Peer Reviewed
2017 Solar Research Conference

ASIA-PACIFIC
SOLAR RESEARCH
CONFERENCE

Vinal Vishal Prakash

Energy Needs Assessment and Strategies for 100% RE Future for A Small Island Community

Vinal Vishal Prakash[1] and Atul Raturi[2]

[1] *School of Engineering and Physics, University of the South Pacific, Laucala Campus, Suva, Fiji*
[2] *School of Engineering and Physics, University of the South Pacific, Laucala Campus, Suva, Fiji*
E-mail: vinalvishal@hotmail.com

Abstract
This work investigates the possibilities of renewable energy (RE) based interventions to build a sustainable community on a small island in Fiji. Yanuca Island is twenty kilometers away from the mainland (Viti Levu) with a population of approximately 210 people. Fishing is the main source of income for the villagers but with no electricity, storage of the catch is a huge challenge resulting in substantial losses. The village has no fresh water supply, and depends on rain water harvesting for cooking and drinking needs. The major challenge with current water supply is the frequent outbreaks of waterborne diseases, which are common in children and during the dry season, drinking water has to be carted from the mainland. Most islanders depend on kerosene lamps, small diesel generators and a few on portable solar lights for lighting. Use of fuelwood for cooking also poses a threat to the health of the community members as well as the degradation of environment.

The aim of this study is to investigate if Yanuca community would be able to satisfy most of its energy and drinking water needs using RE technologies. It involves an assessment of the RE resource potential on the island combined with the energy and water needs analysis of the community. A questionnaire based survey was carried out to assess the energy needs and priorities for the community. Based on the survey results, strategies are being developed to utilize available RE resources. A solar- battery hybrid mini grid system for electrical energy needs is being proposed to replace the defunct diesel generator. A solar thermal desalination system using F Cubed Carocells has been sized and installed to cater for drinking water needs of the community especially children who are vulnerable to waterborne diseases. A small solar powered refrigeration system has been established to support the income generation through enhanced fishing activities. A socio-economic study, through a questionnaire based survey and interviews will be carried out to determine the impacts of integrating strategies for energy access.

1. Introduction
The effects of climate change are becoming increasingly more apparent, with the greenhouse gas concentrations increasing up to 407.06 ppm in October, 2017 (NASA, 2017).The global warming phenomenon is strongly attributed to the greenhouse gases emitted mainly through the use of fossil fuels for energy production.

In contrast to fossil fuels, RE resources are abundantly available to cater for energy services. Many Pacific Island Countries (PICs) have developed plans to become a 100% RE nation. Due to their geographical isolation, islands need to develop sustainable energy resources which are economical and climate friendly. Examples of island energy development include King Island which was one of the first examples to be fully powered by a RE source ("Hydro Tasmania," 2015). Tau'u Island in American Samoa also transformed its electricity generation from 100% diesel to 100% solar in November, 2016 (Lin, 2017). Tokelau is almost fully solar electrified while Cape Verde has developed plans for transformation to 100% RE based electricity generation. Sustainable Development Goals (SDGs) and the Paris agreement are two recent major initiatives undertaken globally in response to climate change and energy security.

The International Renewable Energy Agency (IRENA) reported that 1.2 billion people (16% of the world population) lived without electricity by the end 2015 (REN21, 2017) mainly relying on kerosene lanterns for lighting needs. According to the World Health Organization (WHO), 9% of the global population did not have access to clean water in 2015, accounting for 842,000 deaths which includes 361,000 children under five years of age (WHO, 2016). Statistics revealed that at least 1.8 billion people consume water contaminated by faecal matter (WHO, 2016) .

