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Techno-economic analysis of a hybrid mini-grid system for Fiji islands

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Abstract

The Pacific Island Countries constantly struggle with the challenges of high petroleum dependence for their electricity production and lack of adequate energy services. It is possible to alleviate the energy poverty by utilizing abundant renewable energy resources available in the region. The objective of this work is to investigate the feasibility of a wind/solar photovoltaic/diesel generator-based hybrid power system in a remote location in Fiji islands. We used the Hybrid Optimisation Model for Electric Renewables (HOMER) software to simulate the system and perform system optimisation analysis. The system characteristics were studied in terms of optimal configuration, net present cost and the cost of energy. An entirely renewable energy-based configuration is feasible if 10% annual capacity shortage is allowed, while for a scenario with no capacity shortage, addition of a diesel generator is necessary. The addition of renewable energy components results in greenhouse gas reduction which could be used for carbon trading.

Keywords: Hybrid mini-grid system, HOMER, Fiji islands

Background

The Pacific Island Countries (PICs) suffer from the dual challenge of lack of access to modern energy services and high dependence on imported fossil fuels. Some of the countries like Papua New Guinea and Solomon Islands have less than 20% of their population connected to any kind of electricity system whereas 85% of total electricity production in the region is through diesel-based generators [1]. Figure 1 shows the access to electricity in the PICs.

Fiji is reasonably better off than its larger neighbours with almost 80% of its population (92% in urban areas) having access to electricity. In 2008, average electricity generation mix was composed of 62.1% hydro, 33.8% diesel, 0.6% wind and 3.5% biomass components. The energy consumption in Fiji increased from 202.8 million kWh in 1980 to 715.3 million kWh in 2009 [2]. Since the hydro component is highly variable depending on the weather conditions, the increasing demand has to be met through imported diesel-based generation. The Fiji Electricity Authority has an ambitious plan to produce 90% of its electricity using renewable energy resources (mainly hydro) by 2015.

Renewable energy technologies can help mitigate the twin problems mentioned above significantly as there are abundant natural resources like solar, wind, biomass and small hydro in most of the islands. The dispersed population and remoteness of islands make large grid-connected systems unviable, and mini-grid or stand-alone systems are the only options available for expanding electrification. There is a growing interest among PIC governments to utilise renewable energy resources for electricity generation in the region [3]. One of the major challenges in using renewable energy sources for electricity generation is their intermittent and weather-dependent nature. For reliability of electricity supply, it is better to have a combination of technologies. The so-called hybrid system can have different configurations involving various renewable and conventional technologies.

A wind and solar photovoltaic (PV)-based hybrid system holds the best promise for remote area applications [4–7]. Normally, a diesel generator is added to the system to make it more reliable. The many advantages of replacing a completely diesel generator-based system with a hybrid system include reduced fuel bills, reduced greenhouse gas (GHG) emission and lower maintenance

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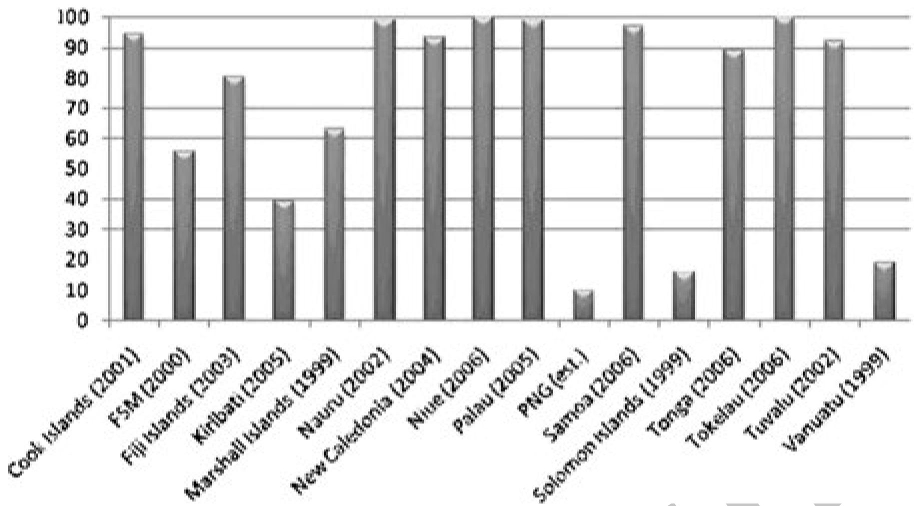


Figure 1 Electricity access in the PICs [1].

costs. The complementary nature of solar and wind resources combined with a storage system significantly increases the reliability of electricity supply [8].

A number of resource assessments have been done in the Pacific region to gauge the possibility of hybrid system development. Table 1 shows wind and solar data for some locations. It can be seen that there are reasonably good prospects for developing such systems.

One of the major barriers in developing renewable energy (RE)-based hybrid systems is the lack of available resource data for the Pacific Islands region. The Asia Sustainable and Alternative Energy Program of the World Bank has produced a wind resource atlas for the region [10], which is very useful in locating sites with good wind energy potential. The NASA Surface Meteorology and Solar Energy website provides global radiation data based on satellite measurements [11]. At the University of the South Pacific, a South Korean-funded project is helping to collect solar and wind resource data for 12 PICs.

Table 1 Wind and solar radiation data for some locations in the PICs [9]

Location	Average wind speed (m/s)	Average wind energy flux (W/m^2)	Average daily solar radiation (Wh/m^2)
Ngatangiia, Rarotonga, Cook Islands	5.5	179	4,300
Vunatovau (10 m), Viti Levu, Fiji	5.5	188	>4,800
Vunatovou (21 m), Viti Levu, Fiji	5.7	204	4,800
Hakupu, Niue	5.9	219	4,600
Tungi Estate, Tongatapu, Tonga	4.2	77	>4,500
White Sands, Efate, Vanuatu	4.7	116	>4,600

A typical hybrid system will comprise a PV array, wind turbines, possibly a diesel generator, inverters and a battery bank with associated control devices. Due to the variability of RE resources, correct sizing of the system components is of paramount importance. Different approaches have been applied to determine the optimal size of the system components and are discussed in detail by Zhou et al. [8] and Bajpai and Dash [12]. Software tools such as Hybrid Optimisation Model for Electric Renewables (HOMER) and HYBRID2 are available to perform simulation and optimisation of hybrid systems.

