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ELECTRICITY ACCESS IN NIGERIA: VIABILITY OF OFF-GRID PHOTOVOLTAIC SYSTEM

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Electricity Access in Nigeria: Viability of Off-Grid Photovoltaic System

Uduak S. Akpan, Salisu R. Isihak
Sustainability, Policy, and Innovative Development Research (SPIDER) Solutions Nigeria
Uyo, Nigeria

Ye-Obong N. Udoakah
Department of Electrical Engineering, University of Uyo, Uyo, Nigeria
yeobongudoakah@yahoo.co.uk

***Abstract*— This study examines the viability of providing electricity to an un-electrified village in North-Eastern Nigeria using a mini-grid based off-grid solar photovoltaic system. The study employs the life-cycle cost to estimate a 25-year life-time cost of an off-grid electrification project using solar photovoltaic panels and compares with the cost of paying for grid-electricity within the same period. Comparing the cost of off-grid electrification with grid-extension is more appropriate; however, data on the cost of grid extension in Northern Nigeria are scarce. Thus, electricity tariff is used as a proxy since the Nigerian electricity market has been deregulated and the electricity tariff is expected to be market-reflective. The result shows that such project will not be economically viable at the prevailing commercial lending rate as it yields a negative net present value. However, the project becomes viable with adequate government support through the reduction in commercial lending rate for such projects and provision of start-up grants (as production subsidy). Such subsidy will not result in economic waste since the target is clearly defined. Apart from government financial incentives, creating necessary support mechanism in terms of legal and regulatory frameworks to encourage private investment will be necessary. In addition, engaging the community in the construction and maintenance of the project will ensure sustainability.**

Keywords: Electricity access, Off-grid electrification, Solar Photovoltaic System, Viability, Nigeria.

1.0 INTRODUCTION

One of the major energy challenges in the world today is ensuring access to clean and sustainable energy in developing countries. The International Energy Agency (IEA) [1] estimated that in 2009 about 1.3 billion people in the world lacked access to electricity[1] of which 585 million were in Sub-Saharan Africa (SSA). Most of these people live in rural areas. The lack of access to electricity poses a significant barrier to achieving the Millennium Development Goals (MDGs). For example, to achieve universal primary education, educational facilities need electricity for teaching aids and good lighting for reading in homes; to reduce child mortality and improve maternal health, health facilities need refrigerators to preserve drugs and vaccines, and need electricity for proper lighting for effective service delivery. Studies have shown that there is a high correlation between annual per capita electricity consumption and human development index in low income countries [2].

The electricity access situation in Nigeria is not different from that of other developing countries. In 2009, about 50.6% of Nigerians lacked access to electricity [1]. However, due to the coverage of the existing grid (see fig 1), the electricity access situation at the different geopolitical zones is different as shown in Table 1. From Fig 1 and Table 1, we observe that the lack of electricity access is more severe in the northern parts of Nigeria with the North-East geopolitical zone having 71.6%. Co-incidentally, the North-East geopolitical zone lags behind other zones in other socio-economic indices like literacy level, access to health care, maternal mortality, access to clean water etc [3].

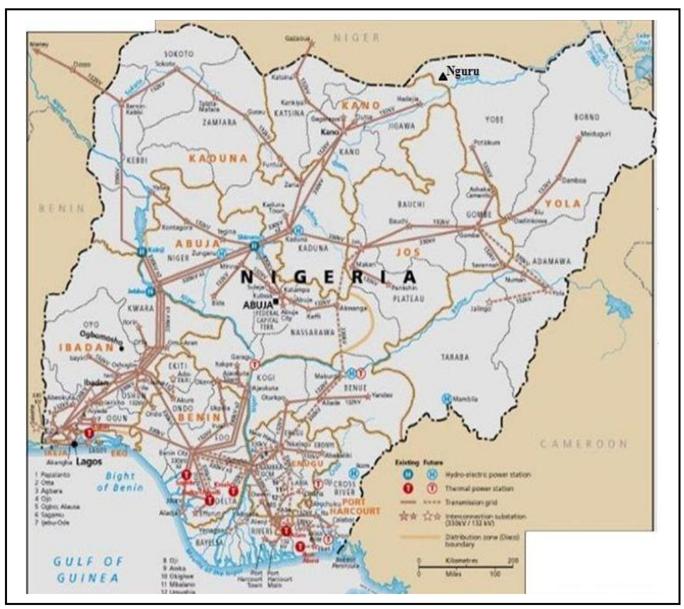

Fig 1: Coverage of electricity grid in Nigeria (in 2010)
Source: Global Energy Network Institute (GENI)

