TECHNO-ECONOMIC FEASIBILITY OF GRID CONNECTED PV SYSTEMS IN THE PACIFIC ISLAND COUNTRIES

Atul Raturi and Aman Singh

School of Engineering and Physics

University of the South Pacific, Suva (Fiji)

1. Introduction

The Pacific Island Countries (PICs) constantly grapple with the extreme dependence on imported fossil fuels for electricity generation even when more than 70% of the regional population is not connected to any source of electricity. The petroleum dependence is reflected in the Oil Price Vulnerability Index (OPVI) developed by the UNDP that depends on a number of local factors such as petroleum intensity and economic strength (Balchandra and Mongia, 2007). A 2009 ADB study of 39 developing countries showed that all PICs are among the most vulnerable countries with seven among the top ten (ADB,2009). The petroleum intensity (ratio of petroleum products consumption compared to total primary energy consumption) for Kiribati and Vanuatu is 100% with others not very far behind (PNG and Fiji are close to 75%). Table 1 shows the OPVI ranks for some of the PICs.

Tab. 1: OPVI and overall rank (out of 39 developing countries) for the PICs (ADB, 2009)

Country	OPVI	Rank
Kiribati	1.00	1
Tonga	0.80	2
Fiji Islands	0.79	3
Vanuatu	0.76	4
Solomon Islands	0.74	5
Samoa	0.73	6
Papua New Guinea	0.66	7

Table 2 shows the cost of electricity in FJD per kWh for a number of PICs. The cost in Fiji is the lowest as more than 50% of the electricity is generated using hydropower. The exorbitantly high tariff in Solomon Islands reflects the cost of imported petroleum used in electricity generation.

Tab. 2: PIC Electricity Tariff - Fiji cents/ kWh (Source : Fiji Commerce Commission, 2010)[1]

Country	Tariff , Fiji Cents
Fiji	39.40
Palau	43.09
Samoa	58.75
PNG	60.12
Kiribati	61.81
Tuvalu	69.08
Niue	83.79
Tonga	89.38
Vanuatu	93.30
Cook Islands	93.56
Solomon Islands	147.83

In Fiji, hydro resource is mostly available only on the main island of Viti Levu and electricity generation is a mix of hydro and thermal. The production is all thermal on other islands. Consequently, generation costs

[1] 100 Fiji cents = 53 US cents

are lowest in Viti Levu and increase considerably for other locations. There is a national tariff of 34 cents per kWh and customers consuming less than 76kWh/month receive a government subsidy of almost 50%.

The PICs are blessed with abundant renewable energy resources and RE based electricity generation can alleviate the lack of energy to a great extent. The plentiful solar energy available throughout the region is one of the best resources available. Solar Home Systems (SHS) have been deployed in islands for many decades now and have proved to be very useful in improving the living conditions of rural communities (Wade et al, 2005). There are number of current interventions helping expand this technology to hitherto unserved communities[2].

While SHSs are very useful in remote locations, larger urban centre RE based systems will have to be built in order to make a significant impact on the fossil fuel consumption. There is an increasing interest in developing grid-connected PV systems in the PICs. Table 3 shows grid connected PV systems installed or being planned in this part of the world.

Tab.3: Grid connected PV systems in the PICs

Country	Project (year)	Funded by
Nauru	40 kW_p system at the Nauru college, roof mounted (Oct 2008)	REP 5 (EDF 10)
Niue	20 Kw_p roof mounted, 30kW_p ground mounted and 2 kW_p (July 2009)	REP 5 (EDF 10)
Palau	100 kW_p roof mounted	REP 5 (EDF 10)
FSM	Five grid connected systems (total 52.5 kW_p) and a number of mini-grid systems (ept 08-March 09)	REP 5 (EDF 10)
Tuvalu	40 kW roof top mounted (2008)	e8
Tuvalu	46 kW (2010)	Austria//Italy/ IUCN
Tonga	1.5 MW (In progress)	Various under Tonga Energy Road Map

2. Present Work

A 54 kW grid-connected PV system is being established at the University of the South Pacific. This paper looks at the preliminary design and economics of this system and feasibility of similar systems in other PICs.

