Original Research Article

Design of Affordable Solar Photovoltaic Systems in Nigeria: A Cost Implication Analysis.

Abstract

Nigeria is blessed with plenty of energy resources, both renewable and conventional, that can sufficiently provide the nation with enough capacity to meet the growing demand of electricity supply both in the rural and the urban areas. Nevertheless, the consumption rates in the country is still low compare to other African countries in electricity per capita. This study examines the designing of an affordable solar photovoltaic (PV) system in Nigeria. Furthermore, a proposed PV electrification model was design to calculate the Financial Internal Rate of Return (FIRR), Net Present Value (NPV) and Sensitivity analysis of installing a mini-grid system within the Federal Capital Territory (FCT). The result however shows that the system efficiency was calculated as FIRR was 17.5% and the NPV was at ₦320,897,841 which suggest that the project on this scale is economically viable in the FCT, making the life cycle cost per kWh, including the grid extension cost relatively low. Furthermore, the result obtained has indicated that electricity generated from solar energy can contribute to the country's economy and also eliminate or cut the pollution and toxic waste from the burning excess fossil fuel that releases large amount of CO_2 into the atmosphere which affects human health and the environment.

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Keywords: solar photovoltaic energy, financial analysis, system design, Nigeria

I. Introduction

Energy is the indispensable force driving all economic activities. It is critical to virtually every aspect of the economy and social development in Nigeria. In other words, it is seen at the top of the political and societal agenda, an instrument for politics, security, and diplomacy and as well serve as an input for the production of goods and services in the nation's industry, agriculture, health, education and transportation sectors (Sambo 2009).

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A continuous access to quality energy infrastructure is an essential ingredient for sustained economic growth and development. Energy is seen as a vital ingredient for fueling a powerful engine that drives social and economic change. It follows therefore that no country can manage to develop and sustain beyond a subsistence economy without having at least minimum access to energy services for the large portion of its population. However, the way it is used poses environmental footprint problems in Nigeria, such as water pollution, acid rain, destruction of natural resources caused by fuel spillage and smog-formation. Hence, the increased concerns for environmental impact of the conventional fossil fuels, has been the main factor driving the transition towards green energy and the generation of power most favorably from renewable energy sources that are abundant and free (Mekilef, Saidur & Safari, 2011).

Nigeria is richly blessed with abundant natural energy resources including crude oil, natural gas, coal and lignite, water bodies for hydropower generation, solar radiation, wind, biomass (animal and plant waste and fuel wood), nuclear among others. Of all these, the most widely used energy sources are the fossil fuels, which account for more than 80 percent of global primary consumption (Alharthi & Alfehaid, 2007).

In the world today, one of the major global challenges government and captains of industries are facing is reducing the greenhouse emissions from their operations with a major focus on the use and installation of sustainable renewable energy system. Thus, solar photovoltaic (PV) energy is seen as the most promising back up energy as it has more advantages compared to other types of renewable energy sources (Long and Izuchukwu 2013). Solar PV has long been identified as a clean and secure energy technology, which draws the direct conversion of sunlight into energy by means of solar cells without any moving parts or environmental emission during operation. Solar PV systems are cheaper to maintain, highly reliable with a life span expectation of 20-30 years, making it a preferable source of energy to be used in the future relative to other sources of renewable energy.

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However, it has been estimated by Florini (2011) that about 1.3 billion people in the world lack electricity supply in the rural areas of which 585 million are in sub-Saharan Africa, thus the shortage in electricity supply has prevented most developing countries to attain the Millennium Development Goals (MDGs) target. Long and Izuchukwu (2013) noted that PV energy generation systems could be seen as one of the significant sources of alternative energy and a unique prospective solution to energy crises in the future.

This study tends to analyze the cost of designing an affordable solar PV system in Nigeria, bearing in mind that only about 30 percent of households in Nigeria have access to electricity supply which is due to physical deterioration of the transmission and distribution facilities, high cost of electricity production, inadequate metering system and basic industries to service the power sector.