[1] Access to electricity in this paper is defined as "Access to adequate, accessible, and affordable electricity to promote socio-economic development"

Table 1: Distribution of households without electricity access in the different geo-political zones of Nigeria (in Percentage)

North-West	North-Central	North-East	South-West	South-East	South-South
Jigawa (56.5)	Benue (72.0)	Adamawa (71.4)	Ekiti (15.2)	Abia (33.3)	Akwa Ibom (38.3)
Kaduna (42.4)	Kogi (48.1)	Bauchi (58.5)	Lagos (0.3)	Anambra (38.3)	Bayelsa (36.9)
Kano (56.2)	Kwara (38.5)	Borno (77.3)	Ogun (20.4)	Ebonyi (68.1)	Cross River (46.3)
Katsina (59.7)	Nassarawa (70.6)	Gombe (55.4)	Ondo (41.9)	Enugu (48.5)	Delta (46.3)
Kebbi (54.4)	Niger (56.6)	Taraba (88.8)	Osun (33.9)	Imo (12.6)	Edo (15.2)
Sokoto (69.5)	Plataeu (71.3)	Yobe (78.0)	Oyo (38.8)		Rivers (21.7)
Zamfara (77.1)					
Average (59.4)	**Average (59.5)**	**Average (71.6)**	**Average (25.1)**	**Average (40.2)**	**Average (34.1)**

Source: National Bureau of Statistics, Nigeria [4]

Given the importance of electricity access to the socio-economic development of a country at micro and macro levels, in August 2010, the Nigerian government set the target of 80% electricity coverage by 2015 in the Roadmap to Power Sector Reforms[2] [5]. This implies providing electricity to the hundreds of small communities presently without electricity – including those far from the existing grid. As electricity utility has been privatized, providing electricity for these rural dwellers implies constructing transmission and distribution (T&D) lines to reach the communities. However, constructing T&D lines is capital intensive. Moreover, most rural communities have dispersed settlement pattern and rural dwellers are low income earners who will need electricity for basic needs of cooking, lighting, refrigeration, entertainment, and to power small-scale agro-based businesses and other enterprises like soap making, tailoring, hairdressing, weaving etc. Thus extending the grid will lead to low capacity utilization due to low demand. Since private firms are usually driven by profit maximization motives, they may be unwilling to extend the distribution network to these rural communities as it may not be cost-beneficial.

This situation gives rise to the possibility of providing electricity access in some of these rural communities using off-grid electrification. The World Bank [6] notes that off-grid electrification is usually considered when providing electricity access to small, low-income rural communities far from the existing grid, with dispersed settlement pattern. Off-grid electrification provides similar benefits as grid extension in terms of enhancing the standard of living and stimulating the creation of micro-enterprises that increase overall economic benefit, although the available power is lower [6]. Foley [7] listed the gains of off-grid electrification to include pumping of water in the village and farming environment, and provision of electricity for heating, lighting, and cooking which provide the necessities of life to these rural dwellers. Different technical options can be considered in implementing off-grid models e.g. Biomass, Wind, Hydro, Solar Power, or the combination of two technologies [8], [9]. The use of each technology depends on the domestic resources available. Communities close to a river will likely use mini hydroelectric projects, and communities with high solar irradiation will likely use solar energy.

Data for some towns in the North-East geopolitical zone of Nigeria which records the lowest electricity access level show a relatively high solar irradiation level as shown in table 2. This indicates a potential for off-grid electrification using solar photovoltaic system in rural communities in this geopolitical zone. Thus, this research intends to consider the viability of using solar energy for off-grid electrification in rural communities in the North-East geopolitical zone of Nigeria. Given the intermittency of solar energy, some studies consider the viability of off-grid electrification using solar PV system in a hybrid mix, usually with a backup diesel engine [10], [11], [12]. However, the downstream petroleum market for diesel in Nigeria is deregulated which makes the cost of diesel to be between ₦120 and ₦160 ($0.80 and $1.07)[3] per litre.