Fiji , one of the PICs, lies between 12° to 22°S latitude, 177°E to 178°W longitude and is made up of more than 300 widely dispersed islands. The two main islands, Viti Levu and Vanua Levu, consist of the 90% of the total Fiji population (IEA, 2015b). The Fiji Electricity Authority (FEA) is responsible for generation, transmission and retail of electricity in the main islands (Viti Levu, Vanua Levu and Ovalau) while other larger islands have solar-diesel hybrid microgrids to cater for the electrical energy needs (FEA, 2017; IRENA, 2016). IRENA also reported that 20% of the rural population of Fiji did not have access to electricity by the end of 2014 (Chen, Gönül, & Zieroth, 2015). Small islands communities, without proper grid connections, solely depend on fossil fuels for lighting needs. Hurricane kerosene lanterns and limited-hours diesel generators are still common amongst the rural dwellers, without grid electricity.

Fiji is a tropical country, with an annual average rainfall of 2000 mm in dry zones and ranging from 3000 mm to 6000 mm in wet zones ("The climate of Fiji," 2006). Many smaller island communities do not have access to ground/surface water and rely solely on rainwater harvesting for their daily water needs. However, the water storage tanks has been stressed with below average rainfall rates in Fiji ("Fiji annual climate summary 2016," 2017). The water has to be carted to these islands, associated with a very high cost to the government or the islanders themselves.

1.1. Context of the Study

Yanuca is one of the islands of Fiji group, located south of Viti Levu and 20 km away from the mainland. The total population in 2016 was approximately 210 including the 5 primary school teachers.

Fishing is the main source of income for the Yanuca community, however, safe storage of the catch is a huge challenge with no electricity on the island. Sometimes, the catch has to be discarded due to unfavourable weather conditions for transporting it to the mainland which leads to substantial losses. Travel to mainland for purchase of ice and returning to mainland soon after catching fish puts additional costs on the fishermen while consuming a lot of time which could be used in other useful activities. A substantial amount of ice melts on the way, with almost only half of it remaining for actual storage of the catch (Lewanivanua, 2016).

The island does not have any ground or surface water and solely depends on rain water harvesting for water needs. Shortage of water and contamination leading to frequent outbreaks of waterborne diseases are common in children. The primary school has been closed many times due to the shortage of water at school.

Kerosene lanterns are most common in many households for lighting needs. Only 5 households have diesel gensets which operate for 2 hours daily on average. Almost all the households have at least 1 portable solar light used as night lights during sleeping hours. Kerosene lanterns however, only provide 1-6 lux of illumination while accomplishing fine tasks such as crafting, studying and weaving requires a minimum of 300 lux (Mills, 2003).

Traditional biomass in inefficient open fire stoves is commonly used in this community for cooking needs. A lot of time is spent on collection of dry wood, while women are involved in cooking and exposed to indoor pollution. Household indoor pollution has lot of health impacts while it attributes to an average of 4.3 million deaths annually around the world, as reported by WHO (Adair-Rohani et al., 2016).

The Fiji Department of Energy (FDOE) and FEA had installed a 45 kW diesel based generator 15 years back which was over sized compared to the requirement of 8 kW. The diesel operation came to a halt within 5 years, due to technical problems and the inability of the villagers to pay for the operations and maintenance costs.

1.2. Objectives and Motivation

The primary aim of this study is to determine feasible strategies to access energy services through clean and sustainable energy sources. The primary objectives are to; assess the RE potential on the island; assess the energy needs of the island community through surveys and questionnaires; determine feasible strategies to provide solutions for energy needs through RE sources and implement at least some of the strategies for the immediate needs of the community.

2. Renewable Energy Potentials

2.1. Solar Resource Potential Assessment

A number of assessments have been carried out in the Pacific region to determine the solar resource potential and these studies confirm that solar resource is abundant in all of the PICs.

Ground based measurements and satellite derived data are two basic methods of obtaining solar irradiation data for resource assessment. Ground based measurements have been taken from Yanuca Island to validate the satellite derived data for simulation studies. Ten years of satellite derived data ("Surface meteorology and solar energy," 2016) was compared with ground based measurements through Mean Absolute Deviation statistics and the results suggest that there is little deviation between the two sets of data. The annual average solar insolation was calculated to be 1.998 MWh/m^2, with the daily average of 5.445 kWh/m^2.

