The potential of solar photovoltaic systems for residential homes in Lagos city of Nigeria

K.E. Enongene*[1], F.H. Abanda[2], I.J.J Otene[3], S. I. Obi[4], and C. Okafor[5]

[1] FOKABS INC, 955 Rotary Way, K1T 0L2 Ottawa ON, Canada.

[2] School of the Built Environment, Faculty of Technology, Design and Environment, Oxford Brookes University, Oxford, OX3 0BP, UK

[3] Department of Soil and Environmental Management, Faculty of Agriculture, Kogi State University, Anyigba, P.M.B. 1008, Anyigba, Kogi State, Nigeria.

[4] Department of Electrical/Electronics Engineering Technology, Akanu Ibiam Federal Polytechnic Unwana, PMB 1007, Ebonyi State, Nigeria.

[5] Department of Soil Science, University of Nigeria Nsukka 410001, Nigeria.

*Corresponding author: kenongene@fokabs.com

Abstract: The development and use of solar photovoltaic (PV) technologies worldwide is considered crucial towards fulfilling an increasing global energy demand and mitigating climate change. However, the potential of a solar PV-system is location specific, influenced by the local solar resource, energy demand and cost among other factors. The main aim of this study is to conduct a detailed assessment of the potential of solar PV-systems in residential buildings in Lagos Metropolitan Area, Nigeria. Nigeria has enormous solar energy potential, it is the most populous country in Africa and occupies a significant place in the development of Africa. Yet, it is a county with one of the lowest per capita electricity consumption in the world – at 149 kWh per capita for a population of about 170 million, about 7% of Brazil's and 3% of South Africa's. To achieve this goal, this study employed the survey of 150 residential buildings in three local government areas (LGAs) in Lagos State, Nigeria to obtain electric load data. HOMER Pro was used to size the PV-systems and to determine the levelized cost of electricity (LCOE). The computed energy results of the study for the base case scenario revealed the PV array, lead acid battery and the converter (inverter) of the PV-systems to be in the following range: 0.3 to 76 kW; 2 to 176kWh; and 0.1 to 13.2 kW respectively. Economic analysis revealed a LCOE of the systems in the range of 0.398 USD/kWh to 0.743 USD/kWh. The use of PV-system generated electricity in the dwellings has potential for an annual reduction of greenhouse gas emissions in the range of 31.24 $kgCO_2eq$ to 7456.44 $kgCO_2eq$. Clearly, the use of solar PV systems in residential buildings possesses potentials for enabling Nigeria to attain its climate change mitigation targets indicated in her National Determined Contributions (NDCs).

Key words: Energy; Nigeria; renewable energy; photovoltaic; residential buildings

1. Introduction

Provision of reliable and adequate energy services in an environmentally friendly manner and in conformity with social and economic developmental needs is important for the attainment of sustainable development goals (Vera & Langlois, 2007). Energy is important for the eradication of poverty, for driving national economies, for raising living standards and improving human welfare. The importance of energy is recognized in the adopted sustainable development goals (SDGs) of the United Nations with the seventh of the 17 goals geared at ensuring access to affordable, reliable, sustainable and modern energy for all (United Nations, 2015). Most patterns of energy supply and use around the world is unsustainable. In most parts of the globe, economic development is limited due to a lack of reliable and secure supply of energy. An approximate 2.7 billion people in the world rely on the use of traditional biomass for cooking (International Energy Agency, 2010) while an estimated 1.7 billion people lack access to electricity. Between 2000 and 2010, annual anthropogenic greenhouse gas emissions (GHG) increased by 10 $GtCO_2eq$ with energy supply accounting for 47% of the increase (IPCC, 2014), implying that the energy sector makes a significant contribution to climate change. According to Su et al. (2016), economic development and population growth in cities alongside increased energy consumption with consequent environmental problems have retarded sustainable development in urban areas. In spite its large population and strategic role in Africa, Nigeria exhibits the aforementioned hallmarks of energy poverty and negative environmental impacts that retard development. The reasons for the characterization of Nigeria in the preceding sentence constitute the choice of it as a case study region in this study. This will be discussed in the ensuing paragraph.

Nigeria's per capita electricity consumption is one of the lowest in the world – at 149 kWh per capita for a population of about 170 million, about 7% of Brazil's and 3% of South Africa's. Furthermore, a large proportion of the Nigerian population lives in rural areas, where most of the villages are not connected to the grid due to lack of infrastructure (Mellersh, 2015). Nigeria's per capita power consumption of less than 150kWh is one of the lowest in Africa, lower than those of many less developed countries, including the Republic of Congo, Zimbabwe, Yemen and Togo (Olaniyi, 2017; Oluseyi et al., 2016). In Nigeria, the generation of electricity dates back to 1896 when electricity was first generated in Lagos (Sambo, 2008a). Notwithstanding that electricity has been present in the country for more than a century, the development of the electricity sector has been occurring at a very slow rate. The demand of electricity in Nigeria exceeds supply which is epileptic in nature irrespective of the enormous natural resources endowed by the country which could be employed in the generation of electricity. According to Sambo (2008a), 20 years prior to 1999, the Nigeria energy sector witnessed unsubstantial infrastructural development investment since existing plants were not adequately maintained while new ones were not commissioned. The author further recounted that the low investment in the energy sector in 2001 resulted to a reduction in the estimated installed generation capacity from 5600 MW to 1750 MW, far lower than the load demand of 6000 MW.

The consumption of electricity in Nigeria is dominated by the residential sector (Azodo, 2014) with lighting being a major contributor. Due to the unreliable nature of the electricity supplied from the grid, it is a common practice for households to use standby generators or kerosene lamps to meet their lighting needs or as an alternative for lighting (Ahemen et al., 2016). The use of diesel generators in residential buildings in Nigeria are not only a source of stress and fatigue to household members as a result of the noise produced but as well constitutes a source of GHG emissions (Oyedepo, 2012). Efforts towards addressing the energy situation by the Nigerian government have been geared towards building more power plants but irrespective of the efforts and financial resources invested, energy generation on average has remained below 4000 MW (Olaoye et al., 2016). The integration of renewable energy into the current energy mix of Nigeria can achieve the required 60 GW needed to place Nigeria in the category of an industrialized nation without significant increase in environmental harm associated with pollution. However, in order to adopt PV-system, it is imperative to establish the requirements and viability of such an initiative especially on a wider scale. The aim of this study is to conduct a detail study of the potential of solar PV-systems in Lagos Metropolitan Area, Nigeria. To achieve this aim, the following objectives will need to be attained:

- Identify the different household energy consumption devices and patterns in some selected regions;
- Investigate the potential of solar photovoltaic systems in Nigeria;
- Investigate the variation of the potential between main housing types in three local government areas in Lagos Metropolitan Area, Nigeria.

2. Renewable energy studies in Nigeria: An overview

2.1 PV-system feasibility studies

Several studies about renewable energy sources in Nigeria could be used to inform the generation of electricity as a way forward to close the energy deficit gap in the country. These studies among others include: the investigation of the potential of the agricultural sector as a source of renewable energy in Nigeria by Elum et al. (2016), Akuru et al. (2017) discussed how Nigeria could transition towards 100% renewable energy , Olaoye et al. (2016) studied the energy crisis in Nigeria and the need for renewable energy mix, Diemuodeke et al. (2016) conducted an assessment of hybrid renewable energy systems for coastline communities in Nigeria, Osunmuyiwa et al. (2016) studied the conditions necessary for the transition and adoption of renewable energy in Nigeria, Olatomiwa et al. (2016) conducted a study on hybrid renewable power supply for rural health clinics in Nigeria, Akorede et al. (2016) studied the current status and outlook of renewable energy development in Nigeria while Riti & Shu (2016) conducted a study on renewable energy, energy efficiency and eco-friendly environment in Nigeria. What emerges from the aforementioned studies is that Nigeria is endowed with renewable energy resources including solar which if well exploited will enable the country to meet its energy demand and overcome the existing energy crisis. Nigeria is endowed with hydropower, biomass, solar, wind, geothermal, wave and tidal energy potentials that can be employed in the generation of electricity (Akuru et al., 2017). Of the renewable energy alternatives, solar appears the most promising and important source for electricity generation in the future for both rural and urban areas (Okoye et al., 2016) and this could be attributed to its apparent abundance and generation potential. For instance, based on the 2030 renewable energy generation target for Nigeria, solar is envisaged to account for over half of the projected energy to be generated (Table 1). The amount of energy that can be generated from a PV-system depends on the local solar resource and the conversion efficiency of the system adopted. Nigeria is located within a high sunshine belt and solar radiation is fairly well-distributed within the country, with an average solar radiation that varies from 12.6 MJ/m^2/day in the coastal latitudes to an estimated 25.2 MJ/m^2/day in the Far North part of the country (Akuru et al., 2017). Olaoye et al. (2016) opine that the use of 1000 W solar power systems on rooftops of one million Nigerian homes will result in a cumulative power production of 7000 MW of which can translate into a 45% addition to the present electricity per capita consumption.