The HOMER is designed to simulate long-term operation of a combination of micro-power system configurations that could include components like solar PV, wind, small hydro, diesel generators and storage devices like battery banks. It can also model grid-connected systems. The three main tasks performed by HOMER are simulation, optimisation and sensitivity analysis [13]. After simulating a number of combinations, HOMER suggests the optimal configuration based on the lowest net present cost (NPC). Using sensitivity variables (e.g. wind speed and diesel price), it is possible to do a sensitivity analysis that enables the designer to determine the best combination of system components under different conditions.

HOMER has been used to conduct feasibility study of hybrid systems in many locations around the world [14–18]. Bekele and Palm determined the optimal system for supplying electricity to a community of 200 families in Ethiopia [14]. They found that in the 2009 diesel price, the diesel generator/battery/converter setup was the most cost-effective. A 51% RE-based system

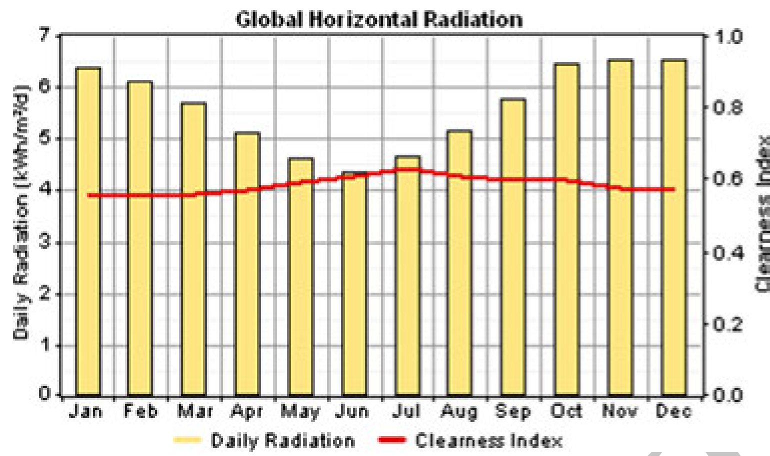


Figure 2 Solar radiation data.

was 19% more expensive but with half the GHG emissions. With the ever-increasing diesel price and continued decrease in solar PV module prices, RE-based systems are becoming more competitive. Al-Karaghouli and Kazmerski applied HOMER to study the life cycle cost of a hybrid system for a rural health clinic in Iraq [5]. A system comprising PV/battery/inverter emerged as the most economic system. Shaahid and El-Amin performed a techno-economic evaluation of PV/diesel/battery systems for rural electrification in Saudi Arabia [15]. They examined the effect of the increase in PV/battery on the cost of energy (COE), operational hours of diesel generators and reduction in GHG emissions. Van Alphen et al. used HOMER to create optimal RE system designs in the Maldives [7]. This study showed that 10% of the total electricity needs of Maldives can be supplied using RE sources.

Methods

Location of the project

This study is done in Nabouwalu (16°59′S, 178°42′E), which is located on the island of Vanua Levu, Fiji. Owing to its distance from the two main town centres on the island, grid electricity is not available at this location. In 1998, a wind/solar/diesel-based hybrid mini-grid system was established at this location, but the hybrid system has fallen into a state of disrepair due to a number of reasons; now, the electricity is supplied using the diesel generators. Considering the high costs involved in the operation and maintenance of these generators, there is a renewed interest in bringing back the hybrid system. This work looks at the feasibility of an optimised wind/solar/diesel hybrid system to replace the existing system.

The following sections describe the main parameters used in the simulation and analysis of the proposed hybrid system.

Solar resource

The Fiji Meteorological Service has been monitoring solar radiation data at Nabouwalu for the last many years. Figure 2 shows the average monthly solar radiation and the clearness index for this location. The annual scaled average value is found to be 5.60 kWh/m^2/day, with the lowest radiation received in the month of June.

Wind resource

The monthly average wind speeds as measured by the meteorological office are shown in Figure 3. The wind

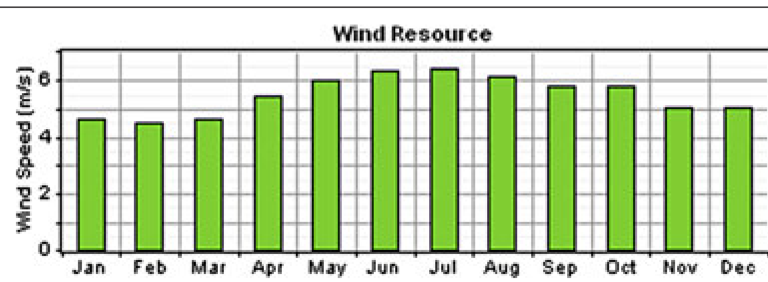


Figure 3 Wind speed data.

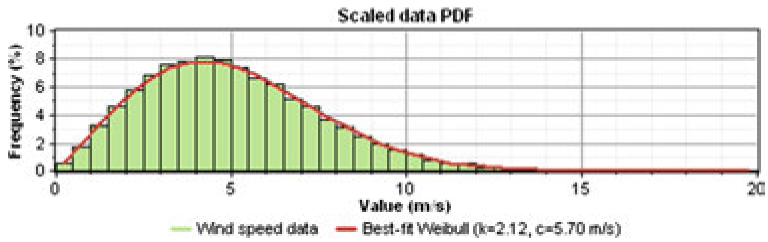


Figure 4 Wind speed distribution.

speed varies between 6.40 m/s in July and 4.60 m/s in January. Figure 4 shows the Weibull distribution for the Nabouwalu wind data with a Weibull factor of 2.1 and peak wind speeds appearing in the afternoon. This would be useful in a solar-wind hybrid system - the wind is picking up as the sun goes down.

Load profile

The Nabouwalu hybrid power system will supply electrical energy to the government hospital, the post office, a primary school, the provincial council building, the Agriculture and Fisheries Department, the police station and staff quarters, the meteorological station, the Public Works Department depot and staff quarters, shops, bakeries, a fisheries ice plant, and 180 residents of the village. Hourly load profile was not available for this location, and the load data were synthesized using daily load profiles. A random variability of daily 10% and hourly 10% noise was added to obtain a peak load of 120 kW. Figure 5 shows the load profile for the proposed system.

