Electrification through Renewable Resources in a Rural Area in Nigeria: Design, Optimization and Techno-Economic Evaluation

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Abstract

The electricity generation through renewable resources is a crying need to increase the rural electrification rate to an appreciable value in Nigeria. Electricity can be supplied through either the national grid being extended or through off-grid systems. The grid extension cost depends on the location of the area, its terrain, the number of households, and distance of the area from a grid point. However, based on these factors and inadequate supply of electricity to even the areas connected to the national grid, renewable energy sources may provide an alternative means of electricity generation in rural areas in Nigeria. This research paper highlighted the design, evaluation, and the techno-economic feasibility of providing electricity to rural Dilchidama in Nigeria through renewable energy sources. Total 77 households, 1 primary school, 1 primary health centre and 4 shops having total estimated load of 306 kWh/d were considered. The design and techno-economic feasibility of the renewable resource was compared with extending the national grid to the area using HOMER and RETScreen tools. The results showed that grid extension is much more cost competitive than the solar photovoltaic system for the study area for a maximum distance of 9.9 km. The sensitivity analysis performed by varying several input parameters indicated that solar photovoltaic renewable resource is a potential alternative beyond 9.9 km distance from the grid.

Keywords
Renewable energy, Photovoltaic, Electrification, Grid

1. Introduction

The requirement for electricity in any community is paramount considering the high benefits that are derived from it which relate to the enhancement of man's quality of life. Electricity to some extent is a major issue in the characteristics of the gap between rural and urban communities in the developing world. It was estimated that about 1.2 billion of the world population have no provision of electricity grid. Most of them reside in rural areas in Sub-Sahara Africa (about 0.590 billion), South Asia (about 0.610 billion), and East Asia (about 0.195 billion) (Breyer and Gerlach 2013). Lack of access to reliable light source or electricity, means productive workday stops when it is dark. Most of the rural dwellers use kerosene lamps, which emit poor light, and very dangerous because they give off an irritating smoke that blackens the walls and fills up closed rooms. If mistakenly tipped over it can start a fire that could burn down houses, particularly in mud-thatched houses, which are commonly found in the rural settlements.

Furthermore, present scheme of provision of electrification to rural area via extension through grid lines of transmission did not succeed in the provision of electricity to the numerous population of rural areas in Nigeria and the hope that many rural areas will be connected to an electric source in the near future is still not known because even those connected receive an epileptic supply. In order to reduce dependence on the conventional grid system and to reduce the number of people living without access to electricity, the design, cost implications and evaluations of renewable resources for rural electrification was considered together and compared with the conventional mode in this project. However, it is also evident that about 1.2 billion people across the globe living in rural remote villages far from electricity grid have no access to electricity supply (Breyer and Gerlach 2013), despite the abundant renewable resources that are yet to be exploited or harnessed. Certainly, with these numbers of people living in darkness with no grid connection, it deemed necessary that off-grid based rural electrification will serve as a better option in providing power to the rural population.

Nigeria is in Sub-Saharan Africa (West Africa), it has 924000 km2 land area, almost 3.1 % land area of Africa (Sambo 2010). Nigeria has many villages including Dilchidama with such predicament. The country has abundant energy sources; ranging from coal, petroleum, natural gas, solar, small hydropower, large hydropower, and biomass (Adewuyi et al. 2020; Ogbonnaya et al. 2019). The economy of the country relies mostly on the revenue generated from the export of crude oil. The country depends largely on fossil fuel to achieve her energy demand. The generation of electricity in Nigeria obtained from hydro power and fossil fuel is 38.1 % and 61.9 % respectively. The estimated reserve of some fossil fuel types as obtained from Sambo (2010) are 36.2 billion barrels of crude oil, 18.7 trillion SCF of Natural gas, 2.7 billion tonnes of coal and lignite and Tar sand of 31 billion barrels of oil equivalent. However, with the gains in the sales of crude oil and the abundant reserves of fossil fuel couple with the dependence of products of petroleum for the provision of electricity, there are the possibilities that fossil fuel usage may continue to be the most suitable means of energy resources in Nigeria for some time (Oisamoje and Oisamoje 2013; Oji et al. 2012). Nigeria has an estimated overall population of 188,375,518, it was estimated that only 40 % (75,350,207.2) of Nigerians are connected to the national grid and even these connected populations experience frequent power outages (Aliyu et al. 2015).

A good number of Nigerian researchers made a lot of study and research work in order to consider the possibility of harnessing renewable energy sources in the country noting that solar radiation received in the country and other renewable sources can be gainfully utilized. The yearly solar radiation recorded was 5250 $Wh/m^2/d$. This varies between 3500 $Wh/m^2/d$ around the coastal areas of the south and 7000 $Wh/m^2/d$ in the northern area (Ajayi et al. 2014; Chineke and Igwiro 2008; Oisamoje and Oisamoje 2013). Estimated result of the average period of hours of sunshine across the country was 6.5 hours with an average yearly intensity of solar radiation at 1.935 MWh $/m^2/yr$. and an approximated solar energy of 1,770,000 GWh/yr. This result equates to multiples of 120,000 total yearly average energy generated by the electricity distribution company of Nigeria called Power Holding Company of Nigeria (PHCN) (Ajayi et al. 2014). Agbo and Oparaku (2006) indicated that some of the policy factors hampering the deployment of some energy technologies and alternative fuels include poor research and development (R&D), lack of pilot and demonstration projects, institutional framework, investment promotion, incentives, and protections.