2. Literature Review

ii

Many studies have been conducted on economic consideration of renewable energy systems. Some scholars have conducted research to evaluate the global feasibility and performance of different Solar PV power plants, and it was concluded that PV power plants are a viable and feasible option to meet the global shortage of power supply at present and in the future. El-Shimy (2009), conducted a viability analysis of 10 MW PV-grid connected power plant taking 29 metrological sites in Egypt. The findings revealed that renewable energy production and capacity factor was found to be minimum at Safaga and maximum at Wahat Kharaga, with 24.202GWh/year, 27.6 and 29.493GWh/year, 33.7% respectively. Similarly, Radhi (2011) used viability analysis and conducted a PV power plant in the Gulf Corporation Council (GCC) countries. The study showed that present PV technology is not a cost-effective option for GCC countries due to existing lower electricity tariff, higher PV system cost and lower system efficiency. Pavlovic, Milosavlievic, Radonji, Pantic, Radivojevic & Pavlovic (2013), in their findings on Serbia, conducted a study on possibilities of generating electrical energy through 1 MW PV power plants by taking different types of solar PV modules available and it was concluded that higher electricity is generated using CdTe solar modules. Alnaser, Flanagan & Alnaser (2008), conducted a research on a solar plant situated in the Kingdom of Bahrain, which produces 12 MW, corresponding to 12,000kW per day) from PV panels installed on the windows and roofs of two buildings along with an annual CO_2 reduction of 48,000 t and revenue generation of €4,800,000 annually.

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Adeyemo (2013), identified the challenges facing solar energy project in Lagos state Nigeria. The study analyzed a failed solar power- project known as the connect-project coordinated by HAMK, Laurea and Lahti University of applied science. The study identified the capacity and performance of the batteries as a major challenge in solar- powered projects, which can be reduced by properly managing the batteries. The research recommended that ensuring proper project management as a whole is a key point to ensuring the minimization of failures in solar powered projects.

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3. Socio-economic Condition of Nigeria

Nigeria is located in West Africa between 3^0 and 14^0 East of Greenwich and latitude 4^0 and 14^0 north of equator. It is Africa's largest exporter of crude oil, with a population of 167million people with 80 percent of the population living below the poverty line. In Nigeria, a myriad of factors drives the growth in poverty rate, which includes rent-seeking economy, weak institutions of the government, inadequate levels of investment in human capital and infrastructure especially in providing energy services.

However, access to energy is critical in the development of any economic, which will help reduce poverty. Nevertheless, about 60 percent of Nigerians live literally in the dark without electricity in rural areas. At the moment, they satisfy their energy needs with kerosene lamps, candles and dry battery cells which are considered as harmful to human health, the environment and costly for users. Hence, the rural areas, which are generally inaccessible due to absence of adequate road networks, long distances from grid and poor income levels have little or no access to conventional energy to meet their daily needs and entirely depend on wood fuel or diesel engine generators that have high maintenance and operational costs.

The price of fossil-based products such as gasoline, kerosene and diesel attract a higher price in the rural areas compared with prices in urban areas by a margin of about 150 percent. This has resulted in making Nigerian rural populace not only socially backward but also renders their economy potentially untapped and forcing closure of business (Sambo 2005). . Notwithstanding, Nigeria is blessed with abundant solar radiation with most parts of the country enjoying 300 sunny days a year, making the PV system a good solution for rural electrification and particularly attractive for the country's energy strategy.

4. Solar PV Application in Nigeria

Nigeria lies within a high sunshine belt and has enormous solar energy potential. Howbeit, solar radiation is fairly distributed in the country, with almost every area in Nigeria being suitable for solar PV application. Table 2 shows the maximum, minimum and yearly average solar radiation in selected states in Nigeria.

Table 1. Solar radiation in minimum, maximum and yearly average in Nigeria

Selected states	Location Lat^0 N	Location Long^0 E	Altitude (m)	Max[a]	Min[b]	Monthly Average
Abuja	9.27	7.03	305	5.899	4.359	5.337
Bauchi	10.37	9.8	666.5	6.134	4.886	5.571
Calabar	4.97	8.35	6.315	4.545	3.324	3.925
Enugu	6.47	7.55	141.5	5.085	3.974	4.539
Ibadan	7.43	3.9	227.23	5.185	3.622	4.616
Jos	9.87	4.97	1285.58	6.536	4.539	5.653
Kano	12.05	8.53	472.14	6.391	5.563	6.003
Katsina	13.02	7.68	517.2	5.855	3.656	4.766
Lagos	6.58	3.33	39.35	5.013	3.771	4.256