Hybrid system design

Considering the solar and wind resources available at this location, the proposed hybrid system will be based on a combination of PV panels, wind turbines, diesel generators and storage batteries. Figure 6 shows the HOMER schematic diagram of the system showing all possible components. The final system configuration is decided after performing the optimisation.

In order to arrive at optimal number of system components, HOMER allows multiple values to be entered. These user-supplied values are then shown in a table depicting the so-called 'search space'. Table 2 shows the different sizes of system components considered. A total of 18,816 system configurations are possible. During simulation, HOMER searches through this space to determine the optimal configuration.

Solar PV

In HOMER analysis, the PV output is taken as directly proportional to the incident radiation. As shown in Table 2, a number of options are available from no solar panels (0 kW) to 400 kW. No restriction was placed for the minimum renewable energy fraction of the total energy mix. The panel costs were taken as Fijian $8,000/kW[a]. The lifetime was taken as 25 years.

Wind turbine

BWC Excel-R wind turbines manufactured from the Bergey WindPower Co. (Norman, OK, USA) were considered in this simulation. Each turbine was rated at 8.1 kW DC and

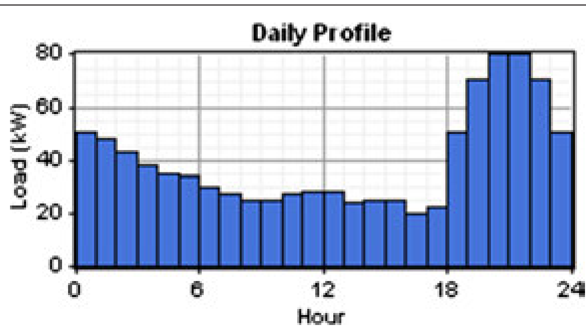


Figure 5 Load profile.

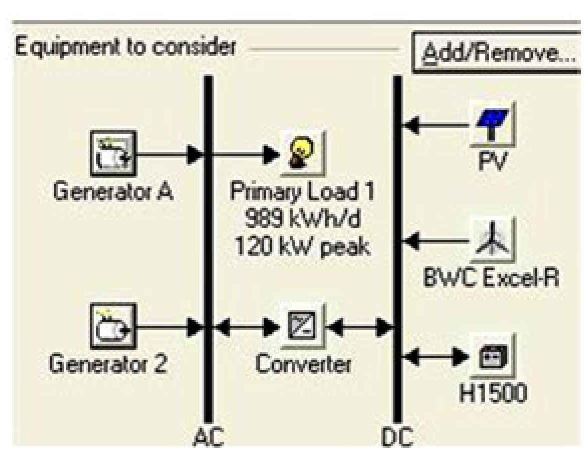


Figure 6 Schematic of the proposed system.

Table 2 System search space

PV array (kW)	XLR (quantity)	Gen A (kW)	Gen 2 (kW)	H1500 (quantity)	Converter (kW)
10	8	85	85	250	150
20	10	150	150	300	200
30	20	200	200	400	
40	25			500	
60	30			550	
80				600	
100					
150					
200					
300					
350					
400					

The components considered include XLR (BWC Excel-R) turbines, Gen A and Gen 2 (85 kW) diesel generators, H1500 (Hoppecke 12 OpzS 1500) batteries and converters.

costs Fijian $76,000. A hub height of 25 m was considered, and turbine lifetime was taken as 25 years. Figure 7 shows the turbine power curve with a cut-in speed of 3 m/s. The number of turbines considered for simulation is shown in Table 2.

Diesel generator

Two diesel generators with a number of size options (Table 2) were considered. The cost of the generators was taken as Fijian $5.00/kW with a lifetime of 40,000 h.

Battery bank

Hoppecke 12 OpzS 1500 batteries manufactured from HOPPECKE Batterien GmbH & Co. KG (Brilon, Germany) were considered as the storage devices. The nominal battery capacity was 1,500 A h with a nominal voltage of 2 V. The initial cost was taken as Fijian $1,200 per battery.

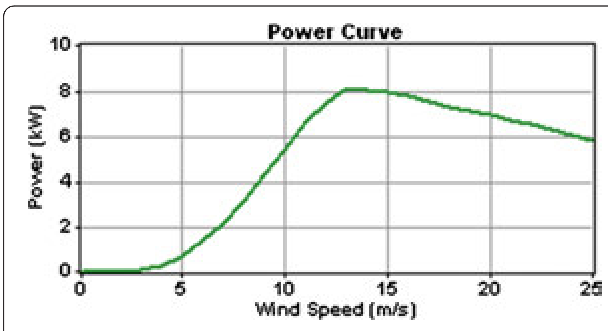


Figure 7 Power curve for the BWC Excel-R wind turbine.

Converter

Two converter sizes were considered: 150 and 200 kW. HOMER suggests an optimal size of 150 kW costing Fijian $50,000.

Hybrid system control parameters and constraints

Two types of dispatch strategies are available in HOMER. In the 'load following' strategy, the generators supply just enough power to service the loads whenever there is insufficient renewable energy contribution. In the 'cycle charging' strategy, the generator (if present) runs at full power and excess electricity is used for charging the batteries. In the present work, an 80% state of charge was set for this strategy.

No minimum renewable energy contribution to the electricity production was set, and simulations were done for 0% and 10% annual capacity shortages. A 6% annual real interest rate was applied

Results and discussion

The input parameters and system constraints, as described above, were used to simulate hybrid systems and perform optimisation and sensitivity analysis. HOMER determines the optimal system by choosing suitable system components (system configuration) depending on sensitivity parameters like wind speed, diesel price and maximum annual capacity shortage. The feasibility of a configuration is based on the NPC and hourly performance.

Sensitivity variables are those over which the designer/modeller does not have any control *viz.* wind speed, solar radiation and diesel price. The HOMER sensitivity analysis assesses the effect of such changes on the configuration rankings. The results are presented in graphical and tabular forms.