2.1 RETScreen[3]

RETScreen Clean Energy Project Analysis Software developed by Natural Resources Canada (NRCan) is a very useful tool for evaluating renewable energy and energy efficiency projects in terns of energy production and savings, economic analysis and greenhouse gas reduction among other features. We have used RETScreen to perform a pre-feasibility analysis for the proposed system and a cash flow analysis under various scenarios.

2.2 Location of the project

The project will be located at the lower campus of the University of South Pacific, Suva, Fiji (latitude: 18.09 S, longitude: 178.27 E).

---

[2] For example 1500 SHSs being deployed in the North Pacific countries under North REP.of EDF 10 ,

[3] RetScreen International ,, http://www.retscreen.net/ang/home.php

2.3 Solar resource:

The solar radiation data for the location was taken from the NASA surface meteorology and solar radiation website[4]. The uncertainty in satellite based solar radiation measurement is in the range 12-13 % on daily basis (Pagola et al, 2010). Fig. 1 shows the average solar radiation and the clearness index for this site.

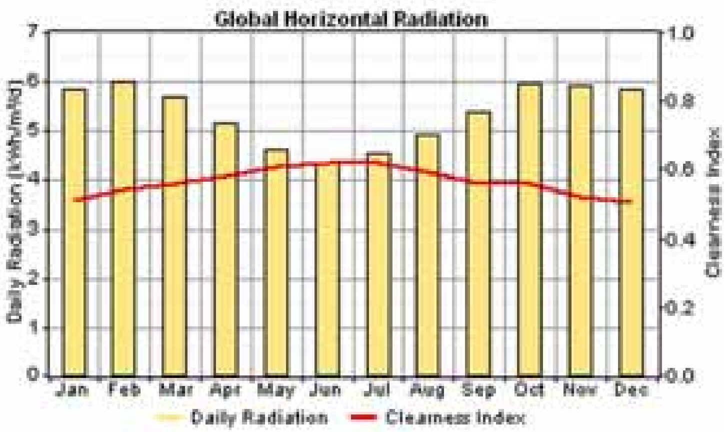


Fig. 1: Average Daily Solar Radiation and Clearness Index

We also employed Solmetric SunEye to get an idea of the solar access at the proposed site and to identify any obstructions to solar radiation (trees, shrubs etc.).

Fig. 2: USP lower campus

Figs.2 and 3 show that the proposed site has an annual average solar access of 89% considering the site-specific shade conditions (shading). Measurements were made for 16 'skylines' within the site. A skyline includes a 'fisheye image', a sunpath diagram and solar access calculation for that location.

[4] http://eosweb.larc.nasa.gov/sse/RETScreen/

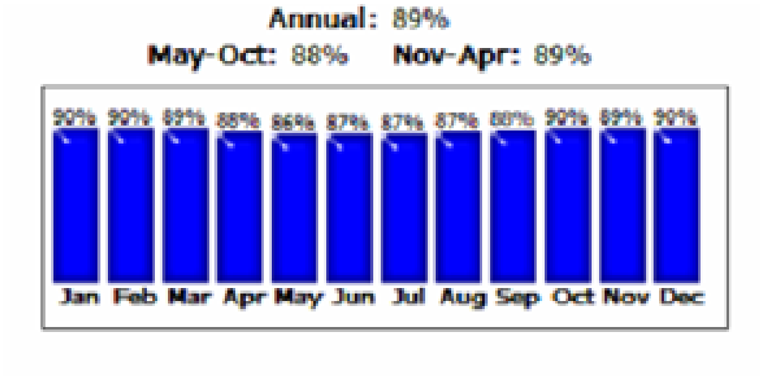


Fig. 3: Solar access (Suneye). Averages for 16 skylines

2.4 *Technical details of the proposed PV system*

The major components of the proposed 54 kW grid connected solar system are given in table 4.