2.2. Other Renewable Energy Potentials

Wind resource assessment has been carried out using the wind data from NASA ("Surface meteorology and solar energy," 2016).The wind power densities range from 133 Wm^{-2} to 330 Wm^{-2} at 50m height and classified as class 2 under wind power classification system (Elliott, Holladay, Barchet, Foote, & Sandusky, 1987), which is marginal for wind energy development.

With no surface or groundwater on the island, hydro power development for power generation is not an option. Bioenergy potential is relatively low on the island, with small landmass area. Biofuel potential, in terms of coconut collections has been investigated through questionnaire based survey. Coconut sales is a major source of income for 3 families on the island hence could not be used for biofuel production. Being surrounded with abundant sea resources, algae farming could be done, however commercial technologies have not been proven in Fiji.

Smaller islands in Fiji like Yanuca have been assessed for geothermal potential but do not have potential for geothermal power developments (Cox, 1982). The annual wave energy flux in Yanuca islands is estimated to be 1.6 kW/m (Bosserelle, Reddy, & Lal, 2015), while an energy flux of 7 kW/m is regarded the benchmark for investigations on wave energy development. Tidal variation on Yanuca shores are relatively low, hence tidal energy development is not an option.

3. Energy Needs Assessment

3.1. Data Collection

Questionnaire based survey, personal interviews and observations were used for the energy and water needs data collection. Talanoa sessions were held with the villagers and the school teachers to enquire the essential energy requirements and the current situation on the island. Each questionnaire was given to 38 households to indicate their preferences and immediate needs of the energy services.

3.2. Needs of the Yanuca Community

From the survey, the most immediate need of this community was access to clean drinking water. Shortage of fresh water on the island has been a major problem, with below average rainfall in recent years. The survey results indicate that total water requirement for the village for drinking needs approximates to 250 liters per day. The total water requirement approximated to 2.2 m^3 of water, of which 1000 l for cooking and and approximately 1800 l for other activities apart from drinking. With a huge amount of money spent on carting clean water for the village, the cost of water turns out to be $0.14 per liter just from the mainland to the island. In events of severe drought conditions, the villagers have to spend almost $250 per week, for carting drinking water only.

A huge burden on the community lies due to the transportation costs associated with transporting fish to the mainland for sales on daily basis, since fishing is the main source of income for the villagers. This includes travel to the mainland for purchase of ice, return to the island, fishing trip and later transportation to the mainland for sales. A significant fraction of fishermen's carbon footprint is emitted to the atmosphere due to travel, while leaving the fishermen with relatively small income.

Preferences on electrical energy needs for the community was also gathered through questionnaire based survey. The table below illustrates the energy needs of this community. Mobile charging is common to all the households, while 37.5% of the households either had TV sets at home, or had an intention of buying one, once supplied with the electricity. The canteen operator had plans to operate a refrigerator for sales of frozen goods. The islanders, in general, did not have much interest in bringing in other electrical appliances, such as washing machines, iron or other kitchen appliances. The electrical loads for the primary school include the computer sets, photocopier and laptops while a sound system is used in the village community hall.

Table 3.1: Electrical energy demand for Yanuca Island community

Appliance	Number of Appliance	Duty Cycle (hours/day)
Lights	140	4
Sleeping lights	50	10
Radio	38	4
Mobile Charging	60	2
Television Sets	17	3
Refrigerator	1	12
Computer Set	3	3
Photocopier & Sound System	1	2
Laptops	3	4

Traditional biomass is usually utilized as fuel for cooking in rural areas. However, this island community depends on a mix of fuel for cooking, as shown in Figure 3.1. An average of 380 liters of kerosene per month is used for cooking by the 35 households. Efficient ‘rocket’ biomass stoves were introduced about 10 years back ("Biological survey of Yanuca MPA," 2008), however the villagers lost interest and some have switched to LPG as an alternative.