However, a techno-economic analysis conducted by Chaurey and Kandpal (2010) based on Photovoltaic micro grid and solar home systems for rural electrification. They reported that the micro grid might the best option economically (in terms of cost) for the energy company and the user (community) having many households especially if the terrain is flat and the population is densely situated. In the case of a spread or sparse population, they reported that the best option might be the solar home system due to the absence of distribution cost. A study by Mahapatra and Dasappa (2012) on the optimization for the selection between grid extension and off-grid non-centralized renewable resources using photovoltaic and biomass gasification and applying cost assessment on the life cycle concluded that renewable energies for electricity generation could be cost competitive. They also reported that the perception of renewables having the huge initial cost of investment is not always the case especially for a rural area with low energy requirement and far from where a grid source can be tapped. However, life cycle costs for biogas came from cost of fuel, the cost of maintenance and cost of operation. As the hours of operation of biomass gasification increases, the life cycle cost of energy from the system decreases, while for a system of photovoltaic, it approximately maintains its value for different times (hours) of operation (Mahapatra and Dasappa 2012).

Shaahid and El-Amin (2009) carried out a techno-economic assessment of off-grid hybrid PV-diesel-battery power system for electrification of a rural area in Saudi Arabia with a view of analysing solar radiation data of Kafha to examine the viability of hybrid-diesel-PV-battery system to accommodate the load needed for a rural area that has a yearly energy need of 15.943 GWh. Their findings from the simulation indicated that for hybrid components comprising 4.5 MW diesel system, 2.5 MWp PV system and 1-hour battery system autonomy, 27 percent PV penetration was obtained and that the energy cost (COE) of the hybrid system was \$0.17/kWh at \$0.1 per litre.

Electrification of rural area is mostly associated with many challenges that include bad terrain, low load demand, the huge cost of investment, inadequate load factor, the cost of maintenance and operation (Rahman et al. 2013). However, some factors such as irrational renewable energy policies; non-availability of subsidies for renewables militates or hampers the use renewable resources and this contributes to making the conventional system more affordable than the renewable resources (Urmee et al. 2009).

Rural electrification is obtainable through either grid extension strategy to remote/rural settlements, or by design using the decentralized systems often called off-grid systems of electrification (Mosberg 2013; Yadoo and Cruickshank 2012). However, the study area currently relies on generators for their means of providing electricity, and to a large extent on kerosene lamps, hand-held torch, and rechargeable lanterns. Therefore, in other to make the population of Dilchidama feels the benefit and impact of having electricity through the adoption of renewable resources, this study investigated the techno-economic evaluation of the potential of renewable resources and technology for electrification of Dilchidama in Hong local government of Adamawa State in Nigeria. Furthermore, to examine the viability of rural electrification through off-grid renewable energy options, this work determined the technology configuration with the use of HOMER tool and finally its financial acceptability with the aid of RETScreen tool. HOMER tool (Hybrid Optimization Model for Electric Renewables) is a micro power optimization software used in evaluating designs of both off-grid and grid-connected power systems for a variety of applications. This software was developed by Mistaya Engineering, Canada for the National Renewable Energy Laboratory (NREL) USA to assist in the design of a power system, sizing of components used, and other parameters involved. Its optimization and sensitivity algorithm simplifies the evaluations of several system configurations and stimulates the operation of energy balance calculations sorted by the net present cost that can be used to compare system design (Ajao et al. 2011). RETScreen tool is a software developed by CANMET Energy Diversification Research Laboratory (CEDRL) that is based on Microsoft Excel spread sheets, consisting of a standardized and integrated renewable energy project analysis (Turcotte et al. 2001). As stated above this tool will also be employed for the project financial viability such as Cost of Energy (COE), Net present Value (NPV), Internal rate of return (IRR) and Benefit to Cost Ratio (B/C. Although, a lot of researches have been conducted and still on-going for the viability and reliability of renewable energy for rural electrification projects in various rural communities around the world, so far, no research has been conducted for electrification through grid extension or off-grid options for Dilchidama. This paper also compared off-grid options (microgrid) with grid extension (conventional) for the study area and indicated the most economically competitive method of providing electricity access in the rural area of Dilchidama using the HOMER and RETScreen tools.

2. Materials and Method

2.1 Location of the study area

Dilchidama is one of the rural settlements in Hong local government area of Adamawa State in Nigeria lying on latitude 10^0 10′ N (10.17^0 E) and longitude 12^0 58′ E (12.97^0 E). The village has an estimated population of about 575 people with 77 houses, 1 church, 1 primary health care centre, 1 primary school and 4 shops. The current means of providing light in this area when it is dark are; using kerosene lamps, hand-held torchlights, rechargeable lanterns, candles, and small generators for those that can afford it.

