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Research article

Rooftop solar PV for urban residential buildings of Nigeria: A preliminary attempt towards potential estimation

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Abstract: To decarbonise the Nigerian electricity sector and ensure stable power supply, rooftop solar PV will play a major role. However, studies aimed at estimating the technical potential of rooftop solar PV in Nigeria are limited. Here, a preliminary attempt has been made using a computationally logical methodology to estimate the technical potential of rooftop solar PV in urban residential buildings of Nigeria. We use the PVSyst® software to estimate the annual energy yield of rooftop solar PV in selected cities across the country. The paper also heads on to estimate the levelized unit cost of electricity and the break-even capital cost of rooftop solar PV. The available roof area for solar PV in urban residential buildings of Nigeria is estimated at 796 km^2 and the technical potential at around 124 GW_p. Annual energy yield and levelized unit cost of electricity analysis shows that Kano and Port Harcourt cities have the highest and lowest potentials of rooftop solar PV respectively. Break-even capital cost analysis suggest that rooftop solar PV is not financially attractive for consumers in R1 and R2s categories in the country presently. The enabling conditions and policy implications for deployment of rooftop solar PV in the country are also highlighted.

Keywords: rooftop solar PV; technical potential; urban residential buildings; Nigeria; PVsyst

1. Introduction

Energy is an essential element in the socio-economic development of any country. It determines the quality of life and the wellbeing of any modern society. Energy is needed for lighting and heating of our homes, running of our industries, pumping of water etc. Hence, energy is an indispensable component of our lives and its consumption determines the level of development of any nation [1].

About 70% of the global electricity supply today is generated from fossil fuels [2]. The use of fossil fuels for electricity generation releases greenhouse gases into the atmosphere which in turn leads to climate change. This current situation has created a dilemma in terms of energy security and climate protection. The use of renewable energy technologies, energy efficiency, and energy conservation practice have been identified as solutions to this problem [3–7].

Renewable energy technologies have become an alternative to the conventional fossil fuels for power generation. Within the last decade, solar PV technology has grown faster than other renewables. For example, in 2016, electricity generation capacity addition from renewable was about 161 GW globally, out of this, 47% was from solar PV while wind and hydro accounted for around 34% and 15.5% respectively [8]. There has also been a significant reduction in the cost of electricity generation through solar PV in recent years. In 2016, tenders for solar PV in India, Argentina, United Arab Emirates, Jordan, and Chile went down significantly with some countries having bids below USD 0.03/kWh [8]. Rooftop solar PV installations have gradually been increasing over the years. In 2013, Japan installed around 6.9 GW of rooftop solar PV as a result of the feed-in tariff that was introduced in the country [9]. Australia has also made a giant stride in rooftop solar PV. As of 2013, Australia had about one million rooftop solar PV installations which is about to 3.3 GW [9]. Other countries are also following the same step and investing in rooftop solar PV.

Nigeria is a developing country situated in the western part of Africa and it occupies a total area of 923,768 km^2 which consists of 910,768 km^2 land and 13,000 km^2 water body. The climate varies from equatorial in the southern part to tropical and arid in the central and northern parts respectively [10]. Nigeria is the most populous country in Africa and its population has been estimated at 186,053,386 as at 2016, and has been projected to be around 392 million in 2050, making it the world's fourth most populous nation [10]. The economy of Nigeria is the biggest in Africa and has grown at average annual rate of 7% between 2000 and 2015 and is expected to continue growing in the same trend in near future [11]. Owing to the growing population and projected economic development, Nigeria's energy demand is expected to grow in the near future. Presently, around 39% of Nigerian population do not have access to electricity [12]. To ensure future energy security, rooftop solar PV will play a major role especially in the urban areas where land availability is a major problem. Also, as a member of the International Solar Alliance (ISA), Nigeria has the objective of efficiently exploiting the potential of its solar resource and rooftop solar PV is one of the available options. Furthermore, to decarbonise Nigeria's power sector and reduce the dependence on fossil fuel, rooftop solar PV will play a significant role.