Optimisation results

Two scenarios are presented below: (I) with 100% capacity and (II) with 10% annual capacity shortage.

Scenario I: Constraints: Maximum capacity shortage - 0%

Under this scenario, 100% annual load requirements are supplied. According to the sensitivity graph (Figure 8), PV/generator A/generator 2 with battery storage appears as the optimal configuration at lower wind speeds. At higher wind speeds, wind turbine-based systems become more feasible.

Figure 9 shows the categorized list of the most feasible systems for a fixed diesel price of Fijian $2.2/L and an average wind speed of 5.04 m/s. According to this table, the most feasible configuration is made up of 200-kW PV panels and two 85-kW diesel generators with battery storage. The dispatch strategy is 'load following', i.e. the generators operate only to supply power to the loads and the PV system charges the batteries. The NPC of

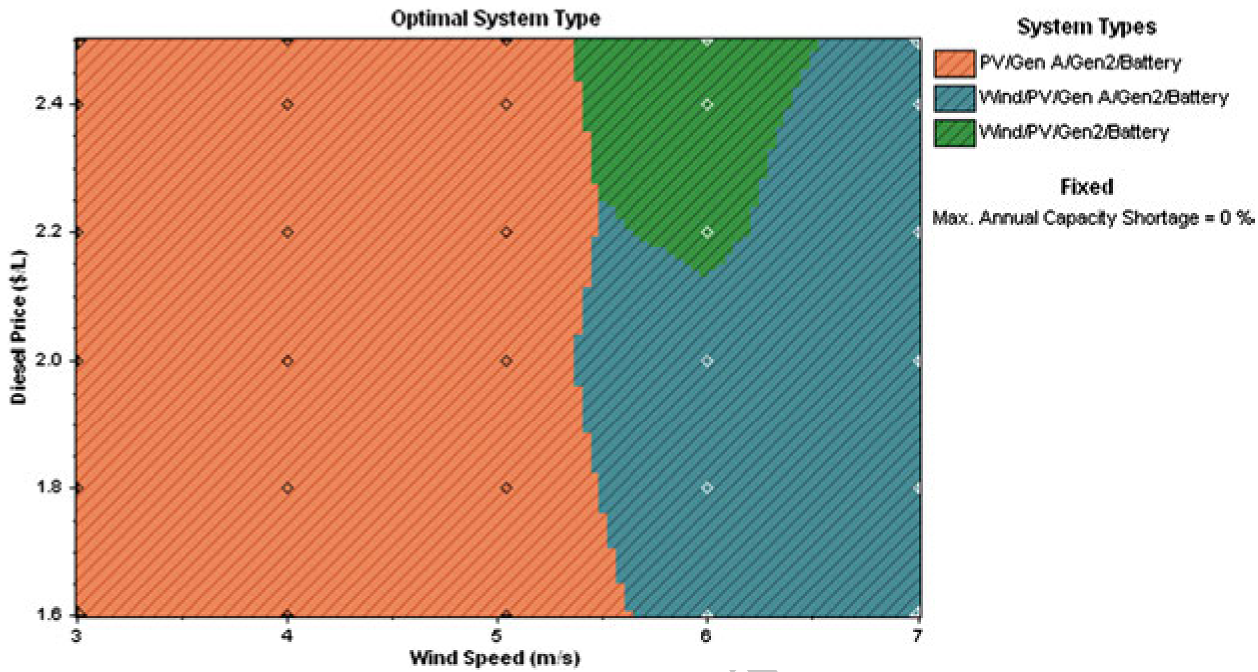
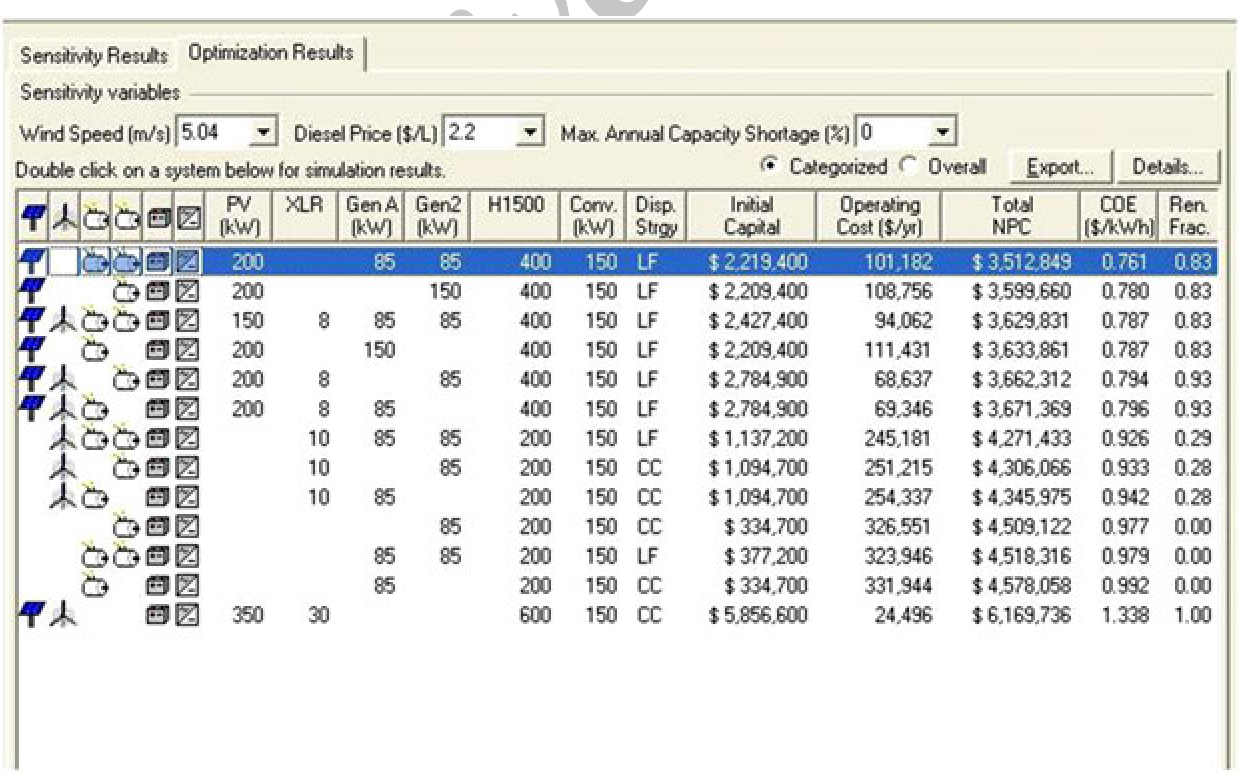


Figure 8 Optimal system graph (0% capacity shortage).



