ANALYSIS OF ECONOMIC VIABILITY OF SOLAR PHOTOVOLTAIC SYSTEMS FOR SMALL SCALE OFF-GRID ELECTRICITY GENERATION IN NIGERIA

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ABSTRACT
Life cycle costs (LCC) of solar photovoltaic (PV) systems and petrol-powered generators for off-grid electricity generation in Nigerian households and small business outfits was evaluated in this study using deterministic LCC and Monte Carlo Simulation approach. Results revealed 91% savings in the LCC of PV systems as compared with petrol generators of 5kVA and 3kVA respectively, after ten (10) years, with a breakeven period of two (2) years. Further analysis also revealed that the levelized energy cost of PV systems is 80% lesser compared to petrol generators. Sensitivity analysis of the LCC factors indicates that the initial capital cost and replacement cost contributes 83.4% and 16.5% respectively to the LCC of PV systems, while operation and maintenance costs, fuel price and fuel consumption rate per hour contributes 61.9%, 20% and 18% respectively to the LCC of petrol generators. Thus, PV systems are economically viable than petrol-powered generators for small scale off-grid electricity generation in Nigeria and it is therefore recommended that where the initial capital cost is available, solar PV systems should be adopted for off-grid electricity generation and local production of PV components should be encouraged as this will greatly reduce the initial capital cost of solar PV systems.

Keywords: *Electricity, household, life cycle cost, petrol-powered generator, small business, solar photovoltaic system*

1. INTRODUCTION

Electricity supply in Nigeria has remained unsatisfactory despite the huge investment put into the sector by the Nigerian government. Some of the challenges faced by the electricity generating and distribution companies in Nigeria, resulting in their inability to meet the electricity demand of the Nigerian consumers include very low installed electricity generating and transmission capacities, inadequate supply of gas, use of outdated equipment, poor maintenance culture and other similar factors inclusive (Arobieke *et al.*, 2012). These have deprived many Nigerians the benefits accruing to the use of electricity (Medugu and Michael, 2014). The unreliability in the electricity supply from the national grid has led households and business outfits to adopt different strategies to cope with their electric energy demand. Some of these strategies include the use of petrol/diesel generators and renewable energy sources. The adoption of petrol generators by various business outfits and households as the quickest way to supplement the erratic power supply is because it requires little or no technical knowledge to operate depending on the brand of the generator, low initial capital cost and it is readily available in the local markets. This situation has not only boosted generator sales across the country, it has also encouraged the importation of generators from different parts of the world into the country.

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According to ECN (2012), about 60 million Nigerians rely on petrol generators for electricity generation and more than 30% of this population are not able to properly manage the generators due to its maintenance and operating costs. Also, these petrol generators create noise and their exhaust emissions are dangerous to health and contribute to global warming. Furthermore, the recent embargo by the federal government of Nigeria on importation of petrol generators into the country and the recent removal of fuel subsidy without any appreciable increase in supply of electricity from the national grid has left most Nigerians with no other choice than to purchase these generators at exorbitant prices with high operational cost due to hike in fuel prices, in the quest to meet their electrical energy requirement. These high operational and maintenance costs, and the health hazard posed by the use of petrol generators has led researchers, households and business outfits to seek renewable energy sources as a viable alternative to petrol generators for electricity generation.

