Sustainably Powering Off-grid Schools in Fiji

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Abstract

Energy poverty is very common in rural areas of developing countries and it is even more pronounced in small island developing states (SIDS). This paper attempts to study the energy requirement of off-grid schools in Fiji and make recommendations on some clean energy supply options to replace heavy dependence on diesel generators for electricity. Of the 173 surveyed schools in Fiji, 17 schools were off-grid schools with an annual average energy consumption of 6,443 kWh (812 L) from diesel fuel, 4,600 kWh from premix fuel (607 L) and 621 kWh (60 L) from kerosene. We have carried out a techno-economic study for these schools and recommend the use of hybrid solar photovoltaics with battery storage where diesel generators will be used only as a backup. This system will replace diesel generators so that schools are supplied with 24/7 electricity and not 3-4 hours every evening as is the case currently. To make these systems resilient to extreme weather conditions such as tropical cyclones, it is suggested that building and installation standards be used and capacity building of community members on ensuring the safety of PV systems during cyclones should be mandatory.

Keywords: off-grid schools, energy consumption, solar photovoltaics, hybrid system, cyclones

1. Introduction

Energy is an enabler for sustainable development in multiple dimensions of any country (Nussbaumer et al., 2012). Being “energy poor” in developing countries means that a certain percentage of the population (rural and poor urban) do not have access to modern energy services that can help communities build socially, economically and environmentally (Sy and Mokaddem, 2022). The uniqueness of Pacific Island countries is that the population is distributed between several dispersed islands within a country and the population on these islands tend to be small and isolated from the main market centres. For such islands and remote villages within large islands, it is economically not viable to extend the electricity grid. Schools in these remote places depend on limited electricity supply produced by expensive and polluting diesel generators. There are many off-grid solutions for such communities; from standalone solar PV systems to hybrid solar systems. However, before the installation of these alternative reliable and sustainable solutions, there needs to be a feasibility study done to determine whether the chosen system can technically, and economically meet the demands of the target community. Researchers have used various tools (Tozzi Jr and Jo, 2017) for analysing the techno-economic feasibility of off-grid renewable energy applications for providing electrical services and the three most commonly used software are ; HOMER, SAM and RETScreen. HOMER makes it possible to optimize hybrid systems that use both renewable and non-renewable energy sources, batteries, and generators. It can also carry out economic and environmental evaluation, as well as sensitivity and uncertainty analysis while RETScreen aids in evaluating the economic viability, efficiency, and overall feasibility of renewable energy systems. The System Advisor Model (SAM) simulates the performance and cost of renewable energy systems, such as solar PV, wind, geothermal and concentrated solar power. The choice of a particular tool will depend on the primary objective of the study and the type of data available.

Giday (2014) used HOMER software to compare the economic viability of a solar photovoltaic/diesel generator/battery hybrid power system with that of a standalone diesel generator only for a hypothetical rural school in Ethiopia. Its results prove that a solar PV system with a backup generator is more affordable and

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environmentally beneficial than a standard diesel generator alone system. Apart from the unavailability of quality power supply for off-grid communities, even for the short time (3-4 hours) that electricity is provided, the cost of electricity is massive as (Lozano et al., 2019) report US$1.21/kWh for diesel generator at one of the island communities in Philippines. By using HOMER software, they found that a solar/diesel/battery hybrid is more cost-effective (US$0.3556/kWh) than a solar PV/battery (US$0.3916/kWh) (Lozano et al., 2019). Similar results were also obtained by (Odou et al., 2020) for a rural community in Benin of West Africa where the hybrid (solar/diesel/battery) system has a cost of energy of US$0.207/kWh.

Li and Yu (2016) used RETScreen to assess the feasibility of different off-grid solar PV hybrid systems for households in China and found solar PV/Diesel/battery of one-axis and two-axis tracking systems to give the best performance for GHG reduction. In terms of the cost of energy, hybrid solar/diesel/battery has $1.319/kWh while solar/battery has $1.805/kWh and they further highlight that solar PV fixed axis has lower COE compared to one-axis and two-axis tracking (Li and Yu, 2016). Fathoni et al. (2014) used RETScreen to assess the technical and economic potential of solar photovoltaic grid-connected systems in Indonesia and used pre-tax IRR and simple payback indicators for assessing financial viability. Further, (Bingham et al., 2016) also used RETscreen to assess the potential of solar PV for an island community in the Bahamas.

