,000 (0.74 x A$690,000) or US$ 0.86 million. Feasibility studies and training costs would bring this to at least US $0.9 million.

Installing the penstock **Penstock & trench**

Figure 3.7: Construction of Talise hydro Project

Source APACE; http://www.apace.uts.edu.au/docpublish/Talise.html

Pico-hydro. There are reportedly several very small 'pico-hydro' systems of 5 kW or less operating in Vanuatu but little information is available. At Loltong Habour in North Pentecost a 3 kW pico-hydro system using a small Pelton turbine has been constructed at a cost of 2.46 million vatu - about US$23,000 – through the Government (62%), a New Zealand government grant (28%) and the community's contribution (10%). The project is about to be commissioned (June 2016) and will serve about 300 people in 70 households which are about 800 metres from the power plant. This project has been inexpensive as there were no consultancy costs for studies or construction. It was a community effort with a local engineer from the community providing his services, including limited stream flow measurement, design and supervision at no cost. The energy produced is unknown but output is estimated as about 1.5 kW in the dry season and up to 3 kW in the wet season. It is an interesting approach but not replicable for designing and constructing a larger number of small hydropower projects, as the engineering costs would need to be included. There is no metering and a users' fee (a fixed amount per household per month) is planned with a local North Pentecost company responsible for O&M.

Fiji's small hydro experience. Fiji has a history of micro-hydro dating to the 1920s. Between 1984 and 1999, five micro-hydro schemes were commissioned of 3, 4, 20, 30 and 100 kW respectively, mostly in rural communities on the main island of Viti Levu. Dry spells have resulted in low firm power, several have been damaged by intense rainfall events associated with cyclones, and some suffered from intake damage due to cobble, gravel and sand.

For comparison with Talise, a smaller 30 kW micro-hydro project at Buca Bay in Vanua Levu, Fiji cost US$444,000, or US$15,000/kW, including a 4.5 km transmission line.[22] It was proposed in 2009, constructed over a 5 month period during 2010 with village labor and foreign supervisors, commissioned in early 2011 and reportedly functions well in 2016.

A small hydro system somewhat larger than Talise is Bukuya in a remote part of Ba province in Fiji. It was designed (Grue+Hornstrup, 2015) with a capacity of 100 kW for supplying electricity to the three villages of Bukuya, Tabalei, and Natabuquto. Electricity was delivered to about 210 households, one primary school, one health clinic, and a road authority depot. In early 2014 the hydro power plant failed and was apparently refurbished in 2015. Bukuya experienced several issues in the past due to

[22] The water flow was monitored since 1998. Cost was F$944,600 of which Fiji paid 45% & Turkey 55%. Buca village provided 30 laborers. From http://www.fiji.gov.fj/Media-Center/Press-Releases/PM-commissions-Buca-Hydro-Scheme.aspx (14 January 2011) and http://www.microhydropower.net/news/viewnews.php?ID=144

the failure of the management system: 1) a lack of secured revenue in the form of regular consumer payments for electricity consumed due to inability or unwillingness to pay; and 2) the lack of regular maintenance. The Bukuya Electricity Cooperative only fixed equipment when it broke down, and did not have the knowhow for continued maintenance.

A recent survey suggests a household demand averaging nearly 3.3 kWh/hh/day for the 270 households in the service area plus a demand from schools, health center, etc. of 13 MWh/year for a total demand (If all households are connected) of 331 MWh/year. This is of interest in the Vanuatu context because the community and Fiji government are grappling establishing a 'Public Private Partnership' (PPP) mechanism to establish a sustainable tariff, sustainable collection of fees and regular O&M. As discussed in the Inception Report, this inability to establish mechanisms for payment of user fees and O&M has been a key issue leading to the failure of many Pacific rural energy initiatives.

Figure 3.8:
EU-VANREPA wind system installation, Futuna, Tafea
Source: UNDP, 2012

Wind

EU Energy Facility support to Vanuatu in 2007 included the development of wind generation with battery backup for the islands of Futuna and Aneityum.[23] However, poor performance, poor reporting and disagreements with the project developer led to cancellation in 2011. The intention had been to install thirteen small turbines with an EU contribution of nearly €403,000, or 75% of the total cost of €537,300. The cost was to include training of local supervisors in system O&M; provision of electricity to 300 households, four schools, five health centers, community offices and enterprises; implementation of awareness campaigns on energy efficiency and renewable energy; and identification of new income-generating activities. Apparently no energy was ever produced although a wind turbine was installed in Futuna (Figure 3.8) and some equipment remains in storage at the school in Aneityum. The system included a hinged tower so the turbine could be lowered during high winds but it was nonetheless destroyed during high wind speeds.