Tab. 4: System components

Components	**Description**	**Quantity**
Solar panels	BP Solar 190W, 24V BP4190T	288
Inverters	SMA Sunny Mini Central 9000 (SMC9000TL)	6
Solar panel mounting	Unirac U-LA Ground Mount	2 x Sub Arrays
Monitoring System	Sunny Web-box	1
Inverter mounting	Sunny Tower	1

i) Solar Panels

The BP4190T series of solar panels comprising 72 cell monocrystalline modules and manufactured by BP Solar will be used in this project. Table 5 gives the main parameters of these modules

Tab.5: Technical Specifications of the BP4190T Module

Solar Panel Manufacturer	BP Solar
Solar Panel Model	BP 4190T
Maximum Power (P_{max})	190W @ STC 1000W/m^2
Voltage at P_{max} (V_{mpp})	37.1V
Current at P_{max} (I_{mpp})	5.12A
Short Circuit Current (I_{sc})	5.56A
Open Circuit Voltage (V_{oc})	45.3V
Nominal Voltage	24V

ii) Inverters

Transformer-less Sunny island inverters manufactured by SMA will be employed in this project. The inverter tower is an outdoor IP44 rated enclosure housing 6x Sunny Mini Central 9000 TL inverters. The inverters are configured as a three-phase output (415V) system where two inverters are connected across each of the three phases. Synchronisation in between per phase inverters and across the three phases is facilitated by a RS485 communications cable across the six inverters.

iii) Solar Array Mounting Structure

A standardised mounting structure by Unirac will be used to mount the solar array on the ground. The U-LA series of mounting system from Unirac is specifically designed for large PV ground mount arrays. A concrete beam will run across both the front and rear legs of the solar array for the footings.

iv) System Monitoring, Control and Analysis

System monitoring, remote diagnosis, data storage and visualization will be facilitated by the Sunny Web box. It continuously collects all the data from the inverters on the system side and can also be configured to upload system performance data to the Sunny Portal.

In addition to the WebBox, a Sunny Sensor Box is also to be installed. The sensor box, installed directly beside the solar array, measures irradiation and module temperature. The Sensor Box communicates with the WebBox to also upload meteorological data to the Sunny Portal for system performance analysis.

v) System Design & Configuration

Table 6 highlights important parameters and configuration of the proposed PV solar grid connected system.

Tab.6: Technical details of the system

PV Peak Power	54.72kW
Total Number of PV modules	288
Total Number of SMC9000TL inverters	6
Grid Nominal Voltage	240/415V
Minimum DC Voltage	347V
Maximum DC Voltage	700V
PV Array Specifications	
Minimum PV Voltage	357V
Typical PV Voltage	396V
Maximum PV Voltage	613V
Single PV Module rating	190W
Number of PV modules per string	12
Number of PV strings in PV array	24 strings between 6 inverters

3. Results and discussion

The main results of RETScreen analysis are shown in table 7 that follows. A total of 81.305 MWh of electricity will be exported to the grid.

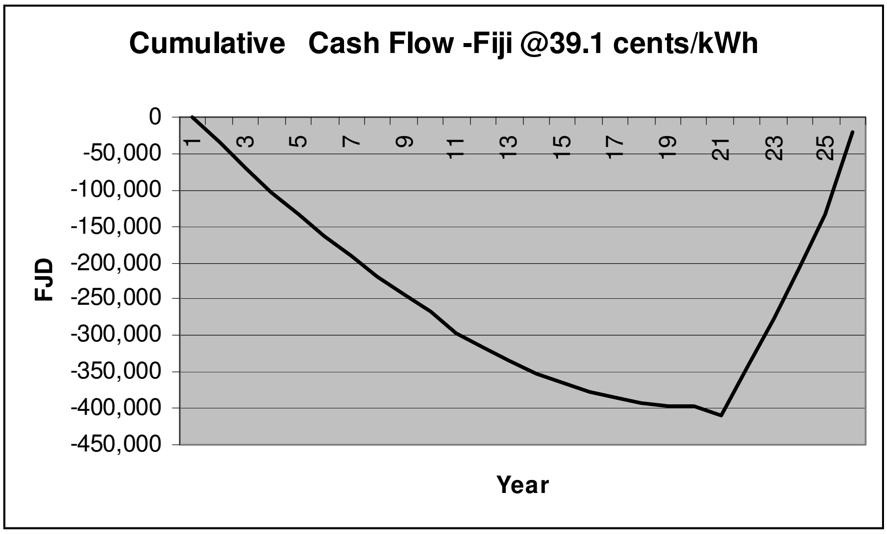
Tab. 7: Main results from RETScreen analysis