This paper attempts to assess the energy demand for schools in rural areas and outer maritime islands in Fiji and makes recommendations for solar energy to be used to meet energy needs. RETscreen tool is used to carry out the techno-economic feasibility study for two schools and we also discuss strategies for overcoming barriers to the implementation of solar energy-based solutions.

2. Methodology

This study used a mixed method to assess the school energy consumption in early childhood education (ECE), primary and secondary schools in Fiji. Approval was sought from the Ministry of Education, Heritage and Arts (MEHA) to conduct the research and a multi-mode survey was carried out in 2022. Altogether 173 schools participated in the survey where 17 were off-grid schools while the rest were connected to grid electricity.

According to the questionnaire survey, out of 17 non grid-connected schools, 6 were secondary schools, 10 were primary schools and 1 was ECE school as shown in Fig. 1a. Six schools have their own diesel generator, another 6 schools have solar PV systems, 2 schools have electricity from community-owned diesel generator and 3 schools have solar lights only. Some schools that use diesel generators also have a few solar lights installed. In terms of building structures, 3 off-grid schools have only wooden buildings while 2 schools have concrete building structures and the rest (12 schools) have a mixture of wooden and concrete buildings. 15 schools have single-storey buildings while 2 schools have both single and double-storey buildings. For schools that have diesel generators, the generator is only used to operate a photocopier and also provides 3 hours of electricity in the evenings to teachers' quarters. Some schools mention that electrical appliances are strictly not allowed in schools because the existing solar PV system would not be able to cater for the increased demand. This indicates that a bigger capacity of solar PV system is needed to meet all electrical demand for off-grid schools. None of the off-grid schools have air-conditioners, while three schools have ceiling fans and 7 schools report that they have a couple of stand fans. The number of lights per school varies from 3 to 62;. Water in off-grid schools comes from a range of sources; boreholes, desalination plants, rainwater, springwater or river water. However, all off-grid schools have water tanks for collecting rainwater in case their usual water supply is not working.

Some off-grid schools have recently renovated their buildings that were damaged in recent cyclones. While some schools have bought or received donations of ICT materials – printers, computers, laptops, etc. Some schools have even bought new solar PV systems for their teachers' quarters or bought diesel generators for their schools. Upon asking schools about their plans, 41 % of off-grid schools mentioned that they would like solar PV installed at their schools while 53% of the off-grid schools mentioned that they need their buildings renovated because they are either damaged by tropical cyclones or buildings are old.

The focus of this paper is on typical off-grid schools' energy consumption, hence, a primary and a secondary off-grid school are taken and RETScreen Expert tool version 9 is used to model the school's energy consumption and its generation capacity when the diesel generator is replaced by solar PV system with battery storage or hybrid systems. Data collected during the survey are used as some input parameters into the model while other input data are taken from literature.

RETScreen is selected for this study as it can simulate the financials when incentives such as government grants or subsidies are given. Mirzahosseini and Taheri (2012) present comprehensive advantages of using RETScreen and use it to simulate energy output, GHG emissions reduction, financial analysis and sensitivity and risk analysis.

2.1 Study Site and climate Data

Two schools (one primary and one secondary) were chosen for RETScreen analysis and are marked in Fig. 1. The primary school was established in 1970 with approximately 40 students (4 classrooms) while the secondary school was established in 2002 with approximately 150 students and comprised 5 classrooms. Currently, both schools have diesel generators and some exterior solar lights.

The climate data for the two schools are shown in Fig. 2 with the secondary school being located in a slightly sunnier location than the primary school. The annual average monthly temperature is 26.4°C and 24.6°C for secondary and primary school respectively. The average monthly solar radiation is 5.60 kWh m^{-2} day^{-1} and 4.40 kWh m^{-2} day^{-1} for secondary and primary school respectively.