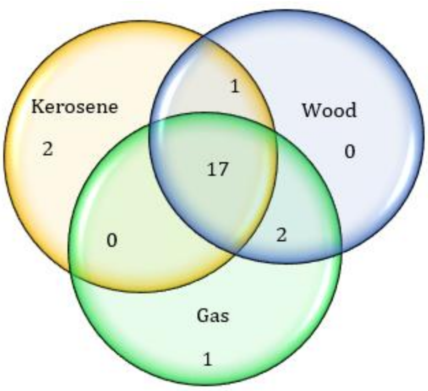

Fig 3.1: Fuel used by Yanuca island households for cooking needs

The survey results indicate that most immediate needs for the community are a RE based clean drinking water system and a solar powered refrigeration system that would significantly improve health, increase income generation opportunities while reducing the fossil fuel expense.

4. Strategies for Sustainable Energy Access

4.1. Water Needs

A solar thermal desalination system was designed and installed at Yanuca after considering various options. A carocell system with almost no moving parts and zero maintenance has been opted for, since remote islands do not have easy access to technical assistance as well as the inability of the community members to pay for high maintenance costs. Figure 4.2 shows the construction of the desalination system in Yanuca.

After analysing the drinking water needs of the community, 16 carocells were purchased from F-Cubed Limited, an Australian company, and tested for efficiency and water production. Water production results from a single carocell on a typical day before installation in Yanuca are shown in figure 4.1.

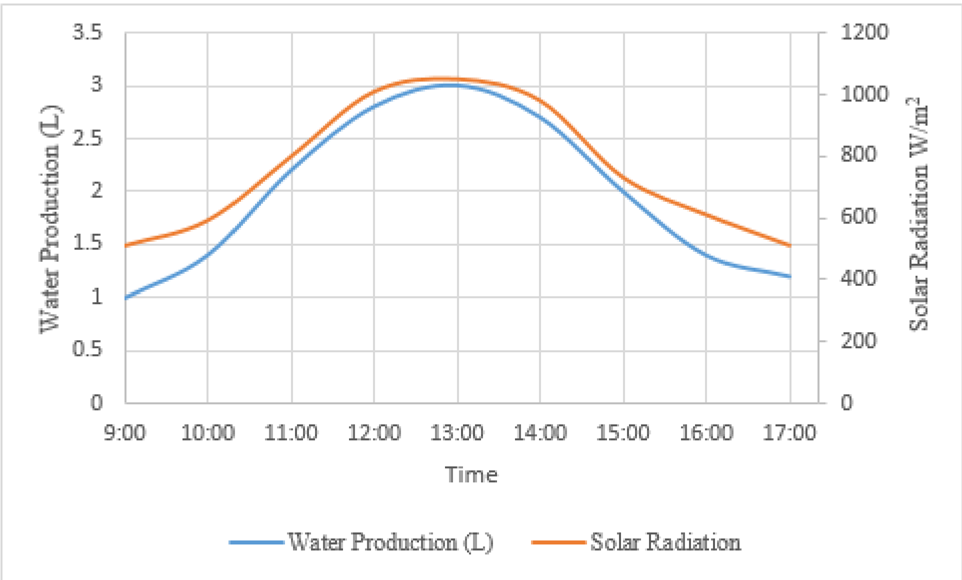

Fig 4.1: Water production compared with the hourly solar radiation

Figure 4.1 shows variation of water production (L) and efficiency of a carocell with hourly solar radiation (Wm^{-2}) on a typical day. The efficiency of the carocells increases during the daytime, with increasing radiation. Table 4.1 shows the variation of efficiencies at one hour intervals on a typical day.

