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Cleaner energy in Nigeria residential housing

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ABSTRACT

Electricity outage is the main challenge facing the residential, commercial and industrial sectors in Nigeria. The country's electricity production is primarily from hydro and thermal sources, yet the available electricity output is far less than the demand. The shortfalls in electricity production and distribution in the residential and commercial sectors are the drive behind the off-grid power generation by individuals and corporate bodies in Nigeria. The off-grid power generation is mainly produced using gasoline/diesel generators which are not environmental friendlies and constitute an increase in the carbon footprint of the country. The use of off-grid power generators, also known as "backup generators" continues to grow, from slightly over 60% in 2002 to more than 80% in 2014, exposing the non-functional power sector in Nigeria. An average of 84% urban household depends on gasoline or diesel-powered generator for electricity supply while the rest live without electricity.

This paper's goal is to evaluate the alternative sources that could expedite electricity availability with less carbon footprint. In this study, clean energy - solar photovoltaic (PV cells) utilization prospects were investigated for the common types of residential buildings in Nigeria. Lastly, the prospects of utilizing solar energy in buildings are discussed with their economic and environmental benefits.

1. Introduction

The adequate supply of energy is largely considered the spine of sustainable growth of any country. In lieu of this, the Sustainable Energy for All (SE4All) Initiative launched in 2011 by the United Nation (UN) is facilitating policies and procedures for realising energy access throughout the world. In response to these calls several African countries have started initiatives to implement SE4All policies and procedures for sustainable energy development. For instance, the Sub-Saharan Africa known to be rich in energy resources, yet very poor in energy supply is making efforts to improve its access to energy. The region which accounts for 13% of the world's population is expected to utilise more than its current 4% of the global energy demand despites its recent 45% rise in economic growth since year 2000. According to World Bank data [1] on world development indication on access to electricity per percentage of population, the Africa continent is below the average world access to electricity. The world access to electricity per percentage population grew from 73.5% in the year 1990 to 85.3% in the year 2014 while the sub Saharan grew from 23.4% to 37.4%. Other African countries like South Africa grew from 56.5% to 86%, Egypt from 93.8% to 99.8%, Algeria from 93% to 100%, Ghana from 23.9% to 78.3%, Nigeria from 27.3 to 57.7%, Morocco from 46.9% to 91%, Gambia from 16.8% to 47.2% and Libya declined from 100% to 98.5%. Most of the African countries access to electricity are below the world average of 85.3% as at 2014. Several African countries are now escalating efforts to tackle policies and partisan obstacles that are threatening investment in national energy supply [2–5]. Reports by the International Energy Agency (IEA) in 2014 on the African Outlook, revealed that within the sub-Saharan Africa an estimated staggering number of over 6 million people do not have access to electricity supply, as seen in Fig. 1, while an alarming number of over 700 million people (especially women and children) are exposed to hazardous conditions resulting from the use of certain inefficient energy forms for domestic activities [6,7]. Table 1 shows the access to electricity per percentage population of some African countries from year 2010–2014 [1]. However, Gunther et al. (2017) report over 500 million people who lack access to electricity in the rural parts of Africa [7]. The SE4All goals emphasizes on three points agenda of i) Access to Energy, ii) Energy efficiency and iii) Renewable energy (RE). Energy efficiency and RE can contribute more to increasing Energy access in Africa, although the latter contribution will be significant. Most African countries will need new sources of energy aside the conventional energy types of coal or fuel fire thermal plants (with 400 parts per million of atmospheric CO2

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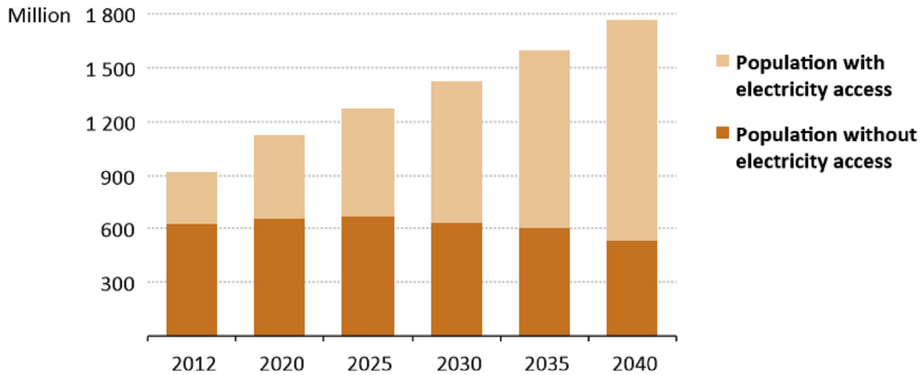

Fig. 1. Access to electricity in sub-Saharan Africa, Source [12].

Table 1
Access to electricity in some selected Africa Countries (% of population) [1].