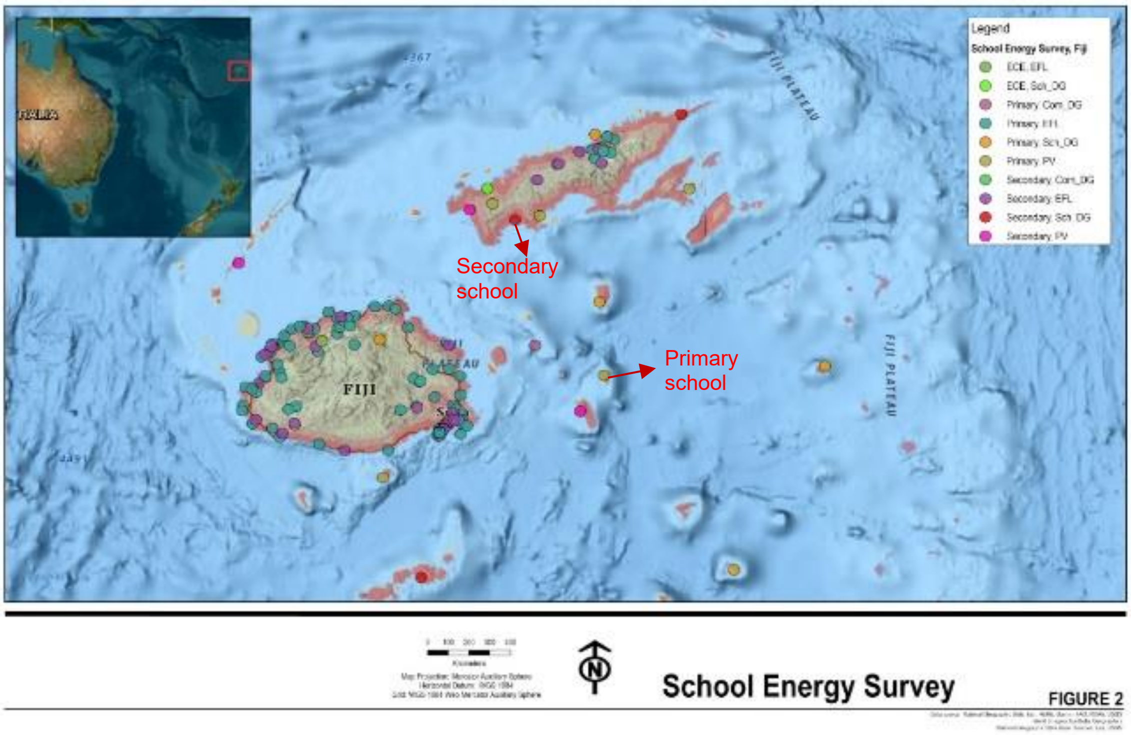

Fig. 1: Map showing the locations of surveyed schools. Note: Sch-DG – school-owned diesel generator, Com_DG -community-owned diesel generator, PV – solar photovoltaic, EFL – Energy Fiji Limited is the grid utility company.

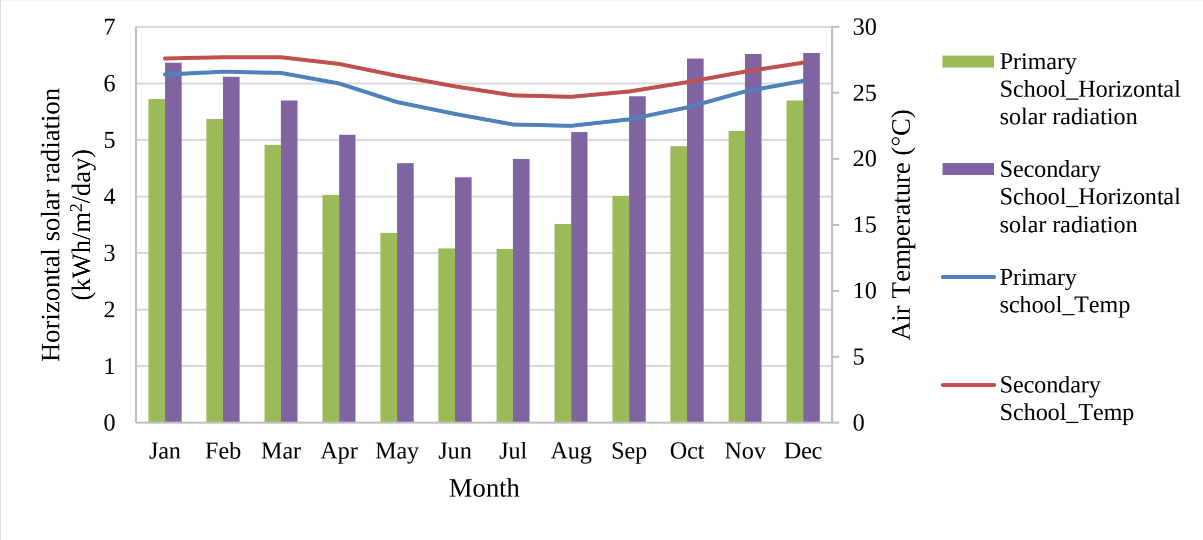

Fig. 2: Horizontal solar radiation and temperature at the two studied schools.