There is a growing awareness that renewable energy sources such as hydro, wind, and solar technologies can substitute petrol generators (Adejumobi *et al.*, 2011), and it is estimated that energy from the renewable energy potentials that are feasible in Nigeria is about ninety three thousand, nine hundred and fifty megawatts (93,950 MW) from energy sources such as onshore and offshore wind, solar photovoltaic (PV) systems, geothermal, biomass, small and large hydro plants, and nuclear resources (Olaoye *et a*l., 2013). Though, this report shows that small and large hydro power technologies has the highest energy potential, however, since Nigeria is a tropical country which lies approximately between 4^o and 14^o above the equator, and receives on the average 20MJ/m^2 of solar radiation per day (Adeyemi, 1997; Abe and Adetan, 2008), therefore, this makes solar PV system a viable source of renewable energy for off-grid, stand-alone electricity generation in Nigeria. Solar energy is the light radiating from the Sun, while solar photovoltaic energy is the conversion of sunlight into electricity. The technology used to convert solar energy directly into electrical power is called photovoltaic cell otherwise known as a solar cell or PV. There is reliable sunshine all year round in all parts of Nigeria to sustain solar power development in the country, but utilization and development of solar energy systems in Nigeria are very poor. This low pace of development is due to the high initial capital cost of PV systems, lack of PV technologies, low awareness and poor governmental policies (Chendo, 2002; Akinboro *et al*., 2012). Households and small business outfits in Nigeria have been skeptical in adopting solar PV systems for electrical power generation because most Nigerians use procurement costs as the primary (and sometimes only) criteria for equipment or system selection based on a simple payback period with little consideration of the life cycle cost/Levelized Energy Cost. This always leads to wrong choice because according to MESA (2003), most equipment's cost of operation, maintenance, and disposal costs usually exceed all first costs many times while supporting costs are often 2 to 20 times greater than the initial procurement costs. Life Cycle Cost (LCC) is the total cost of ownership of machinery and equipment, including its cost of acquisition, operation, maintenance, conversion, and/or decommission (SAE 1995). LCC are summations of equipment and project cost estimates from inception to disposal. Levelized Energy Cost (LEC) incorporates all costs over the lifetime of any power generating system and constitutes the first order economic assessment of the cost competitiveness of electricity generating systems with different life spans (Dyesol, 2011). Thus, this study accessed the economic viability of solar PV systems for small scale electricity generation in Nigeria using the deterministic life cycle cost approach and levelized energy cost technique while Monte Carlo simulation was applied in the sensitivity analysis of the life cycle cost factors.

2. MATERIALS AND METHODS

A quantitative and qualitative survey was carried out using a well-structured questionnaire while the residents of Umuahia constitute the sampled population. The average electrical load demand of the sampled households and small scale business outfits were determined from the questionnaire and it was used to establish the power rating of PV systems and generators to be studied. The costs associated with the ownership, operating and maintenance of the solar PV systems and petrol generators were respectively obtained from Haria Ventures Limited and Lil Engineering Services inventory and maintenance records. A deterministic LCC analysis approach was used to estimate the life cycle costs of the various ratings of the solar PV systems and petrol generators. Life cycle cost approach evaluates all the relevant cost over the lifetime of a project taking into account the initial cost which includes capital cost of an equipment, installation, present value of the annual maintenance cost, replacement costs, fuel costs and salvage value (DLMC, 2006). LCC analysis is the process used to determine the most cost effective option among alternatives, and the standard criterion for deciding whether a program can be justified on economic principles is Net Present Value (NPV), which is discounted monetized. As earlier stated, LCC analysis is particularly helpful when there are more than one competing alternatives for the objective, the alternative with the lowest value of LCC is usually considered to be the most cost effective.

The LCC of a system as stated in Equation (1) is the sum of the ownership cost (OC), operation and maintenance cost (OM), replacement costs (R) and fuel costs (F) minus the salvage value (SV) (Sandria National Laboratories, 2002). The ownership cost includes cost of market survey, equipment purchase, transportation and installation, while the operation and maintenance costs consist of any cost associated with maintaining and operating the equipment. Similarly, the replacement cost refers to the costs of purchasing spare parts and repair of the equipment, while fuel cost is the market value of the annual cost of the fuel used.

$$LCC = OC + OM + R + F - SV \quad (1)$$

Thus, the life cycle cost (LCC_{gen}) of the various ratings of the petrol generator was computed using the relation in Equation (2), which is the sum of the ownership cost of the generator (OC_{gen}), operation and maintenance cost of the generator (OM_{gen}); which include costs of lubricating oil and spark plug changed intermittently during generator use and repairs, replacement cost (R_{gen}) of worn generator parts and overhaul during use, annual fuel (Petrol) cost (F) adopted from Sunita *et al.*, (2002); Peurifoy and Schexnayder (2002); Park (2011); Otasowie and Ezomo (2014) and shown in the Equations (2) to (7) below. Where C_0 is the Initial capital cost/ procurement cost of the generating set; SV_{gen} is the salvage value of the generator at '*n*' year end; i is the interest rate given as 10% for capital costs (DOE, 2014); N & n represent the period or year under consideration; f_e is the fuel escalation value and it is assumed as 33%, which takes care of the hike in fuel price over the last five years; f_a is the average fuel consumption rate (in naira, ₦) per annum of the sampled households and business outfits; d_r is the product discount rate given as 9.5% (Otasowie and Ezomo, 2014); p is the initial cost of the replaceable components of the generator and the relationships $(F/P, i, N)$; $(A/P, i, N)$ are determined using compound interest tables (Park, 2011).