	2010	2011	2012	2013	2014
Angola	35	34	34	33	32
Burundi	5	6	7	7	7
Benin	34.2	36.9	38.4	37.3	34.1
Burkina Faso	13.1	15.7	16.3	16.9	19.2
Botswana	48	53.2	52.2	54.4	56.5
Central Afr. Rep.	9.8	10.8	11.3	11.8	12.3
Cote d'Ivoire	58	59	55.8	61.2	61.9
Cameroon	53	53.7	55.3	56.5	56.8
Congo, Dem. Rep.	12.9	13.5	15.4	14.8	13.5
Congo, Rep.	38.9	40	41.6	42.1	43.2
Cabo Verde	81.1	82.4	85	87.6	90.2
Algeria	99.7	99.9	99.9	99.9	100
Ethiopia	21.9	23	24.	25.2	27.2
Gabon	85.2	86.3	89.3	86.4	89.5
Ghana	65	64.1	69.3	70.7	78.3
Guinea	24.5	25.3	26.2	26.9	27.64
Gambia, The	42.1	43.4	44.7	44.5	47.2
Guinea-Bissau	6	9.4	11.6	13.9	17.2
Equatorial Guinea	65.4	66.1	66.5	67	67.6
Kenya	19.2	26.2	27.2	28.2	36
Liberia	4.8	4.1	6.9	9.8	9.1
Libya	98.7	98.6	98.6	98.5	98.5
Lesotho	19	21.1	23.2	25.3	27.8
Morocco	85.7	87.6	89.6	91.5	91.6
Mali	22.3	23.6	25.6	26.1	27.3
Mozambique	17.	20.2	19.1	20.2	21.2
Malawi	8.7	7.6	7.4	9	11.9
Namibia	45.5	46.5	47.5	47.4	49.6
Niger	12.4	14.3	14.4	13.8	14.3
Nigeria	48	55.9	55.5	55.6	57.7
Rwanda	9.7	10.8	12.8	15.2	19.8
Sudan	37.5	37.8	38.2	38.5	44.9
Senegal	53.5	56.5	56.9	57	61
Sierra Leone	13.9	14.2	13.5	13.5	13.1
Somalia	15.1	16.1	17.1	18.1	19.1

regarded as potentially enough to trigger a warming of 2° Celsius compared with pre-industrial levels). RE alternatives like PV cell, Wind and bioenergy will play significant role in Africa to increase access to energy in the future.

A clean energy revolution in sub-Saharan Africa is urgently needed to win the fight against energy poverty. The Sustainable Development Goals (SDGs) set out an inspiring vision for what Sub-Saharan Africa could look like in 2030. Clean energy provides apathway to delivering on the 2030 SDGs agenda. The SDGs has the ability to bring about improved health-care, eradicate poverty, grow the economy, and empower women and children [27,28]. Apart from the vast economic benefits, access to clean energy build resilience in sub-Saharan African nations reduce the rate of migration, which is current on the rise [29].

Several studies have been carried out globally have been carried out in different regions of the world that is focused on the use of both RE in the built environments. z, M. et al. [23] in their study, presented the results of electricity measurements in a low-energy building in Mid – Europe climatic conditions, the Results reveled that electricity consumption is the highest in December and January. Ogbeba & Hoskara [24] carried out a simulation for single family detached housing in North Cyprus. This was done through the use of passive and active design strategy. The result PV integrated as a shading device produced about 2800 W of electricity for the building.

The recent publicity and awareness of RE potential on the global scale is lending hands to its utilization, especially in the third world countries. RE is a major discussion topic in scientific and governmental forums. The level of high value collaborations between the industries and government agencies on the issue of RE has triggered a huge increase in the application of RE sources since 2008 [8–11]. The progressive growth in RE global market is driving by its synergy of social-economic potential and robust policies that emphasis its framework for global implementation, especially in developing countries with fund constraints. The energy (electricity demand and supply) situation in most African countries limit their economic growth since many business and industries require electricity to function in a competitive market [10]. Energy forecast for Africa postulates about 17% increase in solar energy capacity by 2040 [12] in line with the stated policies scenario. In the Stated Policies Scenario, electricity output increases fourfold, from around 225 TWh in 2018 to just over 900 TWh in 2040. Fig. 2 shows the past and forecasted energy generation capacity in Africa. The Stated Policies Scenario reflects the impact of existing policy frameworks and today's announced policy intentions. The aim of the Stated Policies Scenario is to provide a detailed sense of the direction in which existing policy frameworks and today's policy ambitions would take the energy sector out to 2040.

Nigeria a sub-Saharan country which is strategically located on the equator, receives high solar radiation that is evenly distributed. Severally governmental and non-governmental investigations into solar energy potentials in Nigeria has revealed that the annual daily average of the total solar radiation has been estimated to range from about 12.6MJ/m2/day (3.5 kWh/m2/day) in the coastal region to about 25.2MJ/m2/day (7.0 kWh/m2/day) in the far north, hereby supplying it about 17, 459, 215.2 million MJ/day (17.439 TJ/day) of solar energy falling on its 923,768km2 land surface area [13,14]. With such a high level of sunshine falling on the surface of the land, Nigeria possesses high and viable potential in the use of PV as an alternative source of energy supply, this stand even a more higher chance in the semi-arid region. The solar radiation distribution in Nigeria is shown in Fig. 3. From the map, three different solar radiation zones are identified viz: zones I, II and III with each zone having different radiation levels that may be needed for a certain project selection and sizing. Table 2 gives their radiation range for each zone as distributed among the 36 States of the federation. Zone I comprises of all the states in the North-East geo-political zones. In this paper, the energy situation of Nigeria, a Sub-Saharan country, will be assessed. Furthermore, the impact PV Cells integration in the residential