A very small vertical axis wind system (Figure 3.9) has been installed at the health center at Irarap village in central Tanna, supplementing a solar PV system. This has yet begun to operate so no evaluation is yet possible.

Figure 3.9: Vertical- Axis Wind Energy, Tanna
Photo: J Salong, May 2016

[23] Source is interviews plus http://database.energyfacilitymonitoring.eu/acpeu/PublicProjectOverview.xhtml

3.5 Pacific Island Experience with Management of PV-based Rural Electrification

There has been considerable experience in other Pacific island Countries (PICs) with renewable energy technologies for the provision of electricity to rural areas. The discussion that follows has been summarized from Section 3 of the *Inception Report* of 8 April 2016, which provides more detailed coverage. Although the focus is on PV, the PIC experiences in operating and sustainably managing RE systems are broadly applicable to other renewable energy technologies.

Solar Home Systems

By far, the majority of homes powered by solar energy in the PICs use a solar home system (SHS), with well over 10,000 installations and thousands more being installed in 2016. Installations from about 1983-1992 had inadequate panel capacity, control units that did not properly manage battery charging, and batteries that did not survive more than 3-4 years. Lessons learned during that decade were applied in the design of the 1992-1994 EU Lomé II PV project for Tonga, Kiribati and Tuvalu, and included a well-tested rugged control unit designed for PIC conditions, industrial grade deep-discharge batteries and larger 110 W_p solar panels. The installations performed well with operational lifetimes far exceeding those of earlier installations. In Tonga and Kiribati batteries generally lasted over 10 years, due to high quality components and excellent long-term support service. Post-2000 installations tended to have 150-200 W_p panels with thousands of installations in Vanuatu, Tonga and the Marshall Islands. SHS are well suited to households since the energy is sufficient to light several rooms from a single installation, plus radio, phone charging and other small appliances. At this level of electrification, which is generally considered as true rural electrification, a support system for maintenance is essential and the quality of the maintenance, particularly with regards to battery replacement, becomes the primary determinant for success or failure over the long term.

Institutional Support arrangements for solar home systems. Over 30 years of PIC experience is available for designing a sustainable system for SHS in rural households. Although the great majority have been provided through grant aid, the cost of maintenance – in particular battery replacement – is significant and is generally expected by the donor to be recovered from users through a modest periodic fee. Most analyses of O&M costs for SHS on outer islands in PICs have resulted in monthly costs of US$10-$15. Various management systems used in the region are discussed below.

1. ***Individual and Community-based management.*** Community or individual household based maintenance of SHS has not worked in the PICs. Where maintenance was the responsibility of the individual households or the communities, early failure has inevitably been the result. The two primary reasons for early failure of technically satisfactory projects have been user abuse such as adding appliances that exceed the energy delivery capacity of the SHS – such as charging other batteries from the solar system and using them elsewhere – and lack of a system for accumulating the funds needed to replace the battery when it fails. Although communities have levied PV charges meant for battery replacement, they have universally failed because: i) people or communities are essentially charging themselves and set fees that are too low; and ii) battery replacements for good quality SHS installations are not likely to be needed for 5 to 7 years and sometimes as long as 10 years so individuals and communities have neither continued to collect the fees for such a long period nor have they resisted the temptation to spend it on something else before battery replacement is needed. Therefore, when the battery fails due to abuse or age, there is insufficient money available for replacement.