However, for effective integration of rooftop solar PV into Nigeria electricity sector, a good knowledge of its techno-economic viability is needed. A good understanding of the technical potential of rooftop solar PV is very important for investment decisions, policy formulation, and utility planning. A lot of authors have argued in favour of this assertion. A study developed a model for assessing rooftop solar PV systems in ArcGIS using LIDAR and was implemented in the city of Philadelphia, USA. The authors opined that such assessment is crucial for electricity system operators as well as for policy makers [13]. Brito et al. [14] and Wiginton et al. [15] have used LiDAR data in Lisbon, Portugal and GIS in south eastern Ontario, Canada respectively, to evaluate the potential of rooftop solar PV. The authors have all opined that a good estimate of the technical potential of solar PV is pertinent in developing policies and support instruments such as funding, grid capacity expansion planning etc. which are needed to accelerate the deployment of large scale solar PV. Izquierdo et al. [16] developed a methodology to estimate the potential of rooftop solar PV and its application in Spain. The authors suggested that a thorough knowledge of the potential of rooftop solar PV is an important ingredient in energy policy formulation. Kumar and Shekhar [17] also concurred to this assertion by arguing that the integration of rooftop solar PV into an already existing electricity grid will require an in-depth knowledge of the potential of solar PV.

However, in Nigeria, there has not been any serious study on the estimation of technical potential of rooftop solar PV. Most of the studies found in literature deal with availability of solar resource. Few other studies looked at solar PV design and techno-economic analysis of solar PV projects. Johnson and Ogunseye [18] conducted a study on grid connected solar PV system with energy storage for local government offices in Nigeria. The authors used the PV*SOL software tool to analyse the daily energy yield of a grid connected 148.5 kW_p PV system. The authors concluded that the system can be a source of revenue for the government if the excess 75% of energy generated is sold to the grid. Adaramola [19] used the HOMER software to investigate the techno-economic viability of combining 80 kW_p grid connected solar PV with 100 kW grid power for the city of Jos, Nigeria. The result of the study showed that the combined system can generate 331,536 kWh annually with an average solar irradiation of 6.0 kWh/m^2/day. The result also showed that the levelized cost of electricity from the system was USD 0.103/kWh. The author concluded that grid connected solar PV is economically viable in northern Nigeria.

Akinyele and Rayudu [20] also used the HOMER software tool to study distributed generation for some households in Nigeria. The authors modelled and analysed PV systems and their cost implications. The results of the study showed that without the support of government, it will be extremely difficult for energy-poor communities in Nigeria to meet up with their electricity demand. Udoh et al. [21] used the PVSyst® software to conduct a techno-economic analysis of rooftop solar PV for a lecture theatre at the faculty of engineering of Imo State University, Nigeria. The authors obtained the climatic data of the study area from NASA database. Results of the simulation showed an energy yield of 2,804 kWh/year with a performance ratio of 86% and unit cost of 69.5 ₦/kWh.

Adaramola and Paul [22] investigated the feasibility of grid connected solar PV systems in some states in Nigeria. The authors analysed the amount of energy generated and financial incentives like feed-in tariff. The findings of their work indicate that annual energy yield from solar PV system in Nigeria is in the range of 2,555 kWh in Port-Hacourt, southern Nigeria and 4,391 kWh in Isa, Northern Nigeria. The study also analysed the levelized cost of electricity production and the results showed that the ratio of electricity levelized cost to the present electricity tariff was least at Bauchi, northern Nigeria and highest in Ikeja, southern Nigeria. The authors concluded by outlining some of the challenges facing the implementation of feed-in tariff in Nigeria.

Given the foregoing, this paper therefore, serves as a first attempt to fill this knowledge gap. Here we assess the technical potential of rooftop solar PV in urban households of Nigeria. We also went ahead to estimate the annual energy yield of rooftop solar PV and the levelized unit cost of electricity for selected cities in the country. This paper will be useful to the Nigerian energy stakeholders such as the Energy Commission of Nigeria (ECN), National Electricity Regulatory Commission (NERC), Rural Electrification Agency (REA), and the Federal Ministry of Power (FMP). The paper also has wider importance especially for countries in the sub-Saharan Africa region that are members of the International Solar Alliance.

The remaining part of this paper is structured as follows: Section 2 presents an overview of solar energy development in Nigeria. Section 3 discusses the methodology and assumptions used in the study. Section 4 presents the results of the study. Section 5 concludes the study and highlights the enabling condition for promotion of rooftop solar PV in Nigeria.

2. Solar energy in Nigeria

The energy mix of Nigeria electricity supply sector is dominated by fossil fuels with natural gas and hydro accounting for around 85% and 15% of grid-connected generation respectively [23]. However, due to the erratic grid power supply situation in the country, many households and companies result to captive power generation using gasoline and diesel generator sets during blackouts. In Nigeria, the use of renewable energy technologies is still at an infant stage of development and there is no grid connected renewable source of electricity yet [24]. Solar energy has been identified as one of the most promising renewable energy resource for Nigeria owing to its abundance and its ability to promote energy security in the country as well as mitigate climate change [24]. The solar resource map of Nigeria is presented in Figure 1.