Month	Daily solar radiation - horizontal	Daily solar radiation - tilted	Electricity exported to grid
	kWh/m²/d	kWh/m²/d	MWh
January	6.18	5.85	7.512
February	6.16	6.01	6.943
March	5.58	5.68	7.266
April	4.82	5.16	6.431
May	4.11	4.62	6.005
June	3.78	4.32	5.467
July	3.95	4.51	5.905
August	4.51	4.93	6.435
September	5.17	5.36	6.746
October	6.04	5.97	7.714
November	6.21	5.92	7.390
December	6.21	5.83	7.492
Annual	5.22	5.34	81.305

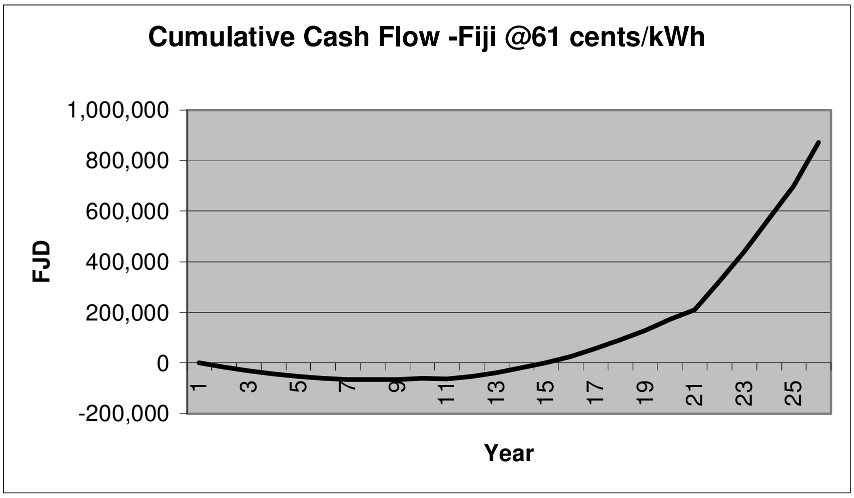
3.1 Cash flow analysis

We have assumed a discount factor of 6%, 100% debt ratio with a 7% interest rate in the cash flow analysis for the proposed system. The Fiji government has made all renewable energy equipment import to be duty free (12% VAT applies). It is envisaged that the independent power producers (IPPs) will play a very important role in renewable energy based electricity generation in Fiji (FEA, 2010) and other PICs. The regional governments are developing incentives to attract more players in this sector. It is imperative that the IPPs receive a reasonable return on their investments.

Figs 4-6 below show the cumulative cash flow based on payment (per Fiji cents/ kWh) made to the project developer. Fig. 4 shows that the a payment of 39.1 cents/ kWh will not be very lucrative to the IPP while increasing it to 61 cents/kWh (close to the cost of current diesel based generation) will make it a more reasonable investment.