Thus, the study will not consider the hybrid solar PV/diesel option since the low income in rural areas will make it ineffective in guaranteeing electricity access due to the high recurrent cost of diesel. In particular, this research answers the question, "Is off-grid electrification using solar photovoltaic system a viable option for achieving the target of 80% electrification by 2015 in Nigeria?"

The study estimates the life-cycle cost of an off-grid electrification project using solar photovoltaic system and compares it with the cost of paying for grid-electricity over the same period assuming that grid-electricity is available. Comparing the cost of off-grid electrification with grid-extension is more appropriate; however, data on the cost of grid extension in northern Nigeria are scarce and obtaining such will require a terrain-specific feasibility study.

Table 2: Average monthly solar irradiation level in some towns in North-East geopolitical zone of Nigeria (in kWh/m^2/day)

	Maiduguri	Nguru	Bauchi	Damaturu	Gashua	Gombe
January	5.61	5.53	5.74	5.63	5.59	5.68
February	6.3	6.34	6.21	6.34	6.41	6.19
March	6.7	6.77	6.4	6.72	6.83	6.45
April	6.62	6.97	6.12	6.78	6.98	6.43
May	6.36	6.82	5.88	6.53	6.72	6.21
June	5.97	6.62	5.66	6.24	6.53	5.79
July	5.43	6	5.25	5.58	6	5.28
August	5.14	5.58	4.95	5.27	5.57	5
September	5.57	5.86	5.43	5.68	5.78	5.36
October	5.89	5.97	5.85	5.86	5.89	5.72
November	5.84	5.7	6.01	5.62	5.7	5.7
December	5.35	5.24	5.71	5.3	5.27	5.45
Average	**5.90**	**6.12**	**5.77**	**5.96**	**6.11**	**5.77**

Source: RETscreen 4 database.

[2] Herein after referred to as Roadmap.

[3] Exchange rate used for the study is $1 = ₦150

Comparing the cost of off-grid electrification with grid-extension is more appropriate; however, data on the cost of grid extension in northern Nigeria are scarce and obtaining such will require a terrain-specific feasibility study. Thus, electricity tariff is used as a proxy since the Nigerian electricity market has been deregulated and the electricity tariff is expected to be market-reflective as stated in the Roadmap.

Many studies have been conducted to ascertain the feasibility, viability, financing options, regulatory and governance structure, and risk involved in implementing off-grid electrification [13], [14], [12]. Bugaje [15] analyzed power supply options for remote areas in Nigeria. The study considered three options: solar powered systems, conventional diesel generating plants, and connection to the national grid, and observed that solar photovoltaic systems are the most economically viable. Ajao *et al*. [16] examined electricity supply in Nigeria using a decentralized approach and recommended that stand-alone renewable energy technologies be adopted especially for rural communities to improve electricity supply and enhance the overall economic development.

Bhattacharyya [9] provides a comprehensive review of off-grid electrification systems in developing countries including developmental implications of lack of electricity infrastructure and a review of alternative off-grid technologies. The study presents experiences in South Asia, China, Africa, South East Asia, and South America and also discusses the business dimensions covering participatory business models, funding challenges, and issues on regulation and governance in off-grid electrification systems. Kuandinya *et al*. [17] carried out a comprehensive review of literature on grid and stand-alone systems.

Depending on the objective of the study, several models have been employed to analyze the viability or technical options in off-grid electrification projects e.g. cost-effectiveness analysis, levelized cost approach, annualized life-cycle cost, and financial indicators [18], [19],[20], [21]. Other studies have employed modern analytical softwares like Hybrid Optimization Models for Electric Renewables (HOMER) [11], [22], [23], and RETScreen [24], [25], [26]

Mirzahosseini & Taheri [26] performed an environmental, technical, and financial study of solar power plants in Iran using RETScreen. The study developed three different scenarios based on the electricity tariff in Iran and reported a positive cash flow in the third scenario where credit is obtained by reducing greenhouse gases and the electricity tariff is 175cents/kWh.