2.2 Scenarios studies in RETScreen

The main purpose of carrying out the RETScreen analysis was to determine the financial viability and potential GHG reduction for the primary and secondary schools. A solar photovoltaic system with battery storage and a hybrid system are modelled to meet the daily energy demand for a primary and secondary school and the summarized results are shown in Tab. 1. For the primary school, average consumption for learning and teaching per day is taken as 11 kWh day^{-1} while for the secondary school, it is taken as 60 kWh day^{-1} based on the average consumption of grid-connected small primary and secondary schools. However, off-grid schools also have teachers' quarters and student hostels, so this demand should also be included. Energy demand for teacher's quarters was not known and hence literature was referred to for assuming the daily demand. (Agrawal et. al., 2020) reports 3.93 kWh/day for rural households in India while (Monyei et al., 2018) report 1.5 kWh/day is usually taken for households in Brazil as the minimum demand for electrification projects. Assuming that one teacher quarter will have a typical rural home consumption of 3 kWh day^{-1} based on the data presented published literature and there are 5 and 13 teachers quarters in primary and secondary school respectively and 0.6 kWh student^{-1} consumption in boarding hostel with 19 and 30 student boarders in primary and secondary school respectively, the total demand for primary and secondary school is taken as 37.4 kWh day^{-1} and 117 kWh day^{-1} respectively as seen in Tab. 1.

Tab. 1: Typical daily load for off-grid schools in Fiji

Description of load	Primary	Secondary
	kWh day^{-1}	kWh day^{-1}
School's learning and teaching activities	11	60
Teachers' quarters	(5 × 3) 15	(13 × 3) 39
Hostel	19 students @ 0.6 kWh day^{-1} =11.4	30 students @ 0.6 kWh day^{-1} = 18
TOTAL	37.4	117

Six cases are studied for each type of school:

Case 1: School power load supplied by solar PV and battery storage – no incentives

Case 2: School power load supplied by hybrid power systems (solar/diesel/battery) – no incentives

Case 3: School power load supplied by solar PV and battery storage – government grant of US$5000 for primary school and US$10,000 for secondary school.

Case 4: School power load supplied by solar PV and battery storage – government grant and carbon credit.

Case 5: School power load supplied by hybrid power systems (solar/diesel/battery) – government grant of US$5000 for primary school and US$10,000 for secondary school.

Case 6: School power load supplied by hybrid power systems (solar/diesel/battery) – government grant and carbon credit.

The input parameters taken in RETScreen are summarized in Tab. 2.

Tab. 2: Input parameters for RETScreen modelling

Parameter	**Unit**	**Primary**		**Secondary**	
INPUT		Solar PV/battery	Hybrid (solar PV/diesel/battery)	Solar PV/battery	Hybrid (solar PV/diesel/battery)
		Nairai Island, Lomaiviti		Ratu Luke School in Bua	
Location					
Latitude		-17.8	-17.8	-16.8	-16.8
Longitude		179.4	179.4	178.6	178.6
Daily electric load	kWh/day	37.4	37.4	117	117
Diesel cost[1]	US$/litre	1.50	1.50	1.50	1.50
Base case					
Diesel generator capacity	kW	5.5	5.5	15	15
Proposed case					
Inverter	kW	20	20	40	40
Inverter efficiency	%	85	85	85	85
Inverter cost	US$/kW	400	400	400	400
Lithium-ion battery					
Days of autonomy		5	1.2	5	1.2
Voltage	V	24	24	96	96
Efficiency	%	80	80	80	80
Nominal battery capacity (calculated using equation 1)	Ah	11,460	2,750	8,962	2,151
Battery cost[2]	US$/kWh	650	650	650	650
Solar PV system					
Tilt angle	°	32	22	32	22
Power capacity	kW	20.13	20.13	43.065	43.065
Number of unit		122	122	261	261
PV cost[3]	US$/kW	2,967	2,967	2,224	2,224
O&M cost[4]	US$/kW-yr	36.94	36.94	25.25	25.25
Financial Parameters					