PV (kW)	XLR	Gen A (kW)	Gen2 (kW)	H1500	Conv. (kW)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.
200		85	85	400	150	LF	$ 2,219,400	101,182	$ 3,512,849	0.761	0.83
200			150	400	150	LF	$ 2,209,400	108,756	$ 3,599,660	0.780	0.83
150	8	85	85	400	150	LF	$ 2,427,400	94,062	$ 3,629,831	0.787	0.83
200		150		400	150	LF	$ 2,209,400	111,431	$ 3,633,861	0.787	0.83
200	8		85	400	150	LF	$ 2,784,900	68,637	$ 3,662,312	0.794	0.93
200	8	85		400	150	LF	$ 2,784,900	69,346	$ 3,671,369	0.796	0.93
	10	85	85	200	150	LF	$ 1,137,200	245,181	$ 4,271,433	0.926	0.29
	10		85	200	150	CC	$ 1,094,700	251,215	$ 4,306,066	0.933	0.28
	10	85		200	150	CC	$ 1,094,700	254,337	$ 4,345,975	0.942	0.28
			85	200	150	CC	$ 334,700	326,551	$ 4,509,122	0.977	0.00
		85	85	200	150	LF	$ 377,200	323,946	$ 4,518,316	0.979	0.00
		85		200	150	CC	$ 334,700	331,944	$ 4,578,058	0.992	0.00
350	30			600	150	CC	$ 5,856,600	24,496	$ 6,169,736	1.338	1.00

Figure 9 Optimisation table for feasible configurations (0% capacity shortage).

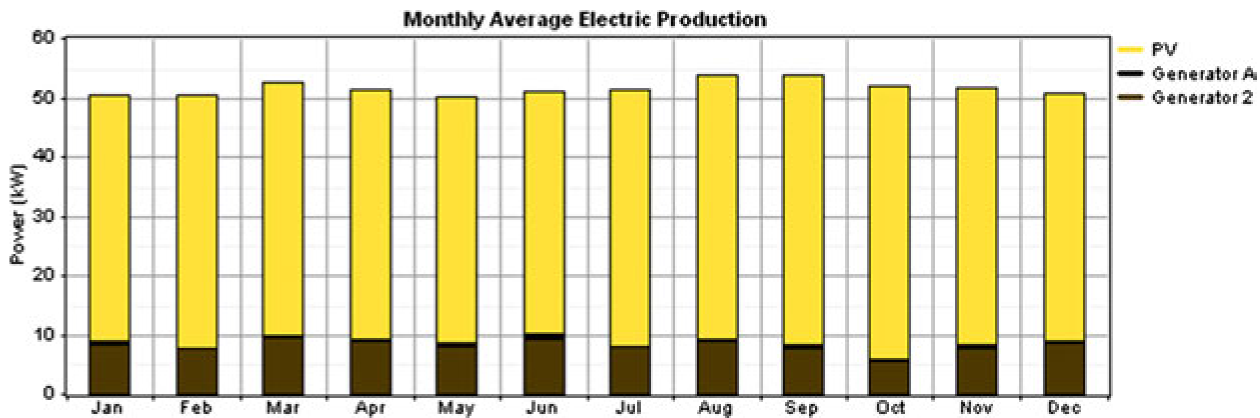


Figure 10 Electricity production (0% capacity shortage).

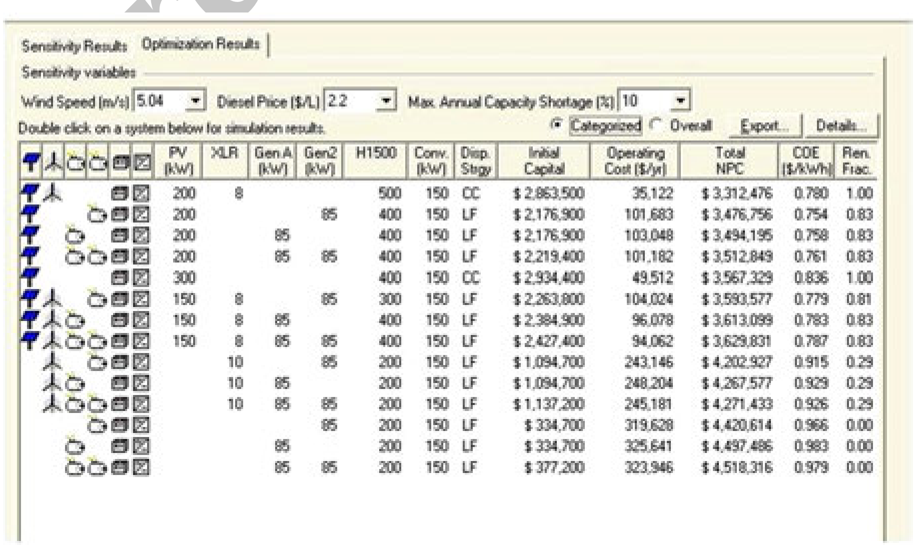
this configuration is Fijian $3,512,849 and the COE is Fijian $0.761/kWh.

Figure 10 shows the contribution to the total electricity generated by individual system components. The PV system has a capacity factor of 21.5% and supplies 83% of the annual electricity production. Generator A has an overall efficiency of 27%, operates for 1,896 h/annum and has a capacity factor of 9.6%. With the increase in future diesel prices and lower PV module costs, a higher contribution from the RE component can be expected.

Scenario II: Constraints: Maximum capacity shortage - 10%

Under this scenario, 10% of annual capacity shortage is allowed. Figure 11 shows the feasible configuration ranking in this situation. Now, a 100% RE system consisting of a 200-kW PV and eight XLR wind turbines with battery storage turns out to be the optimal configuration. The NPC is Fijian $3,312,476 and the COE is Fijian $0.78/kWh.