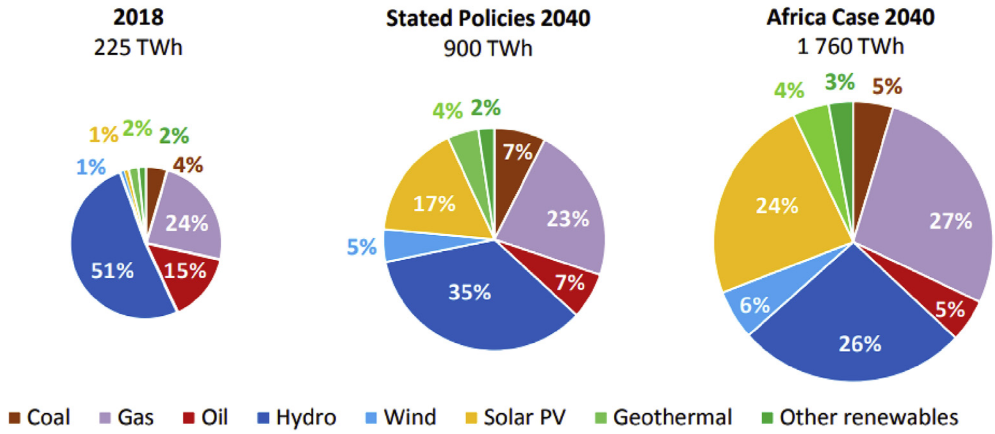

Fig. 2. Electricity supply by type, source and scenario in sub-Saharan Africa 2018 and 2040 [12].

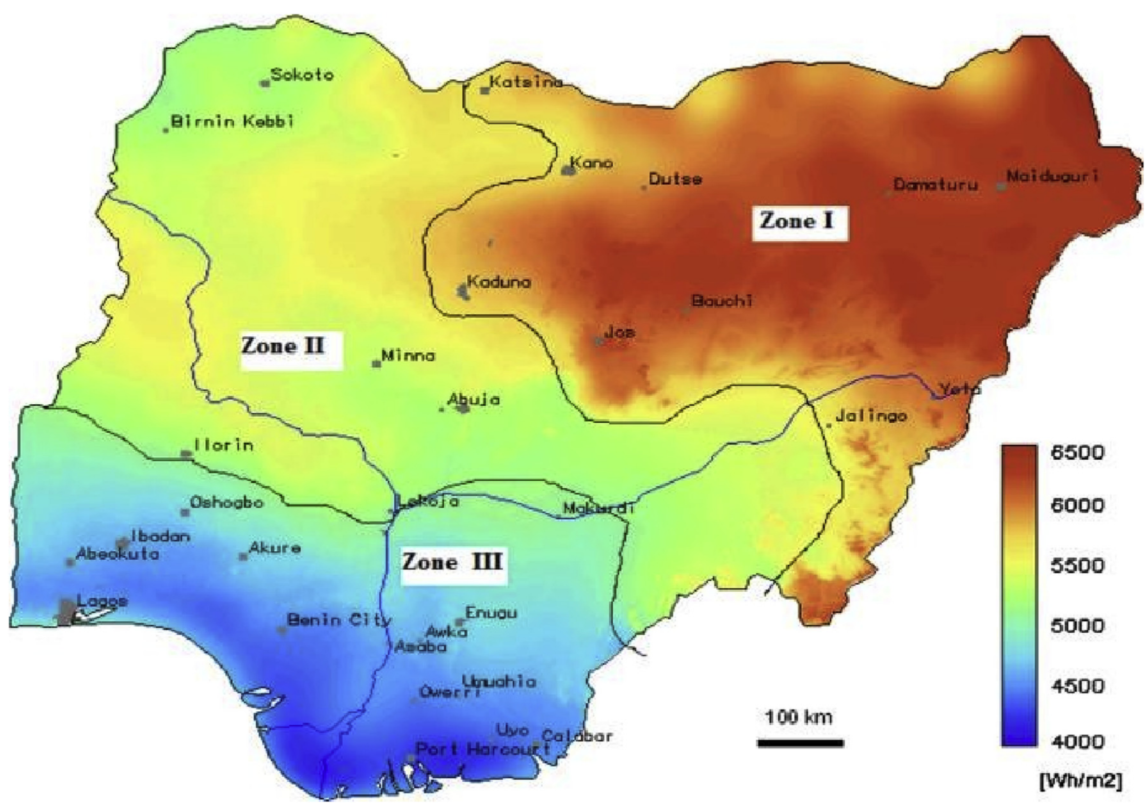

Fig. 3. Solar radiation map of Nigeria [15].

Table 2
Solar radiation zones (global horizontal irradiation) [16].