[1] Diesel price in Fiji in Oct 2023 was FJ$2.83/litre (https://fccc.gov.fj/wp-content/uploads/2023/09/New-Fuel-and-LPG-Prices-for-October-2023-.pdf) which is around US$1.50/litre.
[2] Assumed based on the the pacific report that states “batteries were costed between $200 to $750/kWh in the tenders examined” https://prdrse4all.spc.int/sites/default/files/prif-re-web_2.pdf
[3] Solar PV installed cost has reduced from US$12/W to US$3/W in the Pacific (https://prdrse4all.spc.int/sites/default/files/prif-re-web_2.pdf)
[4] Assumed using RETScreen recommendation

Inflation rate[1]	%	3.1	3.1	3.1	3.1
Discount rate[2]	%	10	10	10	10
Project life	Years	20	20	20	20
Debt ratio[3]	%	70	70	70	70
Government grant	US$ per off-grid school	5,000	5,000	10,000	10,000
Carbon revenue[4]	US$/t$CO_2$/year For first 10 years	16	16	16	16

The battery capacity (Ampere-hour (Ah)) is calculated using eq. (1).

$$Ah\ for\ battery = \frac{AC\ load\ (Wh) \times Number\ \ of\ no\ sun\ days}{\eta_{inverter} \times \eta_{coulomb} \times System\ voltage} \qquad \text{(eq. 1)}$$

Where
$\eta_{inverter}$ is the inverter efficiency.

$\eta_{coulomb}$ is the battery efficiency.

The size of solar PV for off-gris can be estimated by (eq. 2) as suggested by (Ghafoor and Munir, 2015).

$$\text{PV power} = PV\ power = \frac{AC\ load\ (Wh) \times peak\ sun\ (1000\ W\ m^{-2})}{daily\ solar\ radiation \left(\frac{kWh}{\frac{m2}{day}}\right) \times \eta_{inverter} \times \eta_{coulomb} \times temperature\ correction\ factor} \qquad \text{(eq. 2)}$$

Temperature correction factor normally taken as -0.4 to -0.5% per °C for crystalline silicon (Ghafoor and Munir, 2015).

3. Results and discussions

3.1 Energy consumption in off-grid schools

The off-grid schools have no record of the electricity that is generated or consumed by the schools, especially the ones supplied by diesel generators, solar photovoltaic systems or community-owned diesel generators. However, some off-grid schools have records of the quantity of diesel consumed. Apart from using diesel generators to supply electricity, off-grid schools also use premix (mixture of gasoline and 2-stroke oil in a ratio 50:1 (gasoline:oil)) which is used for grass cutting in schools and also in school boats. These schools also use LPG and kerosene for cooking by teachers and student boarders.

Off-grid schools have high diesel and premix use, where on average, 4600 kWh of premix is used annually and 6443 kWh of diesel used annually, as shown in Fig. 3. with an average cost of F$1751/year for diesel and F$1802/year for premix. For schools that have solar PV, only one school reported the size of the system; 6 × 250W panel while some schools reported inverter sizes ranging from 1.5 kW to 10 kW. However, these systems just provide basic lighting to the schools but do not allow the school to expand its learning and teaching tools and methods via the use of ICT so that students in off-grid schools can enjoy the same services as the students in urban settings.

[1] Taken from paper https://doi.org/10.1016/j.jclepro.2021.128519
[2] Assumed from paper https://doi.org/10.1016/j.jclepro.2021.128519
[3] Assumed
[4] Assumed based on Bloomberg report https://www.bloomberg.com/professional/blog/long-term-carbon-offsets-outlook-2023/

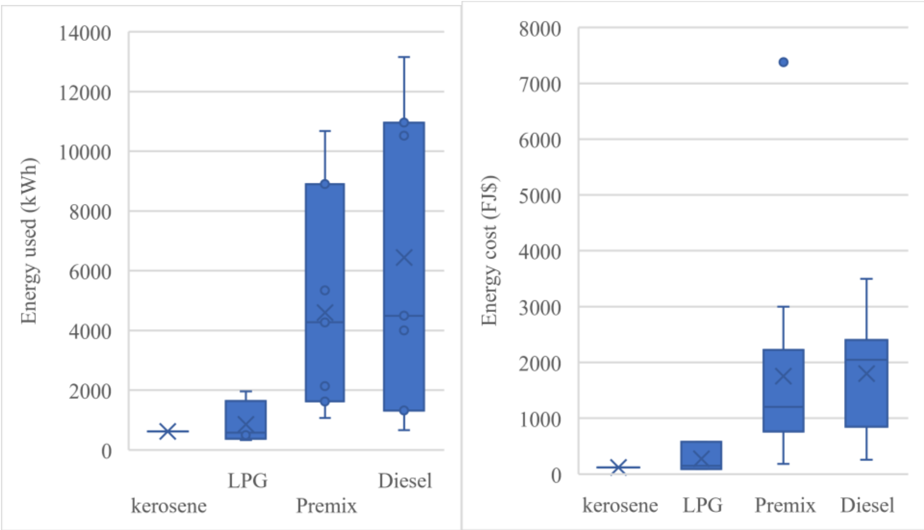

Fig. 3: Box plot of energy used and its cost for different energy sources for off-grid schools.