2.2 Estimated electricity load demand for the study area

The electricity load demand for an average household in a rural area are for lighting points in the house, television, fans, drinking water supply and street lighting (Mahapatra and Dasappa 2012) while for community load; it includes electricity requirements for hospitals (primary health care), street lights, schools, saw mills. However, from personal survey, the basic electricity need for the area presently is for lighting, entertainment (radio, television, and fans), few community loads needed at the primary health care unit and primary school and four shops. Therefore, in the evaluation of the hourly load demand for this study, the list of appliances with their corresponding power ratings and quantities required per household used was considered. The total hourly load (kW) for all the households in the community was used in the evaluation of the microgrid components sizing and design as shown in Figure 1. below.

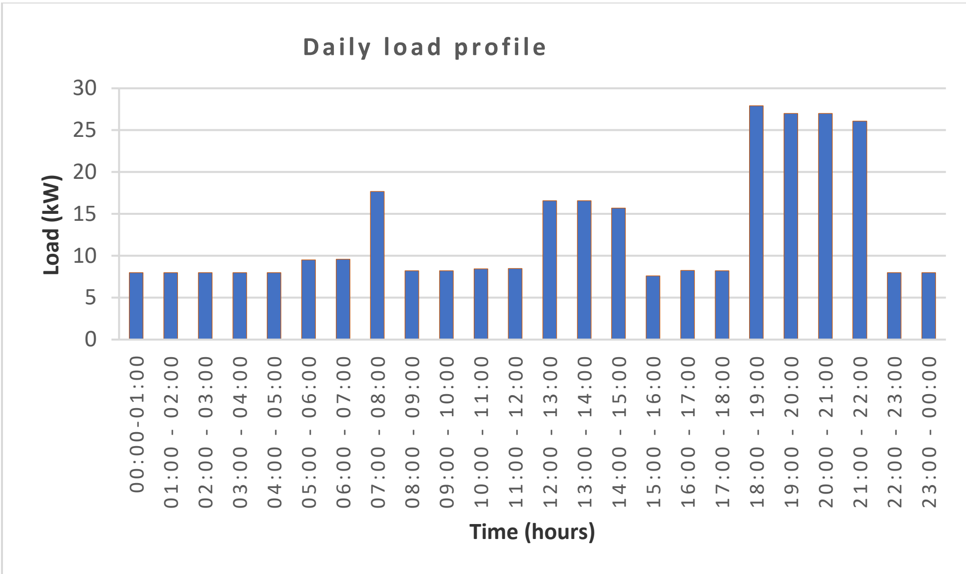

Figure 1. Daily Load Profile

2.3 Solar resource

The average daily solar radiation and ambient temperature data were used to calculate the power produced by the photovoltaic array for each hour of the year. However, due to non-availability of a weather or meteorological station in the village, the solar radiation data was extracted from NASA surface meteorology and Solar Energy Data base. The data provided an annual average daily Solar radiation and ambient annual average ambient temperatures of 5.76 kWh/m^2/day and 27.60 ^{0}C respectively as shown in Table 1. The profile of the daily Solar radiation and Clearness Index is shown in Figure 2.

Table 1. Daily Radiation and Temperature Data

Sl.	Months	Average Daily solar radiation (kWh/m^2/d)	Clearness index	Ambient temperature (^{0}C)
1	January	5.790	0.653	26.7
2	February	6.260	0.656	29.2
3	March	6.510	0.637	32.3
4	April	6.340	0.603	31.0
5	May	6.040	0.579	28.7
6	June	5.650	0.549	26.2
7	July	5.140	0.498	25.0
8	August	4.910	0.471	25.0
9	September	5.320	0.518	25.6
10	October	5.700	0.587	26.9
11	November	5.840	0.650	28.4
12	December	5.610	0.652	26.8
	Average	5.759	0.588	27.6