Table 1: 2030 renewable energy target for Nigeria (Source: Sambo, 2008b).

Resource	Solar PV	Solar Thermal	Wind	Large Hydro	Small Hydro	Biomass	Total
Long term (MW 2030)	36,750	15,500	50	11,250	3,500	1,300	63,345

Several PV-related studies have been conducted in Nigeria including: solar energy potentials (Fadare, 2009; Okoye et al., 2016; Giwa et al., 2017; Ikejemba & Schuur, 2016); solar energy related policies (Ozoegwu et al., 2017); environmental footprints of electricity generation from solar PV (Akinyele et al., 2017); and technical and or economic feasibility related study of solar PV-systems (Bukar et al., 2017; Njoku et al., 2016; Okoye & Tylan, 2017; Adaramola & Oyewola, 2014; Ajoa et al., 2011; Adaramola, 2014; Oparaku, 2002; Akpan et al., 2013). From the aforementioned studies, it could be gathered that Nigeria has a good solar potential which could be harnessed to allay the energy crisis of the country and reduce GHG emissions. However, the cost of electricity generated from PV-systems in the country is not competitive to that supplied from the grid. From literature search, most of the PV-related design and techno-economic assessment conducted in Nigeria have been geared towards off-grid electrification of rural communities with very little focus on residential buildings in grid-connected cities in the country. The existing studies on the design and use of stand-alone solar PV-systems in residential buildings concentrate on a single building and do not cover the different building types. For instance, Guda & Aliyu (2015), Okoye at al. (2016), Ayodele & Ogunjuyigbe (2015), Adaramola et al. (2014) and Ogunjuyigbe et al. (2016) considered just a single (typical) building in its design for a PV-system for a residential building in Nigeria. While their findings demonstrates the potential of solar PV systems in supplying energy to meet the energy demand of the respective buildings, the results cannot be assumed for other building types since energy load differ among dwellings. Our study is innovative in that it covers the different categories of residential buildings and employs a bigger sample size of 150 buildings from three different Local Government Areas (LGAs).

2.2 Energy policies in Nigeria

Nigeria had no comprehensive energy policy before 2003 (Shabaan and Petinrin, 2014). The country had separate policy documents for the different energy sub-sectors including: solid minerals, oil, gas and electricity (Sesan, 2008). The Nigerian energy policy document came into existence in 2003 to serve as a roadmap for a better energy future for Nigeria (Ajayi & Ajayi, 2013). This energy policy document envisaged to ameliorate the energy sector of the country by taking the following steps: commercialization and privatization of the successor Power Holding Company of Nigeria (PHCN) companies, the commissioning of new power plants and distribution entities, inflow of private sector investment and creating an enabling environment for the development of a competitive electricity market.

The analysis of Nigeria's energy demand and supply projections from 2010-2030 was conducted by Sambo (2008a) using Model for the Energy Supply Strategy Alternatives and their General Environmental Impact (MESSAGE). Fuels inputted for the optimization were natural gas, hydro, solar, coal, nuclear, and wind. The future installed electricity generation capacity by fuel for 2030 is presented in Figure 1. The results reveals that of the consumed electricity from fuel types in Nigeria, solar is expected to produce 8.3 %.

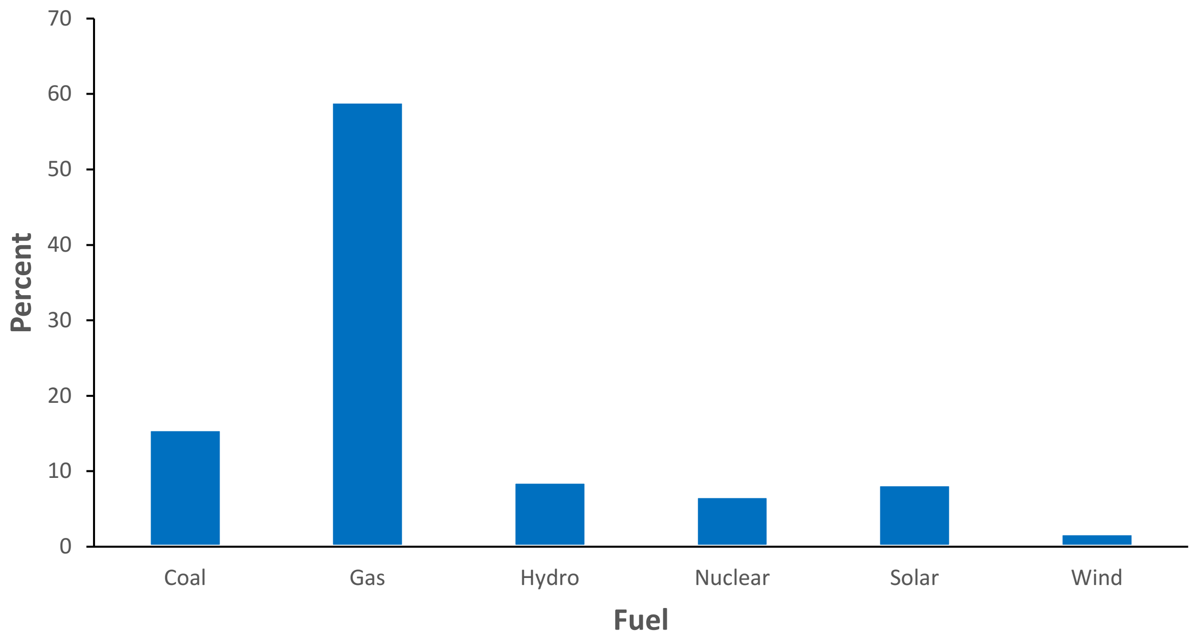

Figure 1: The future installed electricity generation capacity by fuel (Reference Case %, Source: Sambo, 2008a).

Nigeria's monthly per capita electricity consumption is estimated to be 12 kWh (International Energy Agency - IEA, 2017). This national per capita electricity consumption is lower compared to 27 kWh reported by Olaniyan et al. (2018). In South West region where Lagos is located, per capita residential electricity consumption per month is 23 kWh (National Bureau of Statistics - NBS, 2016). Average electricity price in South West Nigeria is 6 US cents/kWh (NBS, 2017; Nigerian Electricity Regulatory Commission - NERC, 2017; Olaniyan et al., 2018).

Nigeria has set a renewable energy target in the transport and electricity sectors (IRENA, 2015). With respect to electricity generation, the country has a target of electricity generation from renewable sources set at 9.74 %, 18 % and 20 % by 2015, 2020 and 2030 respectively (Bamisile et al., 2017). Electricity generation from solar energy alone stands at 1.26 %, 6.92 % and 15.27 % for 2015, 2020 and 2030 respectively while the target of renewable electricity from solely solar is at 12.96 %, 38.43 % and 76.36 % for 2015, 2020 and 2030 respectively indicating that solar will dominate in the long-term. The revised version (November 2012) of the REMP provides a list of economic and financial instruments/incentives that should be employed in order to reduce the high initial investment cost of renewables so as to bolster the penetration of renewables into the energy supply mix of the nation (Ozoegwu et al., 2017). These energy targets and supportive renewable energy policies highlighted in the REMP are not yet binding since the REMP is yet to be approved and signed into a law by the National Assembly and the Executive respectively. However, the National Renewable Energy and Energy Efficiency Policy (NREEEP) developed in 2013/2014 by the Federal Ministry of Power and approved in 2015 by the Federal Executive Council stands in as a binding document for the REMP (Nigerian Energy Support Programme, 2015). The solar electricity target of the NREEEP stands at 117 MW, 1343 MW and 6831 MW by 2015, 2030 and 2030 respectively. In an attempt to create a conducive environment that will promote the entry of renewable energy into Nigeria, NREEEP empowers relevant government ministries and federal government agencies and departments to adopt and develop any of the following instruments: mandatory or voluntary renewable portfolio standards, net metering framework, feed-in-tariffs, adoption of a public benefit funds, power production tax credits, provision of capital grants, tax holidays and exemptions and other incentives for renewable energy projects, bidding rounds through national renewable energy independent power producer procurement program and generation disclosure requirement. According to the Renewables 2015 global status report, support policies for renewable energy in Nigeria include: feed-in-tariffs, biofuel obligation/mandate, public investments, loans or grants, reductions in sales, energy, CO_2, value-added tax (VAT), or other taxes and capital subsidy, grant or rebate.

Characteristics of favourable environment for the adoption and use of solar PV-Systems

Generally, the adoption and use of PV systems for electricity generation in residential homes mainly depend on knowledge of the environmental benefit of PV systems over other source of fuels for electricity generation especially fossil fuel. The consciousness of the population on the environmental benefit of using PV systems over fossil fuel constitutes an enabling environment for its adoption (Palm & Tengvard, 2017). Some households adopt PV systems as a way to promote environmental sustainability. Furthermore, the initial cost of investment (purchase and installation) of PV systems in residential homes may be high compared to electricity supply from the grid system. Vasseur and Kemp (2015) reported that the competitiveness of the price of PV generated electricity with the electricity supplied from the grid plays an important role in its adoption and use. Hence, PV adoption and use will be favourable where electricity from PV is competitive with that supplied from the grid. Also, reduced investment cost of solar PV and increased dissemination of knowledge on its environmental benefits among the population are favourable conditions for their adoption and use.