$$LCC_{gen} = OC_{gen} + OM_{gen} + R_{gen} + F - SV_{gen} \quad (2)$$

$$OC_{gen} = C_o(A/P\,, i, N) \quad (3)$$

$$OM_{gen} = OC(F/P\,, i, N) \quad (4)$$

$$R_{gen} = p(1+i)^n \quad (5)$$

$$F = f_a\left\{\left(\frac{1+f_e}{d_r-f_e}\right) \times \left[1 - \left(\frac{1+f_e}{d_r+1}\right)^n\right]\right\} \quad (6)$$

$$SV_{gen} = C_o(1-i)^n \quad (7)$$

Similarly, the life cycle cost (LCC_{PV}) of the solar PV systems was computed using the relation in Equation (8), which was modified from Equation (1) to comprise the ownership cost (OC_{pv}), operation and maintenance cost (OM_{pv}), and replacement cost (R_{pv}) of the PV systems neglecting fuel cost and salvage value since no fuel is required to operate a solar PV system and it is assumed that the components of solar PV system have no salvage value for the ten year period (Cabraal *et al.,* 1996). The ownership cost (OC_{pv}) is the initial investments for each part of the PV system which includes the PV array/module, DC/AC inverter, batteries, charge controller, battery charger, cables, packaging, transportation and installation etc. The ownership cost is the initial capital cost (C_0) of the solar PV compounded annually as shown in Equation (9) with an interest rate, i= 15% for capital cost of the PV system (DOE 2014). The operation and maintenance cost of the solar PV system is given as 5% of the ownership cost ($OM_{pv} = 0.05 \times OC_{pv}$) for each (*n)* year (DOE 2014), while the replacement cost (R_{pv}) is the monetary value of the replaced PV component, and for solar PV systems, the battery is the component usually replaced. Though, the deep cycle batteries used for solar PV systems can last for more than ten years if properly managed (ESMAP, 2000; Foster *et al.,* 1998). The percentage increase or decrease in the LCC of the petrol generator and PV system at the tenth year interval is determined using the relation in Equation (11) expressed as the ratio of the difference between the LCC of the petrol generator and PV at the tenth year to the LCC of the petrol generator. While the levelized energy cost (LEC), which is expressed as the net present value of the unit cost of electricity over the lifetime of each electricity generating asset, is estimated from the relation in Equation (12), given by (Branker *et al.,* 2011). Where E_t is the electrical energy generated in year t. Also, Equation (13) was used to determine the percentage increase or decrease in the LEC of petrol generators and PV systems after ten years of usage.

$$LCC_{PV} = OC_{pv} + OM_{pv} + R_{pv} \quad (8)$$

$$OC_{pv} = C_o(A/P\,, i, N) \quad (9)$$

$$R_{pv} = p(1+i)^n \quad (10)$$

$$\%\,LCC = \frac{LCC_{gen} - LCC_{pv}}{LCC_{gen}} \quad (11)$$

$$LEC = \frac{\sum_{t=1}^{n}\frac{OC+OM+F+R}{(1+d_r)^t}}{\sum_{t=1}^{n}\frac{E_t}{(1+d_r)^t}} \quad (12)$$

$$\%\,LEC = \frac{LEC_{gen} - LEC_{pv}}{LEC_{gen}} \quad (13)$$

To determine the factors which significantly contribute to the LCC of the various ratings of the solar PV system and petrol generators, Monte Carlo Simulation using Excel 2013™, was employed in the sensitivity analysis of all the factors considered in the LCC models of both systems.

3. RESULTS AND DISCUSSION

The summary of the average load demand of the respective households and small business outfit is presented in Table 1, indicating that the average load demand for households occupying three (3) bedroom, two (2) bedroom and one (1) bedroom apartments are 4.52 kWh, 3.0 kWh and 2.71 kWh respectively, while that of a small business outfits is 3.0 kWh.

Though, electric iron and air conditioner whose load capacities increased the load demand of these households can be alternately used, thereby reducing the load demand to a minimum of 3.52kWh, 2.0kWh and 1.71 kWh for the households respectively. Therefore, solar PV systems and petrol generators of 5kVA and 3kVA standard capacities were selected for this study.