2. ***Kiribati's Solar Utility Concept***. Kiribati established a successful system for SHS installation, operation and maintenance in 1989 when the Kiribati Solar Energy Corporation (KSEC) was converted from a sales organisation to a government-owned "solar utility" with the principles of conventional utility operation applied to solar electrification. As with a conventional power utility, KSEC owned the generation system (solar panels, charge controller and battery). The end-user owned the wiring and appliances and paid a monthly fee to KSEC for the PV power. KSEC hired and trained island-based technicians and arranged additional annual training for at least one KSEC technician/agent on each island. The agents were required to visit each installation at least monthly to confirm that users were not abusing the system and to provide the basic maintenance (battery water, connection cleaning, etc.) needed to keep the system fully operational. In return for the electricity, the households paid a monthly fee of AUD $9, much less than the cost of kerosene previously used for comparable hours of lower-quality lighting. 320 systems on 3 islands operated successfully from 1994-2004 with on-time fee collection rates of over 85% and virtually 100% collections within 3 months of the due date. This high rate of collection, comparable to that of a conventional island utility, was due to the high level of user satisfaction that was the result of frequent maintenance visits resulting in few power outages and a very long battery life. There were later problems due to too-rapid expansion (1,600 more SHS for 18 widely-spread islands; refusal of the government to raise fees caused by inflation) but Kiribati demonstrated a very successful approach which ran well for a decade. A Vanuatu SHS program should learn from the Kiribati experience: a solar utility can be effective but should not expand too rapidly and must be allowed to recover reasonable costs of O&M. A similar approach worked for some years in Tuvalu.

3. ***Fiji's Renewable Energy Service Company (RESCO) concept***. Early SHS projects in Fiji used community cooperative type management structures that failed within a few years. In the early 2000's, Fiji's Department of Energy (FDoE) decided to expand their SHS program using a variant of the Kiribati solar utility concept. Under this Renewable Energy Service Company (RESCO) model, the government owned the SHS, in essence renting them to rural households. The FDoE design included a solar pre-payment meter that turned on power for 30 days when a purchased code was entered into the meter. The initial SHS sites were accessible by road so the FDoE contracted with a private company to travel to each village on a fixed schedule and perform maintenance as needed, rather than training and hiring individual agents in each village. Payments were made through the local Post Office. The fee was initially about US$8 per month of which US$0.28 went to the Post Office for their services. The approach functioned reasonably well for a few years. However, the SHS expanded to include outer islands, where access was difficult and expensive, reducing the level of support provided. Also the fees went directly to the Government with the contracted company paid a fixed amount that was not affected by payment or non-payment of fees by users; there was no incentive for the contractor to work with customers to pay their arrears. Finally, the South African company manufacturing and supporting the prepayment meters ceased production. An alternative supplier in New Caledonia also ceased production and by 2012 the meters failed, worsening the problem of fee collection. The Fiji experience suggests that a RESCO approach can be successful but the contractor must have an incentive to see that fees are paid and care must be taken to avoid components (e.g. proprietary meters) that rely on the continued survival of one small company.

4. **Tonga's Outer Island Solar Electrification Programme** (TOISEP). The TOISEP focuses on SHS for islands that are too small to justify a diesel powered grid. SHS installations began in the late 1980s and continues to the present with over 1,000 SHS installed. The initial management approach was for the Government Energy Unit to own the SHS and arrange maintenance by local trained technicians. Battery replacements were expected to be funded through fees charged to end-users. The approach did not work well because of the difficulty and expense involved in accessing all of the islands. In the Ha'apai group of islands, in the late 1900s TOISEP was turned over to an oversight committee that includes national government, the Ha'apai regional government, and village government. The committee is responsible for hiring a renewable energy manager to hire,

train and oversee local technicians on each island, to maintain a stock of spare parts, and to interface with the oversight committee. User fees are set by the committee and collected by the trained island technicians who are required to periodically visit each installation and perform preventive maintenance (e.g. cleaning wiring connections, adding battery water, ensuring that shade is not blocking solar panels and helping end users manage power use to fit the capacity of the SHS installation). If the technician does not perform his/her work well, end-users are encouraged to report poor performance to the village mayor who contacts the oversight committee for action. This multilevel committee approach has worked well over the long term, has resulted in the most successful SHS program in the Pacific Islands and has been replicated in Tonga's Vava'u group of islands. Ha'apai is a long volcanic island chain, similar to Vanuatu though smaller, and access is costly. Its electrification problems are similar to those of remote islands in Vanuatu.

5. ***The Republic of the Marshall Islands (RMI) outer island solar program***. In 2000 the Australia/France funded PREFACE project provided 150 W_p PV installations for several islands in the RMI, with the Marshall's Energy Company (MEC), the government-owned power utility based in the capital Majuro, providing support. MEC hired and trained at least one local technician on each atoll receiving SHS and set a monthly fee of US$12 per household for the SHS service, based on O&M costs. Subsequently several thousand SHS installations have spread over the 29 atolls with over 80% of all outer island households now having access to electricity through a SHS. The system worked well until the RMI legislature arbitrarily decided that the $12 fee was too high and required the MEC to drop the fee to $5 with promises to provide subsidies to cover the additional cost of maintenance. With the promised subsidies slow to materialize, maintenance services to outer islands have been greatly reduced and the funds needed to replace batteries that are expected to fail in the next year or two may not be available. Nonetheless, the RMI experience shows that a utility-led O&M system can work for a large number of systems in widely-separated islands.