Port Harcourt	4.85	7.02	19.55	4.576	3.643	4.023
Sokoto	13.02	5.25	350.75	6.29	5.221	5.92

[a] Average for the months of March, April and May. [b] Average for the months of July and August

Solar radiation in Nigeria ranges between 3.5-7.0 kWh/M^2/day with peak radiation occurring at the far North of the country. Solar energy is the most promising renewable energy resource in Nigeria due to its abundance (Ilenikhena & Ezemonye, 2010). Bugaje (2006) argues that solar energy in Nigeria complements rapid development of small scale industries and reduces the rural and urban drift, and emphasized further that the energy demand of the nation could be met if only 0.1% of the total solar energy radiant on land mass is converted at an efficiency of 1%. Energy radiated from the sun is about $3.8x10^{23}$kW, which is 1.082 million tons of oil equivalent per day (Sambo 2005).

Nigeria has an average of $1.804x10^{15}$ kWh of incident solar energy annually based on Nigeria's land area of $924x10^3$ km^2 and an average solar energy of 5.535 Kwh/m^2/day. The sunshine on the average is 6.5h/day, and the annual solar energy value is about 27 times the country's total fossil energy resources in energy units and is over 115,000 times the electrical power produced (Augustine & Nnabuchi, 2009).

Nevertheless, the current solar energy installation in Nigeria is relatively insignificant compared with that of South Africa, which already has more than 200,000 off-grid installation of PVs. Moreover, the country has a good radiation site, which can boost the development of solar PV energy with adequate utilization if appropriate energy policies are implemented.

Table 2. Application for solar in Nigeria

Solar PV Application
Residential (Mostly Lighting)
Street lights, Billboard etc.
Industrial
Village electrification
Health Centre/Clinic
Offices/Commercial lighting and equipment
Water pumping
Telecommunication and Radio

Source: author's computation

Table 3 highlights some major area of solar energy application within the society, solar can be used to power lightening bulbs in residential buildings, street lights, billboards etc. solar energy is also a highly reliable source of energy which can be used in powering plants and machineries used by industries for production. With most Nigeria villages still experiencing shortage in electricity the use of solar in generating electricity has become inevitable. Solar energy ~~are~~is used mostly at local health centers to power refrigerators, hospital and laboratories equipment's in most villages. Similarly solar energy can be used for pumping water, used by media and broadcasting firms for outdoor coverage.

5. Financial and Economic Analysis of PV Application in the Federal Capital Territory (FCT) of Nigeria

5.1 Analysis of Energy Demand

A questionnaire-based survey was conducted to ascertain the energy demand and the willingness of individual to pay for the installation of a PV in Abuja, Federal Capital

Territory (FCT) Nigeria from January to December 2015 for energy demand estimation. After the
Primary survey, the questionnaire was modified and used. The questionnaire comprised of monthly energy demand in terms of heat and power, average of temperature and total rainfall and the amount of money (naira) individuals will be willing to pay for the installation of the PV. The estimated average monthly energy requirement for the selected state FCT is summarized in Table 5.

Table 3; Monthly Average Solar Irradiation for FCT 2015

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
5.49	6.19	6.00	6.85	5.56	5.25	4.47	3.50	4.82	5.41	6.73	5.95	5.60

The annual mean quantity of solar radiation of 6.8 kWh/m^2/day is high compared to the national average of 5.50KWh/m^2/day, the figure drops as low as 3.50 kWh/m^2/day in August during the rainy season. The electrified household ratio in the FCT is 7.1% which is substantially higher than the national average of 44%, indicating the geographical spread of the existing 33/11KV distribution lines which are mainly along the major trunk roads, to reach important towns and also the rural areas. However, the monthly average solar irradiation in the FCT was 5.60 kWh/m^2-day and this value was used for the design of PV systems. Therefore, a Panel Generation Factor (PGF) was implemented to determine the solar photovoltaic cells on the basis of total watt peak rating and then for estimating the number of panels required for a particular PV, which varies with the solar intensity and sunshine period.

$$Panel\ generation\ factor = \frac{Solar\ irradiance\ X\ sunshine\ hours}{Standard\ test\ conditions\ irradiance} = \frac{5.60\ X\ 6}{1000} = 0.0336$$

The table below shows the historical changes in the number of users and the maximum demand respectively in the FCT. The annual increase rate of the number of users was as high as 16-30%. Thus, the increase in maximum demand was due to population inflow from neighboring states, which caused insufficient transmission and distribution capacity, thereby suggesting a much larger potential power demand.