Zones	kWh/ m^2	h/ d	kWh/ m^2/yr	States
Zone I	5.7–6.5	6.0	2186	Borno, Yobe, Jigawa, Kano, Kaduna, Bauchi, Gombe, Adamawa, Plateau and Katsina
Zone II	5.0–5.7	5.5	2006	Sokoto, Zamfara, Kebbi, Niger, Abuja, Nassarawa, Taraba, Kwara, some section of Plateau and Katsina
Zone III	<5.0	5.0	1822	Oyo, Osun, Ekiti, Kogi, Benue

sector of the country will be analysed.

The first electricity plant in Nigeria, a 60 kW power plant, was installed in Lagos in 1898 fifteen years after electricity was introduced in England. Other regional towns did not generate electricity until after the amalgamation of the Northern and Southern protectorates in 1914. Today, there are 23 grid-connected generating plants with a total installed capacity of 11,165.4 MW and obtainable capacity of 7,139.6 MW [17]. Thermal power plants constitute 81% of the installed capacity (9,044 MW) while hydropower plants constitute the rest (1,938.4 MW). Of the 9,044 MW installed thermal plants, 81% is accessible while 83% of the hydropower capacity is available from the 1,938.4 MW installed capacity. The total installed and available electricity capacity in Nigeria is a combination of government and Independent Power Producers (IPP) investments. IPP entities in Nigeria includes Shell (Afam VI plant of 642 MW capacity), Agip (Okpai plant of 480 MW) and AES Barges (Barges plant of 270 MW). Nigeria with more than 170 million in population is energy poor. Its demand is more than supply from available electricity generation. Nigeria needs to generate a total of about 20,000 MW of electricity to be able to adequately meet its current demand [22]. Currently, Nigeria's per capita consumption of electricity is around 144 kWh, and the highest peak in recent time was recorded in 2012 with an average of 156 kWh [1,8,9]. Nigeria's per capita power consumption is far less than the global average of 3,126 kWh. The most household use of electricity in Africa was basically for powering appliances, thermal regulation of indoor spaces (heating and cooling), lighting, and cooking [18].

Although Nigeria's electricity generation is predominantly powered by hydro and thermal source, (countries like Germany, Denmark, Sweden are powered with more than 20% by RE are shifting to Renewable and Nuclear Energy) the available electricity output is not meeting the huge demand. This shortage accounts for more than 40% of the Nigerian population not having access to electricity supply, and with 72% of the population residing in urban areas and 28% in rural areas. The huge shortfalls in electricity production/distribution and inability to meet the demand for electricity in the residential and commercial sector by the government in short term is driving the individual and private corporates bodies to off grid power generation [19]. Fig. 4 shows the percentage of the off-grid power generation in the total energy demand in Nigeria. The off-grid power generation are mainly produced using gasoline/diesel generators. These sources however constitute an increase in the carbon foot print of the country. The use of backup generators continues to grow as seen from year 2002 with slightly over 60% to more than 80% in 2014, thereby exposing the non-functional national power sector. The poor electricity generation and distribution has thus forced many households to depend on alternative energy sources such as gasoline, diesel, kerosene, coal and fuel wood for their energy need. Kerosene accounts for a high usage of alternative energy in the residential sector, especially for cooking. An average of 84% urban household depend on gasoline or diesel-powered generator for their electricity supply [21].

Nigeria is expected to achieve a 49% electricity generation by solar powered technology by the year 2030; 20% of this development is expected to be reached by the year 2020 and a further 19% by the year 2030. The current trend of events on electricity generation in Nigeria poses a threat to its expected 19% RE mix considering it's currently financial constrains due to fall in crude oil price.

2. Objective, object of observation, methodology

The major goal of this article is to evaluate alternative sources that could accelerate the availability of electricity generation with less carbon footprint. This study looked at prospects for the use of clean energy - solar photovoltaic cells (PV cells) for common types of residential buildCings in Nigeria.

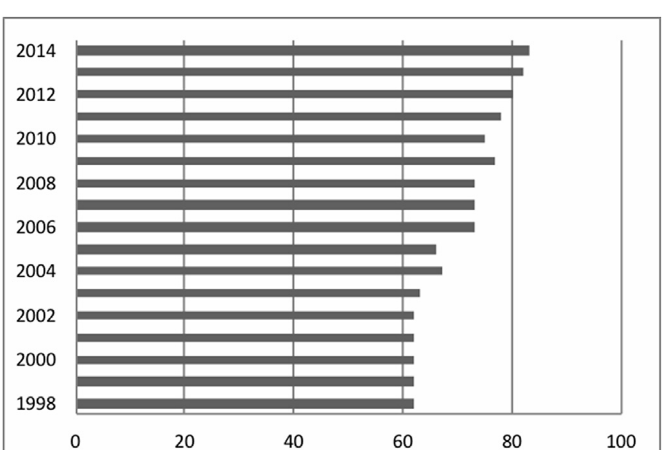

Fig. 4. Electricity demand met by backup generators in Nigeria [21].

2.1. Analysis of residential electricity alternatives

In determining Electrical Load for residential buildings in Nigeria, three kinds of residences were considered. They include; Studio, 3 bedroom, and 4 bedroom apartments. To determine their monthly electrical load, electricity utility bills for 50 of each of the apartments were collected and the average monthly bill was cumulated. Table 3 gives the monthly average electricity consumption in each of the apartments considered (see Table 4).