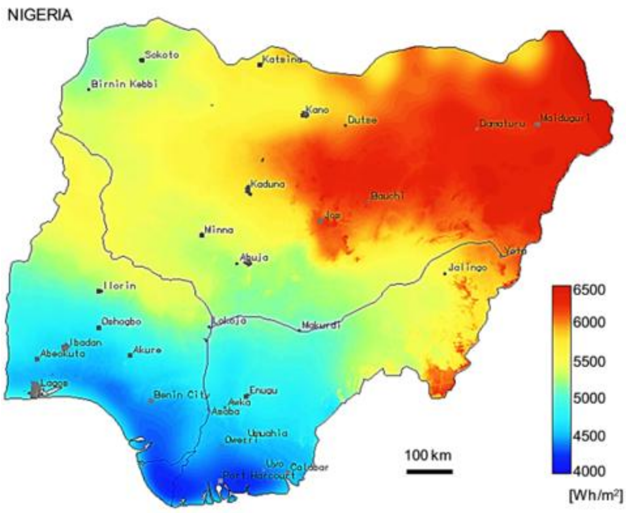

Figure 1. Solar resource map of Nigeria [25].

Figure 1 indicate that Nigeria has a strong potential of solar energy most especially in the northern region. The Global Horizontal Irradiation (GHI) in the northern region of the country varies from 5500–6500 Wh/m^2 which is very suitable for solar PV electricity generation. Nigeria is blessed abundantly with solar resource with an annual average sunshine hours of 9.0 in the north and 4.0 in the southern part of the country [26]. Some authors have argued that all parts of Nigeria are suitable for solar PV electricity production if the appropriate technologies are deployed [27,28]. However, despite the abundance of solar resource in Nigeria, the potentials are still grossly underutilised. The available solar energy technologies in the country are mainly the standalone systems which are used for community water pumping, street lighting, and vaccine refrigeration [29].

The federal government of Nigeria has acknowledged the need for solar energy development in the country and has taken some bold steps towards its development. The Energy Commission of Nigeria (ECN) has established six energy research centres in different universities in the country. The National Centre for Energy Research and Development (NCERD) at the University of Nigeria, Nsukka and the Sokoto Energy Research Centre at the Usman Danfodiyo University, Sokoto which both have the mandate of research specifically in solar energy [30]. In 2011, the National Agency for Science and Engineering Infrastructure (NASENI) commenced the assembly of solar PV modules in the country. Though, none of the component parts are produced in Nigeria [26].

In 2015, the federal executive council of Nigeria approved the National Renewable Energy and Energy Efficiency Policy (NREEEP) for the power sector. The NREEEP outlines different targets for renewable energy integration into the country's electricity mix. The document includes the short-term target, 2015, the medium-term target, 2020, and the long-term target, 2030. Solar electricity target (including PV and thermal) has been reported as 117 MW, 1343 MW, and 6831 MW for the short, medium and long terms respectively [31].

Furthermore, the Federal Ministry of Environment and the NERC have both come up with programmes to encourage the large-scale deployment of solar energy in the country. The NERC has been granting licenses to different investors to develop solar PV projects in the country; though none has been commissioned yet [24]. However, it is worthwhile to note that the proposed Anjeed Kafanchan 15 MW_p grid connected solar PV project in Kaduna state has received the Environmental Impact Assessment certificate from the Federal Ministry of Environment, and significant progress has been made so far in the project [24]. Some other solar energy projects that have received licenses from the NERC are listed in Table 1.

Table 1. NERC Solar energy licenses [24].

Company	Capacity (MW_p)	Location
Pan African Solar	54	Katsina
KVK Power Pvt Ltd.	50	Sokoto
Lloyd and Baxter LP	50	Abuja
Nigeria Solar Capital Partners	100	Bauchi
Quaint Global Nigeria Ltd.	50	Kaduna
Rook Solar Investment Ltd.	50	Osun

Towards stimulating renewable energy development in the country, the Nigerian government has established some financial incentives for private manufactures and investors in renewable energy. One of these incentives is the tax holiday which is tagged "Pioneer Projects". It provides a tax holiday of seven years for qualified companies across the Nation [32]. The qualified companies are those involved in the production of renewable energy electricity and equipment, energy efficient products and other electrical related items such as control panels, cable, and transformers [32]. At present, about 70 industries have been approved eligible and can benefit from the tax holiday. Also, the NERC has established a feed-in tariff (FiT) scheme to stimulate renewable electricity generation [24]. However, this FiT doesn't accommodate electricity generation from rooftop solar PV. The Nigeria FiT is presented in Table 2.