Table 4. Number of Users and Maximum Demand in the FCT

Years	Numbers of Users	Annual Increase Rate %	Maximum Demand
2007	143,675	N/A	100
2008	152,129	30	104
2009	157,045	27	N/A
2010	168,909	20	180
2011	170,595	16	201
2012	171,546	25	230
2013	172,500	19	250

Source: Authors computation

Proposed PV Electrification Models

The village socioeconomic survey results indicate that the average monthly expenditure (i.e the total expenditure for Kerosene, diesel oil and dry cells) in un-electrified villages compared with that in the FCT is fairly high at ₦3, 153 thereby causing many local households to desist from the introduction of Battery Charge Station (BCS) due to the restrictions on the capacity of the electrical appliances which can be used and also on the hours of use. The proposal of a PV electrification mode with high specifications despite a high monthly charge is necessary. Moreover, as the existing grid spreads over a wide area along the main trunk roads, the distance for grid extension to un-electrified villages are short, making the life cycle cost per kWh, including the grid extension cost, relatively low. For this reason, the FCT PV systems are considered to be tentative measures until the realization of on-grid electrification and the introduction of the mini-grid system, which can be easily relocated once on-grid electrification is realized in the nearest future.

5.2 Off –Grid Electrification Targets

The establishment of short-term, medium and long term targets for off-grid electrification in the FCT is however necessary. This process has compelled the National Energy Policy of Nigeria to plan the supply of electricity (including electricity generated by renewable energy to 75% of the total population in 2020. The target electrification rate for FCT to achieve the National target is set at 85% in 2010 and 99% in 2020.

The National population commission has predicted an increase of number of households in FCT to approximately 210,000 by 2020. This means that electricity supply to 200,000 households (210,000 x 0.99) will be required in 2020. The Nigerian government intends the use of PV generation to supply electricity to some 1.8% of new users in the coming years, the supply of electricity to approximately 1,700 households by means of off-grid PV rural electrification is however necessary.

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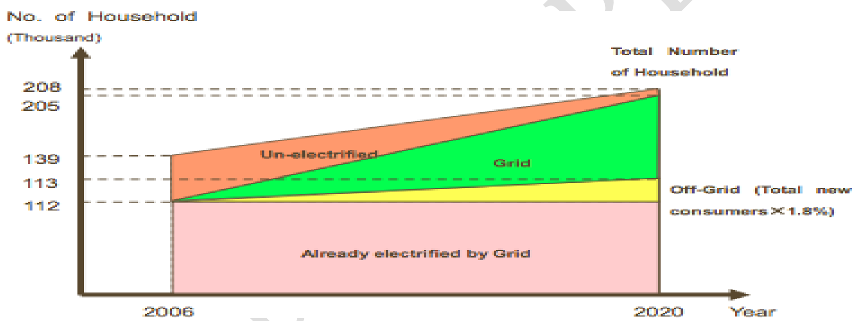

Fig 1 Planned Number of Electrification Household in FCT 2020

Figure 1 shows the planned scheme to supply electricity to new users in the FCT. The planned quantity of off-grid PV systems to be introduced in the FCT in the coming years is small because of high current electrification rate of 71% in 2006 and the small estimated population in 2020.

5.3 Financial Analysis of Mini-grid System in the FCT

The implementation of mini-grid based electrification project in the FCT will be based on the calculation of 20 systems serving 400 units of households (20 households/system x 20 systems), over a three-year period from 2008-2010. (7 systems serving 140 households each in 2008-2009 and 6 systems serving 120 households in 2010). Over a 10-year period from 2011-2020, a further 65 systems serving 1,300 households (20 households/systems x 65 systems) will be installed at an annual rate of six systems (serving 120 households) in the first five years and 7 systems (serving 140 households) in the second five years.