Figure 12 depicts the sensitivity analysis for this scenario. At very low wind speeds and low diesel prices, the PV/Gen/battery system is the most feasible configuration, but at higher wind speeds and prevailing diesel price, the wind/PV/battery system becomes the optimal one. The monthly electricity production is shown in Figure 13. The PV system supplies 81% of the total electricity, while the wind turbines contribute 19% with a capacity factor of 15.6%. The 10% capacity shortage might look unacceptable from a utility point of view, but in most rural areas of Fiji, diesel-based electricity is normally available only for 4 h/day. The mini-grid system would be a major step towards an improved rural energy supply. The transportation costs for diesel are


Sensitivity Results | Optimization Results

Sensitivity variables

Wind Speed (m/s) 5.04 | Diesel Price ($/L) 2.2 | Max. Annual Capacity Shortage (%) 10

Double click on a system below for simulation results. Categorized / Overall | Export... | Details...

PV (kW)	XLR	Gen A (kW)	Gen2 (kW)	H1500	Conv. (kW)	Disp. Stgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.
200	8			500	150	CC	$ 2,863,500	35,122	$ 3,312,476	0.780	1.00
200			85	400	150	LF	$ 2,176,900	101,683	$ 3,476,756	0.754	0.83
200		85		400	150	LF	$ 2,176,900	103,048	$ 3,494,195	0.758	0.83
200		85	85	400	150	LF	$ 2,219,400	101,182	$ 3,512,849	0.761	0.83
300				400	150	CC	$ 2,934,400	49,512	$ 3,567,329	0.836	1.00
150	8		85	300	150	LF	$ 2,263,800	104,024	$ 3,593,577	0.779	0.81
150	8	85		400	150	LF	$ 2,384,900	96,078	$ 3,613,099	0.783	0.83
150	8	85	85	400	150	LF	$ 2,427,400	94,062	$ 3,629,831	0.787	0.83
	10		85	200	150	LF	$ 1,094,700	243,146	$ 4,202,927	0.915	0.29
	10	85		200	150	LF	$ 1,094,700	248,204	$ 4,267,577	0.929	0.29
	10	85	85	200	150	LF	$ 1,137,200	245,181	$ 4,271,433	0.926	0.29
			85	200	150	LF	$ 334,700	319,628	$ 4,420,614	0.966	0.00
		85		200	150	LF	$ 334,700	325,641	$ 4,497,486	0.983	0.00
		85	85	200	150	LF	$ 377,200	323,946	$ 4,518,316	0.979	0.00

Figure 11 Optimisation table for feasible configurations (10% capacity shortage).

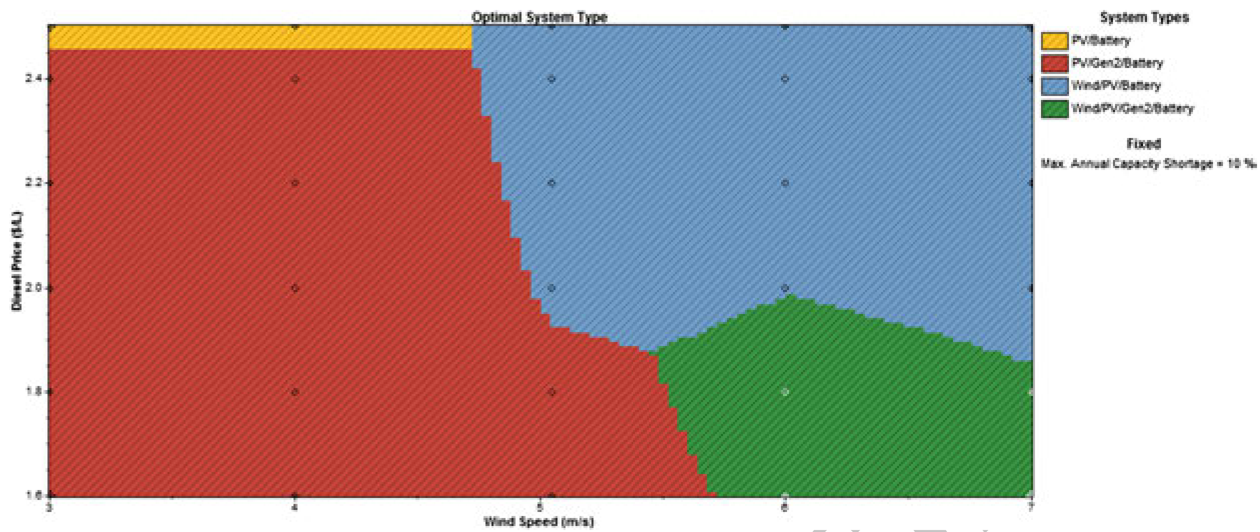


Figure 12 Optimal system graph (10% capacity shortage).

prohibitively high in most of the outer islands in the Pacific region, and idle diesel generators are a common sight in many locations. The operation and maintenance issues are critical for any electricity system, and RE-based hybrid systems have an obvious edge over the conventional diesel generators.

GHG emission reduction

Figure14 shows CO_2 emission from a hybrid system as a function of wind speed and the diesel price. As discussed above, at higher wind speeds and/or higher diesel prices, RE-based configurations become more feasible, resulting in less CO_2 emission. A diesel generator/battery-based system will generate approximately 250 tonnes of CO_2 annually, whereas a wind/solar hybrid system (scenario II) will have zero emissions. This emission reduction can bring in additional income to the project developers through carbon trading. PICs have not really benefited (only two projects) from the Clean Development Mechanism (CDM) activity under the Kyoto Protocol. The main hindrance is the low capacity for the CER generation - the total power generation capacity in the region is only around 1,100 MW. The recently introduced programmatic CDM (p-CDM) might be able to make regional carbon trading projects plausible. A number of solar and wind-based mini-grid systems can be developed as programme activities to be part of a regional p-CDM project. Obviously, a number of institutional and regulatory interventions will be required for this scheme to be successful.