Solar Micro-Grids, Mini-Grids and Solar-Diesel Hybrid Mini Grids

1. **Solar micro-grids and mini-grids.** Although there is no specific line separating a micro-grid and a mini-grid, in general a micro-grid is smaller and is assumed to serve a single facility, whereas a mini-grid typically serves a number of individual households and small businesses in a village.[24] Mini-grids are similar to micro-grids but typically consist of multiple micro-grid type modules that are operated in parallel to increase power availability and overall system reliability. Micro-grids for schools and remote government buildings in the PICs dates from about 2003 with some remote schools electrified with AC distribution instead of the 12V DC lighting and fans installed earlier. AC distribution was requested by the countries primarily to make it practical to include computers, audio-visual equipment and, in some cases, the Internet. The first PIC village electrification by solar mini-grid went on-line in 2006 to power the 10 household village of Apolima, Samoa, completely replacing the existing diesel generation, with no diesel backup. It has operated reliably with no major maintenance for 10 years although batteries are expected to require replacement soon. In 2008 two additional 100% solar village installations were constructed on outer islands of Yap State of the Federated States of Micronesia. The installations have operated reliably and both survived a category 5 cyclone (called a typhoon in the North Pacific) in 2015 with no significant damage to either installation.

2. **Solar-Diesel Hybrid Mini Grids.** In the rural electrification context, a solar-diesel hybrid is typically a solar mini-grid with an associated diesel engine with generation by solar until the battery charge

[24] There are various inconsistent definitions of micro- and mini-grids. The concepts are discussed further in *Preliminary Technical Design of Potential Renewable Energy Projects for the Selected Islands* (report 4, June 2016).

is depleted and then generation shifts to diesel. Some more complex designs operate the diesel and solar simultaneously but for long term reliability, such installations need well trained operators and good technical support. An example of such a failure is a solar/wind/hybrid AC installation at Nabouwalu on the island of Vanua Levu in Fiji in the year 2000. Although it initially worked well, the Public Works Department operators who were trained in the operation of the system were soon reassigned elsewhere and problems with the wind system and with the control system tying the three technologies together resulted in its failure after less than five years of operation. Its generation then reverted to 100% diesel operation.

A small AC solar/diesel system has been operational at the high school on the island of Vaitupu in Tuvalu for a number of years, but the diesel and solar do not operate simultaneously. In Tokelau, there is nearly one megawatt of solar mini-grids with diesel back-up operating satisfactorily since 2012. Fiji has converted three outer island provincial centre diesel-powered grids to solar/diesel hybrids, Tuvalu and the Cook Islands are currently converting outer island diesel systems to AC solar/diesel hybrids and the Tonga power utility has announced a project to convert all small diesel generation on the outer islands to solar diesel hybrids. It is important to note that all of the diesel/solar hybrid installations in the PICs to date are being managed and maintained by the same organisation that operated the diesel grid, usually the national electric power utility or (in Fiji) the Public Works Department. Thus far, they have adequately maintained the installations and the solar generation has generally provided better quality and more reliable power than the diesel mini-grids they replaced.

3. **Institutional Arrangements for Micro and Mini Grids.** Most of the micro-grids in the Pacific are associated with government facilities, although some eco-tourist facilities (e.g. Fafa Island, Tonga) and banks (e.g. ANZ Banks on Kiritimati Island and Aututaki and the National Bank of Vanuatu on Aneityum) have themselves installed solar micro-grid power. Typically the facility owner (often the Department of Education or Department of Health) is expected to arrange for system maintenance. The quality of maintenance varies from good to non-existent and of course so does the reliability of the installation. Those facilities that have contracted with the national utility or a local solar company for maintenance have generally had good results but self-maintenance has not worked well.

4. Viable Least Cost Renewable Energy Options for the Selected Islands

4.1 Energy Use Priorities, Willingness to Pay and Ability to Pay

In brief, the *Site Visits and Survey Report* (report 2; June 2016) of this study results in the following general observations.