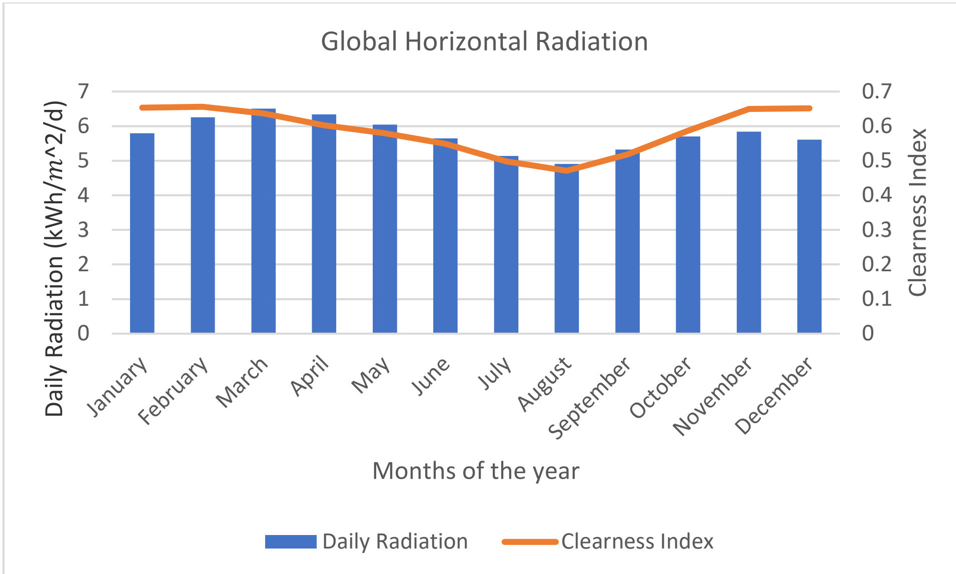

Figure 2. Profile of the Daily solar radiation and Clearness Index

2.4 Designing and optimization of renewable based electrification system

2.4.1 Sizing of solar photovoltaic components

The design of solar PV components for the microgrid system to serve the village load, employed the use of some inbuilt modelled equations in the HOMER optimization tool that processed the input data assigned to it. In the economic window, the design considered 6.13 % as the annual real interest rate, project lifetime of 25 years, US$25,000 as the system fixed cost in order to take care of the distribution cost and the cost of building a place to place the batteries, a value of US$1967.21 was estimated as the system fixed operation and maintenance cost per year to serve as the salary of a technician that can supervise the system.

2.4.2 Solar (PV) panel power output, specifications, and selection

The PV array output (P_{pvao}) of the system is dependent on the cell temperature and solar irradiance, increase in temperature reduces the output of the PV array and vice versa while the power output increases with increase in irradiance; the PV array power was calculated in the simulation work using the relation in equation 1 below.

$$P_{pvao} = PV_{RC} \times PV_{DF} \left(\frac{G_{i,PV}}{G_{i,STC}}\right)\left[1 + \tau_p\left(T_{Cell} - T_{Cell,STC}\right)\right] \qquad (1)$$

Where, PV_{RC}, PV_{DF} are the PV array rated capacity (kW) and PV array derating factor (%) respectively. $G_{i,PV}$ is the incident radiation on the array at that time (kW/m^2), $G_{i,STC}$ is the incident radiation at standard test condition (1kW/m^2), τ_p, T_{Cell} *and* $T_{Cell,STC}$ are the temperature coefficient of power (% / ^{0}C), cell temperature of PV (^{0}C) and cell temperature of PV at standard test conditions (25 ^{0}C).
The cell temperature (T_{Cell}) was evaluated using equation 2 below.

$$T_{Cell} = T_S + \left(T_{Cell,NOCT} - T_{S,NOCT}\right)\left(\frac{G_R}{G_{R,NOCT}}\right)\left(1 - \frac{\eta_{mpp}}{\tau_a}\right) \qquad (2)$$

Where, T_S, $T_{Cell,NOCT}$, $T_{S,NOCT}$ are the surrounding temperature (^{0}C), the nominal operating temperature of the cell (^{0}C) and the surrounding temperature where NOCT is defined (20^{0}C). G_R, $G_{R,NOCT}$, η_{mpp} and τ_a are the radiation acting on the array (kW/m^2), radiation at which the NOCT is defined (800W/m^2), efficiency at maximum power point (%) and the PV array solar absorbance (%). However, if the effect of temperature on the PV array is neglected and temperature coefficient of power is assumed to be zero, equation 1 becomes.

$$P_{pvao} = PV_{RC} \times PV_{DF} \left(\frac{G_{i,PV}}{G_{i,STC}}\right) \qquad (3)$$

However, the selection of 250 W monocrystalline PV cell was selected in this design over other types of PV cells like polycrystalline and Amorphous cells due to some of the following advantages it possesses:

i) It has the highest efficiency between 15 - 20 %.
ii) They are space-efficient (acquire the use of small space).
iii) Live longer (have 25-year warranty).
iv) Perform better than same capacity of polycrystalline at low-light conditions.
v) They have greater heat resistance.

The specifications of the 250 W selected for the design is shown in Table 2 below.

Table 2. Solar PV module Design parameters, Cost and Specifications

S/No.	Parameters	Values	Units
1	Maximum Power (Model SM660-250)	250	W
2	Project Lifetime	25	yr.
3	Slope	10.17	Degree
4	Derating Factor	80	%
5	Temperature Coefficient of Power	-0.39	%/^{O}C
6	Azimuth	0	Degree
7	Ground Reflectance	20	%
8	Nominal operating cell temperature	46	^{O}C
9	Efficiency at standard test condition	15.4	%
10	Capital cost	391.57	US$
11	Replacement Cost	0	US$
12	Operation and Maintenance cost	0.37	US$/yr.
13	Nominal Voltage	24	V

2.4.3 Sizing of the battery

A microgrid or an off grid set up requires a storage unit to enable it to preserve excess electricity generated from a renewable resource to be used at night. It serves as a backup for the system in the event of any low generation in capacity and also when a constant voltage is required especially during peak load (Ugirimbabazi 2015). However, two independent factors reduce the lifetime of a battery bank; these are either old age or usage. In this design, the model calculates the battery bank life using the following equation.