Table 2. Applicable feed-in tariffs in Nigeria (₦ (Nigerian Naira)/MWh) [24].

Renewable Electricity	2012	2013	2014	2015	2016
Solar PV plants, ground mounted, fixed	67,917	73,300	79,116	85,401	92,192
Small hydro (30 MW)	23,561	25,433	27,456	29,643	32,006
Onshore wind	24,543	26,512	28,641	30,943	33,433
Biomass	27,426	29,623	32,000	34,572	37,357

Rooftop solar PV has been developing sluggishly in Nigeria over the years, solely due to its high initial capital cost and lack of awareness. However, of recent, there has been much attention on developing rooftop solar PV in Nigeria. In January 2017, the acting president of Nigeria Professor Yemi Osibanjo commissioned a solar home system in Wuna village in the Federal Capital Territory of Nigeria [33]. Recently, the Honourable Minister of Power, Works and Housing, Mr. Babatunde Raji Fashola commissioned a 100 kW_p rooftop solar PV system in Abuja. In his speech, the Minister said that the development of solar energy is now gathering momentum in the country and that government will continue to invest in the development of rooftop solar PV systems [34].

3. Methodology and assumptions

3.1. Classification of renewable energy potential

Renewable energy potential can be classified into various categories. There is no sharp classification of the renewable energy potentials. Voivontal et al. [35] classified the potentials as theoretical potential, available potential, technical potential and economic potential. The theoretical potential is defined as the total amount of solar radiation falling in a particular area without considering constraints like technology availability and physical restrictions [36]. The available potential refers to that fraction of the theoretical potential that can be harnessed without causing harm to the environment [36]. The technical potential refers to that part of the available potential that can be harvested with the available technologies and as such, the result is only valid as at the time of assessment. Economic potential can be defined as the fraction of the technical potential that is economically viable. It usually depends on the cost of competing technologies [37].

Sun et al. [38] described three types of renewable energy potentials; the geographic, technical and economic potentials. Lopez et al. [39] classified renewable energy potentials as resource potential, technical potential, economic/market potential. Izquierdo et al. [16] grouped renewable energy potentials into three, which are: Physical potential, geographic potential, and technical potential. The physical potential refers to the total amount of solar irradiation falling on a given area. The geographic potential refers to the fraction of the physical potential that can be harnessed as a result of natural restrictions. Generally, we can say that all the patterns of classification follow a hierarchical order. The available potential is a subset of the theoretical potential while the technical potential is a subset of the available potential and so on. The hierarchy of renewable energy potentials is summarised in Figure 2.

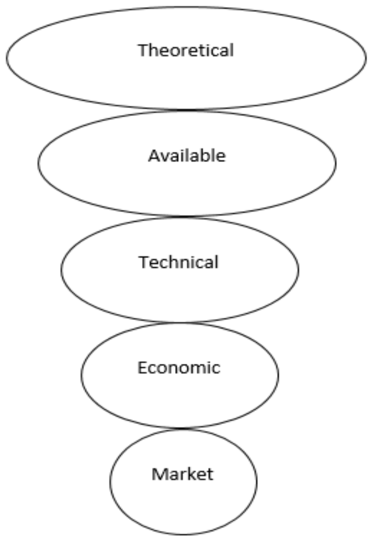

Figure 2. Hierarchical structure of renewable energy resource potentials.

This present study focusses on estimating the technical potential of rooftop solar PV systems for urban residential buildings of Nigeria. Rooftops in Nigeria are usually left plain and thus, provides a large space for solar electricity generation. This will go a long way to mitigate the costs of electricity generation and transmission. It will further help to reduce electricity transmission and distribution losses. Distribution companies in Nigeria have faced significant set-backs with about 46% energy losses as a result of commercial and technical challenges [23].

3.2. Rooftop technical potential estimation methods

There is no specific approach for estimation of potential of rooftop solar PV. Many scholars have used different approaches in the past. However, a detailed review of literature has shown that rooftop solar PV can be estimated using three different methods which are constant value, manual selection and GIS based methods [40].

The constant value method involves logical assumptions that a fraction of the rooftop of a building is available for PV installation. This methodology is computationally light and applicable when results are needed quickly [40]. The manual selection approach involves a detailed analysis of the individual rooftops which usually involve the use of aerial photographs and renewable energy software tools such as the System Advisory Model (SAM) and PVWatts calculator of the U.S NREL [41,42]. However, this approach is cumbersome and is not practicable for a large area [40]. The GIS method involves the use of GIS-based images to analyse the suitability of rooftops for PV installation. This is the commonest method which has been used in many studies in the past [43].