Most villages surveyed have a number of households that indicate their unwillingness to pay more than around 500 Vt per month for electricity services. If O&M costs are unsubsidized, that is probably going to provide around 3 kWh per month (0.1 kWh/day) from a mini-gird. That can be comparable to the services provided by a larger pico-solar kit but is too low a payment for a high quality, 100 Wp SHS installation to be economic. Although the actual cost per kWh for a mini-grid varies according to size and usage, 500 Vt per month for electricity would generally provide only very minimal lighting and the cost of wiring the household to the grid and wiring the house to meet 230VAC standards would probably never be recovered unless heavily subsidised. For the lowest overall cost both to the customer and to the operator, pico-solar seems the best choice for those very low cash income homes, at least for the near term.

Productive uses of electricity that expand the island economy are unlikely except for villages near developable tourist venues (such as Marae in Emae and those along the southern coast of Aneityum). The primary reason is the lack of affordable access to urban markets for village products that can have value added through the use of electricity. The great majority of electricity services installed will be to improve local life styles and there will be net cash outflow, not inflow as a result of having the electricity available. While improving rural lifestyles is certainly a desirable development, it actually tends to reduce cash availability in villages [25]because, at least according to the survey results, the cost savings for kerosene would be nil (almost no kerosene is now used for lighting). Although there would be savings in dry battery purchases while getting much better light from the solar PV, the cost of electrical services is generally substantially more than the cost of the batteries that it can replace. Additionally, if the solar installation has sufficient capacity, household cash may also be spent outside the island for the purchase of new appliances to connect to the electricity – a benefit for the urban areas but a detriment to the island economy if not balanced by the productive uses made possible by the electricity access.

Virtually all the villages have i) a few relatively cash-rich households (usually salaried employees of government or commercial entities) that are willing and able to pay for good access to electricity; ii) a moderate sized group of households with some access to cash who are willing to pay for SHS type access (~1000 Vt/month or more); and iii) a larger group of cash-poor households that are willing to pay 500Vt or less, an amount that is suitable for a pico-solar kit. In larger villages, the scale of a mini-grid can be sufficient that all households can have the electrical services that meet their needs at a cost comparable to pico-solar and SHS. Unfortunately the per household capital cost of a mini-grid tends to increase rapidly as the number of households served decreases so the donor/government money for capital investment will go further if the desired services are provided through SHS and pico-solar instead of using mini-grids when the number of households in a village of average rural income falls below around 20. However, in that case it is vital that the sizes of the individual SHS fit the needs and willingness to pay of each household (i.e. not all households would have ta SHS of the same size) so that the end services for the village overall are comparable to those that could be provided by a mini-grid connection.

The usual "one size fits all" requirement by donors (and sometimes local politicians) for SHS implementation will not be acceptable. Each village should be assigned a total allocation based on the needs of all households (just as would be the case if a mini-grid were being installed) and the SHS/pico-solar sizing for each house set to fit each household's specific needs. User fees would not increase linearly with solar capacity, larger SHS would be slightly lower in monthly cost per Wp of installed solar – with the notable exception of battery replacements which will increase linearly – because many of the O&M costs of maintenance are the same for SHS whether big or small. Except for expensive battery replacement costs, most maintenance costs will be the cost of access by a local technician plus the time needed for the technician to perform system checks, clean the connections and do general preventive maintenance. Those services will require about the same time and cost whether the SHS is small or large.

[25] A report published by UNDP (Bangkok) about 2007 on energy and poverty in the Pacific Islands reached the same conclusions.

4.2 Likely Electricity Consumption

As discussed in the *Preliminary Technical Design of Potential Renewable Energy Projects for the Selected Islands* (report 4; June 2016), it is reasonable to assume that newly-electrified households in remote islands will consume less than those who have been electrified for some years and are connected to the grid (e.g. pre-pay customers of UNELCO and Tanna) and no more than the newly-connected rural customers of VUI. To summarize the findings of report 4:

- Pre-pay households connected to the UNELCO grid in the island of Tanna increased consumption on average from 0.6 kWh/hh/day in 2002 to 1.1 kWh in 2013, whereas the consumption for households on the island of Malekula increased from 0.6 kWh to 0.7 kWh in the same period.
- A study of consumption for the Port Orly biofuel system on the island of Espiritu Santo in 2010 estimated (based on a sample of 15% of households) that average consumption was less than 0.5 kWh/hh/day, with most households even lower.
- An assessment of newly connected households in four rural communities on the VUI grid in Santo in late 2015-early 2016 showed an average of 1.2 kWh/hh/day in a small community with 23 newly-connected households, 3.0 kWh/day for another community (67 households), 1.1 kWh/day for a third community (68 households) and 1.2 kWh/day for a fourth community of 98 households. In all four communities, consumption was skewed with the bulk of households using less than 1 kWh/day with a few outliers consuming far more. In the community with the highest average consumption (3 kWh/day), over 50% of consumers used under 1 kWh/day.