3. Methodology

This study surveyed residential buildings from three Local Government Areas (LGAs): Kosofe, Oshodi and Alimosho in Lagos Metropolitan Area, Lagos State of Nigeria. The survey was conduced using a structured questionnaire. The approach consisted of using purposeful sampling. The purposive sampling enabled the selection of units based on particular purposes linked to achieving research objectives of the study as well as representativeness and comparisons among different types of cases. Lagos is divided into five Administrative Divisions (Lagos, Epe, Badagry, Ikorodu and Ikeja) which are further divided into 20 Local Government Areas (LGAs) and 37 Local Council Development Areas (LCDAs). The "Lagos Metropolitan Area" also known as Metropolitan Lagos contains about 85 % of the population of Lagos State, and includes semi-rural areas. The three LGAs (Alimosho, Kosofe, and Oshodi) selected for this study fall under the five largest LGAs out of the 16 LGAs in Metropolitan Lagos - 2006 population census (National Population commission Nigeria, 2010). In each of the LGAs, the different residential building types were identified and an equal number (10) of each building type were surveyed for the collection of data. In each household surveyed, the questionnaire administrator together with a household member completed the energy audit section of the questionnaire while the time-of-use diary section of the questionnaire was left with the household for completion. The data from the time-of-use diary was used in Microsoft Excel for the computation of the hourly electricity load profile for the seven days of the week for each building surveyed. The hourly energy load (in watts) for each building was obtained by summing up the power rating of all the appliances used during the 24 hours period of the day and the obtained value converted to kWh by dividing by 1000. The daily load profile for each dwelling was obtained as an average of the load profile for the seven days of the week. The technical, economic and environmental potential for the use of solar PV-systems for the onsite generation and use of electricity to meet the electricity needs of the buildings was analyzed. The technical and economic assessments were conducted using HOMER Pro and the economic analysis was based on the Levelized Cost of Electricity (LCOE). Sensitivity analysis was performed using

HOMER Pro by varying the economic parameters (inflation and discount rates) and the solar PV-system sizing parameters.

4. Description of survery and analysis

4.1. Household surveys

Jiboye (2014) reported five categories of residential buildings in Nigeria: duplex, single family bungalow, traditional court yard, flat/apartment dwelling and *'face-me-I-face-you'*. These five categories of buildings were considered for this study. Hence, while the study is conducted for Lagos, results for each building type obtained in this study could be relevant for similar building types in other parts of Nigeria. In each of the LGAs, 50 households (10 per building category) were randomly sampled with the use of a questionnaire amounting to a total of 150 households for the entire study (Table 2). The number of local governments and buildings selected in Lagos Metropolitan Area were based on the existing challenges to sustainable development in these areas such as limited and inefficient power supply from the grid system, environmental, sociocultural, economic and administrative/legislative problems reported in previous studies (Oduwaye, 2009; Otegbulu, 2011; Adama, 2017). The questionnaire was structured into four different sections. Section 1 was designed to obtain socio-econimic data of the households, section 2 was geared at capturing characteristics of the buildings, section 3 was desgined to obtain information about the electrical applicances used in the surveyed buildings while section 4 was designed as a time-of-use diary to capture information related to the time and duration of use of the different appliances in the buildings, as used by Enongene et al. (2017) and Manjia et al. (2016). The survey had a response rate of 100%. This high response rate was due to the fact that research assistants walked through the neigbourhood, handed the questionnaire and return later to collect. The research assistant provided help to those residents who striuggled with completing the questionnaires.

Table 2: Selection of number of buildings in Local Government Areas

Building type	**Kosofe**	**Oshodi**	**Alimosho**
Duplex	10	10	10
Simple family bungalow	10	10	10
Traditional court yard	10	10	10
Flat/apartment	10	10	10
'*Face-me-I-face-you*'	10	10	10
Total	50	50	50

LGA: Local Government Area

4.2. Sizing of solar PV-system components

Computation of load profiles

The energy load profile for the appliances for all the buildings surveyed was computed using Excel spreadsheet. The hourly energy load (in kWh) for each building was obtained by summing up the power rating of all the appliances used at specific periods of the 24 hours of the day. The daily load profile for each dwelling was obtained as an average of the load profile for the seven days of the week. The minimum and maximum load of buildings employed in the sizing of the systems is presented in Appendix A (see Data in Brief).

System design

A stand-alone PV-system was designed to meet the minimum and maximum load profile for each building type per LGA. A total of 30 PV-systems were therefore designed.

For this design to be effected, site details or locations were edited in Homer Pro. In the case of this study, the 3 locations or LGAs were edited separately. Other information edited into Homer Pro were the minimum and maximum electric load profiles, PV-system components (battery, PV-system array and converter) technical and cost details and the solar resource data (Global Horizontal Irradiation-GHI) for the study locations (LGAs).

Based on the edited data, HOMER Pro was used to conduct the simulation process by modelling the behaviour of the system configuration each hour of the year in order to determine the system's technical feasibility and life cycle cost. This includes the optimization of the system by simulating different system configurations with the objective of searching for the system that satisfies the technical constraints at the lowest life cycle cost. The base case scenario calculation was performed based on the following: a minimum battery state of charge (SOC) of 40%, 0% maximum annual capacity shortage, 5% discount rate, 2% inflation rate and a PV-system lifetime of 25 years. The capacity shortage was set at 0% in order to investigate the potential of the system to serve 100% of the buildings' load while 40% battery SOC coincides with the recommended depth of discharge of the battery bank that will safeguard its lifespan.

Sensitivity analysis

HOMER Pro was used to perform sensitivity analysis based on five different variables: maximum annual capacity shortage, PV-system lifetime, minimum battery SOC, inflation and discount rate in order to determine their effect on the system's LCOE. Table 3 presents the sensitivity parameters used.

Table 3: Sensitivity parameters employed in the HOMER Pro modelling

Sensitivity variable	**Base case**	**Sensitivity case(s)**
Maximum annual capacity shortage	0%	5%, 10% and 15%
Discount rate	5%	10%
PV-system lifetime	25 years	20 years and 30 years (e.g. J.v.G Desert Module)
Inflation rate	2%	5%
Minimum battery SOC	40%	30%

Computation of PV-system array area

The size (area) of the PV-system array for the different buildings was computed using equation 1 as purported by Birajdar et al. (2013).

$$A_{PV} = \frac{L_{el}}{H_{avg}\ x\ n_{pv}\ x\ n_b\ x\ n_i\ x\ T_{CF}} \qquad (1)$$

Where A_{PV} represents the required PV-system array area in m^2, L_{el} is the required daily electric load of the building in kWh/day, H_{avg} is the location's average daily solar irradiation in $kWhm^{-2}d^{-1}$, n_{pv} represent the PV panel efficiency in %, n_i is the efficiency of the inverter in % while T_{CF} stands for the temperature correction factor, n_b is the battery efficiency. The battery and inverter efficiency were adopted from Abdul and Anjum (2015) as 85% and 90% respectively while the T_{CF} was adopted from Caisheng and Nehrir (2008) as 80%. It is important for the PV-system area to be adjusted to take into consideration variation of the PV-system output over its lifetime as a result of degradation. This adjustment is effected by dividing the PV-system area by the module derate factor which accounts for PV-system output reduction due to the accumulation of dust and degradation over time. A module derate factor of 0.9 was adopted from Sandia National Laboratories (1995).

4.3. Economic analysis

HOMER Pro was employed in conducting the economic analysis using the information presented in Table 4. The LCOE generated by the system using 2% inflation rate and 5% discount rate was determined. The operation and maintenance cost was considered as 2% of the initial PV-system module cost while the installation cost of the system was considered as 10% of the initial PV-system module cost.

Table 4: Cost of solar PV-system components (obtained from a local supplier)

System component	Cost (USD)
Module (100W monocrystalline)	158
Charge controller (60 AMP)	190
Battery (Deep acid lead, 83.3Ah)	160
Inverter (1 kW)	158
Total	666

4.4. Environmental analysis

A life cycle assessment (LCA) data for electricity generated from PV systems in Nigeria is used to estimate the environmental benefits or potentials of the PV-systems employed in this study. Since such information is scarce, the average LCA data of 162 gCO_2eq/kWh of electricity generated from monocrystalline modules obtained by Sherwani et al. (2010) was adopted. From Brander et al. (2011), the emission associated with a kWh of electricity from the grid in Nigeria stands at 440 gCO_2eq. The emission saving (Es) associated with the use of a kWh of electricity generated by the PV-systems employed in this study was computed using the approach employed by Abanda et al. (2016):

$$Es = EG - EPV = 440\ gCO_2eq - 162\ gCO_2eq = 278\ gCO_2eq$$

Where EG represents emissions associated with a kWh of grid electricity while EPV represents emissions of a kWh of PV-system generated electricity. This implies that if a building uses a kWh of PV generated electricity rather than a kWh of electricity from the grid, an emission saving of 278 gCO_2eq constituting a 63.2% emission reduction would be achieved. The daily emission saving that would result from the use of electricity from the PV-systems by the buildings was computed by simply multiplying the daily load of the buildings in kWh by 278 gCO_2eq.