In this paper, we use the constant value method for our analysis. We first calculate the total number of urban households in Nigeria. Then we use a correction factor to estimate the total number of urban residential buildings. We study the types of roofing materials in Nigeria residential buildings that can withstand solar PV installation and then estimate the total number of available roofs for solar PV. We use a typical urban building to calculate the roof availability factor. The result is further extrapolated for the entire urban residential buildings of Nigeria.

It is worthwhile, to state that our analysis has been limited due to non-availability of data which is a major problem in Nigeria. We also tried as we can to rely on the local available data. Furthermore, data from foreign organisation were employed only where we couldn't find local data and the assumptions that have been made are based on experts' opinions. Nevertheless, we believe that our findings will be useful to policy makers as they can use our results as preliminary evidence in developing robust policies and strategies for mass deployment of rooftop solar PV in the country.

3.3. Total number of urban residential roofs

The latest housing census in Nigeria is the 2006 population and housing census which estimated the total number of regular households in Nigeria at 28,197,085 [44]. However, the 2006 census report didn't distinguish the total number of households according to urban and rural households and there is no specific census yet for the number of urban households in Nigeria. In order to estimate the total number of urban households, we use 91,533,000, the total urban population of Nigeria in 2016 taken from the UN 2015 medium variant population prospects [45], and the average urban household size of 5.5 person per household taken from the Nigeria Bureau of Statistics Living Standard Measurement Survey [46] to calculate the total number of urban households. The total number of urban households (TUH) is estimated at 16,642,364 households from Eq 1.

$$TUH = \frac{total\ urban\ population}{average\ urban\ household\ size} \quad (1)$$

However, it is also important to note that the total number of urban households is different from the total urban residential building rooftops available for PV installation, as some households might be living under the same roof area as in the case of multi-storey buildings. To account for this (i.e. more than one household under a roof), we introduce a correction factor. For this purpose, the average number of multi-storey residential buildings is estimated on the basis of population density of Nigerian cities. A sample of eighteen cities which accounts for around 75% (or 12,884 km^2) of the total urban land area of Nigeria[1], and encompasses the highly populated and sparsely populated cities, spread across the six geo-political zones of the country are taken into consideration. We also took into consideration that old residential buildings stock in the highly populated cities are limited to an average of 3 storeys, owing to the fact that lift facilities were not common when most of these buildings were constructed. However, most of the urban residential households are bungalow types of building with few one-storey residential buildings in the highly populated cities like Lagos and Aba. The basis for deciding the number of storeys and the correction factor of multiple-storey building are summarised in Tables 3 and 4 respectively.

[1] Total urban land area of Nigeria has been estimated at 17,196 km^2 according to the Centre for International Earth Science Information Network (CIESIN) of Columbia University. URL: http://dx.doi.org/10.7927/H4MW2F2J (accessed August 18, 2017).

Table 3. Assumption on number of storeys in a building.

Population density (Persons/km^2) of city	Average number of storeys in a building
<5000	1
5000–7000	2
>7000	3

Table 4. Estimated average number of storeys in urban households [44].

S. No.	City	Population (No. of persons)	Land area (km^2)	Population density (Persons/km^2)	Average number of storeys
1	Aba	531,340	72	7380	3
2	Abuja	776,298	1769	439	1
3	Asaba	123,746	268	462	1
4	Awka	301,846	120	2515	1
5	Bauchi	493,810	3687	134	1
6	Benin	1,147,188	1204	953	1
7	Calabar	375,196	406	924	1
8	Ilorin	777,667	765	1017	1
9	Kano	2,828,861	499	5669	2
10	Lagos	8,048,430	1171	6871	2
11	Maiduguri	543,016	137	3964	1
12	Ogbomoso	299,535	1183	253	1
13	Onitsha	261,604	52	5031	2
14	Owerri	127,213	104	1223	1
15	Port Harcourt	1,005,904	369	2726	1
16	Suleja	216,518	153	1415	1
17	Uyo	427,873	362	1182	1
18	Zaria	695,089	563	1235	1
Total		18,981,134	12,884	43392	Average = 1.28

For national level estimation, average value of correction factor of 1.28 is computed (Table 4) and considered for accounting urban households residing in multi-storey buildings. Consequently, the total number of urban rooftop (TUR) is estimated at 13,001,847 using Eq 2.

$$TUR = \frac{total\ number\ of\ urban\ households}{correction\ factor} \tag{2}$$

3.4. Number of urban households with suitable rooftop

As not all urban residential buildings roofing materials are suitable for solar PV installation, it is necessary to identify the roofing materials that can withstand the weight of a PV installation. Generally, the available roofing materials in Nigeria are corrugated metal sheets, asbestos sheets, thatch, and grass. As per Living Standard Measurement Survey of Nigeria Bureau of Statistics (NBS), about 83.5% of urban households roofing material are corrugated metal sheet and 7.4% are the asbestos sheet which sums up to approximately 90% [46]. The detailed classification of roofing material in urban households of Nigeria is provided in Table 5. In this paper, the metal sheets and asbestos roof types are considered suitable for PV installation. Although cement roofs have sufficient strength to support rooftop PV, however their share is very low, therefore are not considered here.