Due to the insufficient supply of electricity in Nigeria, residencies have to augment their supply of electricity with fuel generators. According to data collected, studio apartments are likely to use generators less than 1 kW in capacity, 3 bedroom apartments are likely to use generators with less than 2.5 kW in capacity and 4 bedroom apartments are likely to use generators less than 5.5 kW in capacity. It is assumed that residences on the average use these generators for about 9 h daily. Based on this, Table 3 shows the estimated consumption of these residences under full load conditions using generator capacity of 1 kW, 2.5 kW and 5.5 kW for studio, 3 bedroom and 4 bedroom apartments respectively.

In many countries around the world the cost of Electricity is completely determined by the electricity utility companies. However, in the case of Nigeria, the cost of electricity is not only determined by the utility companies but also the cost of electricity supplied by the fuel generators. Utility companies in Nigeria charge approximately about 7 cent/kWh1. However, that is not the total cost of electricity. This study also calculates the cost of electricity supplied via self-owned fuel generators. The following generators were used to determine the cost of

Table 3
Average monthly consumption from Utility Company.

Month	Average consumption for studio (kWh)	Average consumption 3 Bedrooms (kWh)	Average consumption for 4 Bedrooms (kWh)
Jan	145	198	250
Feb	285	398	542
Mar	286	476	640
Apr	244	316	380
May	83	132	225
Jun	175	254	424
Jul	88	134	251
Aug	117	218	251
Sept	132	203	246
Oct	150	194	264
Nov	81	108	162
Dec	93	124	199

Table 4
Average monthly consumption from fuel generator.

Month	Average consumption for studio (kWh)	Average consumption for 3 Bedrooms (kWh)	Average consumption for 4 Bedrooms (kWh)
Jan	279	697.5	1534.5
Feb	252	630	1386
Mar	279	697.5	1534.5
Apr	270	675	1485
May	279	697.5	1534.5
Jun	270	675	1485
Jul	279	697.5	1534.5
Aug	279	697.5	1534.5
Sept	270	675	1485
Oct	279	697.5	1534.5
Nov	270	675	1485
Dec	279	697.5	1534.5

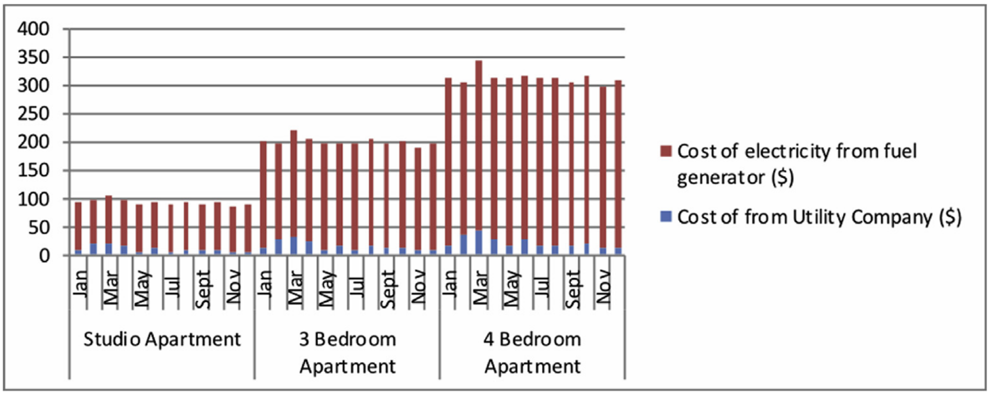

Fig. 5. Variation of cost of electricity in the apartment types.

electricity. 1 kW Winyou WY1200 generation to supply studio apartments, 2.5 kW Winyou WY2.5GF-3 and Hats 5.6 kW were assumed to supply 3 bedrooms apartments and 4 bedroom apartments respectively. Based on the generator cost, fuel consumption, cost of petrol, and cost of maintenance. Fig. 5 shows the total monthly cost of electricity from both utility companies and fuel generator.

2.2. Building photovoltaic integration

Building integrated photovoltaic (BIPV) system has been identified as one of the viable technologies to improve building energy performance and to reduce environmental effects by the on-site electricity generation with solar energy. The system involves combining solar photovoltaic electricity technologies with typical building fabrics. Part of the cost of the photovoltaic system is offset by the cost of the material replaced.

A rapidly growing opportunity for photovoltaic applications lies in using photovoltaic modules in place of conventional building materials. BIPV products are high quality construction materials with warranties that match the lifespan of the solar cells. The roof-top mounted Photovoltaic module (PV) is considered as an alternative to electricity generation in Nigeria.

2.3. System Advisor Model (SAM)

SAM is a simulation tool that helps in designing and performing economic feasibility analysis of energy systems. The input data required are the following: solar resource data, size of system, economic constraints, technical specifications for PV modules and inverters, cost constraints, types of equipment, controls etc. Once the required data are available, the simulation can be run. A complete simulation would provide a list of possible configurations for a power system ranked according to the NPV. The main technologies represented in SAM are PVs flat plates, concentrated solar power CSP (towers, linear Fresnel, parabolic troughs and dish-Stirling, wind, solar water heating, geothermal, and biomass [25].