5. Analysis of results and discussion

5.1. Sources of energy and fuel consumption in buildings

The main source of energy for all the building types in the study locations is diesel generators and rechargeable lanterns which are charged either by the diesel generators or electricity from the grid, accounting for 48.4 % of the total source of energy available in the area. Our findings concerning the use of diesel generators in residential buildings concord with the claim of Ayodele & Ogunjuyigbe (2015) that almost every household in Nigeria have resorted to the use of petrol/diesel generators as a result of the inadequate power supply in the country. The unstable power supply also explains the availability of rechargeable lanterns in some households as they are mostly used during grid electricity outages.

Heating, lighting, leisure and air conditioner accounts for the highest (24.8%) of energy consumption in the study locations. Heating observed in the field survey is mainly composed of the source of heating for cooking (hot plate, microwave oven, boiling ring, electric kettle, rice cooker, kerosene and LPG cook stoves) as compared to boiler for residential heating in the temperate regions of the world. Lighting includes the use of compact fluorescent, fluorescent lamps, and incandescent lamps. Leisure refers to entertainment (the use of audio, video and television for leisure, and charging of mobile phones and PCs- desktops and laptops). Air conditioner for cooling in the studied areas have higher power ratings compared to fans. Higher rates of energy consumption from heating, lighting, leisure and cooling recorded from studied areas can be attributed to location (urban) and socioeconomic status of the residents. This is consistent with the findings of Emagbetere and Oreko (2016); and Olaniyan et al. (2018). High energy consumption from luxurious and high power rating electrical appliances are prevalent with urban dwellers like those in Lagos city compared to rural dwellers (Olaniyan et al., 2018). This is due to their socioeconomic status and the advantage of having longer hours of electricity supply from the grid system compared to those in the rural areas. Emagbetere and Oreko (2016) reported that the choice of the source of energy used for cooking in Lagos State, Nigeria is influenced by the level of income, education and the job of the individual. The average weekly consumption of diesel, kerosene, and candles in study locations is about 28 litres, 1 litre and 7 bars of candles respectively. In some cases, consumption differs with building types and utility. The average weekly consumption of diesel for traditional court buildings is equal to 12 litres, duplex and *'Face-me-I-face-you'* is equal to 14 litres, single family bungalow and flat dwellings is equal to 28 litres. It was observed that traditional court buildings use more kerosene (average of 7 litres per week) followed by duplex (average of 5 litres per week) compared to 1 litre used in single family bungalow and flat buildings. The highest number of candles (average of 20 bars per week) was recorded from flat buildings. The use of kerosene lamps and candles in households could be attributed to the high cost of running a diesel generator. Consequently, the diesel generator would not be used for 24 hours of the day and residents will need to use kerosene lamps so as to keep the home illuminated at night after the generator has been turned off. Power consumption in the study locations are greatly increased during dry seasons and festive periods. This indicates that meteorological conditions represents an important factor that influences electricity load of dwellings and our findings concord with that of Novoselac et al. (2014) who reported a variation of daily electricity loads between seasons. Similarly, Fotsing et al. (2014) reported the occurrence of minimum and maximum load in Cameroon in the month of

August (wet season) and December (hot season) respectively. As attested by Aldossary et al. (2014), more electricity is needed for air conditioning during periods of higher temperatures.

5.2. PV-system for maximum and minimum loads of buildings

The results of the HOMER Pro simulations of the PV-systems for meeting the minimum and maximum loads of each building type according to each LGA is presented in Table 5. The technical specifications presented in Table 5 are for the base case scenario: 0% capacity shortage, 40% battery minimum state of charge, 25 years PV-system's lifetime, 5% discount rate and 2% inflation rate.

With regards to the PV-systems designed for the maximum loads of buildings, the largest size of PV-array (78kW) will be required for "Face-me-I-face-you" building type in Alimosho LGA with 176 kWh lead acid battery, 20 kW converter. On the other hand, traditional court buildings in Kosofe LGA will require the smallest size of PV-system array (0.6 kW) with 4 kWh lead acid battery and lowest converter of 0.6 kW.

For solar PV-systems designed for the minimum loads, the largest size of PV-system array, lead acid battery and converter (22 kW, 80 kWh, and 4.6 kW respectively) will be required for duplex in Alimosho LGA. Conversely, 'Face -me –I- face -you' in Kosofe LGA will require the smallest size of PV-system array, lead acid battery and converter (0.2 kW, 2 kWh, and 0.1 kW respectively). A variation in the capacity of the system components is a function of the variation in the electric load of the dwellings.

Table 5: Specifications for PV-system components

Building type	LGA	PV-array (kW)	1 kWh lead acid battery	Converter (kW)
PV DESIGN FOR MAXIMUM LOAD OF BUILDINGS				

Single family bungalow	Kosofe	3	30	1.6
	Oshodi	24	125	6.4
	Alimosho	15	108	7.5
Duplex	Kosofe	6	32	2
	Oshodi	30	130	7.2
	Alimosho	40	132	9
'Face-me-I-face-you'	Kosofe	1.6	16	1.6
	Oshodi	6	36	5.8
	Alimosho	78	176	20
Traditional court	Kosofe	0.6	4	0.6
	Oshodi	6	30	2.8
	Alimosho	16	68	3.4
Flat apartment	Kosofe	3	18	2.8
	Oshodi	16	88	6.8
	Alimosho	42	76	13.2
PV-SYSTEM DESIGN FOR MINIMUM LOAD OF BUILDINGS				
Single family bungalow	Kosofe	0.6	3	0.4
	Oshodi	4.5	19	1.2
	Alimosho	7	28	2.5
Duplex	Kosofe	0.8	9	0.6
	Oshodi	3	12	2.6
	Alimosho	22	80	4.6
'*Face -me -I face –you'*	Kosofe	0.2	2	0.1
	Oshodi	2.5	22	0.7
	Alimosho	7	42	5.4
Tradition court	Kosofe	0.3	2	0.4
	Oshodi	0.6	4	0.6
	Alimosho	1	8	0.4
Flat apartment	Kosofe	0.7	3	0.6
	Oshodi	0.7	6	0.4
	Alimosho	5	22	1.4

PV-system array area

The computed required PV-system array area for the different buildings is presented in Table 6. From literature (Eruola et al., 2010; Fagbemi, 2011), the rooftop area of typical buildings in Southwest Nigeria are as follows: single family bungalow (332.12 m^2); duplex (218.3 m^2); *Face-me-I-face-you'* (156.78 m^2); traditional court (282.24 m^2); and flat apartment (280.72 m^2).

Comparing the PV-system array area obtained from our study to the rooftop area of the different types of building obtained from the literature, the building types can accommodate their respective PV-system array on their rooftops except for the *Face-me-I-face-you'* building in Alimosho LGA. This implies that the rooftop area is an important factor that should be taken into consideration in the assessment of the technical feasibility for the application of solar PV-systems in the onsite generation and use of electricity in residential buildings. Although most of the buildings have roof area large enough to accommodate the PV-array, shading of the PV panelsy on the rooftops could result to system losses thereby affecting the capacity of the system to meet the load of the building. Our computation assumes that the PV-systems installed in the buildings would have minimal shading.

Table 6: Required PV-system array area for the different buildings

Building type	**LGA**	**PV-system array area (in m^2)-low loads**	**PV-system array area (in m^2)-High loads**	**Roof area (m^2) of building**
	Kosofe	1.69	12.44	
Single family bungalow	Oshodi	13.30	76.15	
	Alimosho	20.71	50.38	332.12
	Kosofe	3.32	17.57	
Duplex	Oshodi	8.73	98.87	
	Alimosho	53.24	93.69	218.3
	Kosofe	0.79	6.41	
'Face-me-I-face-you'	Oshodi	9.63	16.85	
	Alimosho	26.35	187.63	156.78
	Kosofe	0.89	1.94	
Traditional court	Oshodi	2.37	18.84	
	Alimosho	4.37	46.19	282.24
	Kosofe	2.12	9.32	280.72
Flat apartment	Oshodi	2.50	47.50	
	Alimosho	14.78	65.83	

Overall, reducing the load of the buildings would reduce the PV array size and consequently, the required rooftop area. Observations from field survey revealed that power ratings of appliances of the residents is a major contributor to electric loads. As pointed out by Edomah and Nwaubani (2014), it is imperative that minimum efficiency standards for domestic appliances be set in Lagos since residential energy consumption accounts for 70 % power demand in the state. Implementing policies or enforcing minimum standards for appliances will influence consumer behaviour to adopting energy efficient appliances and also prohibit the importation, production and sales of energy- consuming appliances. However, the Nigerian governance system on energy efficiency of residential electrical appliances is weakly formulated due to lack of policy, non-engagement of the key stakeholders (households) in the design of agenda and participation in decision-making processes, shortage of allocated resources, and the over-lapping work of different governmental organizations (Gana & Hoppe, 2017). Therefore, awareness/sensitization of the residents on the adoption of energy efficient appliances in their homes can be an effective way to reduce electric loads.