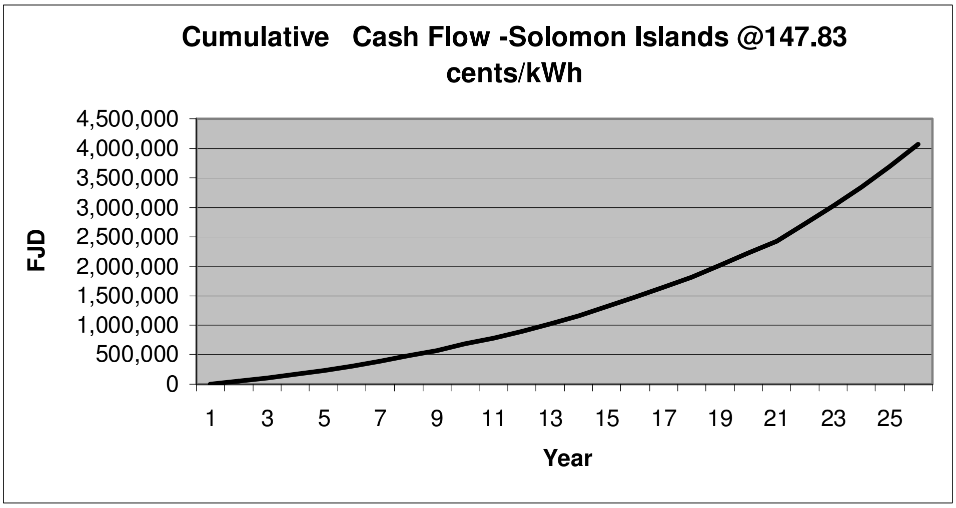


Fig, 4: Cumulative cash flow analysis (Fiji IPP rate Fiji 39.1 cents/ kWh)



Fig, 5: Cumulative cash flow analysis (Fiji IPP rate 61 cents/ kWh)

As mentioned in the Introduction, the cost of electricity in Solomon Islands is the highest among all PICs. A grid-connected PV system similar to the above would make a sensible investment for an independent power producer.



Fig, 6: Cumulative cash flow analysis - Solomon Islands (Tariff Fiji 147.83 cents/ kWh)

3.2 Emission Analysis

This project will be able to reduce 48 tonnes of CO_2 emission annually considering that only 40% of the electricity in Fiji is produced using diesel. In Solomon Islands, where the generation is entirely thermal, the reduction would be about 80 tonnes per year.

It should be possible to develop a number of such systems as part of a Programmatic Clean Development Mechanism (p-CDM) project in these countries. The PICs have not been able to participate in this process due to small mitigation capacities. Programmatic CDM is a step in the direction of helping them participate in the process and will bring additional income to the project proponents.

3.3 Issues with Grid connect systems

Most of the PIC grids are weak with a large variation in voltages and frequencies. It has been reported from Nauru that the poor grid quality is affecting the performance of the newly installed PV system. The diesel generator based grid frequencies were found to be out of range requiring the inverter settings to be regularly monitored (McCracken, 2009). Similar problems have been reported from Niue (private communication).

3.4 Capacity Building

One of the major objects of this project is to use the system for training and capacity building in the Pacific region. At present, Fiji does not have a grid-connected PV system in existence and this set-up will be used as a training ground for future solar technical personnel and USP students. The system–grid coupling will be continuously monitored in terms of frequency, voltage and harmonic distortions.

This project is being financed by the government of South Korea under its East Asia Climate Partnership and implemented by the USP and Korea International Cooperation Agency (KOICA).

4. References

Asian Development Bank, 2009, Taking control of oil- managing dependence on petroleum fuels in the Pacific, ISBN 978-971-561-862-5

Balchandra, P. and Mongia, N., 2007, Oil Price Vulnerability Index (OPVI) for the Developing Countries of Asia and the Pacific, Regional Energy Programme for Poverty Reduction. http://regionalcentrebangkok.undp.or.th/practices/energy_env/rep-por/documents/Oil-Price_Vulnerability_Index%20_OPVI_%20for_the_Devloping_Countries_of_Asia_and_the_Pacific-Full_Technical_Paper.pdf, accessed on 15th July 2011

Fiji Commerce Commission, 2010, http://www.commcomm.gov.fj/Press/FEA%20Det%20211010%20Reddy.pdf, accessed on 5th August 2011

Fiji Electricity Authority, Annual report, 2010. www.fea.com.fj, accessed on 1st August 2011

Philippe Mccracken, Grid-connected PV in the Pacific, www.exposolar.org, accessed on 15th June 2011

Pagola, I. and Gastón, M., Fernández-Peruchena, C., Moreno, S., Ramírez, L Renewable Energy, 2010, New methodology of solar radiation evaluation using free access databases in specific locations 35, 12, 2792-2798

Wade, H., Johnston, P. and Vos, J. 2005. Pacific Regional Energy Assessment 2004: An Assessment of the Key Energy Issues, Barriers to Development of Renewable Energy to Mitigate Climate Change, and Capacity Development Needs to Removing the Barriers, Regional Overview Report. Volume 1. SPREP, Apia.