F Cubed carocells were opted for as they have high efficiencies, up to 65%, and do not require any electrical energy for operations, other than pumping water into the panels. The desalination system consists of 16 carocell to cater for the drinking water needs. These units also have a built-in rainwater collection system providing clean during rainy days. On a typical sunny day, each carocell installed at Yanuca is expected to produce up to 16 liters of water per day, totalling 250 liters for the whole system enough for the drinking water needs (250 l) of the community. Given the specifications, the expected life span of these carocells are 15-20 years while the cost of water is estimated to be $0.02 per liter. A bottled liter of water would cost more than a dollar in comparison.

Table 4.1: Carocell efficiency versus solar radiation.

Time	Production (L)	Average Solar Radiation (W/m^2)	Efficiency (%)
8 am – 9 am	1.0	508	47.3
9 am – 10 am	1.4	590	57.0
10 am – 11 am	2.2	798	66.3
11 am – 12 pm	2.8	1009	66.7
12 pm – 1 pm	3.0	1050	68.7
1 pm - 2 pm	2.7	980	66.2
2 pm – 3 pm	2.0	730	65.9
3 pm - 4 pm	1.4	609	55.3
4 pm- 5 pm	1.2	509	56.7
Average			**62.7**

Fig 4.2: Construction of the Desalination system

Table 4.2 shows the desalinated water quality test results .

Table 4.2: Water quality test levels compared with seawater and accepted levels in drinking water

	Accepted Level	Sea Water	Desalinated Water
pH	6.5-8.5	7.68	7.33
Salinity	-	22%	0%
Conductivity (µS)	<1000	15100	150

The tests (Table 4.2) confirm that the desalinated water is safe for drinking. An H_2S strip test was also carried out to test for bacterial content while the results indicate that no bacterial content is present in the desalinated water. Five villagers were randomly selected to take a blind drink test where 4 of them indicated that desalinated water had better taste compared to other samples of bottled water; tap water from main and; and water from the village storage tank.

With the installed desalination system, shortage and contamination of water for drinking is no longer an issue for the Yanuca Islanders. The system, reduces the expense and carbon footprint of carting water to island in times of need. With the availability of clean drinking water, a decrease in outbreaks of waterborne disease in children is evident as well (Vutevute, 2017).

4.2. Solar Powered Refrigeration System

A solar PV powered electric refrigeration system has been installed in the community to cater for the cold storage needs of the community. The respondents of the survey indicated their urgent need for this facility as 50% of the households depend on fishing as their source of income.

The solar PV operated refrigerator system was slightly oversized with no back up generator. Table 4.3 shows the specifications of the installed freezer system.

Table 4.3 Solar PV powered refrigerator specifications table

Item	**Specifications**
Solar Panels	1 kWp Installed Capacity, Trina Solar, 250 Wp modules
Batteries	600 Ah storage Capacity 48 V, VLRA AGM Deep Cycle Batteries
Inverter	2.3 kW Outback Inverter
Charge Controller	80 Amps MPPT Outback controller
Freezers	2 Energy Efficient Modyl Chest Freezers, 360 kWh/Year
Lights	2 Energy Efficient LED light bulbs (10 W each)

The input characteristics are stored in the charge controller and are used for the monitoring of the installed system. Fig 4.3 shows the input energy from the solar panels to the batteries for a period of 3 months.