The above communities were all grid-connected and (except Port Olry) had 24 hour per day electricity supply. For newly-electrified Vanuatu consumers in remote households and villages, it can be safely assumed that the bulk of households will use no more than 1 kWh/day. For those connected to new mini-grids, it is unlikely that annual growth rate would exceed the Tanna average of 5% per household per year from 2002-2013, or 63% growth in a decade.

4.3 Renewable Energy Options for the Four Islands

Solar PV. From earlier sections of this report, it is concluded that the most practical option for rural electrification at present for the specific four islands assessed is solar photovoltaics. For the majority of rural households, solar has been and is likely to continue to be the preferred choice as it has both technical and cost advantages over other renewable energy technologies available in rural Vanuatu.

The four types of solar technologies being proposed for villages in the project islands are:

- *Solar mini-grids that provide 24 hour power at 230V AC and urban grid quality.* These are proposed for villages that have more than about 20 households of which several are willing to pay over 2000 Vt per month for services and most remaining households will accept between 500 and 1000 Vt/month as payment for electrical services. The village must be compact so that grid costs per household are minimized and land close to the village is likely to be available for the solar array and power house. Land access rights for the grid must be obtained as well.
- *Solar home systems ranging from 100 Wp to over 1000 Wp capacity and delivering DC power to the house but providing AC power through inverters dedicated to each AC appliance in the house.* Most villages will have some households use SHS because even those with mini-grids will have outlier houses that are too distant to connect economically to the grid. Those too small or too spread out to economically justify mini-grids are proposed to use SHS for customers with expected loads above about 0.4 kWh per day, with user fees per household starting at around 1000

Vt/month for O&M payments. A variety of sizes and capacities of SHS should be included so the generation closely fits the customer's load: all households receive the energy they need and are willing to pay for.

- *Pico-solar installations from a few Wp up to about 30 Wp of solar.* These are expected to be the most acceptable technology for the cash-poor households because they are the most cost effective for electrification when the energy requirement (and cash availability) is low, with payments around 500 Vt/month and less.

Options for other islands of Vanuatu. At this time, solar PV is recommended as the only practical and cost effective option for these particular islands as it is the only significant resource available that is known from experience elsewhere to be sustainable for energy production in remote rural villages. However, it is likely that other technologies such as biofuel, wind and small hydro may be technically and economically feasible for some remote islands of Vanuatu and should be considered when planning for nationwide rural energy development.

Biofuel could potentially be a technical option for Emae when the coconut resource recovers from cyclone damage in a few years' time. If, as expected, about 15 tonnes of copra are produced in Emae in 2016, and if all of it were made available at an acceptable price to generate electricity, the resource would be sufficient to generate about 1,400 kWh/month (enough for 160 households[26]) if the system operates efficiently with a high load of 60-75% of generator capacity; uses high quality copra and includes good O&M so the high efficiency of operation is maintained. But based on actual Port Orly experience when evaluated in 2010, more likely generation would be around 890 kWh per month (suitable for around 100 hh). However, even after the coconut resource recovers from the cyclone damage, the nearest village to the existing Emae coconut resource, Tabakoro, has only 16 households, the island's largest villages of Sangave (52 hh) and Tongamea (40 hh) are each well over 2 km distant by rough track and communities reportedly prefer to make high quality CNO for soaps and other high value products. Their income should be substantially higher than it would be selling the same amount lower quality oil for use as fuel.

Small-scale wind might be technically viable for Aneityum as it is at a higher latitude where wind speeds are generally higher than the lower latitude northern islands but there are no wind resource data suitable for energy resource estimation. Also the topography is such that year-round good wind speeds are likely to be found only a considerable distance from the populated areas on the northern and southern coasts. Unlike solar PV, the cost of small wind systems have not dropped appreciably in recent years and maintenance costs are high. Installations must also be designed to survive cyclone passages.