Sensitivity analysis for technical specifications for system components

Sensitivity analysis was conducted on the annual capacity shortage (5%, 10% and 15%) and the minimum battery state of charge (30%). The effect of varying annual capacity shortage and minimum battery state of charge on the technical specifications of the systems designed for the minimum loads of the single family bungalow building type is presented in Table 7 (See Appendix B in Data in Brief for other types of buildings).

An overview of the results of the sensitivity analysis shows that increase in maximum annual capacity shortage (from 0 – 15 %) will lead to decrease in the size of PV-system array and lead acid battery. This is supported by the claim of Enongene (2016) that an increase in capacity shortage decreases the amount of the load of the dwelling that must be met by the system and consequently a reduction in the PV-system array and battery bank. However, the case is different for lead acid battery in Alimosho (increase between 5- 10 % and subsequent decrease at 15 %). For minimum battery state of charge (at sensitivity value of 30 %), results reveal that Alimosho will require the largest size of PV-system array and lead acid battery (7 kW and 24 kWh respectively). In contrast, Kosofe will require the smallest size of PV-system array (0.5 kW) and lead acid battery (3 kWh).

Table 7: Effects of minimum battery state of charge and capacity shortage on system components (for minimum loads of single family bungalow building type)

LGA	**Sensitivity value (%)**	**PV-system array (kW)**	**1 kWh lead acid battery**	**PV-system power output (kWh/year)**
Sensitivity variable: Maximum annual capacity shortage				
Kosofe	0	0.6	3	839
	5	0.3	3	419
	10	0.3	2	419
	15	0.3	2	419
Oshodi	0	4.5	19	6 291
	5	2.5	12	3 495
	10	2	12	2 796
	15	2	8	2 796
Alimosho	0	7	28	9 787
	5	4	20	5 593
	10	3	22	4 194
	15	3	14	4 194
Sensitivity variable: Minimum battery state of charge				
Kosofe	40%	0.6	3	839
	30%	0.5	3	699
Oshodi	40%	4.5	19	6291
	30%	4	19	5 592
Alimosho	40%	7	28	9787
	30%	7	24	9 787

5.3. Economic analysis

The economic analysis results of the PV-systems in terms of the LCOE (for the base case scenario) are presented in Table 8. The LCOE of electricity of the designed systems (30 systems) for the base case scenario ranges from 0.398 USD/kWh (Oshodi, maximum load for duplex building) to 0.743 USD/kWh (Alimosho, maximum load for flat apartment). This wide variation in the LCOE could be due to the fact that there exists a difference in the nature of the loads of the buildings. There are some buildings with very high loads that occur after sunshine hours and such buildings require a large battery bank for energy storage to support these high night loads, culminating in higher LCOE. The values of the LCOE obtained in this study are higher compared to USD 0.098/kWh cost of electricity from the grid power system in some locations in Nigeria. This supports the claim of Baurzhan and Jenkins (2016) that solar PV is unaffordable to rural households in Sub Sahara Africa from an economic and financial perspective. Such households are unable to afford the up-front capital cost of the system due to low or irregular income. The range of LCOE obtained from this study is higher compared to that (0.206 USD/kWh to 0.502 USD/kWh) obtained by Okoye et al. (2016) for selected cities (Onitsha, Kano and Lagos) in Nigeria. The LCOE obtained for the city of Lagos by the authors were 0.417 and 0.495 USD/kWh. Meanwhile the study by Okoye et al. (2016) considered all the components of a stand-alone PV system as our study, their study used an estimated energy load data of a hypothetical building (typical large household in Onitsha) for the design of the PV-system using intuitive and numerical methods while in our case, household specific electricity load data for 50 buildings (covering five building types) were considered in the simulation of the PV systems using the HOMER Pro software. Hence, the disparity that exists between the range of LCOE from our study and theirs is not unexpected. Studies by Ohijeagbon & Ajayi (2014) estimated the unit cost of electricity generated from diesel generators in Nigeria at 0.62 USD/kWh. Only one of the thirty systems designed had a unit cost of electricity that was superior to 0.62 USD/kWh. Hence, PV-systems are more economically viable for use as stand-alone systems compared to diesel generators. While this could constitute an incentive for the adoption of solar PV, the viability of households to adopt solar PV will depend on their ability to afford the associated up-front capital cost. The unit cost of electricity from PV-systems obtained from this study could be lowered if the Nigerian government ensures an enabling condition that will bolster the adoption of the technology.

Table 8: Results of the economic analysis of the PV-systems

Building type	**LGA**	**LCOE (USD/kWh)**	
		Maximum loads	**Minimum loads**
Duplex	Kosofe	0.497	0.552
	Oshodi	0.398	0.459
	Alimosho	0.411	0.502
Single family bungalow	Kosofe	0.508	0.529
	Oshodi	0.452	0.439
	Alimosho	0.513	0.432
'Face -me -I -face -you'	Kosofe	0.538	0.531
	Oshodi	0.571	0.498
	Alimosho	0.429	0.422
Traditional court	Kosofe	0.54	0.575
	Oshodi	0.453	0.43
	Alimosho	0.45	0.417
Flat apartment	Kosofe	0.547	0.449
	Oshodi	0.501	0.533
	Alimosho	0.743	0.488

Using the duplex building type as an example, the effect of the inflation rate and discount rate on the LCOE is presented in Figure 2. Increasing the discount rate from 5% to 10% culminates in an increase in the LCOE while an increase in the inflation rate from 2% to 5% reduces the LCOE. Using the duplex building type (maximum load) for the Kosofe LGA as an example, an increase in the discount rate from 5% to 10% results in an increase in the LCOE from 0.497 USD/kWh to 0.706 USD/kWh. The other building types for the different LGA observed the same trend (Appendix C - see Data in Brief). Ayompe and Duffy (2014) witnessed a similar increasing trend of the LCOE as a result of an increase in the discount rate. According to Enongene (2016), as the discount rate increases, the present value of future cash flows of the PV- system is decreased culminating in an increased LCOE of the system.

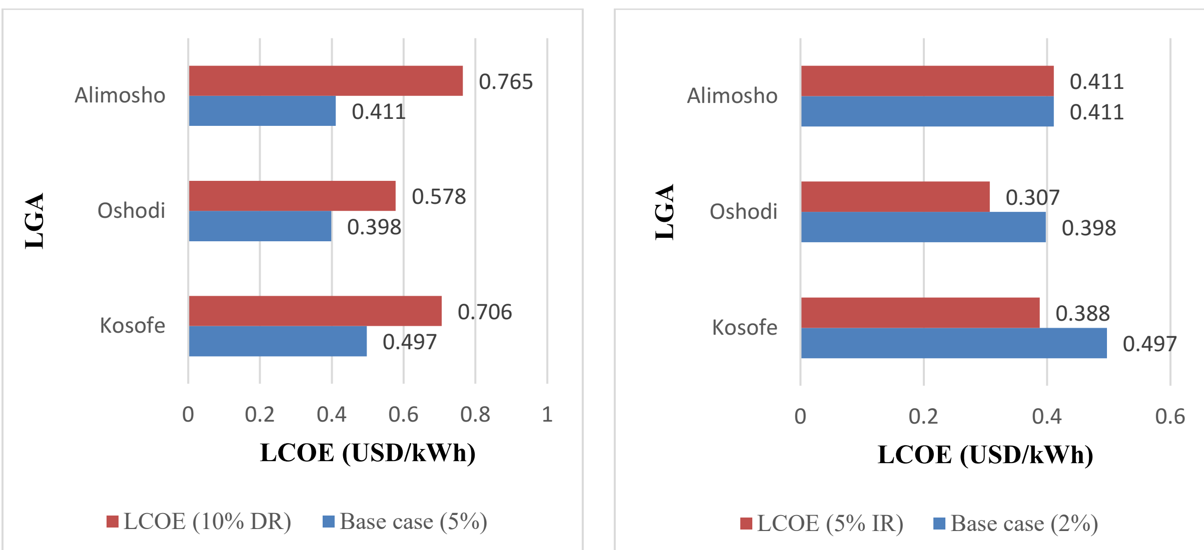

Figure 2: Influence of discount rate (left) and inflation rate (right) on the LCOE for the system designed for the maximum load for the duplex building type.