Table 5. Required Equipment Investment for Mini-Grid System in FCT 2007-2020 (unit: Naira millions)

Installation Year	Prices of Mini-grid system	No of Mini-grid system to be installed	Investment Cost	Necessary subsidy for 50%
2007	0	0	0	0
2008	3.55	7	25	12
2009	3.39	7	24	12
2010	3.22	6	19	10
2011	3.05	6	18	9
2012	2.89	6	17	9
2013	2.72	6	16	8
2014	2.55	6	15	8
2015	2.38	6	14	7
2016	2.22	7	16	8
2017	2.05	7	14	5
2018	1.88	7	13	3
2019	1.72	7	12	2
2020	1.55	7	11	0

Source: Authors computation

In table 5, given the significance to examine the financial viability of the assumed mini-grid projects in the FCT for the study, it was assumed that the study was conducted by applying the Financial Internal Rate of Return (FIRR) and Net Present Value (NPV) to ascertain the result under the present financial analysis.

5.4 Financial Internal Rate of Return (FIRR)

The FIRR is obtained by equating the present value of investment cost and the present value of net incomes. This can be expressed as follows.

$$\sum_{n=0}^{m}\frac{In}{(1+r)^n}=\sum_{n=1}^{m}\frac{Bn}{(1+r)^n}$$

$$I_0+\frac{I_1}{(1+r)^1}+\frac{I_2}{(1+r)^2}+\frac{I_m}{(1+r)^m}=\frac{B_1}{(1+r)^1}+\frac{B_2}{(1+r)^2}+\frac{B_m}{(1+r)^m}$$

Where; I_0 is the initial investment cost in the year 0 and I_1~I_m are the additional investment cost for maintenance and rehabilitation for entire project life period from year1 to year m.

5.5 Net Present Value (NPV)

Net Present Value (NPV) analysis is the most widely used method in analyzing investment projects. NPV is the difference between net cash inflow that will be provided during the economic life of a project an investment expenses that discounted to present value with a certain amount of reduction that previously accepted. However, for a project to be accepted according to this method the NPV should be greater than or equal to zero (NPV ≥ 0). In the selected of alternative projects, the NPV of a project that has the highest value is given the priority on the condition that being greater than or equal to zero. Therefor the capital budget profitability of an investment or project and it can be expressed as follows:

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$$PV = \frac{C_n}{(1+r)^n}$$

$$NPV = C_0 + PV = C_0 + \frac{C_n}{(1+r)^n}$$

$$FV = C_0(1+r)^n$$

Where;

PV = Present Value
C_n = Cash flow will take place after n period
r = The discount (interest) rate
n = The Number value of periods
NPV = Net Present Value (NPV)
C_0 = The initial cash flow
FV = The Future Value

$$NPV = \left[\sum_{t=0}^{n} \frac{B_t}{(1+r)^t} \right] - \sum_{t=0}^{n} \frac{C_t}{(1+r)^t}$$

Where;

$C_{t\,in}$ = The cash inflows of t year
$C_{t\,out}$ = The cash outflows of t year

In case of a positive result of the assessment (NPV>0), the investment project is accepted, otherwise (NPV<0) is rejected. If NPV=0, that means the annual cash flow is only enough to meet the operating cost and the investment costs.

In order to examine the power generation cost of grid electrification in the FCT, the life cycle and the unit cost per kWh were calculated. Therefore, the formation of PV electrification program in FCT is assumed as follows:

- Period of calculation: 20 years project life
- Discount rate of Present Value calculation: 10%
- Maximum power demand per consumer household: 300w
- Load factor (average power demand divided by maximum demand): 0.5
- Duration of power use per day: 5.2 hours
- Annual electricity consumption: 219KWh
- Initial investment subsidy: 50%.
- Unit power distribution cost by 33kV line: Naira (₦) 3,900,000/km
- Unit generation cost; ₦ 1.2495/Wh
- Transmission and distribution cost loss ratio; 0.40.