5. Recommended Renewable Energy Options based on National Energy Roadmap Principles

The National Energy Roadmap. Vanuatu's National Energy Roadmap: 2013-2020 was endorsed by the Council of Ministers in 2014. An Updated NERM: 2016-2030 was completed on 24 May 2016 and was expected to be considered for adoption by the Council of Ministers on Thursday 9 June 2016. Although

[26] This assumes that one tonne of dry copra produces 500 litres of coconut oil and with 2.25 kWh generated per liter (good O&M) or 1.4 kWh (Port Olry actual). Demand is assumed to be 8 kWh/m/hh with 10% station and line losses.

the overall NERM guiding principles are unchanged in the updated version, the time to reach some goals has been extended from 2020 to 2030. The guiding principles of the NERM 2013-2016 include: i) an Overall Vision; and ii) five areas of priority with specific goals:

- **Overall Vision**: "To energise Vanuatu's growth and development through the provision of secure, affordable, widely accessible, high quality, clean energy services for an Educated, Healthy, and Wealthy nation."

- **Priorities**. The five NERM priorities are:

  1) **Access: "**Access to secure, reliable and affordable electricity for all citizens by 2030;"

  2) **Petroleum Supply: "**Reliable, Secure and Affordable Petroleum Supply throughout Vanuatu" and also "Reduce reliance on imported diesel and petroleum products;"

  3) **Affordability: "**A more affordable and low cost of energy services in Vanuatu;"

  4) **Energy Security: "**An Energy Secure Vanuatu at all times" and this includes "Achieve a greater diversity of energy sources; and provide a framework for investment;" and

  5) **Climate Change: "**Mitigating climate change through renewable energy and energy efficiency."

  The NERM Update may have been considered by the Council of Ministers as this is being written in June 2016. It has a revised list of priorities as follows:

  1) **Accessible energy:** Electricity access to all households and public institutions

  2) **Affordable energy:** Includes developing mechanisms for competitive, affordable energy

  3) **Secure and reliable energy:** Includes increased diversity of energy sources away from petroleum.

  4) **Sustainable energy:** A sustainable energy system with increased efficiency of energy end-use but no specific text on financial or management mechanisms for sustainability.

  5) **Energy for green growth:** Includes renewable energy and energy efficiency for rural businesses.

The scope of work for this consultancy includes consideration of renewable energy options for remote islands based on NERM priorities, specifically the targets for access and affordability of energy. The NERM 2013-2020 and Updated NERM 2016-2030 covers these targets as follows:

- **Access**. The original NERM includes "access to secure, reliable and affordable electricity for all citizens by 2020" whereas the NERM Update changes this to "all households and public institutions" by 2030.
- **Affordability**. Regarding affordability, the original NERM refers to "a more affordable and low cost of energy services in Vanuatu,"… "well designed and targeted subsidies to address affordability of energy access especially for the poorer segments," a priority to "explore options (financial and technical) to increase affordability for … off-grid consumers," and finally promotion of "least cost investment in the electricity sector." The Updated NERM goes no further in defining affordability but notes that "in many cases, RE resources can be a lower-cost substitute for diesel and gasoline, and can therefore improve affordability for households and businesses" and that for rural off-grid households, "there may … be ongoing concerns with the ongoing costs of electricity as well as the connection costs. Future initiatives should focus on these areas to make the greatest gains against affordability and access targets."

In brief, the Updated NERM aims to provide access to affordable electricity to all citizens by 2030, although affordability is not defined. Considering the principles and targets of the NERM (both the original 2013 version and the 2016 update), there is no reason to change the recommendations of Section 4 of this report.

Annex 1: Documentation and Sources

This annex lists only documentation used for this report. A more complete list is annexed to other reports in this series.