Table 5. Roofing material of urban house in Nigeria [46].

S. No.	Roofing material	Percentage of total roofs
1	Mud	3.7
2	Thatch	2.0
3	Wood	0.6
4	Iron sheets	83.5
5	Cement	1.3
6	Roofing tiles	1.0
7	Asbestos	7.4
8	Others	0.5

Using Eq 3 total suitable urban residential building rooftops (SUR) for PV installation is estimated at 11,701662.

$$SUR = 0.9 \times TUR \quad (3)$$

3.5. Gross roof area of a typical urban residential building

Precise estimate of the gross roof area available in the entire urban households of Nigeria is a very cumbersome task as it will require detailed measurements of individual urban residential rooftops in Nigeria. To simplify this task, in this paper, Nigeria building bye laws have been used for approximations and further extrapolated to all urban residential buildings in the country.

As per the Nigeria National Building Code (NBC), the gross floor area required per occupant for residential building type is 18.6 m^2 [47]. This value is being multiplied by the average urban household size of Nigeria to estimate the average roof area for a typical urban residential building. The average size for a flat roofed urban residential building is estimated at 102.3 m^2. However, we used 100 m^2 in this study. It is also important to note that almost all the urban residential rooftops in Nigeria are tilted at an angle and this will certainly increase the surface area available for solar PV installation. According to the National Building Code, a minimum pitch of 30^o is required for residential roof [47]. In this paper, a roof pitch of 45° is used to account for the many buildings having roof pitches well above 30°. Schematics of a typical urban residential building and roof pitch are shown in Figures 3 and 4.

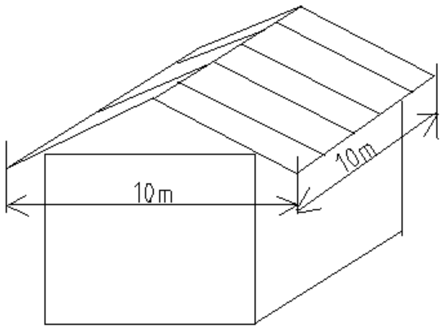

Figure 3. Schematic of a typical urban building (Area = 10 m × 10 m).

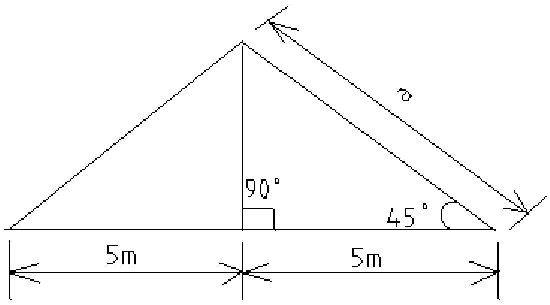

Figure 4. 2D schematic of a typical urban residential roof pitch.

From Figure 4, it is seen that due to the sloppy nature of urban residential roofs in Nigeria, the gross surface area available for PV installation will be greater than the gross floor area. Using Sine rule (Eq 4), the inclined length (a) of the roof has been calculated at 7 m.

$$\frac{Sin\ 90}{a} = \frac{\text{Sin}\ 45}{5} \tag{4}$$

Therefore, the gross roof area (G_r) of a typical urban residential rooftop has been estimated at 140 m^2 (Eq 5).

$$2 \times (7 \times 10) = 140\ m^2 \tag{5}$$

3.6. Usable rooftop area

The total roof area of a typical residential building cannot be suitable for solar PV installation due to some factors such as shading and array spacing. Hence, these factors need to be brought into consideration in order to determine the useful area for PV installation.

3.6.1. Clearance

Some clearance is required between the tip of the roof and the solar PV arrays in order to allow for mounting and also prevent easy falling off of PV panels from rooftops. Also, some space is required to be maintained between PV arrays to facilitate cleaning and other maintenance activities.

To provide sufficient space for the above-mentioned purposes, a space of 0.6 m is required from the tip of the roof and in between the PV modules from all four sides [48].