Table 1: Average load demand for sampled households and small business outfits

S/N	Appliance	Power (W)	3 Bedroom Apartment		2 Bedroom Apartment		1 Bedroom Apartment		Small Business Unit	
			Quantity	Total Power (Wh)	Quantity	Total Power (Wh)	Quantity	Total Power (Wh)	Quantity	Total Power (Wh)
1	Television	70	2	140	1	70	1	70	-	-
2	Home theatre	57	1	57	1	57	1	57	-	-
3	Air conditioner	1000	2	2000	1	1000	-	1000	1	1000
4	Electric bulbs	20 40	8 8	160 320	6 6	120 240	4 4	80 80	2 4	60 160
5	Refrigerator/ Freezer	150	2	300	1	150	1	150	1	150
6	Electric iron	1000	1	1000	1	1000	1	1000	-	-
7	Ceiling fan	100	4	400	3	300	2	200	1	100
8	Standing fan	25	2	50	2	50	1	25	-	-
9	Desktop	120	-	-	-	-	-	-	4	480
10	Laptop	45	2	90	1	45	1	45	3	135
11	Photocopier	250	-	-	-	-	-	-	2	500
12	Big industrial fan	220	-	-	-	-	-	-	1	220
13	Printer	100	-	-	-	-	-	-	2	200
	Total (Maximum)			**4.52 kWh**		**3.0 kWh**		**2.71 kWh**		**3.0 KWh**

The initial capital cost of solar PV systems and petrol generators of 5kVA and 3kVA minimum rated capacities are given in Tables 2 and 3 respectively. As seen in the tables, the initial capital costs vary with the power ratings of the systems. Also, shown in Table 3 is the fuel consumption rate in liters per hour at 75% load for the two different capacities of petrol generators (SUMEC, 2015). To determine the average fuel consumption rate of the generators per day, the following considerations were made; households may only operate their petrol generators in the evening while for rendering services, generators used in small business outfits may be operated for about eight (8) hours in a day. Thus, duration of operation for both alternatives was assumed to be eight (8) hours in a day. Though, solar PV systems can operate for twenty-four (24) hours, provided the batteries are charged. The petrol generators were considered to operate at an average of twenty-eight (28) days per month, which is in contrast with solar PV systems that operate every day given that the batteries are charged.

Table 2: Initial setup cost of solar PV systems

S/N	Components	Initial ownership cost of 5 kVA solar PV system			Initial ownership cost of 3 kVA solar PV system		
		Qty. Req.	Unit Cost ₦	Total Cost ₦	Qty. Req.	Unit Cost ₦	Total Cost ₦
1	iPowerPlus 3kVA Inverter	1	314,500.00	314,500.00	1	172,750.00	172,750.00
2	iPowerPlus 200AH/24V Batteries	4	118,000.00	472,000.00	2	118,000.00	236,000.00
3	iPowerPlus 250W Solar Panel	12	123,750.00	1,485,000.00	8	123,750.00	990,000.00
4	iPowerPlus Solar Panel Roof Mount	3	105,000.00	315,000.00	2	105,000.00	210,000.00
5	iPower plus charge controller	1	106,750,00	106,850.00	1	106,750,00	106,850.00
6	Battery Rack	1	25,000.00	25,000.00	1	15,000.00	15,000.00
7	Installation materials	1	174,000.00	174,000.00	1	101,500.00	101,500.00
8	Installation cost	1	70,000.00	70,000.00	1	35,000.00	35,000.00
9	Delivery	1	60,000.00	60,000.00	1	35,000.00	35,000.00
	Gross total			**3,022,350.00**			**1,902,100.00**

Table 3: Initial set up cost for petrol generators

S/No.	Petrol Generator Make/Model	Maximum Power rating (KVA)	Average Fuel Consumption rate (Litres/hour)	Current Price of generator (₦)
1	SUMEC Firman SPG7600E2	5.5	2.3	238,000
2	SUMEC Firman SPG5600E2	3.6	1.43	124,500

The results of the LCC analysis of the various standard capacities of the solar PV systems and petrol generators required to supply the average energy demand of the different households and small business outfit in Nigeria are shown in Figures 1 and 2 for the 3kVA and 5kVA systems respectively. Both figures depict a breakeven point of two years for both the 3kVA and 5kVA alternatives. This implies that the petrol generators are economically viable within the first two years of usage, however, exceeding the breakeven point, the life cycle cost of both petrol generators astronomically increased from less than two million Naira to about nineteen million Naira (₦2, 000,000 - ₦19, 000,000) for the 3kVA petrol generator and less than five million Naira to about thirty million Naira (₦5, 000,000 - ₦30, 000,000) for the 5kVA petrol generator at the end of the tenth year. While, the life cycle cost of the solar PV systems was decreasing continuously to about one million, five hundred thousand Naira (₦1, 500,000) and two million, eight hundred thousand Naira ((₦2, 800,000) for the 3kVA and 5kVA solar PV system respectively for the ten-year period. In both cases, at the end of the tenth year, it was observed that there is about 91% increase in life cycle cost for both petrol generator ratings as compared to their solar PV system counterpart.