CPS system is a growing means of generation solar power. Its uses mirrors to concentrate a large area of solar radiation to a small surface area. It generates electricity by converting the converged light into solar thermal energy, which is used to drive a heat eengine. SAM has been used severally to evaluate the energy performancells of solar systems. Ezeanya et al., 2018, used SAM to model a simulate a 50 kW concentrated solar power (CSP) system in Louisiana. The analysis showed that 70% reduction in the cost of electricity can be achieved when the power plant is operated at the optimal combination of solar multiple and hour of storage [26]. Blair et al.'s work using SAM model clearly describes the ability of SAM modeling PV applications.

The heat transfer coefficients of the construction elements of the building are tabulated in Tables 5–7.

The total costs of installation, operating and maintaining of the energy system are as follows:

Table 5
Building data.

Building description	Studio	3 Bedroom	4 Bedrooom
Area of building	80m^2	110m^2	140m^2
Climatic region	tropical wet and dry climate	tropical wet and dry climate	tropical wet and dry climate
Window type	PVC	PVC	PVC
Door material	Wood	Wood	Wood
HVAC system	None	Split unit	Split unit
single clear glass	6.25 W/m2 K	6.25 W/m2 K	6.25 W/m2 K
Window area	1.2 m × 1.1 m	1.2 m × 1.1 m, 1.8 m × 1.2 m	1.2 m × 1.1 m, 1.8 m × 1.2 m

Table 6
Heat transfer coefficient (U) for construction components.

City	U – Value (W/m^{2}k)			
	Wall	Roof Ceiling	Floor	Windows
Abuja, Nigeria	0.50	0.67	0.42	0.82

Table 7
The buildinfgs' electricity parameters.

Lighting	Illuminance (lux)	150
DHW	Consumption rate (l/m2-day)	0.72
	Delivery temperature (C)	65
Equipment	Unit consumption (W/m2)	3

2.4. Levelized cost of energ

SAM assumes that the RE system provides energy for at least a part of a building's electric load, so the Levelized Cost of Energy (LCOE) is often compared to the retail rates sold by the utility company in $/kWh retail electricity rate. For a BIPV option to be economically viable, the project's LCOE must be equal to or less than the average retail electric rate.

$$\text{Real LCOE} = \frac{-C_0 - \frac{\sum_{n=1}^{N} C_{AfterTax,n}}{(1-d_{\text{nominal}})^n}}{\frac{\sum_{n=1}^{N} Q_n}{(1-d_{real})^n}} \tag{1}$$

where.

Qn (kWh): Electricity generated by the system in year shown in the energy row in the project cash flow. The performance model

calculates this value based on weather data and system performance parameters.
N: Analysis period in years as defined C0: The project's initial cost
CAfterTax: The annual project cost in Year n
dnominal: This is the discount rate with inflation
dreal: is the real discount rate

2.5. Net Present Value (NPV)

SAM Calculates NPV as a measure of a system's economic feasibility which includes savings for residential projects and cost. When net present value is a positive value it means the project is economically feasible. A negative net present proves that a project is not a financially feasible investment, although projects can still be invested in if profit making is not a primary consideration.

$$\mathrm{NPV} = \sum_{n=0}^{N} \frac{C_{AfterTax,n}}{(1+d_{\mathrm{nominal}})^{n}} \tag{2}$$

2.6. System components

2.6.1. System design

Based on the load demand of each of the selected apartment type, equivalent PV module sizes were selected to produce 100% of their load demand

2.6.1.1. Studio apartment. The module capacity that would supply 100% of load demand is 3.6 kWdc

Using an inverter with a capacity of 3.8kWac (fig. 6).

2.6.1.2. Bedroom apartment. The module capacity that would supply 100% of load demand is 7.0 kWdc. Using an inverter with a capacity of 8.0kWac (fig. 7).

2.6.1.3Bedroom Apartment: The module capacity that would supply 100% of load demand is 15.0 kWdc. Using an inverter with a capacity of 12.2kWac (fig. 8).