Rehman *et al*. [24] employed RETScreen to analyze the cost of generating electricity using solar PV panels in locations having different average solar irradiation levels in Saudi Arabia. The study found that from economic indicators like internal rate of return, net present value, and annual lifecycle savings, Bishah was best site for solar PV power plants while Tabuk was the worst. In a similar study, El-Shimy [27] carried out a techno-economical and environmental study on the feasible sites in Egypt to build a 10MW PV-grid connected power plant. The study employed data on solar radiations, sunshine duration, air temperature and humidity for 29 sites in Egypt from National Aeronautics and Space Administration (NASA) renewable energy resource website and used RETScreen to perform energy production analysis, financial analysis, and greenhouse gas emission analysis. The results of the study identified Wahat Kharga site as the best for the PV power plants projects.

The remaining part of this research is organized as follows: Section 2 presents the methodology and the assumptions used in the analysis; section 3 presents the results of the analysis while Section 4 provides the concluding remarks.

2.0 METHODOLOGY

2.1 Study Location

The proposed site for the project is Nguru, Yobe State, Nigeria. The area is located at $12^0$86'N, $10^0$40'E (see fig 1) and has an average annual solar irradiation of 6.12kWh/m^2/day as shown in table 2. The location is chosen because it is beyond the coverage of the existing transmission line, is situated in the North-East geopolitical zone, and has a relatively high average daily solar irradiation. The closest transmission line to Nguru terminates at Hadejia which is about 64Km to Nguru. Yobe State is one of the 36 states in Nigeria located in the North-East geopolitical zone of the country. The state lies mainly in the dry Savannah agro-ecological region and it is dry and hot for most part of the year, except in the southern part which has a milder climate. The state is predominantly rural with few towns like Nguru, Damaturu, Fika, and Potiskum. The land is generally a flat plain and nucleated settlement patterns have been developed mainly on stabilized sand dunes and around water points or where oases exist. Rural communities are well spaced out on the plain to allow each community enough land to support economic activities. Agriculture is the main economic activity in the rural areas with groundnut, beans, and cotton being the predominant crops cultivated. The energy needs by household in the state are mainly for cooking, where about 97.7% is gotten from fuelwood [4]; lighting, where kerosene lamp is the major source; and agricultural activities which is usually done manually [28]. Machines and equipments used in micro-scale enterprises like tailoring, weaving etc are powered manually.

2.2 Mathematical Model

This study employs the lifecycle approach to estimate the lifecycle cost of an off-grid electrification project using solar photovoltaic panels and compares it with the cost of paying for grid-electricity [N22/kWh ($0.15/kWh)[4]] over the same period assuming grid-electricity was available. The model for the lifecycle cost is specified as follows:

[4] See "Establishment of a market reflective tariff structure" in Roadmap for Power Sector Reforms.

$TLC = IC + MC_{pv} + RC_{pv} - S_{pv}$[5] ....(1)

Where:

is the total lifecycle cost,

is the initial cost of the project which includes cost of panels, batteries, inverters, engineering and installation cost etc.

is the present value of total cost of yearly maintenance (excluding the cost of equipment replacement).

is the present value of total cost of equipment (batteries, inverters etc) replacement.

is the present value of the salvage value of the system.

The analysis is carried out using RETScreen. RETScreen is a Microsoft Excel-based renewable energy technology (RET) analytical software developed by Natural Resources Canada. The software is capable of analysing the technical feasibility and financial viability of different renewable energy technologies following a multi-step procedure which includes energy production analysis, financial analysis, emissions analysis, and sensitivity analysis. For this study, we used only the energy worksheet and the cost analysis worksheet. The emission analysis worksheet was not used because of lack of data for greenhouse gas emissions and other required variables for Nigeria.

2.3 Village Load Specification

Introduction of electricity to a rural community will lead to a gradual switch in energy sources for both household and commercial use. For household energy use, it is expected that the source of lighting will gradually shift from kerosene lamps to modern energy-saving electric bulbs. Switch in source of energy for cooking is expected to be low as studies have shown that rural communities with access to electricity still rely on traditional biomass to meet their cooking needs [29]. In addition, the demand for electricity for productive uses will be created, and electricity will also be needed for other uses that improve the living standard of the people e.g. pumping water and in health facilities. As the life span of modern solar PV panels is between 20 and 30 years, the research assumes the project life of 25 years. Within these years, the demand for electricity is expected to increase gradually. The study considers an initial load structure for the first three years. This is done for three inter-related reasons: the need to ensure effective capacity utilization to curb energy wastage; solar PV panels are modular so increasing the generating capacity of the project to meet an increasing demand will not be difficult; and, the cost of solar panels is decreasing steadily so it will be cheaper to add additional capacity in future to meet increasing demand.