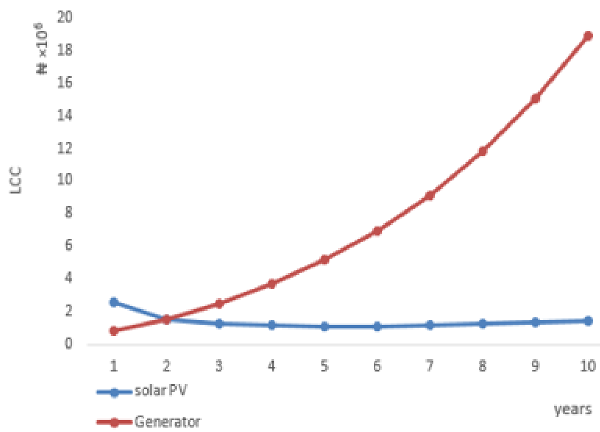

Figure 1: LCC analysis of 3kVA PV and petrol generator.

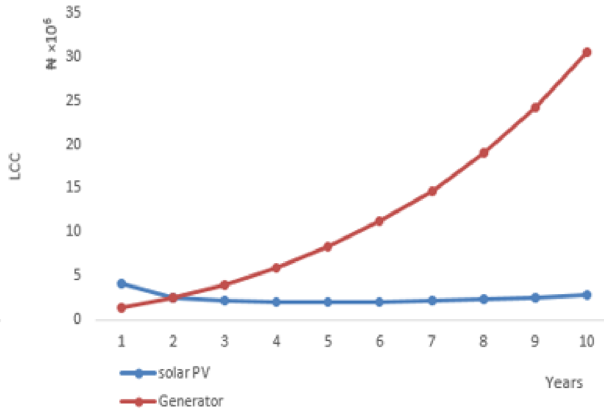

Figure 2: LCC analysis of 5kVA PV and petrol generator.

The levelized energy cost (LEC) of the 5 kVA and 3 kVA PV systems were computed as ₦43/kWH and ₦42/kWH respectively, whereas the LEC of the 5 kVA and 3 kVA petrol generators was determined as ₦247/kWH and ₦274/kWH respectively. It was also observed that the LEC for the solar PV systems reduced as the electrical power rating reduced contrary to that of the petrol generator, and this observation is consistent with the reports of Effion *et al.,* (2016), regarding other renewal energy sources.

Figures 3 and 4 show the results of the sensitivity analysis for the petrol generator and PV systems respectively. In Figure 3, it is seen that operation and maintenance costs, fuel price, fuel consumption rate and initial capital cost significantly affect the life cycle costs of petrol generators. The operation and maintenance is the major factor affecting the life cycle costs of petrol generators contributing 61.9%, while the fuel price per liter and fuel consumption rate per hour contributes 20% and 18% respectively. The initial capital cost of petrol generators has the least impact on its life cycle cost which is estimated at 0.3%, which is in contrast with the sensitivity analysis of PV systems where the initial capital cost contributes massively to its life cycle cost with an estimated 83.4% and the equipment replacement cost contributes 16.5% to the life cycle cost of PV systems as shown in Figure 4.