An increase in the maximum annual capacity shortage decreases the LCOE of the systems. The LCOE for the flat apartment building type (maximum load) for Kosofe decreased from 0.547 USD/kWh (0% capacity shortage) to 0.459 USD/kWh (15% capacity shortage) as can be verified from Figure 3. Such a reduction in LCOE could be explained by the fact that, as the capacity shortage is increased, the proportion of the building’s load to be left unmet increases and consequently, load culminating in an increase in LCOE of the system (such as high load occurring after sunshine hours) is left unserved. The reduction in LCOE associated with an increase in capacity shortage is indicative of the fact that hybrid PV-systems are more economically viable compared to the stand-alone ones. The effect of capacity shortage for the other building types for the different LGAs is presented in Appendix C. A remarkable difference is observed between the LCOE at 0% capacity shortage and 5% capacity shortage. Using Kosofe as an example (Figure 3), the LCOE (USD/kWh) at 0% and 5% capacity shortage is 0.547 and 0.461 respectively culminating in a difference of 0.088. This difference is large when compared to 0.002 which represents the difference in the LCOE between 5% (0.461) and 15% (0.459).

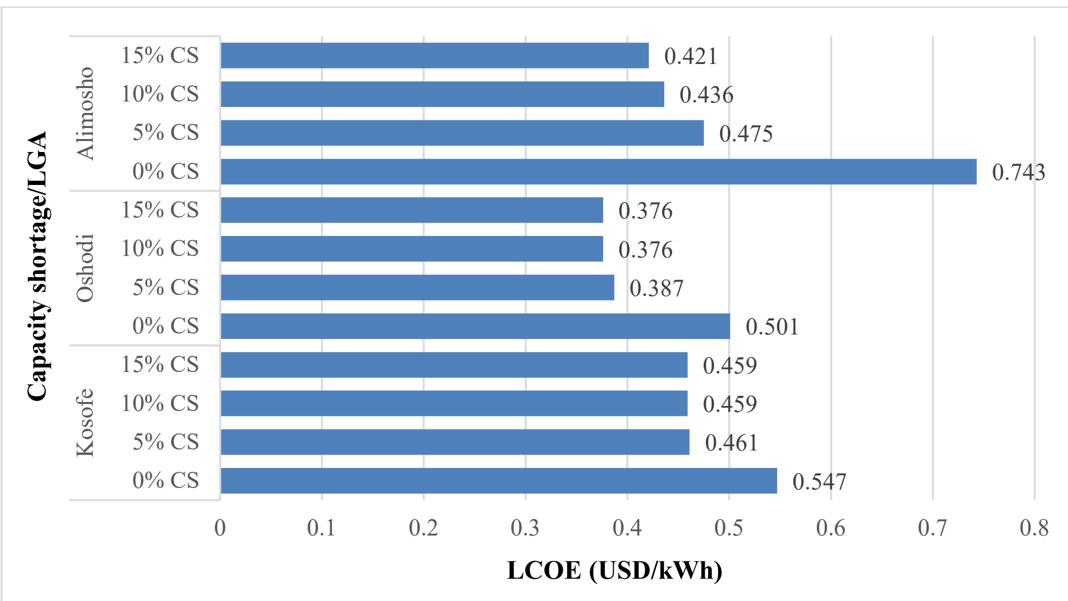

Figure 3: Influence of capacity shortage on LCOE for the maximum load of flat apartments

Regarding the effect on the PV-system lifetime on the LCOE, the PV-system lifetime is inversely proportional to the LCOE of the system. A decrease in the PV-system's lifetime from 25 to 20 years increases the LCOE of the system while the reverse is true for an increase in the PV-system's lifetime from 25 years to 30 years as presented in Figure 4 for the case of flat-apartment (See Appendix C for details for the other buildings types). As reported by Enongene (2016), increase in the lifetime of the PV-systems translates into more energy generated by the system for the same initial capital cost and this explains a decrease in the system's LCOE.

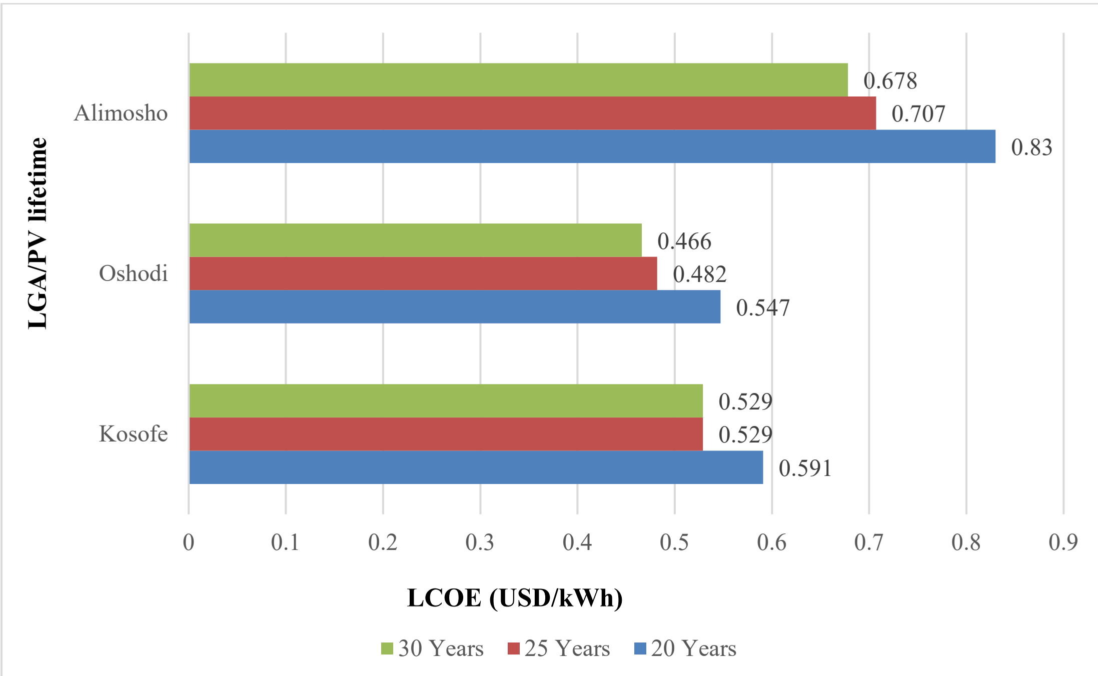

Figure 4: Effect of PV-system lifetime on the LCOE for the system designed for the maximum load for the Flat-apartment building type

5.4. Environmental potential of the PV-systems

The environmental analysis associated with the use of solar PV-system generated electricity for meeting the entire load of the buildings (0% capacity shortage) is presented in Table 9. The emission reduction associated with the use of electricity from the PV-system varies with different buildings. Pertaining to the high loads, the annual emission reduction varies from 76.90 (Traditional Court, Kosofe) to 7456.44 kgCO_2eq ('*Face- me –I- face –you*', Alimosho). For the low loads, the emission reduction varies from 35.95 (traditional court, Kosofe) to 2115.95 kgCO_2eq (duplex, Alimosho). This observed variation is due to the existence of differences in the daily loads of the buildings. In a nutshell, the use of electricity generated from PV-system in each building reduces annual emissions by 63.2% compared to the business-as-usual scenario in which case the buildings would solely rely on the grid to satisfy their respective electricity requirements.

Table 9: Annual emission reductions (kgCO_2eq) associated with the use of PV-system generated electricity in buildings

Building types	Kosofe	Oshodi	Alimosho
Maximum loads			
Single family bungalow	493.56	3025.76	2001.86
Flat Apartment	370.58	1887.20	2615.87
'*Face- me –I- face –you*'	254.56	3673.65	7456.44
Duplex	697.97	3930.15	3723.08
Traditional court	76.90	748.85	1830.43
Minimum loads			
Single family bungalow	66.46	528.95	822.69
Flat apartment	84.29	99.95	587.58
'Face -me –I- face- you	31.24	382.61	1394.63
Duplex	132.49	347.39	2115.95
Traditional court	35.95	71.32	173.88

6. Conclusion and Policy implications

This study focused on the assessment of the technical, economic and environmental potential of onsite PV-systems for generating electricity in different residential building types in the Lagos Metropolitan Area of Nigeria.

The computed energy results of the study for the maximum load of buildings for the base case scenario revealed the PV array, lead acid battery and the converter (inverter) of the PV-systems to be in the following range: 0.3 to 76 kW; 2 to 176kWh; and 0.1 to 13.2 kW respectively. For the minimum load of the buildings, the results of the PV array, lead acid battery and converter of the system were found to be in the following order: 0.3 to 7kW; 2 to 80 kWh; 0.1 to 5.4kW respectively. Results of the economic analysis revealed a LCOE of the systems in the range of

0.398 USD/kWh to 0.743 USD/kWh for maximum loads and 0.422 USD/kWh to 0.552 USD/kWh for minimum loads. The use of PV-system generated electricity in the dwellings have potential for an annual reduction of greenhouse gas emissions in the range of 76.90 gCO_2eq to 7456.44 kgCO_2eq (for maximum loads) and 31.24 gCO_2eq to 2115.95 kgCO_2eq (for minimum loads). Generally, from a technical perspective, solar PV-systems have the potential for use as a stand-alone source of electrical energy in the different categories of residential buildings in Lagos, Nigeria. While the LCOE for the PV-systems is lower than that of diesel generator used by households, it is high compared to the LCOE of the grid.