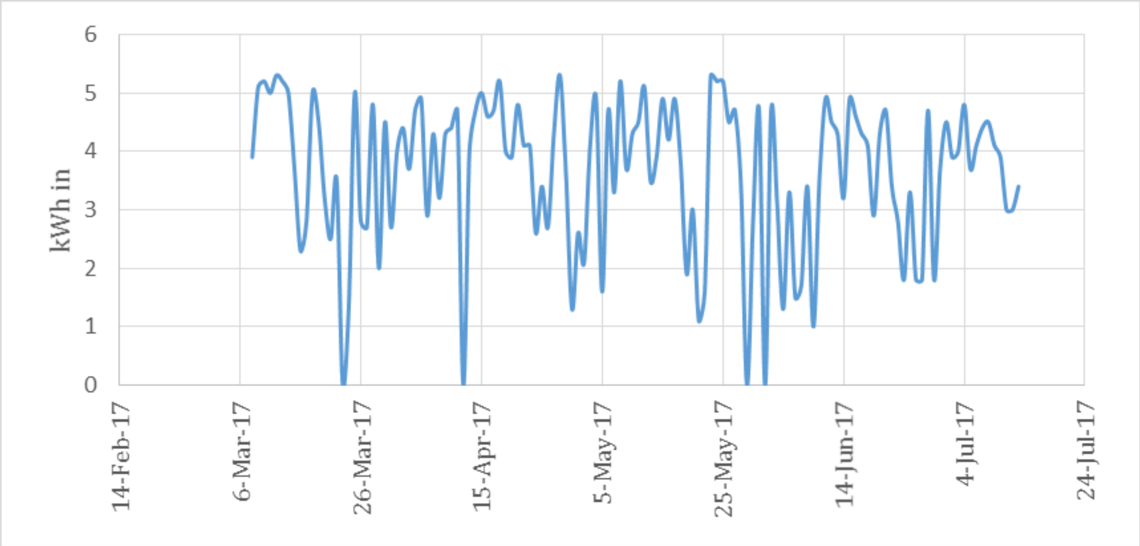

Fig 4.3: Input energy from solar panels to batteries over a period of 3 months

The data was retrieved from the charge controller to monitor the input energy from the solar panels. Zero input from the solar panels corresponds to the battery at 100% state of charge, with no load on that particular day.The daily energy consumption averages to 3.46 kWh with the storage capacity of 14.4 kWh, corresponding to 4 days of autonomy.

With the installed facility, the fishermen store fish and only deliver to the mainland for sales once enough stock is available. This intervention has cut down on the number to trips made to mainland for ice buying and transportation of small amounts of fish . Income generation, travel and carbon footprint reduction are the two main outcomes of this project.

A committee comprising village women, manage this facility and charge certain amount of fee to store fish in the freezer. An average of 300 FJD per month is collected as fee and profit from sales of ice cream and frozen goods. The simple payback time of this facility is calculated to be 6 years and this project would be self sustainable if managed properly.

4.3. Solar PV system for Electrical Needs of Yanuca Community

Yanuca island is blessed with plentiful sunshine and solar systems are the most feasible source for electricity production in remote areas, with small loads and absence of hydro power. Reticulation wires are still intact in the village from the defunct diesel mini-grid, while a solar-battery hybrid system is proposed for future electrical energy needs of the community.

Simulation studies for a community PV-battery system for Yanuca island have been carried out using the PVSyst 6.47 software. The peak load of this community turns out to be 9 kW, occurring between 10 am to 12 pm, with use of sound systems and photocopier machines at the school. The average daily electricity requirements for this village is approximately 62.5 kWh/day. Table 4.4 shows the details of a PV system proposed for the Yanuca Island Community.

Table 4.4: Proposed PV system for electrical needs of Yanuca community

Item	Specifications
Solar Panels Capacity	20.1 kWp
Batteries Capacity	4800 Ah
Inverter	15 kW
Charge Controller	MPPT 48 V Inverter

The total solar energy produced by the system would be 22.3 MWh/year with an excess of 3.5 MWh/year. The excess energy is available in the summer months in Fiji, which could not be fully utilized by the loads that the community members intended to use as the system was optimized on yearly basis.