3.6.2. Shading from trees and adjacent buildings

During the installation of PV systems, factor such as shading is brought into consideration. Shadings usually occur due to nearby trees or falling of leaves and adjacent buildings. This results to poor energy yield [49]. Thus, to improve the energy yield of a rooftop PV system, it should be installed in an area that is free of obstruction in order to optimise solar irradiation [50,51]. However, in Nigeria, most of the settlements are unplanned with only the Federal Capital Territory being the planned city in the country [52]. Thus, we expect that shading losses will be high in the old unplanned settlements and a bit low in the newly developed settlements like Abuja. Various authors [16,43,53,54] reported that shading losses are in the range of 5–30%. In this paper, an average value of 22% is taken as shading losses.

3.6.3. Other miscellaneous items

Due to uncertainty, we consider additional roof areas to account for other household items such as television antenna that might be placed on the roof. To factor in this, a space of 1.5 m^2 has been subtracted from net available roof area as estimated in 3.6.2. Further, an additional area 1.5 m^2 to account for shadings that might be coming from such items. In sum, 3 m^2 is provided for other items that might be placed on the roof. However, many urban residential rooftops in Nigeria are left plain without any item on them. Image of a typical residential building in urban Nigeria is shown in Figure 5.

Figure 5. Typical urban residential building in Nigeria.
Photograph credit: https://www.tolet.com.ng/ (accessed July 28, 2017) [55].

Other items like solar water heaters and storage tanks are not considered in this study. In Nigeria, less than 1% of the urban residential buildings are fitted with solar water heaters. While for the case of water tanks; most of the urban households receive water from the central water boards directly into their homes and they store the excess in jerry cans or basins which are usually placed in the kitchen or in the courtyard. For households with personal boreholes, water is pumped and stored in plastic tanks which are placed on a concrete or metal elevated platform which is different from the roof.

Given the above reduction factors, the usable rooftop area (R_a) for a typical urban residential building in Nigeria is determined from Eq 6.

$$R_a = G_r - (C_f + S_f + M_f) \tag{6}$$

Where G_r represents the gross rooftop area, C_f the reduction due to clearance, S_f the reduction due to shading, and M_f the reduction due to miscellaneous items.

3.7. Technical potential of solar rooftop PV

The rooftop PV technical potential (T_P) for entire urban residential buildings of Nigeria has been estimated as the direct current system power rating (kW_p) under Standard Test Conditions (STC) from Eq 7 [56].

$$T_P = \frac{(SUR \times R_a) \times \eta}{m^2} \tag{7}$$

Where SUR represents the total number of suitable urban residential building rooftops, R_a the usable roof area of a typical urban residential building, and η the reference module efficiency.

A SolarWorld module is taken as reference solar module and its detail characteristics are presented in Table 6.

Table 6. Characterisation of reference module [57].

Manufacturer	SolarWorld
Module type	Polycrystalline silicon
Model	Sunmodule Plus SW 260 poly
Dimensions	Length: 1675 mm, Width: 1001 mm, Thickness: 31.0 mm, Weight: 21.20 kg, Area: 1.677 m^2
Nom. Power (at STC)	260.0 W_p
Efficiency	15.51%

3.8. Energy output

The annual energy yield is the amount of electricity actually generated by rooftop solar PV systems in a year. The electricity output of a solar PV system in the field is usually different from the one stated by the manufacturer under STC. This is due to varying climatic conditions in the field in different locations and at different times of the year. Other factors, such as roof tilt angle, soiling, mismatch, wiring etc. also affects energy yield.

To estimate annual energy yield of rooftop solar PV, PVSyst® software (version 6.6.3) has been employed. PVSyst® is used for studying, sizing and simulating grid-connected and off-grid solar PV systems. PV systems can be sized either by estimating the daily power requirement or the available roof area for PV installation [58]. Using the characterised solar module in Table 6; considering technical specifications of commercially available GE Solar inverter (4.0 kW 200–500 V Trnsfo 50/60 Hz GES-4K); net available roof area of 68 m^2 (which translate into 10 kW_p of a rooftop PV system) for a typical urban residential building; fixed roof tilt angle of 45° and azimuth angle of 0°, grid-connected rooftop solar PV systems are simulated in PVSyst® software to obtain annual energy yields of selected cities. Solar radiation and weather data of selected cities is imported into PVSyst® from Meteonorm 7.1 software. The average annual climatic parameters for the selected cities are presented in Table 7.

Table 7. Climatic data of selected Nigerian cities.