The promotion of an enabling environment for the adoption and use of solar PV-system in residential buildings will support the attainment of Nigeria's mitigation target spelt out in the country's nationally determined contribution (NDC). However, just creating a favourable environment for the adoption and use of PV-systems may not constitute a solution to all dwellings. For instance, this study revealed a building with high electric load which requires a PV array size greater than the available rooftop area. For such a building, a reduction in the electric load through energy efficiency measures would reduce the size of the PV-array, rendering the rooftop adequate to accommodate the PV array. Therefore, there is need for the government of Nigeria to use a mix of energy policy options that can support the deployment and uptake of solar PV-systems in the country on the one hand, while reducing residential energy consumption through the promotion of energy efficiency on the other hand.

Future research should investigate periods during the day which power outages occur and based on this information, explore the possibility of designing a solar PV-system grid-connected hybrid system for the residential buildings.

Acknowledgement

The authors would like to thank the Economic Community of West African States (ECOWAS) Centre for Renewable Energy and Energy Efficiency (ECREEE) for funding this study. We would also like to thank Monica Maduekwe, Yuri Lima Handem and Francis Kemausuor for reviewing the manuscript. Lastly, we thank Ana Apueyo for developing a poster from this work for presentation at the ECOWAS Centre for Renewable Energy and Energy Efficiency (ECREEE) 2nd Edition of the ECOWAS Sustainable Energy Forum (ESEF2018) from 13 -15 November 2018 at the Radisson Blu Hotel in Dakar, Senegal.

References

Abanda, F., Manjia, M., Enongene, K., Tah, J., & Pettang, C. (2016). A feasibility study of a residential photovoltaic system in Cameroon. *Sustainable Energy Technologies and Assessments*, 17, 38-49.

Adama, O. (2017). Urban imaginaries: funding mega infrastructure projects in Lagos, Nigeria. *GeoJournal.* doi: *10.1007/s10708-016-9761-8*

Adaramola, M. S. (2014). Viability of grid-connected solar PV energy system in Jos, Nigeria. *International Journal of Electrical Power & Energy Systems*, 61, 64-69.

Adaramola, M. S., Paul, S. S., & Oyewola, O. M. (2014). Assessment of decentralized hybrid PV solar-diesel power system for applications in Northern part of Nigeria. *Energy for Sustainable Development*, 19, 72-82.

Adejumobi, I., Adebisi, O., & Oyejide, S. (2013). Developing small hydropower potentials for rural electrification. *International Journal of Research and Reviews in Applied Sciences*, 17(1), 105-110.

Aldossary, N. A., Rezgui, Y. & Kwan, A. (2014). Domestic energy consumption patterns in a hot and arid climate: A multiple-case study analysis. *Renewable Energy* 62, 369-378.

Ahemen, I., Amah, A. N., & Agada, P. O. (2016). A survey of power supply and lighting patterns in North Central Nigeria -The energy saving potentials through efficient lighting systems. *Energy and Buildings*, 133, 770-776. doi: http://dx.doi.org/10.1016/j.enbuild.2016.10.029

Ajao, K., Oladosu, O., & Popoola, O. (2011). Using HOMER power optimization software for cost benefit analysis of hybrid-solar power generation relative to utility cost in Nigeria. *International Journal of Research and Reviews in Applied Sciences*, 7(1), 14.

Ajayi, O. O., & Ajayi, O. O. (2013). Nigeria's energy policy: Inferences, analysis and legal ethics toward RE development. *Energy Policy*, 60, 61-67. doi: http://dx.doi.org/10.1016/j.enpol.2013.05.095

Akinyele, D., Rayudu, R., & Nair, N. (2017). Life cycle impact assessment of photovoltaic power generation from crystalline silicon-based solar modules in Nigeria. *Renewable Energy*, 101, 537-549.

Akorede, M., Ibrahim, O., Amuda, S., Otuoze, A., & Olufeagba, B. (2017). Current status and outlook of renewable energy development in Nigeria. *Nigerian Journal of Technology*, 36(1), 196-212.

Akpan, U. S., Isihak, S. R., & Udoakah, Y.-O. N. (2013). Electricity access in Nigeria: Viability of off-grid photovoltaic system. Paper presented at the AFRICON, 2013.

Akuru, U. B., Onukwube, I. E., Okoro, O. I., & Obe, E. S. (2017). Towards 100% renewable energy in Nigeria. *Renewable and Sustainable Energy Reviews*. doi: http://dx.doi.org/10.1016/j.rser.2016.12.123

Ayompe, L. M. and Duffy, A. (2014). An assessment of the energy generation potential of photovoltaic systems in Cameroon using satellite-derived solar radiation datasets. *Sustainable Energy Technologies and Assessments* 7, 257-264.

Ayodele, T. R. & Ogunjuyigbe, A. S. O. (2015). Increasing household solar energy penetration through load partitioning based on quality of life: The case study of Nigeria. Sustainable Cities and Society, 18, 21 – 31.

Azodo, A. P. (2014). Electric power supply, main source and backing: A survey of residential utilization features. *International Journal of Research Studies in Management*, 3(2).

Bamisile, O., Dagbasi, M., Babatunde, A., & Ayodele, O. (2017). A review of renewable energy potential in Nigeria; solar power development over the years. *Engineering and Applied Science Research*, *44*(4), 242-248.

Baurzhan, S. & Jenkins, P. (2016). Off-grid solar PV: Is it an affordable or appropriate solution for rural electrification in Sub-Saharan African countries? *Renewable and Sustainable Energy Reviews*, 60, 1405-1418.

Brander, M., Sood, A., Wylie, C., Haughton, A. & Lovell, J. (2011). Technical Paper | Electricity-specific emission factors for grid electricity. Retrieved from: https://ecometrica.com/assets/Electricity-specific-emission-factors-for-grid-electricity.pdf

Bukar, A. L., Modu, B., Gwoma, Z. M., Mustapha, M., Buji, A. B., Lawan, M. B., Mai, K. B. (2017). Economic Assessment of a PV/Diesel/Battery Hybrid Energy System for a Non-Electrified Remote Village in Nigeria. *European Journal of Engineering Research and Science*, 2(1).

Diemuodeke, E. O., Hamilton, S., & Addo, A. (2016). Multi-criteria assessment of hybrid renewable energy systems for Nigeria's coastline communities. *Energy, Sustainability and Society*, 6(1), 26. doi: 10.1186/s13705-016-0092-x

Edomah, N., & Nwaubani, S. (2014). Energy security challenges in developing African mega cities: the Lagos experience. *Built Environment*, 1-9.

Elum, Z. A., Modise, D. M., & Nhamo, G. (2016). Climate change mitigation: the potential of agriculture as a renewable energy source in Nigeria. *Environmental Science and Pollution Research*, 1-14. doi: 10.1007/s11356-016-8187-7

Emagbetere, E., Odia, J., & Oreko, B.U. (2016). Assessment of Household Energy Utilized For Cooking In Ikeja, Lagos State, Nigeria. *Nigerian Journal of Technology (NIJOTECH),* 35 (4), 796 – 804.

Enongene, K. E. (2016). Feasibility of a solar photo-voltaic system as an energy source for lighting in grid-connected residential buildings in Cameroon: Case study of Buea (master's thesis, Massey University, Palmerston North, New Zealand).

Enongene, K. E., Murray, P., Holland, J. & Abanda, F. H. (2017). Energy savings and economic benefits of transition towards efficient lighting in residential buildings in Cameroon. *Journal of Renewable and Sustainable Energy Reviews*, 78, 731-742.

Fadare, D. (2009). Modelling of solar energy potential in Nigeria using an artificial neural network model. *Applied Energy*, 86(9), 1410-1422.

Fotsing, F. I. M., Njomo, D. & Tchinda, Rene (2014). Analysis of Demand and Supply of Electrical Energy in Cameroon: Influence of Meteorological Parameters on the Monthly Power Peak of South and North Interconnected Electricity Networks. *International Journal of Energy and Power Engineering*. 3(4), 168-185. doi: 10.11648/j.ijepe.20140304.12

Gana, J., & Hoppe, T. (2017). Assessment of the Governance System Regarding Adoption of Energy Efficient Appliances by Households in Nigeria. *Energies,* 10(1), 132.

Giwa, A., Alabi, A., Yusuf, A., & Olukan, T. (2017). A comprehensive review on biomass and solar energy for sustainable energy generation in Nigeria. *Renewable and Sustainable Energy Reviews*, 69, 620-641.

Guda, H. A. & Aliyu, U. O. (2015). Design of a Stand-Alone Photovoltaic System for a Residence in Bauchi. *International Journal of Engineering and Technology*, 5(1), 34-44.

Ikejemba, E. C., & Schuur, P. (2016). Locating solar and wind parks in South-Eastern Nigeria for maximum population coverage: a multi-step approach. *Renewable Energy*, 89, 449-462.