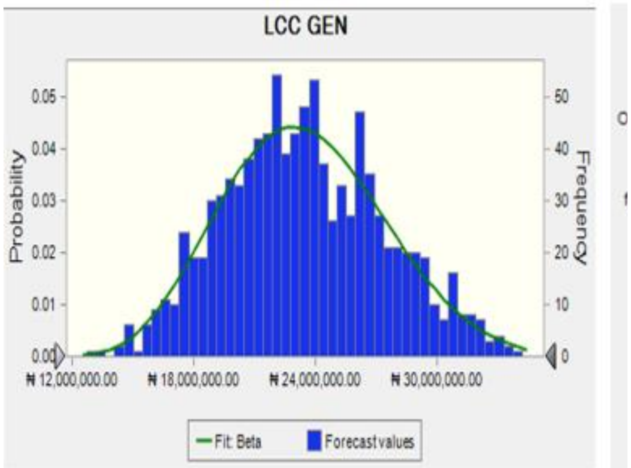

Figure 3: Sensitivity Analysis of Petrol Generator

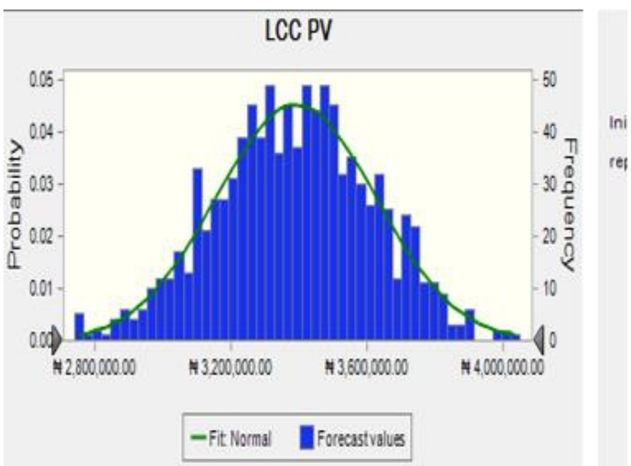

Figure 4: Sensitivity Analysis of PV systems.

The values of the LCC at the tenth year for the petrol generators are exorbitantly high and this is because the annual fuel cost which is a main component of the LCC has a significant effect on the LCC of petrol generators. A business outfit using a petrol generator with an estimated fuel consumption rate of 1litre per hour and operating at 8 hours per day, 28 working days in a month and at a fuel cost of ₦145 per liter will spend the sum of ₦389, 760 per annum. If this figure is compounded annually for a ten-year period, the business outfit will spend at least ₦3million on fuel consumption alone (assuming the fuel consumption rate of the generator remains the same and the fuel cost per liter remains unchanged). However, for a PV system, no fuel is required and the business outfit can save this sum of money. Also, during the life time of a petrol generator, routine maintenance will be carried out intermittently and it is reported that at least every five (5) years, the petrol generator will undergo an engine overhaul at an estimated 25% of the initial capital costs (Allison 2007). Furthermore, at least every 150 operating hours, a preventive maintenance such as change of engine oil, change of defective piston rings, spark plug and starter are carried out on the generator incurring more cost to the owner (Honda 2011). However, it is important to note that the performance of a photovoltaic array is dependent upon sunlight. Also, climate conditions such as clouds and fog have a significant effect on the amount of solar energy received by a photovoltaic module and, in turn, its performance. Most recent photovoltaic modules are about 10 percent efficient in converting sunlight into electricity and this efficiency is being improved upon to 20% (Toyo Engr. Corp 2005; Ogunleye and Awogbemi, 2010). Operating the generators beyond the breakeven points is very uneconomical and hence the solar PV system provide the most cost effective option for an off-grid electricity generation in Nigeria as the year progresses. This observation is consistent with the results of Guda and Aliyu (2015) and Sako *et al.* (2011).

4.CONCLUSION

This study revealed 91% savings in life cycle cost using solar PV systems for power generation as compared with petrol generators of 5kVA and 3kVA respectively. Also, the levelized energy cost for solar PV system is 80% less than that of petrol generators in the two rated capacities studied. The operation and maintenance costs constitute the major factors affecting the life cycle costs of petrol generators contributing 61.9%, while the fuel price per litre and fuel consumption rate per hour contributes 20% and 18% respectively. The initial capital cost of petrol generators has the least impact on its life cycle cost which is estimated at 0.3% and this is in contrast with the sensitivity analysis of PV systems where the capital cost contributes significantly to its life cycle cost with an estimated 83.4% and the equipment replacement cost contributes 16.5% to the life cycle cost of PV systems. Thus, solar photovoltaic systems are more viable than petrol-powered generators for small scale off-grid electricity generation in Nigeria. Solar PV initial capital costs, increases proportionately with the size of the solar module, required number of batteries and connection technique used (either series or parallel connection). Therefore, appropriate sizing of the PV system is required as under-sizing the system will cause battery leaching and leads to frequent battery replacement, which advertently will increase the LCC of the PV system and also over sizing the

PV system will cause an overly high initial capital cost and may make the PV system uneconomical. In addition, production of solar modules using local source material should be encouraged as this will greatly reduce the initial capital cost of PV systems.

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