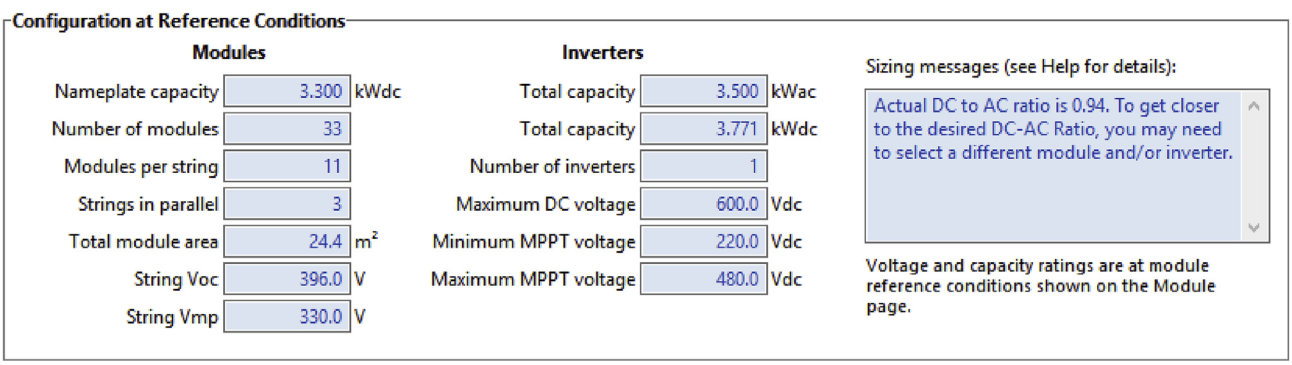

Fig. 6. Configuration of roof-top BIPV system for Studio apartment in Nigeria.

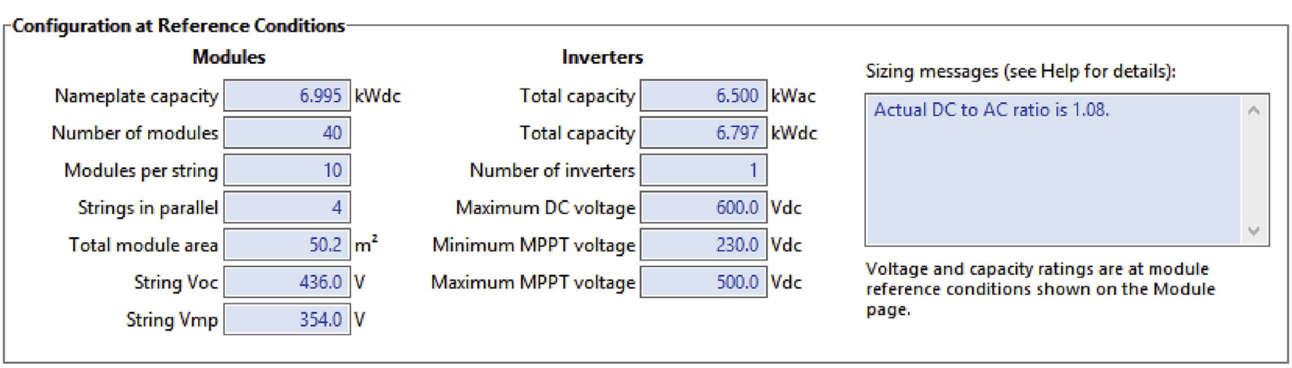

Fig. 7. Configuration of roof-top BIPV system for a 3 Bedroom apartment in Nigeria.

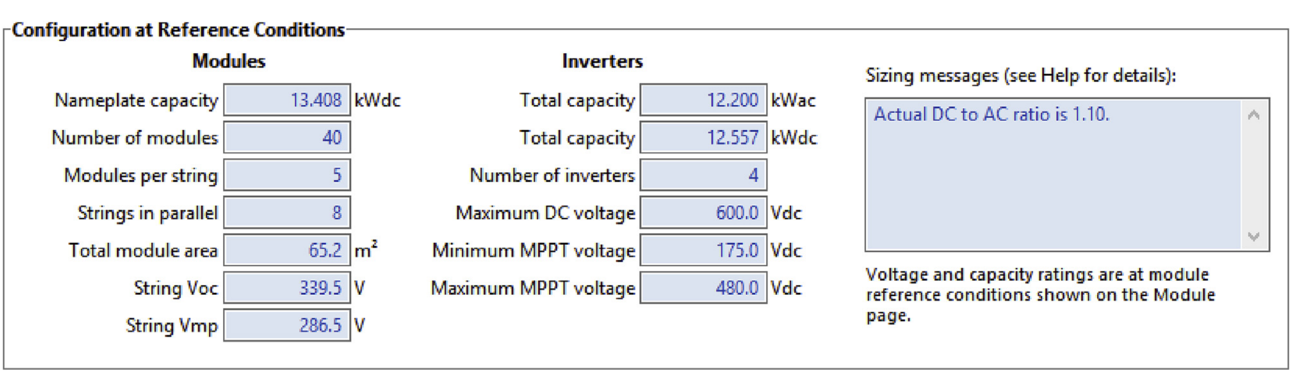

Fig. 8. Configuration of roof-top BIPV system for a 4 Bedroom apartment in Nigeria.

2.6.2. System cost

We describe the cost of integrating 3.3 kWdc, 7.0 kWdc and 13.4 kWdc BIPV systems into Studio, 3 Bedroom and 4 Bedroom apartments respectively. Cost of land is assumed to be negligible since the roof space of the building will be used (Table 8).

2.7. Financial analysis parameters

The period for analysis is 25 years. Average inflation late in Nigeria over the last 20 years is estimated to be about 11%. The Central Bank of Nigeria (CBN) discount rate is 4.25% and the nominal discount rate is 15.72.