However, the economic appraisal in the study of PV rural electrification in Nigeria is done from the viewpoint of consumer surplus to count the benefit, by adding the merit of fuel consumption saving which is a previous alternative method for saving the cost with computation of cost. The calculation is done by excluding the subsidy and the tax in the economic evaluation model by applying the consumer surplus approach. The financial Internal Rate of Return (FIRR) and the Net Present Value (NPV) are calculated as shown below.

FIRR (Financial Internal Rate of Return)	**17.5%**
Financial NPV (Net Present Value)	**₦320,897,841**

5.6 Sensitivity Analysis

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The sensitivity analysis is applied to the income side (income from collected fees) about two cases in 15% down and 30% down from the forecast. Moreover, the investment cost (price of PV equipment and installation cost) is analyzed about the case of 15% up and 30% up from the forecast

Table 6: Sensitive Analysis

Case	FIRR (%)	NPV (₦)
Base case	17.5%	320,897,841
Case 2 (income: 15% down from the expected level)	14.0	184,739,889
Case 3 (income: 30% down from the expected level)	10.5	45,398,379
Case 4 (investment cost: 15% up from the expected level)	15.3	260,281,076
Case 5 (investment cost: 30% up from the expected level)	13.3	199,125,857

Source: Authors computation

From table 6 above, with regards to the sensitivity analysis, cases of the income and investment were analyzed. Two cases where income (collected electricity charge) was 15% and 30% below the expected level were analyzed; also, two further cases where investment cost was 15% and 30% above the expected level were also analyzed. This meant that the PV equipment cost and the installation cost do not fall below the expected levels. This suggests that a project on this scale is economically viable in the FCT. However, it is seen in the financial analysis, that the PV equipment has not yet penetrated the Nigerian market, so it highly depends on price reduction to enable it penetrate.

The results suggest that investment cost should be adequately provided for FCT mini-grid electrification for meeting the energy demand in the selected area of study. The results shed light on the wisdom of past policy initiatives, and also carry implication policy for the future. Indeed, the sensitivity analysis to the cost of capital indicates that at income 15% down from the expected level there is a change in 14% and also investment cost: 15% up from the expected level there is a change in 15.3%, which explains that money spent to raise capital to finance the mini-grid electrification construction in the FCT does not vanish, rather it flows into the hands of financial institutions and investors in the country. This will lead to greater transfer of wealth from public funds or electricity rate-payers to the government or the people who bear the cost of the subsidy.

5. Willingness to pay for the Installation of a PV in the FCT by individuals

Table 7**.** Number of individuals willing to pay for the installation of a PV system

	Yes	No
Respondents	2480	520
Percentage	82.67	17.33

Source: Authors computation

From the table above 2480 respondents of the entire 3000 questionnaires served in the FCT are willing to pay for the installation of the PV system for electrification in their houses, this accounts for 82.67 % of the sample population. While 520 respondents are not will to pay for the installation of a PV system, this accounts for 17.33% of the sample population. Evidence from the result showed that more individuals are willing to pay and switch to the use of PV system.

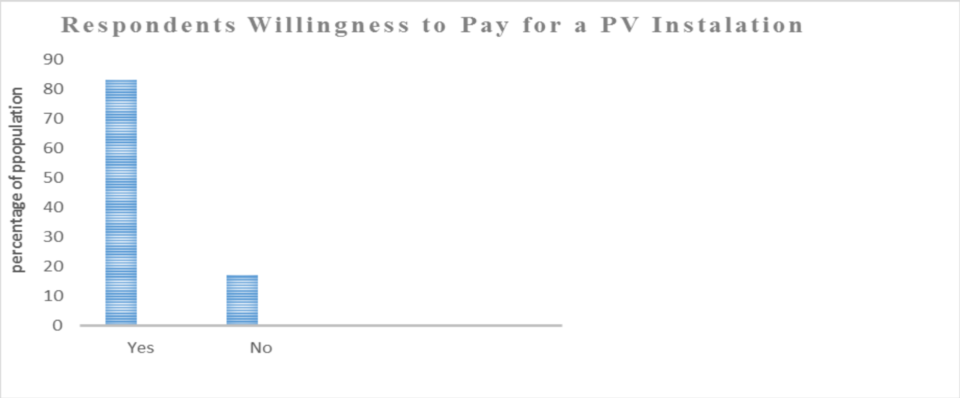

Fig 2. Respondent's willingness to pay for a PV Installation in FCT

Table 8. Amount of money individuals are willing to pay for the installation of a PV (Naira)