3.2 Modelling results

3.2.1 Energy output

The annual energy output for primary school is 13,651 kWh for hybrid systems where the PV system meets the load 97% of the time while the rest is met by a diesel generator as shown in Tab. 3. However, for the solar PV system with battery storage, it is seen that only for 0.1% of the time in the year the system is not able to meet the demand. If the system size is increased with battery storage then this deficit will be met but the cost of the system and energy production cost (EPC) will be high.

Similar results are also seen in Tab. 4 for secondary school. For the hybrid system, the annual energy generated is 42,705 kWh where 97.7% of the demand is met by solar PV while the rest is met by diesel generator. Here we see that solar PV has a slightly greater share in generation output compared to the primary school because the location of the secondary school is at a location where the average daily solar radiation is 5.60 kWh m^{-2} day^{-1} while for primary school it is 4.40 kWh m^{-2} day^{-1}.

3.2.2 GHG saving

When solar PV is considered then for primary school 27.3 tCO2-e y^{-1} of GHG emissions is saved while for hybrid system it is 26.7 tCO2-e yr^{-1} which is a 2.2% decrease. This is because as seen earlier, the hybrid system has a diesel generator operating and supplying 3% of the demand. Similarly, for secondary school, only solar PV saves 45 tCO2-e yr^{-1} while hybrid saves 43.9 tCO2-e yr^{-1}.

3.2.3 Financials

From Tab. 3, it is seen that for primary school the solar PV with battery storage has an EPC of $1.61/kWh, the simple payback period is 8.4 years and the net present value (NPV) US$55,723 making it a financially viable system considering that diesel generator is not used to supply the load 24/7. However, the EPC is high, so when a hybrid is considered the EPC reduces to US$1.16/kWh; which is almost a 28% decrease in generation cost. However, for secondary school, because the load is high, and 5 days of storage is taken, the battery cost is very high which makes a completely solar PV system with battery storage not a financially viable solution. When a hybrid system is modelled, it gives a financially viable option. With a solar with battery storage and a diesel generator as backup, it requires less battery storage so makes the system even more financially attractive as shown in Tab. 4.

Tab. 3: Output parameters for RETScreen modelling for primary school

Parameter	**Unit**	**Primary**					
		Nairai Island, Lomaiviti					
System description		Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
Base case		Generator	Generator	Generator	Generator	Generator	Generator
Proposed case		Solar + battery storage	Solar + battery storage + generator	Solar + battery storage	Solar + battery storage	Solar + battery storage + generator	Solar + battery storage + generator
Incentives		None	None	Government grant US$5000	Government grant US$5000 Plus carbon revenue of US$16/t$CO_2$ for the first 10 years	Government grant US$5000	Government grant US$5000 Plus carbon revenue of US$16/t$CO_2$ for the first 10 years
Annual Electricity delivered to load	kWh	13,626 (99.9% of load met)	13,651 (97% solar and 3% diesel)	13,626	13,626	13,651	13,651
Annual GHG emissions saved	tCO_2-e yr^{-1}	27.3	26.7	27.3	27.3	26.7	26.7
Simple Payback Period	Years	8.4	5.8	8.1	7.9	5.5	5.4
Net Present Value (NPV)	US$	55,723	107,321	60,723	63,404	112,321	114,947
Benefit to cost ratio		2.3	4.7	2.4	2.4	4.9	5
GHG reduction cost	US$ tCO_2-e^{-1}	-167	-423	-189	-189	-445	-445
EPC	US$ kWh^{-1}	1.61	1.16	1.56	1.56	1.12	1.12