Furthermore, the study assumes that in a rural community of about 40 households, only a fraction of the households will own electrical appliances in the first three years, albeit at varying levels depending on the end-use, and institutional load may also arise. The load specification for the first three years used in the analysis is given in table 3. An underlying assumption is that only energy-efficient appliances will be used by the households. All items use AC current; the total daily electricity demand is 48.85kWh; the annual electricity demand is 17.83MWh; the maximum load for the system is 3.74kW; and the study assumes peak load of 5kW.

2.4 Description of PV System

The research adopts a selection criteria used by [27] to select an appropriate PV-module to be used. First, a survey of the characteristics of most of the available PV modules from different manufactures is done, PV-modules with efficiency less than 15% are excluded, and a list of prospective modules is formed. Second, a ratio of capacity/Frame Area is calculated for all the prospective modules. The PV modules with highest capacity/frame area are: mono-Si-HIP-205BA3 (173.7W/m^2) and mono-Si - HIP-215NKHA5 (170.6W/m^2) respectively. The study selects mono-Si - HIP-215NKHA5 because of availability of data on cost of panels. Other specifications of the selected module are: Rated Power (215W); Maximum Power Voltage (42.0V); Maximum Power Current (5.13A); Normal Operating Condition Temperature (46^0C); Module Area (1.26m^2); Weight (16Kg); Dimensions L x W x H (1580 x 798 x 46 mm) etc[6].

The capacity of the inverter used is 5kW, with 90% efficiency, 5% miscellaneous loss and lifespan of 5 years. In addition, to ensure optimal functionality, the study proposes a 24V 1200 Ah battery, with 80% maximum depth of discharge, 90% charge controller efficiency, one day of autonomy, and lifespan of 5 years for the project.

Table 3: Village load specification used in the analysis (as specified in the Energy Model Worksheet)

Description	Base case load (W)	Hours of use per day	Days of use per week
3 x 15W x LED bulbs x 20 households	300	8	7
1 x 60W x TV set x 10 households	600	8	7
1 x 15W x DVD player x 10 households	150	8	7
1 x 250W x refrigerator x 4 households	1,000.00	18	7
2 x 60W x others* x 8 households	960	12	7
1 x 250W x refrigerator x 1 health centre	250	18	7
5 x 60W x appliances x 1 health centre	300	18	7
3 x 60W x appliances x 1 school	180	8	5

Where (*) represent other electrical appliances that may be used for micro-scale enterprises

[5] The study excludes energy cost because it assumes an off-grid system without a backup power system.

[6] The complete specification for the PV module can be found at: http://us.sanyo.com/dynamic/LinkListingItems/Files/HIT%20Power%20215N-1.pdf (accessed on March 27, 2013)

2.5 System Configuration

The 45 PV panels (see next paragraph) will be series-connected in strings of 22 and 23 respectively, which will then be connected in parallel to form an array using a fixed point tracking method. The choice of the fixed point tracking method instead of a maximum point tracking method is to reduce the maintenance needs of the system. Thus, the solar panels will be fixed in an open area at a slope of 12.9^o and azimuth of 0.0^0. The choice of the slope and azimuth is to ensure maximum sunlight incidence on the fixed panels. The supply will be connected to a DC isolator, storage battery, inverter, generation meter, AC isolator, consumer unit, export meter, and finally, fed to the mini-grid built to connect the different households.

PV systems, in reality, often operate at sub-optimal level due to accumulation of dirt and dust particles on the panels and temperature variations which affects the rated current and voltage. In addition, module mismatch, wire resistance, inefficiencies of conversion devices (DC to AC inverter) and other components (charge controller, battery) of the PV system contribute to losses in the PV system. The study assumes that the total loss in the system will not exceed 8% of the rated output and uses the minimum number of PV modules that will deliver at 100% electricity to the load after accounting for system losses, i.e. 45 units, giving a total capacity of 9.68kW. Peak load power system is not required. The schematic representation of the system is presented in figure 2.