Fiji's electricity sector and the role of renewable energy systems

The Fiji Electricity Authority (FEA) is a corporate body responsible for electricity generation and transmission in

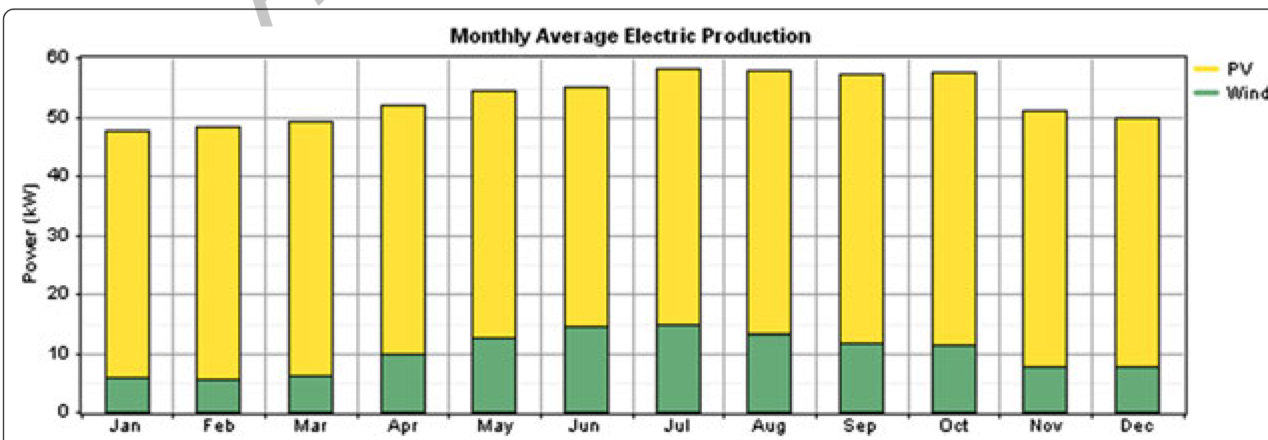


Figure 13 Electricity production (10% capacity shortage).

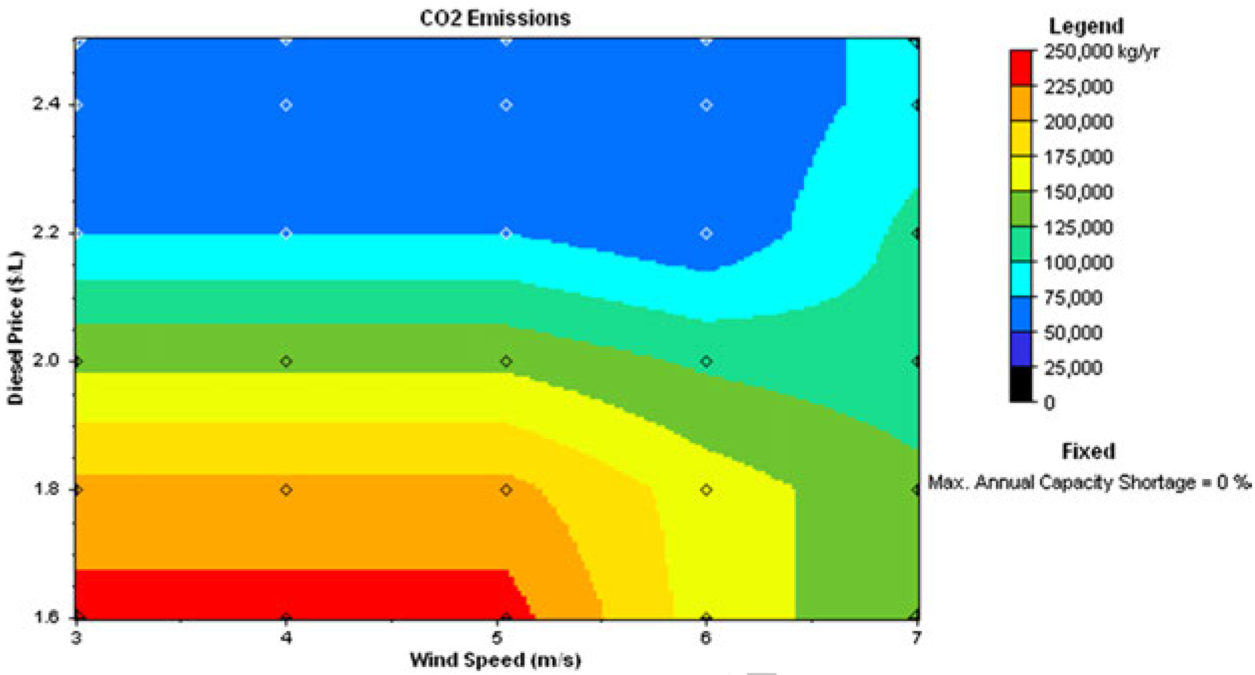


Figure 14 CO_2 **emissions under various scenarios.**

Fiji. Its mission is 'to provide clean and affordable energy solutions to Fiji and the Pacific' [2]. Under the Fiji Commerce Act, the Commerce Commission controls the electricity price and any changes in the tariff rates have to be authorized by the commission. Fiji's tariff rates are the lowest among the Pacific Islands region, and until recently, the rates had stagnated despite a marked increase in demand and resulting diesel usage. One of the major implications of lower tariffs is the lack of interest from the independent power producers (IPPs) as FEA was unable to pay them a suitable buying rate. As Figure 2 shows, at present, FEA is able to supply only about 54% of the demand from its hydropower stations and the rest is from thermal generation. This will change when a new 42-MW hydropower system becomes operational in 2012. According to FEA estimates, diesel-based electricity generation in Fiji is 15% costlier than hydro-based generation, and in 2010 alone, FEA reported a loss of Fijian $17 million ascribed mainly to higher diesel consumption.