Tab. 4: Output parameters for RETScreen modelling for secondary school

Parameter	**Unit**	**Secondary**					
		Bua, Vanua Levu					
System description		Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
Base case		Generator	Generator	Generator	Generator	Generator	Generator
Proposed case		Solar + battery storage	Solar + battery storage + generator	Solar + battery storage	Solar + battery storage	Solar + battery storage + generator	Solar + battery storage + generator
Incentives		None	None	Government grant US$10,000	Government grant US$10,000 Plus carbon revenue of US$16/t$CO_2$ for the first 10 years	Government grant US$10,000	Government grant US$10,000 Plus carbon revenue of US$16/t$CO_2$ for the first 10 years
Annual Electricity delivered to load	kWh	42,598 (99.8% of load met)	42,705 (97.7% solar and	42,598 (99.8% of load met)	42,598 (99.8% of load met)	42,705 (97.7% solar and 2.3% diesel)	42,705 (97.7% solar and 2.3% diesel)

			2.3% diesel)				
Annual GHG emissions saved	tCO_2-e yr^{-1}	45	43.9	45	45	43.9	43.9
Simple Payback Period	Years	10.7	6.7	10.3	10.1	6.3	6.1
Net Present Value (NPV)	US$	-220,985	4,341	-210,964	-206,543	14,341	18,653
Benefit to cost ratio		-1.4	1.1	-1.3	-1.2	1.3	1.4
GHG reduction cost	US$ tCO_2-e^{-1}	670	42.06	644	644	15.28	15.28
EPC	US$ kWh^{-1}	1.62	0.999	1.59	1.59	0.971	0.971

With incentives and government grants, the financial viability of the project further improves. The results suggest that by providing government grants to schools, their NPV increases while the simple payback period and energy production cost are reduced. In addition, when receiving carbon-saving revenue from some carbon credit scheme, the schools can further reduce their simple payback period, and increase their NPV but the EPC remains unchanged compared to scenarios when only government grants are given.

For the secondary school just having solar PV with battery storage, even when a government grant of US$10,000 is given with carbon revenue, the project is still a loss for the school and they are not able to recover their investments. The financial viability is not positive. Hence for off-grid secondary schools, it is good to consider a hybrid system (solar/diesel/battery). The main reason is the cost of batteries. For solar PV alone it requires a large battery size to get a reliable power supply which increases the system cost while for the hybrid system, the generator provides the backup power and battery capacity can be reduced. As seen from the cases that are studied, for solar PV alone, the "no sun days" is taken as 5 while for hybrid it is 1.2, so fewer batteries are required in hybrid which makes the system cost relatively cheaper. One option to make only Solar PV with battery storage financially viable is to have some income generation activities at the school such as renting their buildings for functions or external training.

3.3 Climate/weather conditions' impact on Solar PV systems

Extreme weather conditions affect the performance of solar PV and its longevity. In addition, its impacts on the energy infrastructures in small developing economies are devastating (Bundhoo et al., 2018). For small island nations, especially the South Pacific region, it experiences intense tropical cyclones (TC) every year. A Tropical Cyclone, as categorized by the Australian and South Pacific category system is shown Tab. 5 and its mean annual occurrence is more than any other natural climate events in Fiji as seen in Fig. 5. Tropical cyclones usually cause fatalities and substantial economic damage, which has slowed down economic growth and the power sector is not an exception. This section discusses the ways for keeping the power infrastructure safe and resilient to TCs. A resilient energy infrastructure provides reliable power to meet the demand. In addition, the discussion will also be on the impact of salt air breeze on the parts of solar PV systems.

Tab. 5: Categories of tropical cyclones in Fiji and the South Pacific. Source: (FMS, 2017).

Category	1 (Tropical Cyclone)	2 (Tropical Cyclone)	3 (Tropical Cyclone)	4 (Tropical Cyclone)	5 (Tropical Cyclone)
10-min mean wind (km/hr)	63-87	88-117	118-157	159-200	>200
Max 3-sec gust (km/hr)	<125	125-169	170-224	225-279	>280
Comments	Damaging winds	Destructive winds	Very destructive winds	Very destructive winds	Very destructive winds