$$L_{bb} = MIN\left[\frac{N_b \times Q_{lt}}{Q_{tp}}, L_{bf}\right] \qquad (4)$$

Where, L_{bb} is the battery bank life (yr.), N_b is the number of batteries in the battery bank, $Q_{lt}$is the lifetime throughput of a single battery (kWh), Q_{tp} is the annual battery throughput (kWh/yr.) and L_{bf} is the float life of battery (yr).
However, the ratio of the battery bank size to the electric load is called the battery bank autonomy and is calculated using:

$$\frac{N_b V_n C_n \left[\left(1 - \frac{q_m}{100}\right)\left(\frac{24h}{d}\right)\right]}{l_{av}\left(\frac{100Wh}{kWh}\right)} \qquad (5)$$

Where, V_n is the nominal voltage of a single battery (V), C_n is the nominal capacity of a single battery (Ah), q_m is the minimum state of charge of the battery bank (%) and l_{av} is the average primary load (kWh/d).

2.4.4 Inverter selection

A 24 V DC to 230/50Hz AC pure sine wave inverter was selected. 1000 W solar inverter with a power factor of 0.8 and capital cost of US$ 500.04 was chosen and possesses some good properties which include; an inbuilt maximum power point tracking (MPPT) charge controller of 10-40A that is able to regulate up to 10 pieces of 200 W solar modules, it has an inbuilt AC charger of 20 A which can charge up to 2 pieces of 200 Ah batteries and has an isolation transformer which makes it suitable to be used for inductive loads.

2.4.5 Break-Even grid extension distance

The grid extension from a village 1 km from a grid source was evaluated and the cost shown in Table 3 below. These costs consist of laying of high-tension poles from a 33-kV grid point, setting up of a transformer and distribution lines. The break-even grid extension distance (D_{GEX}) was evaluated using the equation (6).

$$(D_{GEx}) = \frac{C_{T\,NPC} \times CRF\left(i, N_{PROJ}\right) - C_{p,grid} \times E_{AD}}{C_{CGEx} \times CRF\left(i, N_{PROJ}\right) + C_{O\&M}} \tag{6}$$

Where; $C_{T\,NPC}$, is the total net present cost of a power system on a stand-alone ($), CRF stand for capital recovery factor; i is the real discount rate, N_{PROJ} is life span of the project, $C_{p,grid}$ is the cost of power from grid ($/kWh). E_{AD} is summation of the demand of electricity in a year (kWh/yr.), C_{CGEx} is the capital cost of extension of grid ($/km) and $C_{O\&M}$ is the operation and maintenance of extension of grid ($/yr./km).

Table 3. Estimated Grid Extension cost for a village 1 km from a grid source

Sl.	Capital cost of Grid Extension	Estimated Cost (US$)*
1	Laying of HT line from a 33-kV grid point and setting up of a transformer.	17 267US$ /km
2	Laying of distribution lines	12 261
3	Wiring each household, internal wiring, fixtures	4250
4	Testing, commissioning fees, inspection, permission, logistics and Contingencies	4951
*Total estimated Capital cost required to extend grid 1 km from a grid source to service a village load with similar terrain to that of the study area is US$ 38,729.		

2.4.6 Generator inputs

The existing power source to the inhabitants of the study area is the generator for the few that can afford. In the design analysis, a 61 % of a PV system was considered with a 39 % diesel generator input so as to introduce the PV into the electrification system and to discourage the use of generators in due course in order to control emission. A 25 percent (25 %) of the generator cost was used as the installation cost with 5 % adopted as the operation and maintenance cost [22,23]. Some of the generator input parameters used in the design configuration are shown in Table 4 below.

Table 4: Generator input data

Sl.	Description	Value	Unit
1	Size	12	kW
2	Capital cost	10 279	US$
3	Replacement cost	10 279	US$
4	Lifetime	15 000	h
5	Minimum load ratio	30	%
6	Fuel	diesel	-
7	Fuel cost	0.79	US$/L

2.4.7 Parameters for economic evaluation

The Net Present Value (NPV) which is also called life cycle cost of a component (s) or system was evaluated by deducting all the current values incurred (cost of initial investment; designing, installing and operating the system) throughout the life time of the project from the present amount, considering the life time of the project and discounted at their present time value. The following equation gives the *NPV*.

$$NPV = \sum_{n=0}^{N} \frac{C_{n\prime} - C_{ti}}{(1+i)^n} \quad (7)$$

Where; $C_{n\prime}$ is the net cash coming in during the year n, C_{ti} is the total cost of investment, i is the discount rate and N is the life time of the project in years.
The internal rate of return (IRR) was obtained when the net present value of the project is equal to zero. The IRR is not defined in a situation where there is a quick cash flow (positive) from the project in the beginning (zero) year. The internal rate of return can be evaluated from the equation below (RETScreen).