3. Results and analysis

The BIPV system is a stand-alone electricity generation system and consists of Solar PV modules to supply the residence demand load. Solar panel is array in connecting to an inverter. Individual features of the SAM tool are in the following paragraphs:

3.1. Electrical energy generation by the systems

The annual generation for the 3.3 kW BIPV systems is 5344 kWh, the 7.0 kW system produces 11379 kWh and the 15.25 kW BIPV system produces about 22523 kWh of energy as shown in Table 9.

3.2. Economic analysis of BIPV systems

The NPV of the studio BIPV system is $ 2,330 with a payback period of 12.3 years. It has nominal LCOE and real LCOE of 20cent/kWh and 8cent/kwh respectively. For the 3 Bedroom BIPV systems, its NPV is $7,947, it has a payback period of 12.3 years and a nominal LCOE and real LCOE of 6cent/kWh and 3cent/kwh respectively. The 4 Bedroom BIPV has the highest payback period of 18.2 years with a NPV of $8,075. It also has a nominal LCOE and real LCOE of 6cent/kWh and 3cent/kwh respectively (Table 10).

4. Conclusions

The objective of this study was to determine the technical and economic feasibility of integrating photovoltaic roof-top panels into 3 building types in Nigerian. This BIPV were sized using the monthly consumption of the building from the utility companies and also a 9- hour daily consumption from fuel generators. It was calculated that on the average each building type cost of electricity is 37cents/kWh (Table 11). Three BIPV systems were sized for each building type; 3.3 kW for Studio, 7.0 kW for 3 Bedroom and 15.25 kW for a 4 Bedroom apartments respectively. This BIPV system provides 100% of the annual Energy currently demanded by the building types and 3% excess for future Load demand.

Technical and Economic simulation were evaluated using NREL's System Advisor Model software. The simulation in SAM was performed for a 3.3 kW BIPV system, 7.0 kW BIPV system and a 15.25 kW BIPV system. From the simulation results, 3.3 kW BIPV system is $ 2,330 a payback period of 12.3 years. It has nominal LCOE and real LCOE of 20cent/kWh and 8cent/kwh respectively. For the 7.0 kW systems its NPV is $7,947, it has a payback period of 12.3 years and a nominal LCOE and real LCOE of 6cent/kWh and 3cent/kwh respectively. The 15.25 kW BIPV has the highest payback period of 18.2 years with a NPV of $8,075 it also has a nominal LCOE and real LCOE of 6cent/kWh and 3cent/kwh respectively. The findings of this study suggest that all the building types considered are financially feasible based on their positive NPV.

Implementation of BIPV is both economical and cleaner than fuel generation and assures of constant electricity. With the worries of sporadic power supply from utility companies in Nigeria and the rapidly depleting supply of fossil fuels, this BIPV system is a step towards a cleaner and greener future.

Table 8
System integration cost.

	Cost 3.3 kWdc BIPV Systems ($)	Cost 7.0 kWdc BIPV Systems ($)	Cost 13.4 kWdc BIPV System ($)
Module Cost	2310	4896.53	9385.74
Inverter Cost	957	2028.56	3888.38
Balance of system equipment	1749	3707.37	7106.35
Installation Labour	1089	2308.36	4424.71
Installer margin and overhead	3498	7414.74	14212.69
Environmental Duties	363	769.45	1474.9
Taxes	249.68	529.24	1014.46
Total	10215.68	21654.25	41507.23

Table 9
Electrical Energy generation by the systems.

	Annual Load Demand (kWh)	Annual BIPV generation (kWh)	Generation Excess (kWh)	Excess (%)
Studio	5164	5344	180	3.49
3 Bedroom Apartment	10967.5	11,379	411.5	3.75
4 Bedroom Apartment	21901.5	22,523	621.5	2.84

Table 10
Economic Analysis of the BIPV systems.

	Studio BIPV	3 Bedroom BIPV	4 Bedroom BIPV
Net Present Value (NPV) $	2330	7947	8075
Levelized COE (nominal) c/kWh	20	6	6
Levelized COE (real) c/kWh	8	3	3
Payback period (Year)	12.3	12.3	18.2

Table 11
Price of energy.

	Levelized COE (nominal) c/kWh	Price of Energy from Fuel generators (cent/kWh)	Price of energy from Utility company (cent/kWh	Current price of energy (cent/kWh
Studio BIPV	20	30	7	37
3 Bedroom BIPV	6	30	7	37
4 bedroom BIPV	6	30	7	37

Credit

Conceptualization, U.K.E, J.E.O.; and P·O.; Methodology, U.K.E, J.E.O. and P·O.; Software, U.K.E, J.E.O. and P·O.; Validation, P·O., U.K.E.; Formal analysis, U.K.E, J.E.O.; Investigation,U.K.E, J.E.O.; and P·O.; Resources, U.K.E, J.E.O.; and P·O.; Data curation, U.K.E, J.E.O.; and P·O.; Writing—original draft preparation, U.K.E, J.E.O.; and P·O.; Writing—review and editing, U.K.E, J.E.O.; and P·O.; Visualization, U.K.E, J.E.O.; and P·O.; Supervision,P·O., U.K.E.; Project administration, J.E.O, P·O.;

Declaration of competing interest

The authors of the paper "Cleaner Energy in Nigeria Residential Housing" declare no conflict of interest.

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