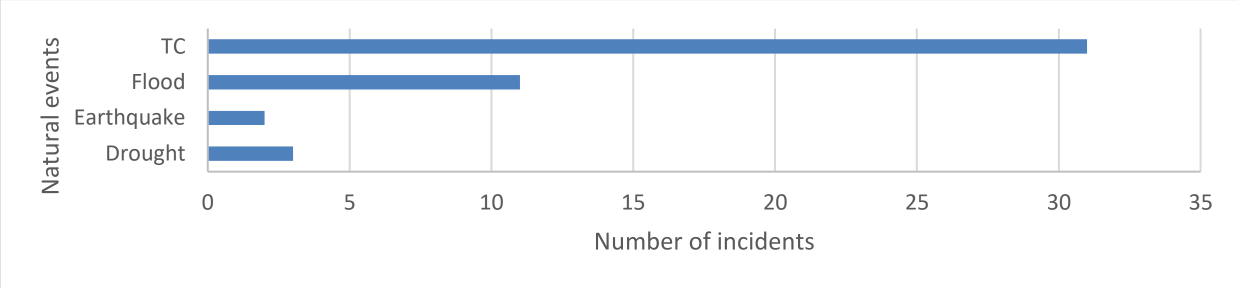

Fig. 5: Number of incidents of natural events between 1980 and 2020. Data Source: (CCKP, 2021).

NREL has developed a set of pre-storm/cyclone checklists to keep solar PV systems either utility-scale or distributed generation (roof-top and ground-based) safe (NREL, 2022). They provide a checklist on the modules, fasteners, racking, electrical (wiring and connectors) and overall system which must be done before the cyclone and during the cyclone it is recommended to power down the PV systems. Further, the Australian PV Association recommend that for the installation of PV systems in cyclone-prone areas the building standards must be enforced when installing PV arrays so that they can withstand the high winds and gusts during cyclones (APVA, 2011). Weir and Kumar (2020) discuss that PV systems can withstand cyclones if they are well-fastened and give an example of Tongan 3 MW of grid-connected PV on the island of Tongatapu, which survived TC Gita in 2018 as it passed right over them. They further observe that, in the Pacific, ground-mounted PV or PV on special poles are able to withstand tropical cyclones much more than rooftop solar PV. It is also recommended that community-based awareness-raising and capacity strengthening should be strengthened to scale up resilient energy infrastructure in climate-vulnerable off-grid islands (Delina et al. 2020; Hills et al. 2018). The communities need to know what impact adverse weather has on the performance of the PV system, what needs to be done when there is a tropical depression warning and what happens during and after cyclones. Moreover, (Castro et al., 2023) recommend hardening the solar PV system such as using sturdier materials in the construction of energy assets or burying powering lines so that it does not get damaged by storms/cyclones/typhoons. They also recommend insuring energy systems against natural disasters. This will ensure that communities would not have the financial burden of maintaining their energy system in times of natural disasters as they will be focusing on other urgent matters in the aftermath of cyclones. Furthermore, most Pacific Island Countries require installations of PV systems that are category 5 cyclone compliant which make the system resilient (PPA and SEIAPI, 2019).

Further, for off-grid applications in the outer remote maritime islands of Fiji where the salt breeze is high, the chances of solar PV components corroding are high, especially the batteries. So, even though the technology may be superior but if it is not installed in a proper manner it will stop working. Installers need to understand the ambient conditions in Fiji and how it will affect different parts of the PV systems. This makes a case for the policymakers to consider proper standards to be established so that quality parts are imported and installation standards ensure that proper housing for batteries and inverters is done and that it is not directly exposed to salty air breeze.

4. Conclusions

This is the first study that considers the energy demand for off-grid schools in Fiji and makes recommendations on some clean energy solutions such as solar PV systems with battery storage that can reduce their dependence on expensive fossil fuels and reduce their carbon footprint. With 4.40 and 5.60 kWh m^{-2} day^{-1} of solar radiation at the sites of primary and secondary schools respectively, the hybrid solar PV system is a favourable renewable energy option that can be used to power off-grid schools, given its relatively low capital cost.

The results show that solar PV system with battery storage and having a diesel generator as backup is a financially viable option for sustainably powering off-grid schools where government grants or incentives make the cost of energy production lower. However, just having solar PV systems with battery storage has significantly higher investment costs which is not financially viable for schools. In addition, to make the system resilient, proper training and awareness must be carried out in communities or solar PV users on how to protect their systems before and during natural disasters, especially tropical cyclones. Providing electricity 24/7 to off-grid schools would mean a higher tier of electricity access for schools that will give opportunities to teachers and students for better teaching and learning techniques. Students in rural or outer smaller islands would enjoy the same services and be able to do research for their learning as students on the main island where grid electricity is taken for granted. The need for concurrent energy efficiency measures cannot be over emphasized.

This study can provide information for potential donors and government departments on the investment needed for off-grid schools and a similar approach can be taken for other schools around Fiji and the region which share most of the characteristics.

5. Acknowledgements

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