$$0 = \sum_{n=0}^{N} \frac{C_n - C_{ti}}{(1+i)^n} \quad (8)$$

Where, i is the internal rate of return.
The simple pay back gives the period (years) it takes for cash flow to be the same with the total investment. It can be determined from:

$$SPB = \frac{Initial\ investment}{Cash\ coming\ in/period} = \frac{C_{ti} - V_{ig}}{(S_E + C_{cap} + C_R) - (C_{o\&m} + C_F)} \quad (9)$$

Where, V_{ig} is the incentive and grant value where available, S_E is the yearly energy saving, C_{cap} is the yearly capacity income and C_F is the fuel cost where necessary.
The Benefit cost ratio is normally evaluated to determine the relationship between the benefits of an intended project with the cost of the project. It is evaluated using the Equation 10.

$$B - C = \frac{All\ benefits - initial\ cost}{initial\ cost} = \frac{NPV + C_{ti}}{C_{ti}} \quad (10)$$

3. Results and Discussion

3.1 Optimized system for only solar PV system

The results obtained indicated that the capacity of the components of the solar PV system required to serve the load (302 kWh/d) are: PV array of 100 kW (400 of 0.25 kW solar panels), 400 (12V 200 Ah) AGM Batteries and 50 kW Inverter, having a load following dispatch strategy. It was observed from the load profile that the peak load demand of about 27.923 kW was required around 18:00 to 19:00 h, this was increased to 39 kW by setting the day-day (standard deviation in the sequence of daily averages) and the time-step-to-time-step (standard deviation in the difference between the hourly data and the average daily profile) to be 10 which also changed the load factor and energy consumption per day from 0.454 to 0.322 and 304 kWh/day to 302 kWh/d respectively.

3.2 Optimized system considering Solar PV technology and grid extension

The results from the configuration comprising Solar (PV) technology and grid extension provided a total net present cost (NPC) and cost of energy (COE) of US$ 720,502 and US$ 0.542 respectively and also indicated that grid extension is more competitive than the Solar PV System up to a distance of 9.99 km from a grid source as shown in figure 3 below.

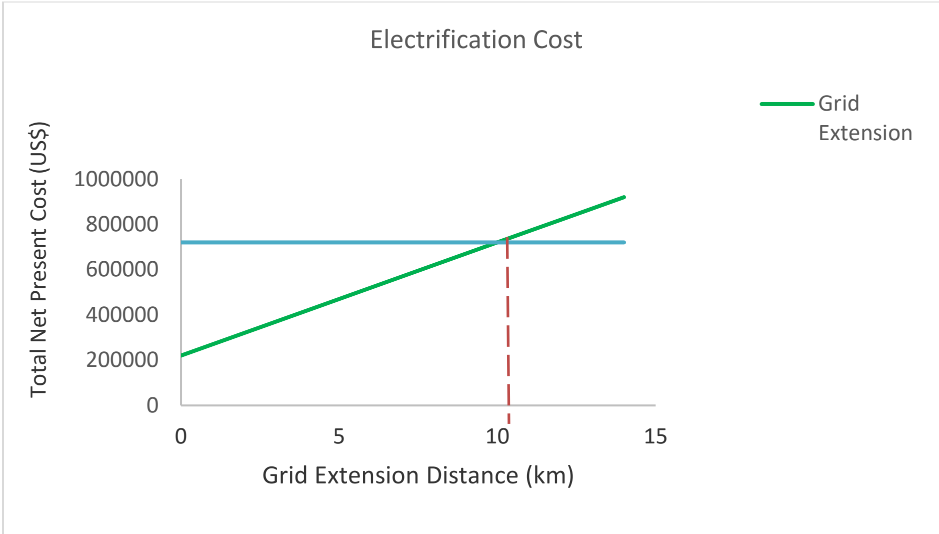

Figure 3. Breakeven Grid Extension Distance

3.3 Electrification in case of hybrid system (Solar PV, diesel generator and grid) Sources

In the design evaluation considering a hybrid system consisting of a diesel generator (which is presently the source of electricity in the area for those who can afford), Solar (PV) system and the grid extension. The diesel generator was used despite the fact that it is not a renewable energy source to support the solar PV system whenever there is low solar radiation, in the configuration, about 39 % of the electricity comes from the diesel generator while the remaining 61 % is from the PV renewable energy source. Several results were given by the model starting with the one having the least total net present value. The optimum option given based on the least net present cost comprises a PV array of 50 kW (200 of 0.25 kW panels), 30 kW diesel generator, 80 quantities of 12 V 200 Ah AGM batteries and 30 kW Inverter adopting a load following strategy of dispatch. Figure 4 below shows a reduction in the breakeven grid extension distance to 6.90 km.