Amount	350,000-500,000	500,000-650,000	650,000-800,000	800,000-950,000
Respondents	2140	542	118	200
Percentage (%)	71.33	18.06	3.94	6.67

Source: Authors computation

Table 8 shows the amount of money the respondents are willing to pay for the installation of a PV system, about 71.33% of the respondent are willing to pay an about between 350,000 and 500,000 naira for the installation of a PV. While 18.06 % of our respondents are willing to pay the sum between 500,000 and 650,000 Naira and 3.94% are willing to pay between 650,000 and 800,000 Naira for the installation of a PV system. Finally, the remaining 6.67% of our respondents will be willing to pay an amount between 800,000 and 950,000 naira. The evidence from table 9 shows that the larger percentage of the sample population will be willing to pay for the installation of the PV system if it ranges between 350,000 and 500,000 naira.

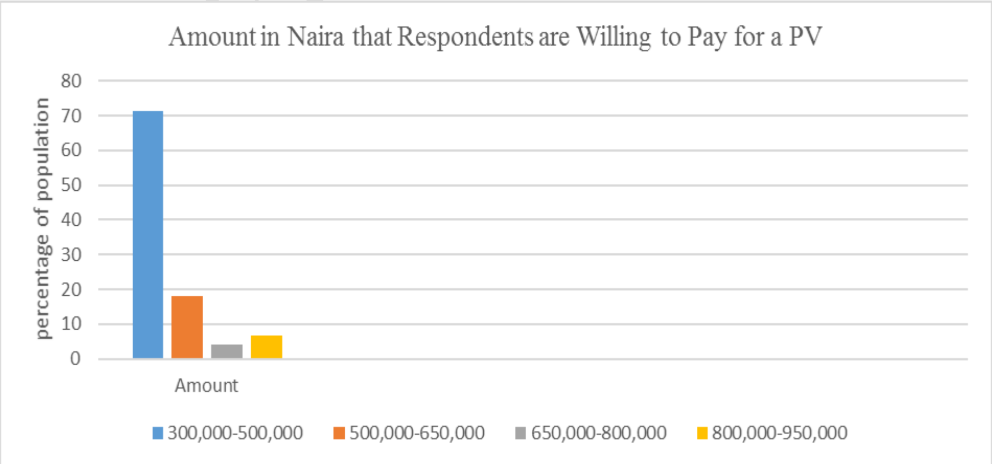

Fig 3. Amount in Naira Respondents are willing to pay for a PV

6. Conclusions and Recommendation

The study was carried out to analyze the cost of designing an affordable solar photovoltaic system in the FCT, bearing in mind that a significant proportion of the Nigerian population lacks access to energy supply. Notwithstanding the fact that Nigeria is generally blessed with ample conventional and renewable energy resources, the demand is significantly higher than the energy generated. This paper is advocating the use of PV system of electrification to bridge the gap between energy demand and supply as well as improve the lives and wellbeing of the masses in the country by significantly reducing fossil fuel consumption. It is imperative to know that CO_2 (carbon dioxide) is the primary greenhouse gas, which contributes to climate change. The burning of fossil fuels releases large amounts of carbon to the atmosphere, causing CO_2 concentrations in the atmosphere to rise, which are harmful to human race.

Market research has shown that the mini-grid systems have an impact in improving the living conditions of the rural populace. It is said that PV systems have one of the highest kWh electricity production costs and are very competitive. However, the financial burden of risk assessment, electric grid management cost compared to the real ability to pay, makes a private investment looking for profitability not attractive. The financial model has shown that within a private public partnership and upfront subsidy of 50% of the total project costs, the PV system can break even after an investment period of 10 years. However, the results indicate that the expansion of PV into less developed markets will be sensitive to make low cost capital more readily available.

In order to extensively develop the PV market in Nigeria, the government should come up with policies that would make access to capital for PV installation more competitive and take out the place of PV subsidies as a means of stimulating market growth.

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