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IUCN, 2009	Energy Ecosystems and Sustainable Livelihoods Initiative 3rd Quarter Report (IUCN Oceania October)
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PPA, 2010	The Port Olry Biofuel Project in Vanuatu – A Pacific Case Study: Technical Evaluation Report (prepared by Iese Toimoana with Thomas Jensen of UNDP and Rupeni Mario of SPC; September)
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SPC, 2015	Waves and Coasts in the Pacific: Cost Analysis of Wave Energy in the Pacific (Cyprien Bosserelle, Sandeep Reddy & Jens Krüger for SPC, USP & UNESCO); http://wacop.gsd.spc.int/WACOP-COE_Wave_Pacific-FINAL.pdf
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UNIDO, 2013	World Small Hydropower Development Report 2013 (*United Nations Industrial Development Organization & International Center on Small Hydro Power;* http://grein.irena.org/UserFiles/casestudies/Fijipdf *and* http://grein.irena.org/UserFiles/casestudies/Vanuatu.pdf
World Bank, 2009	Wind Resource Maps of the Far East islands (prepared by AWS Truewind, June)
World Bank, 2014	Vanuatu Rural Electrification Program (October)

Annex 2: DoE Evaluation of Vanuatu's PV Experiences and Lessons learned (2010)

(Original file name: 'Best Practice for Solar PV Systems - Island of Vanuatu')

There has been some minor editing of text to improve clarity.

Past experience	What happened?	What can be done to improve the situation?
Battery failure in rural areas	Lack of proper maintenance knowledge to maintain batteries in rural area (i.e. filling up water), batteries quickly became useless	Install maintenance free, sealed lead-acid batteries
Ceiling switches poor functionality (performance)	Ceiling switches quickly damaged and rendered useless due to positioning and location	Install wall switches
Standardising system parts	PV systems using all types of items; no set requirement for each building institution	Standardise systems in following categories; a) Classrooms, b) Staff houses, c) Dormitories, and d) Dispensaries
Missing parts	Missing parts were commonly noted among PV systems assessed	a) Set up institutional system to manage for long term sustainability; b) Employ & train local technicians to check & maintain system on scheduled intervals
Technicians leaving solar PV sites	Energy Unit trained school & health staffs to maintain the PV systems, but they tend to transfer from one institution to the next, i.e the Government system	Train local villagers instead of Government staff, they do not move around
Faulty items	Faulty switches, fluorescent tubes, regulators, batteries, etc were common at all sites	Set up institutional system to manage for long term sustainability
All types of brands were used	Battery models; Steco 3000, Fiamm, Trojan, N60, etc. Regulator models; Solsum, Omega, Prostar, Steca Solarix, etc…	Use specific brands that are sold in all range of capacities
Different types of battery capacities	Battery capacities were 6V 300Ah and 12V 105Ah	Upgrade systems; install mainly 12V 105Ah batteries
PV generally operational for maximum of 4 years	Systems installed in 2001 under Vanuatu Rural Solar PV project. By scoping mission in late 2009, Health & School heads advised they were not operational for more than five years ago.	Set up an institutional system to manage the system for long term sustainability
One school closed down due to Land issues	Botovro Primary school in Malekula island closed down due to land issues. Landowner dismantled and sold the PV systems	School name removed from list of schools to be rehabilitated
Institutions required extra PV capacity	New buildings were found at some sites and required additional PV systems	Improvement depends on availability of funds
Life time of PV batteries	Solar batteries generally have a life time of 5 to 7 years. Most installations were not operating due to these battery lifetimes	Technician advised that earlier recommendations for solar battery recharging stations is not practical idea as sites are scattered. Cheap option to re-charge batteries will help sustain them for long term
Different types of light capacities	Fluorescent tube capacities used were 12V 8W, 12V 13W, 12V 25W, 12V 18W, etc..	Install only 12V 7W on all sites, except maternity spot lights of 12V 35W

Annex 2 continued:
DoE Evaluation of Vanuatu's PV Experiences and Lessons Learned (2010)

Past experience	What happened ?	What can be done to improve the situation?
Lack of proper maintenance checklists	Maintenance checks are done without standard procedures and proper logs to document the items checked	Energy Unit is developing maintenance checklists to be issued to new local site technicians to assist them in routine checks. They will be required to tick each item checked and make comments where necessary. These lists are to be collected after 6 months for further analysis and future system upgrades.
Faulty medical fridges	Some health dispensaries have medical refrigerators that are not operational	Repair and or replace them
Frequency of PV systems checks	The PV systems must be checked on a routine basis	PV sites require a well-trained technician to do routine inspections every month
Batteries and regulators sustained damage easily	Due to their exposure, batteries and regulators sustained damage easily	Re-locate new batteries and regulators to safe storage locations, with proper boxes/casing for protection and safety
Solar PV System failure	It is difficult to repair or obtain parts readily for the systems / equipment when they break down	a) Set up an institutional system to manage for long term sustainability; b) Employ and train local technicians to check and maintain the system on scheduled intervals