The FEA grid is only available on two main islands: Viti Levu and Vanua Levu, while a smaller network is available in Ovalau. The Fiji government has enacted a rural electrification policy under which a rural community can request for access to electricity. This policy provides three options for rural electrification [19]:

1. Grid extension by FEA. The government subsidizes grid extension by providing 95% of the costs, and the community contributes the remaining 5%. The number of communities benefiting from this scheme depends on the rural electrification budget. FEA also implements a grid extension policy based on the internal rate of return (IRR). For projects with an IRR greater than 15%, the grid is extended without any cost to the community; for those with a lower IRR, a contribution from the community is required. This option is available only on the two main islands and in Ovalau.
2. Diesel generator-based mini-grid systems. The Fiji Department of Energy (FDOE), through its Rural Electrification Unit, is responsible for bringing electricity to rural communities spread all over Fiji islands. Presently, the department operates 600 diesel generator-based systems. Due to the costs of involved in operation and maintenance of these systems, electricity is usually available only for 4 h in the evening.
3. Renewable energy-based systems (mainly PV systems). FDOE has supplied more than 1,200 homes with solar home systems (SHSs) in Vanua Levu under its rural electrification scheme. This scheme is run on a Renewable Energy Service Company model where the consumers pay for the service but do not own the systems.

It is obvious that FEA will not be able to extend its grid network to rural communities living on dispersed islands and SHSs are useful only for providing lighting. Diesel-based generation is very expensive and unreliable due to maintenance issues. This is where renewable energy-based hybrid mini-grid systems become important and help in the sustainable development of rural communities. With the new tariffs in place, IPPs will be attracted to develop renewable energy-based systems.

A number of grid-connected PV and wind energy systems have been established or are under construction in the PIC region. Utilities are actively considering newer tariff regimes like feed-in tariff and net metering for renewable energy-based generation. This development augurs well for renewable energy developers and IPPs.

Capacity building

For any RE-based programme to be successful, availability of a sustained cadre of trained professionals is essential. The University of the South Pacific, a regional university, provides RE education and training to students from its 12 member countries. A number of demonstration projects that include a 45-kW grid-connected PV system and stand-alone and wind/solar hybrid systems are part of the training infrastructure. Plans are afoot to develop a certification scheme and competency standards for RE installers/designers. This is being done in cooperation with the Sustainable Energy Industry Association of Pacific Island (SEIAPI).

Conclusions

Renewable energy-based mini-grid systems can play a vital role in bringing sustainable energy to rural communities in the Pacific Islands. In this work, an optimisation and sensitivity analysis of a solar PV/wind/diesel hybrid mini-grid system in Fiji islands has been presented. This study indicates that for the chosen location, the most feasible system consists of a 200-kW PV, 170-kW diesel generators and battery storage if no capacity shortage is demanded. Allowing for 10% capacity shortage, a fully renewable energy-based system becomes feasible.

Endnote

[a]Fijian $1 = US $0.54.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

SL carried out the site survey and helped in HOMER modeling. AR performed the analysis and drafted the manuscript. Both authors read and approved the final manuscript.

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References

1. SPC: Pacific regional information system (PRISM). http://www.spc.int/prism/ (2012). Accessed 1 Feb 2012
2. Fiji Electricity Authority: Fiji electricity authority. www.fea.com.fj (2012). Accessed 5 Jan 2012
3. CROP Energy Working Group: Ministers' communiqué, Proceedings of the Pacific Energy Minister's Meeting and Regional Energy Officials' Meeting, Nuku'alofa, Tonga. http://ict.sopac.org/VirLib/JC0200.pdf (2009). Accessed 10 Oct 2011
4. Khan, MJ, Iqbal, MT: Feasibility study of standalone hybrid systems for applications in Newfoundland. Renew. Energy **30**, 835–854 (2005)
5. Al-Karaghouli, A, Kazmerski, L: Optimization and life-cycle cost of health clinic PV system for a rural area in southern Iraq using HOMER software. Solar Energy **84**, 710–714 (2010)
6. Mondal, AH, Denish, M: Hybrid systems for decentralized power generation in Bangladesh. Energy Sustain. Dev. **14**, 48–55 (2010)
7. Van Alphen, K, Wilfried, GJHM, Hekkert, MP: Renewable energy technologies in the Maldives—determining the potential. Renew. Sustain. Energy Rev. **11**, 1650–1674 (2007)
8. Zhou, W, Lou, C, Li, Z, Lu, L, Yang, H: Current status of research on optimum sizing of stand-alone hybrid solar–wind power generation systems. Applied Energy **87**, 380–389 (2010)
9. SOPAC: SOPAC Report ID JCO 121. www.sopac.org (1995). Accessed 10 Oct 2011
10. AWS Truewind/ASTAE: The 2009 Pacific Islands Wind Energy Resource Atlas. http://siteresources.worldbank.org/INTEAPASTAE/Resources/FarEastIslandsWindResourceMap_2009.pdf (2009). Accessed 1 June 2012
11. NASA: Surface Meteorology and Solar Energy. http://eosweb.larc.nasa.gov/sse/ (2004). Accessed 12 Oct 2011
12. Bajpai, P, Dash, V: Hybrid renewable energy systems for power generation in stand-alone applications: a review. Renew. Sustain. Energy Rev. **16**(1), 2926–2939 (2012)
13. HOMER Energy LLC: Hybrid optimization model for electric renewables. http://www.homerenergy.com/ (2009). Accessed 5 Aug 2011
14. Bekele, G, Palm, B: Feasibility study for a standalone solar–wind-based hybrid energy system for application in Ethiopia. Applied Energy **87**, 487–495 (2010)
15. Shaahid, SM, El-Amin, I: Techno-economic evaluation of off-grid hybrid based hybrid energy system for photovoltaic–diesel–battery power systems for rural electrification in Saudi Arabia—a way forward for sustainable development. Renew. Sustain. Energy Rev. **13**(3), 625–633 (2009)
16. Hassan, K, Faitma, K, Mahmood, HS: Feasibility of hybrid power generation over wind and solar standalone system. 5th Power Engineering and Optimization Conference (PEOCO), Selangor **7**, 6–7 (2011)
17. Nandi, SK, Ghosh, HR: Prospect of wind–PV-battery hybrid power system as an alternative to grid extension in Bangladesh. Energy **35**, 3040–3047 (2010)
18. Rehman, S, Al-Hadhrami, ML: Study of a solar PV–diesel–battery hybrid power system for a remotely located population near Rafha Saudi Arabia. Energy **36**, 4986–4995 (2010)
19. Fiji Department of Energy: www.energy.gov.fj (2012). Accessed 5 Jan 2012

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