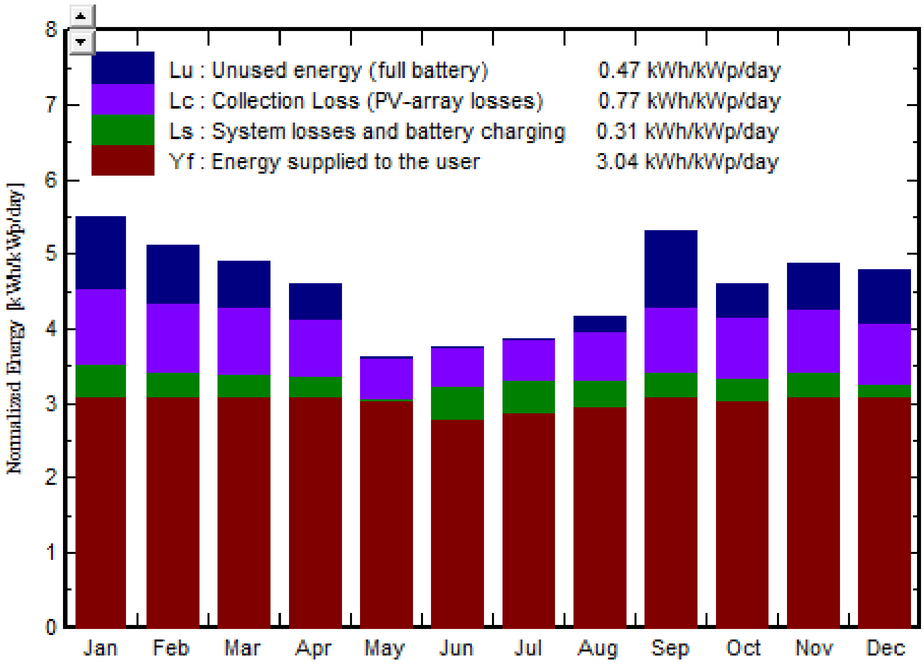

Fig 4.2: Normalized PV production (per installed kWp): Nominal power 20.1 kWp

Economic analysis suggests the cost of energy of the proposed system would be $0.69/kWh. The cost of energy generation through the proposed system is lower than the cost of diesel based electricity generation, of about $1.88/kWh. The proposed system would reduce the carbon footprint of 203.8 tonnes of CO_2 compared to a diesel based electricity generation (Mani, 2017). Installation of the system would promote activities such as extended study hours , weaving and other income generation activities in the evenings, as well as reduced exposure to indoor pollution.

5. Discussion and Conclusion

This study aimed to assess the energy needs of the small island community of Yanuca, develop strategies for energy services using RE sources and implement solutions for the most immediate needs of this community. RE potential has been assessed on the island and with a solar resource of 5.445 kWh/m^2/day, solar energy seems to be the most feasible for providing energy services

The most immediate needs of the community was the availability of potable water totalling approximately 250 liters per day. F-cubed carocell based thermal desalination system now caters for this need. A solar PV refrigeration system helps the community members in income generation while cutting down their expenses on sea transport.

A solar PV mini grid system has been proposed for electrical energy access to the villagers. A 20.1 kWp system coupled with 4800 Ah battery storage could cater for the electrical needs of the whole community including the primary school. Installation of the system could allow activities such as studying, weaving and crafting in the evenings, as well avoid exposure to indoor pollution, reducing impacts on human health. Clean cook stoves are recommended for cleaner options in the community, while there is slow transition from fuel wood to LPG for cooking needs.

The bottom line approach to achieve sustainable development has been applied in this study, namely, economic development in terms of income generation, environmental action through reduction of carbon footprint and social inclusion through eliminating health impacts on human health in the community. This study provides a foundation for future directions for a remote 100% RE island and implementation of the recommended systems would enable Yanuca community to contribute towards meeting sustainable SDG 7, 6, 3 and 13.

References

Adair-Rohani, H., Lewis, J., Mingle, J., Gumy, S., Neira, M., Dora, C., Brinkman, V., Bruce, N., Drisse, M., Charney, A., Clancy, J., Dorner, D., Freeth, R., Hellpap, C., Kees, M., Janik, V., Patech, H., Pattersen, M., Prüss-Ustün, A., Puzzolo, E., Rasanathan, J., Vera, I., Vogel, J., Whiteman, A., Zachary, B., & Zhang, T. (2016). Burning Opportunity: Clean Household Energy for Health. *Sustainable Development, and Wellbeing of Women and Children (WHO, Geneva) Tech Rep*.