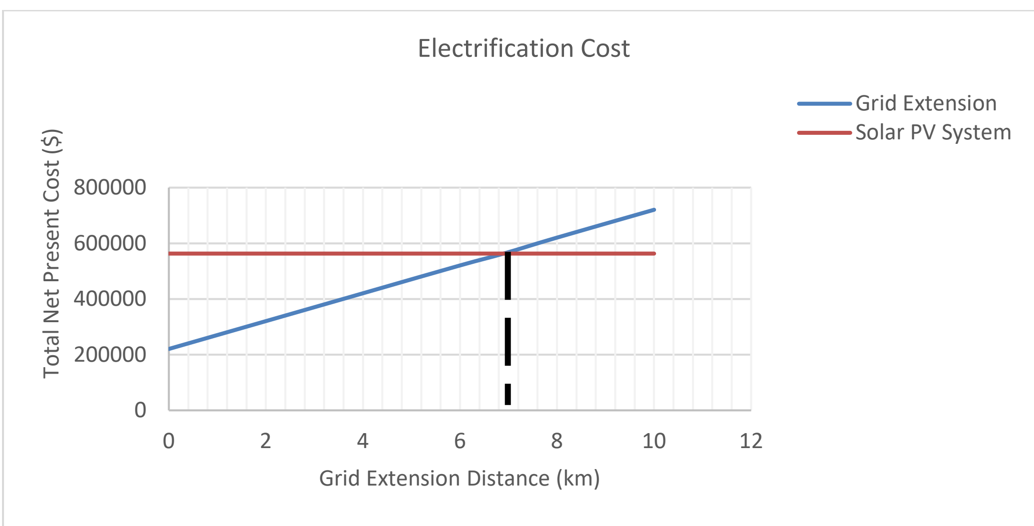

Figure 4. Breakeven Grid Extension Distance

3.4 Techno-economic evaluation

3.4.1 Viability analysis of the Solar PV System

The financial viability such as the net present value (NPV), simple payback (SPB), benefit-cost (B-C) ratio for the possibility of providing electricity using the Solar Photovoltaic (PV) System was evaluated with the aid of an RETScreen tool. However, the components cost of the system was extracted from the optimized result in the design evaluation conducted in the HOMER design.
Moreover, the initial cost includes the cost estimated for the feasibility study, development, engineering, power system, the balance of system cost, contingencies, and other miscellaneous costs. An estimated inflation value of 8 % was used instead of the 17.78 % inflation rate in the Nigeria, this was chosen and assumed for this study because the country is in recession with a 17.78 % inflation rate which may likely change or improve as times goes by. Values of 5.0 %, 6.13 %, 25 years, 70 %, 6.13 % and 24 years were used for fuel cost escalation rate, discount rate, project lifetime, debt ratio, debt interest rate (real) and debt term, respectively. Table 5 below shows the results of the parameters required for the financial viability of the project.

Table 5. Parameters required for the financial viability of the project

Sl.	Financial Indicators	Quantity	Unit
1	Internal rate of return (IRR)	2.4	%
2	Simple payback	13.7	yr.
3	Equity payback	8.0	yr.
4	Net Present Value (NPV)	42 653	US$
5	Annual life cycle cost	3378	US$/yr.
6	Energy production cost	142.13	$/MWh
7	Cost of CO2e	(44)	$/tCO2
8	Benefit to cost ratio (B/C)	1.38	-

The results obtained from the evaluation (Table 5) with a tariff of US$ 0.152 per kWh (US$ 152/MWh) as adopted for the electricity cost per kilowatt hour in Nigeria and the input of financial parameters (project lifetime, fuel escalation rate, discount rate, inflation rate) indicated that solar PV system technology is a feasible and acceptable system due to the positive Net present value of US$ 42,653 indicating a financial gain, also a positive annual life cycle cost of US$ 3,378 supported the acceptability of the project. Moreover, some indicators like the simple payback of 13.7 years and equity payback of 8 years also show the project's feasibility as they are not close to the end of the project's lifetime. The Cumulative graph of cash flows as shown in Figure 5 below accentuated to the viability of the project, the beginning and the first eight (8) years have negative cash flow while the remaining years which is about two-third (2/3) of the projects lifetime are having positive cash flows. The financial evaluation of the configured components also provided a salvage value (end of project life cost) and total annual savings and income of US$ 149,269 and US$ 28,559, respectively.