International Energy Agency. (2010). Energy Poverty: How to make modern energy access universal? Special early excerpt of the World Energy Outlook (WEO) 2010 for the UN General Assembly on the Millennium Development Goals. (Paris, 2010) p. 9, 20. Available from http://www.iea.org/publications/freepublications/publication/weo-2010---special-report---how-to-make-modern-energy-access-universal.html

International Renewable Energy Agency (IRENA), Renewable Energy Target Setting June 2015.

International Energy Agency (IEA, 2017). Key World Energy Statistics; International Energy Agency: Paris, France.

Jiboye, A. D. (2014). Significance of house-type as a determinant of residential quality in Osogbo, Southwest Nigeria. *Frontiers of Architectural Research*, 3(1), 20-27.

IPCC, 2014: Summary for Policymakers. In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Manjia, M. B., Abanda, F. H. & Pettang C. (2015). Household energy appliances in Cameroon. *Environmental Management and Sustainable Development*, 4(1): 73–84.

Mellersh N. (2015) A scramble for power – the Nigerian energy crisis explained. Available from https://www.africanlawbusiness.com/news/5679-a-scramble-for-power-the-nigerian-energy-crisis-explained

National Bureau of Statistics (NBS, 2016). LSMS-Integrated Surveys on Agriculture General Household Survey Panel 2015/2016. National Bureau of Statistics Abuja, Nigeria.

National Bureau of Statistics (NBS, 2017). Premium Motor Spirit (Petrol) Price Watch for April 2017. National Bureau of Statistics Abuja, Nigeria.

National Population commission Nigeria (2010). 2006 Population and Housing Census. Pp 64. Retrieved from catalog.ihsn.org/index.php/catalog/3340/download/48521

Nigerian Electricity Regulatory Commission (NERC, 2017). How Much Do I Pay for Electricity? Retrieved from http://nerc.gov.ng/index.php/home/consumers/how-much-do-i-pay-for-electricity

Njoku, H. (2016). Upper-limit solar photovoltaic power generation: Estimates for 2-axis tracking collectors in Nigeria. *Energy*, 95, 504-516.

Novoselac, A. Cetin, K. S. & Tabares-Velasco, P. C. (2014). Appliance daily energy use in new residential buildings: Use profiles and variation in time-of-use. *Energy and Buildings,* 84, 716-726.

Oduwaye, L. (2009). Challenges of Sustainable Physical Planning and Development in Metropolitan Lagos. *Journal of Sustainable Development,* 2(1), 159-171.

Ofikhenua, J. (2014). Power supply drops to 2,954.51 MW. The Nation Newspaper 14th December 2014. Retrieved from: http://thenationonlineng.net/new/power-supply-drops-2954-51mw/

Ogunjuyigbe, A.S.O., Ayodele T.R. & Oladimeji, O.E. (2016). Management of loads in residential buildings installed with PV system under intermittent solar irradiation using mixed integer linear programming. *Journal of Energy & Buildings*, 130 (15), 253-271

Okoye, C. O., & Taylan, O. (2017). Performance analysis of a solar chimney power plant for rural areas in Nigeria. *Renewable Energy*, 104, 96-108.

Okoye, C. O., Taylan, O., & Baker, D. K. (2016). Solar energy potentials in strategically located cities in Nigeria: Review, resource assessment and PV system design. *Renewable and Sustainable Energy Reviews*, 55, 550-566. doi: http://dx.doi.org/10.1016/j.rser.2015.10.154

Olaoye, T., Ajilore, T., Akinluwade, K., Omole, F., & Adetunji, A. (2016). Energy Crisis in Nigeria: Need for Renewable Energy Mix. *American Journal of Electrical and Electronic Engineering*, 4(1), 1-8.

Olaniyi O. (2017) Research: Tackling the energy crisis in Nigeria – a case for solar. Available from https://www.ntusbfcas.com/african-business-insights/content/research-tackling-the-energy-crisis-in-nigeria-a-case-for-solar

Olatomiwa, L., Mekhilef, S., & Ohunakin, O. S. (2016). Hybrid renewable power supply for rural health clinics (RHC) in six geo-political zones of Nigeria. *Sustainable Energy Technologies and Assessments*, 13, 1-12.

Olaniyan, K., McLellan, B.C., Ogata S., & Tezuka, T. (2018). Estimating Residential Electricity Consumption in Nigeria to Support Energy Transitions. *Sustainability*, 10(.;1440), 1-22. doi:10.3390/su10051440

Oluseyi, P. O., Babatunde, O. M., & Babatunde, O. A. (2016). Assessment of energy consumption and carbon footprint from the hotel sector within Lagos, Nigeria. *Energy and Buildings*, 118, 106-113. doi: http://dx.doi.org/10.1016/j.enbuild.2016.02.046

Oparaku, O. (2002). Photovoltaic systems for distributed power supply in Nigeria. *Renewable Energy*, 25(1), 31-40.

Osunmuyiwa, O., & Kalfagianni, A. (2016). Transitions in unlikely places: Exploring the conditions for renewable energy adoption in Nigeria. *Environmental Innovation and Societal Transitions*.

Otegbulu, A.C. (2011). Economics of Green Design and Environmental Sustainability. *Journal of Sustainable Development,* 4(2), 240-248.

Oyedepo, S. O. (2012). Energy and sustainable development in Nigeria: the way forward. *Energy, Sustainability and Society*, 2(1), 15.

Ozoegwu, C. G., Mgbemene, C. A., & Ozor, P. A. (2017). The status of solar energy integration and policy in Nigeria. *Renewable and Sustainable Energy Reviews*, 70, 457-471. doi: http://dx.doi.org/10.1016/j.rser.2016.11.224

Ozoegwu, C. G., Mgbemene, C. A., & Ozor, P. A. (2017). The status of solar energy integration and policy in Nigeria. *Renewable and Sustainable Energy Reviews*, 70, 457-471. doi: http://dx.doi.org/10.1016/j.rser.2016.11.224

Palm, J. & Tengvard, M. (2017). Motives for and barriers to household adoption of small-scale production of electricity: examples from Sweden. *Sustainability: Science, Practice and Policy*, 6-15.

REN21 (2015). Renewables 2015 global status report. REN21 Secretariat, Paris. Retrieved from: http://www.ren21.net/wp-content/uploads/2015/07/REN12-GSR2015_Onlinebook_low1.pdf

Riti, J. S., & Shu, Y. (2016). Renewable energy, energy efficiency, and eco-friendly environment (R-E5) in Nigeria. *Energy, Sustainability and Society*, 6(1), 13. doi: 10.1186/s13705-016-0072-1

Sambo, A. S. (2008a). Matching electricity supply with demand in Nigeria. International Association of Energy Economics. Fourth Quarter, Pp.32-36. Retrieved from https://www.iaee.org/documents/newsletterarticles/408sambo.pdf

Sambo, A. S. (2008b). Renewable energy options for the environment and sustainable development in Nigeria. Natl. Work. Energy Invest. Priv. Sect. Particip. Pet. Train. Inst. Warri; 4th–5th June, 2008

Sesan, T. (2008). Status of renewable energy policy and implementation in Nigeria. Institute of Science and Society, Faculty of Social Sciences, Law and Education, University of Nottingham, United Kingdom. Retrieved from: http://www.gbengasesan.com/temidocs/REPStatusNigeria.pdf

Shabaan, M. & Petinrin, J. O. (2014). Renewable energy potentials in Nigeria: Meeting rural energy needs. *Renewable and Sustainable Energy Reviews*, 29, 72 – 78.

Sherwani, A. F., Usmani, J. A., & Varun. (2010). Life cycle assessment of solar PV based electricity generation systems: A review. Renewable and Sustainable Energy Reviews, 14(1), 540-544. doi: http://dx.doi.org/10.1016/j.rser.2009.08.003

Su, M., Chen, C., & Yang, Z. (2016). Urban energy structure optimization at the sector scale: considering environmental impact based on life cycle assessment. *Journal of Cleaner Production*, 112, Part 2, 1464-1474. doi: http://dx.doi.org/10.1016/j.jclepro.2015.01.059

The Nigerian Energy Support Programme (2015). The Nigerian Energy Sector -an Overview with a Special Emphasis on Renewable Energy, Energy Efficiency and Rural Electrification, 2nd Edition, June 2015

United Nations (2015). Goal 7 - Ensure Access to Affordable, Reliable, Sustainable and Modern Energy for All. Retrieved from: https://unchronicle.un.org/article/goal-7-ensure-access-affordable-reliable-sustainable-and-modern-energy-all

Vasseur, V. & Kemp, R. (2015). The adoption of PV in the Netherlands: A statistical analysis of adoption factors. *Renewable & Sustainable Energy Reviews*, 41, 483-494.

Vera, I., & Langlois, L. (2007). Energy indicators for sustainable development. *Energy*, 32(6), 875-882. doi: http://dx.doi.org/10.1016/j.energy.2006.08.006