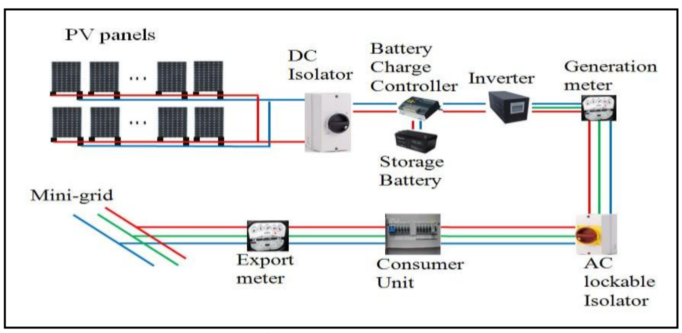

Fig 2: Schematic Diagram of the Project

Table 4: Breakdown of cost components

• INITIAL COST	
Feasibility study	site investigation, preliminary design, report preparation
Development	permits and approvals, project management, travel and accommodation
Engineering	PV system design, electrical design, tenders and contracting, construction and supervision
Renewable energy equipments	PV module(s), inverters, transportation
Balance of plant:	module support structure (batteries, tracking system), electrical equipments, system installation, construction of mini-grid, transportation
Miscellaneous:	training, contingencies
• ANNUAL COST	
Operation and maintenance :	Property taxes/insurances, others, contingencies

2.6 Specifications for Cost Analysis Worksheet

The cost components are divided into initial cost and annual (operation and maintenance) cost. The initial cost is further broken into: feasibility study, development, engineering, power system, and balance of system & miscellaneous. The cost categories are further broken down as shown in table 4.

Due to unavailability of data, the study adopts estimate of the shares of the various cost components from a previous study as follows: Feasibility study (0.2%); Development cost (0.2%); Engineering cost (0.2%); Renewable Energy Equipments (69.6%); Balance of plant cost (27.8%); and Miscellaneous (2%) [24]. For this study, we estimated the cost of the renewable energy equipment, and apportioned other cost components as shown above for the base-case scenario. The unit cost of the photovoltaic panels is estimated from as US$800 per panel. Since the panels will be shipped to Nigeria, the study makes a 5% adjustment to reflect the cost, insurance, and freight (CIF) landing cost in Nigeria. Thus, the total panel cost is estimated as US$39270.

2.7 Specifications for Financial Analysis Worksheet

Studies that have explored the viability of PV systems have often made use of low parameters in the financial analysis. For example [24], [27] and [30] used an inflation rate of 2.5% and discount rate of 5%; and [27] used 7% for debt interest rate. However, these are not realistic for Nigeria. Thus, this study uses an inflation rate of 8.5%, discount rate of 8%; and assumes that 50% of the cost of the project will be financed with term loan of 15 years at 11% interest rate. In addition, the study uses fuel cost escalation rate of 4%.

2.8 Scenario/Sensitivity Analysis

The study carries out scenario analysis for two reasons: first, the study makes some assumptions in calculating the financial viability or otherwise, which makes the results of the analysis susceptible to changes in the assumptions. Second, since the Nigerian government is encouraging private sector participation in power generation there is a possibility of adjusting financial variables to lower the investment barriers in renewable energy projects. Thus, the study examines scenarios where some of these assumptions and financial variables change. In particular, the study examines four (4) scenarios:

(1) Reduction of debt interest rate and inflation to 7% and 6% respectively.

(2) Conditions in scenario (1), and availability of start-up grant from government. To examine the sensitivity of government grant the study considers two levels of start-up grant in terms of percentage of the initial total cost: (i) 20% (ii) 30%.

(3) Conditions in scenario (1) and reduction in cost of PV system. To examine the sensitivity of reduction in cost of PV system the study considers two levels of reduction: (i) 10% (ii) 20%.

(4) Conditions in scenario (1), availability of a flat start-up grant of US$20,000 and 20% reduction in cost of solar panels.