Annual report 2015. (2015) *Hydro Tasmania* (Vol. 10).

Biological survey of Yanuca MPA. (2008) Pacific Blue Foundation 2008 Annual Report.

Bosserelle, C., Reddy, S., & Lal, D. (2015). Fiji nearshore wave hindcast, Yanuca Island *WACOP wave climate reports*.

Chen, Y., Gönül, G., & Zieroth, G. (2015). Fiji renewables readiness assessment *International Renewable Energy Agency* (pp. 60).

Cox, M. E. (1982). *Geothermal assessment of the Fiji islands: an overview.* Paper presented at the Pacific Geothermal Conference, New Zealand.

Atmospheric CO2 (2017). *Earth's CO2 Home Page.* Retrieved 13 October, 2017, from https://www.co2.earth/

Elliott, D., Holladay, C., Barchet, W., Foote, H., & Sandusky, W. (1987). Wind energy resource atlas of the United States NASA STI/Recon Technical Report N (Vol. 87).

FEA. (2017). About Us. *Fiji Electricity Authority*. http://www.fea.com.fj/about-us/; accessed on 1st June 2017
Fiji annual climate summary 2016, Retrieved 10 October,2017, from http://www.met.gov.fj/Summary2.pdf
IEA. (2015a). Energy and Climate Change *World Energy Outlook Special Report* (pp. 18). Paris: International Energy Agency (IEA).
IEA. (2015b). Fiji's intended nationally determined contribution. *International Energy Agency*. Retrieved 5 June, 2017, from http://www4.unfccc.int/submissions/INDC/Published%20Documents/Fiji/1/FIJI_iNDC_Final_051115.pdf
IRENA. (2016). A path to prosperity: renewable energy for islands *International Renewable Energy Agency*. Masdar City, Abu Dhabi.
Lenz, L., Montenbruck, L., & Sievert, M. (2017). Accidents caused by kerosene lamps: New evidence from African household data: Ruhr Economic Papers.
Lewanivanua, J. (2016, 24 November).
Lin, D. (2017). How a Pacific Island changed from diesel to 100% solar power. *National Geographic*. Retrieved 18 September, 2017, from http://news.nationalgeographic.com/2017/02/tau-american-samoa-solar-power-microgrid-tesla-solarcity/
Mani, J. S. (2017). Carbon footprinting and mitigation strategies for the USP Marine Campus. (Master of Science), The University of the South Pacific, Fiji.
Mills, E. (2003). Technical and economic performance analysis of kerosene lamps and alternative approaches to illumination in developing countries *Lawrence Berkeley National Laboratory*.
NASA. (2017). Vital signs of the planet. *Global Climate Change*. Retrieved 18 October, 2017, from http://climate.nasa.gov/vital-signs/carbon-dioxide/
REN21. (2017). Renewables 2017 global status report. Paris.
Surface meteorology and solar energy. (2016). Atmospheric Science Data Center. Retrieved 30 July, 2017, from https://eosweb.larc.nasa.gov/sse/
The climate of Fiji, Retrieved 10 October, 2017, from http://www.met.gov.fj/ClimateofFiji.pdf
The Paris agreement summary. (2015) *Climate Focus*. Netherlands.
The sustainable development agenda. (2016). *Sustainable Development Goals*. Retrieved 08 September, 2017, from http://www.un.org/sustainabledevelopment/development-agenda/
Vutevute, R. (2017, 24 November).
WHO. (2016). Drinking-water. *World Health Organization*. Retrieved 04 May, 2017, from http://www.who.int/mediacentre/factsheets/fs391/en/