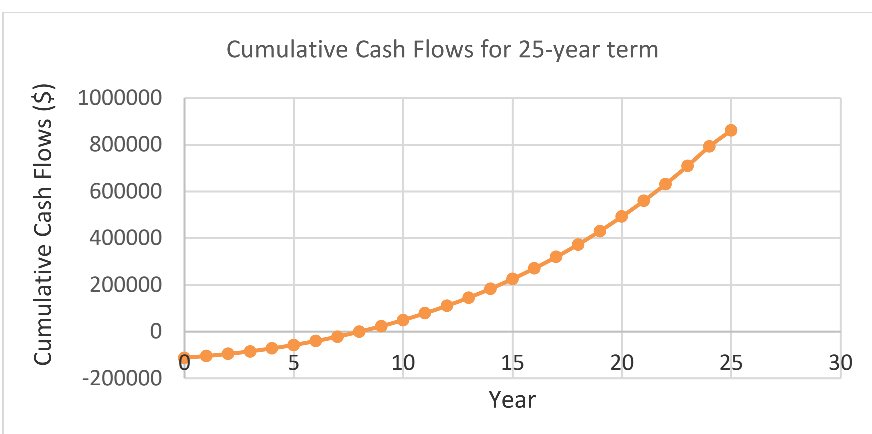

Figure 5. Graph of Cumulative Cash Flows

From the design results and their corresponding financial parameters, there is an indication that solar PV technology can be used as a renewable energy source for providing electricity for the inhabitants of the study area considering the basic appliances and the primary load used in the analysis although, the NPC and COE is high but will reduce with time since the cost of PV panel is gradually reducing. The optimized results obtained from RETScreen also yielded a positive NPV and annual life cycle savings. However, it is pertinent to note that, grid extension is the most competitive option and in terms of economy if available because of the proximity of the study area to a grid source, but the possibility of grid extension to the rural Dilchidama by the government in the near future remains a mirage due to the high cost of extending grid per kilometer; the cost incurred in electrifying rural settlements is far more expensive when compared to urban places due to a high electricity line cost, maintenance cost, reduced load densities and low rate of capacity utilization (Mahapatra and Dasappa 2012).

Furthermore, the use of a Solar PV system was observed to have no any form of emission when compared with a hybrid PV and generator system which has some amount of carbon-dioxide emission, the possibility of having a diesel generator (hybrid system) working with the Solar system and providing about 39 % of electricity was investigated and provided a good option as it does not only lowered the NPC and COE when compared to a Solar PV (standalone) system but also the capacities of the system architecture. Results obtained for a Solar PV system with an assumed grid connected system providing electricity in the ratio of 23:27, this system has a reduced renewable system architecture of 40kW PV panel, zero number of batteries, 20 kW of converter, and also a very low NPC and COE of US$ 269,256 and US$ 0.193/kWh respectively when compared to other configurations evaluated.

Consequently, among the analysed system architectures, the optimum system configuration that can provide the required electricity to serve the design loads, without any unmet load or capacity shortage to the study area if accessible is the grid extension. It was analysed in the design configurations and found that when uncertainty evaluations were performed on the various system configurations, the design of the system architectures (capacities or quantities) are grossly affected with a corresponding effect on the economic outputs. An increase in the solar resource for the Solar PV system increases the NPC but lowered the COE while a decrease in PV panel price reduces the NPC, COE and the breakeven grid extension distance. Uncertainty analysis gives a good check to do away with variations in some input parameters and to make decisions from different alternatives.

3.4.2 Uncertainty analysis for inflation rate

This study examined the impacts from variation in inflation rates by incorporating it into the real interest rate. It was found that as the percentage of the annual real interest rate was increased by about 14.19 %, the NPC was reduced by about 4.34 % and the COE increased by 3.63 %, but was recorded that the NPC increased and COE reduced when the annual real interest rate was reduced by 10 %. In another sensitivity examination, considering range of PV panel cost, results obtained signified the importance in the reduction of PV capital cost; a reduction of about 20 % in the PV capital cost, it was noted that NPC and COE dropped by about 3.95 % and 3.97 % respectively and also lowering the initial capital cost with the system's capacity and quantities remaining the same, the opposite was the case with an increase in the PV capital cost.

3.4.3 Economies of scale for increasing average load

In the design optimization, the scaled annual average load was 302 kWh/d, as a sensitivity examination was performed on this parameter; with an increase of 10 %, it was observed that some of the parameters of the system architecture such as the number of batteries required doubled while maintaining the capacities of the PV array and Inverter respectively. This also leads to an increase in the breakeven grid extension distance by about 1.31 km and a consequential reduction in the excess electricity generated from 17 % to 8.07 %. It scaled up the NPC by about US$ 90,479 but decreases the COE with a value of US$ 0.02. However, as the scaled annual average load was reduced by 10 %, the components capacity and quantities remain unaltered with the exception of the converter whose capacity reduced by 14.29 % with a low NPC of US$ 682,398 as against its initial value of US$ 720,502 and decreased the breakeven grid extension distance to 9.66 km. Despite the reduction in the NPC, grid extension offers the best option economically for the case study but when the area from the grid is more than 9.66 km, the solar PV system becomes the most preferable.

4. Conclusions

This study presented the design and economic evaluation of electrifying 77 residential houses, 4 shops, a primary school and a primary health centre in rural Dilchidama. The design, optimization and sensitivity results indicated that Solar PV technology is a viable means of electrifying Dilchidama due to the electricity production rate and good economic prospect in energy investment with a COE at US$ 0.579/kWh. However, when the design considered extending grid to the study area and compared it with a Solar PV system technology and Solar PV & diesel generator based system, the results indicated that grid extension if adequately supplied is more competitive for the village and villages with the same geographical data and terrain and are at a distance of less than 9.99 km and 6.90 km respectively. Although, the prices of solar PV components are gradually decreasing, Nigerian government can expand the renewable technology market and utilization by providing; loans, subsidies & grants, Feed-in-Tariff, etc. and also making a percentage of renewable energy sources into the energy-mix of the country thereby making renewable sources becoming more competitive in the near future.

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