3.0 RESULTS AND DISCUSSION

3.1.1 Financial Viability (Base Case)

From our results, with a tariff of N22/kWh (US$0.15/kWh), the annual total electricity cost of annual electricity demand of 17.83MWh is US$2674 which is the annual cost-savings assuming the off-grid option is used. Assuming the electricity tariff is not reviewed, households will spend US$66,850 in 25 years on electricity bills. On the other hand, investing in solar PV system yields a negative net present value (-US$21,195) indicating a huge financial loss; and negative annual lifecycle savings per year (-US$1,986/yr). Other financial indicators for investing in the solar PV panels do not support the investment. The internal rate of return on equity (3.0%) and internal rate of return on asset (0. 2%) are low. The simple payback time (28.9years) and the equity payback time (21.2 years) for the project are also long. The cumulative cash-flow graph presented in fig. 3 provides a clearer picture of the viability of the project under the base case scenario. The result shows that the use of solar PV panels is not financially viable at the prevailing market condition

Table 5: Financial indicators of the four scenarios

Financial Indicators	Net present value ($)	Annual life-cycle savings ($/yr)	Internal rate of return on equity (%)	Internal rate of return on assets (%)	Simple payback time (years)	Equity payback time (years)
Scenario 1	-9,016	-924	5.9	2.4	29.1	18.3
Scenario 2(i)	1,768	162	8.3	3.5	23.4	16.5
Scenario 2(ii)	7,245	686	10.4	4.2	20.4	15.7
Scenario 3(i)	-5,416	-544	6.6	3	27.1	17.6
Scenario 3(ii)	-1,818	-178	7.3	3.6	25.2	16.7
Scenario 4	18,183	1,703	19.2	6.8	14.3	10.5

3.1.2 Scenario/Sensitivity Analysis

The results of the scenario analyses are presented in table 5. From the results, we observe that reduction in inflation and debt interest rate does not make the project to be viable since the net present value (-US$ 9016) and annual life-cycle savings (-US$924/yr) are still negative. The viability of the project increases in scenario 2 where there is a government start-up grant to cover a percentage of the initial total cost. Increasing the percentage covered by the grant also increases the viability of the project. The results of scenario 3 shows that the project will not be viable even if the cost of the PV system reduces by 20% coupled with the reduction in the inflation and debt interest rates. Scenario 4 is most favourable for investment as the financial indicators are more attractive as shown in the positive net present value and annual life-cycle savings of US$18,183 and US$1,703/yr respectively. Other financial indicators for scenario 4 are: internal rate of return on equity (19.2%); internal rate of return on asset (6.8%); simple payback time (14.3years); and equity payback time (10.5years). The cumulative cash-flow graph for scenario 4 is presented in fig. 4.

4. CONCLUDING REMARKS

In line with the government's target of ensuring 80% electricity coverage in Nigeria by 2015, this study examined the viability of using solar photovoltaic system in a mini-grid based off-grid electrification project for a typical rural community in Northern Nigeria. The choice of Northern Nigeria is based on its solar energy potential, and low population density. The study compared the total cost of providing electricity using solar PV system for 25 years to a rural community of 40 households with an initial electricity load of 5kW with paying electricity bills assuming grid connection is possible. The results show that such project will not be economically viable at the prevailing commercial interest rate.

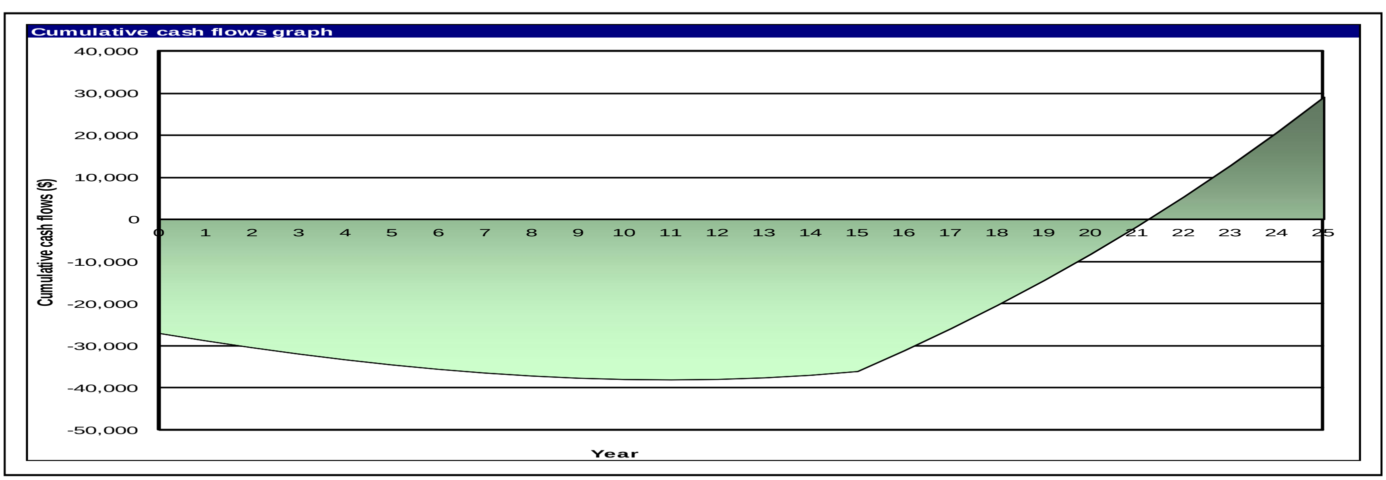

Fig 3: Cumulative Cash-flow graph of the base case scenario

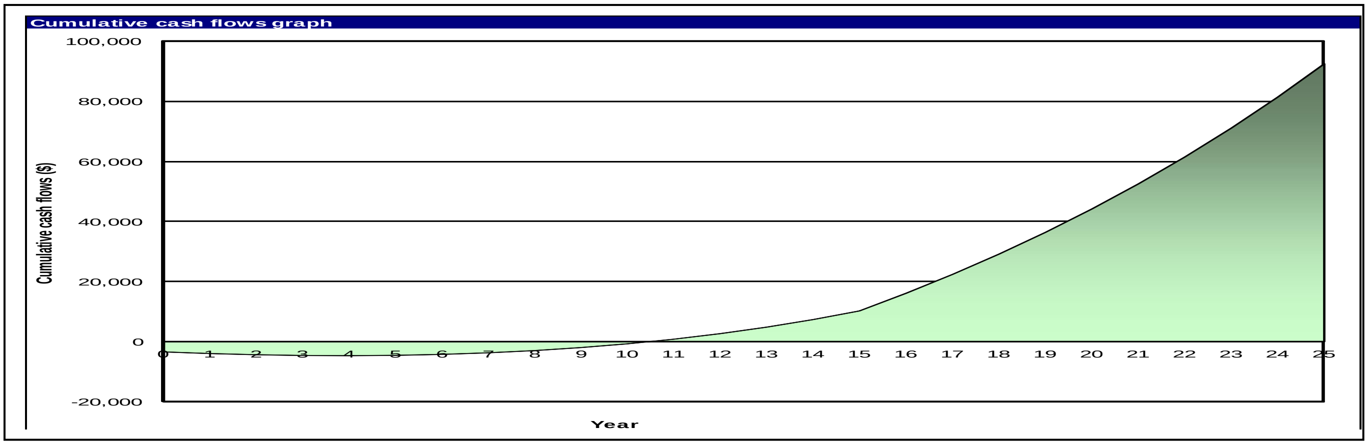

Fig 4: Cumulative cash-flow graph of scenario 4

However, the project becomes viable if the cost of the PV system reduces and there is adequate government support through the provision of low interest loans or financial grants (as production subsidy). Such subsidy will not result in economic waste since the target is clearly defined.

Furthermore, implementing such projects is not without possible risks e.g. legal, regulatory, governance, institutional, commercial, technical, organizational, design, and implementation [31] which are difficult to capture in a financial analysis.

Lessons from off-grid electrification experiences from other parts of the world as discussed in [9] can provide useful insights on minimizing the risks involved in such projects. The following recommendations are hereby made:

(1) Government should create support mechanisms to support private sector investment in mini-grid based off-grid electrification programmes using PV systems in Northern Nigeria to meet the 80% electricity coverage by 2015.

(2) A legal and regulatory framework that encourages private sector participation in ensuring access to electricity in rural areas should be introduced

This study could be improved by using more precise estimates of those cost components that were assumed.

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