S. No.	Cities	Elevation (m)	Latitude (N)	Longitude (E)	Annual Global Irradiation (kWh/m^2/yr)	Annual temperature (℃)	Annual wind speed (m/s)
1	Aba	67	5.12	7.37	1527.7	26.6	1.2
2	Abuja	456	9.08	7.40	1803.3	27.9	3.0
3	Asaba	44	6.21	6.70	1682.3	27.2	2.7
4	Awka	142	6.22	7.08	1682.6	27.0	2.5
5	Bauchi	600	10.30	9.82	2137.2	29.0	3.3
6	Benin	88	6.33	5.60	1606.7	27.3	2.9
7	Calabar	57	4.98	8.34	1523.4	26.6	1.2
8	Ilorin	294	8.48	4.54	1749.6	26	3.0
9	Kano	469	12.00	8.59	2194.0	29.5	3.5
10	Lagos	12	6.52	3.38	1636.6	27.4	2.9
11	Maiduguri	325	11.83	13.15	2176.9	28.5	3.4
12	Ogbomoso	325	8.12	4.24	1697.7	25.8	3.0
13	Onitsha	106	6.14	6.80	1682.5	27.1	2.6
14	Owerri	75	5.49	7.02	1641.2	26.7	1.6
15	Port Harcourt	5	4.82	7.05	1474.1	26.6	1.2
16	Suleja	458	9.21	7.20	1796.4	27.9	3.1
17	Uyo	64	5.04	7.91	1561.1	26.5	1.2
18	Zaria	640	11.09	7.72	2150.8	29.2	3.4

3.9. Levelized unit cost of electricity

Levelized unit cost of electricity (LUCE) is a measure that is used to determine and compare the cost of electricity generation from various available options [59]. A rooftop solar PV owner will like to sell excess electricity generated to the central utility at a price that is equal or greater than the LUCE of rooftop solar PV. The LUCE of rooftop solar PV is estimated from Eq 8 [60].

$$LUCE = \frac{C_{rsp} \times CRF + m \times C_{rsp}}{E_{rsp}} \quad (8)$$

Where C_{rsp} represents the capital cost of rooftop solar PV (including installation costs), m the percent value of C_{rsp} as annual operation and maintenance cost, E_{rsp} the annual energy yield and CRF the capital recovery factor which is given in Eq 9 [60].

$$CRF = \frac{d(1+d)^{t_{rsp}}}{(1+d)^{t_{rsp}} - 1} \quad (9)$$

Where d is the discount rate and t_{rsp} is the useful life of the system.

The Nigeria Electricity Regulatory Commission (NERC) has provided the economic parameters used for estimating LUCE of renewable energy power plants [61]. However, it does not provide estimates for rooftop solar PV systems. Hence, some of the economic parameters used in estimating the LUCE in this study have been taken from other sources having good economic estimate of grid connected rooftop solar PV that can be applicable in Nigeria and they are presented in Table 8.

Table 8. Economic parameters used for estimating LUCE of rooftop solar PV in Nigeria.

Parameter	Unit	Value	Source
Capital cost	₦/kW (Nigerian Naira per kilowatt)	375000[2]	[62]
Discount rate	%	14	[63]
Life cycle	years	25	[61]
Annual operation and maintenance cost	%	2% of capital cost	[64]

3.10. *Break-even capital cost of rooftop solar PV (BE_{Crsp})*

It has been observed that there has been a continuous declining trend in the cost of solar PV module around the world and similar trend is expected in near future as well which will likely bring down the LUCE of rooftop solar PV. Therefore, it will be useful to estimate the break-even capital cost (BE_{Crsp}) of rooftop solar PV system (₦/kWp) up to which a rooftop system would be financially viable even for all categories of households given the current economic situation in the country. BE_{Crsp} is defined as the capital cost at which LUCE of rooftop solar PV will achieve grid parity. By substituting the electricity tariffs (T_d) of distribution companies (DISCOS) in Eq 8 for the LUCE of rooftop solar PV, the BE_{Crsp} of rooftop solar PV in the selected cities have been estimated from Eq 10.

$$BE_{C_{rsp}} = \frac{T_d \times E_{rsp}}{CRF + m} \quad (10)$$

Where T_d represents the electricity tariffs of the DISCOs while other parameters have been defined earlier in Eqs 8 and 9.

4. Results and discussion

We determined the usable roof area by subtracting the space required for clearance between the roof edge and module array, the area due to shading and the area required for other domestic miscellaneous items from the gross roof area. The result is summarised in Figure 6.

[2] Value of capital cost has been taken from Indian official document using conversion rate of INR (Indian Rupee) 1 = NGN (Nigerian Naira) 5, as on xx-08-2017.

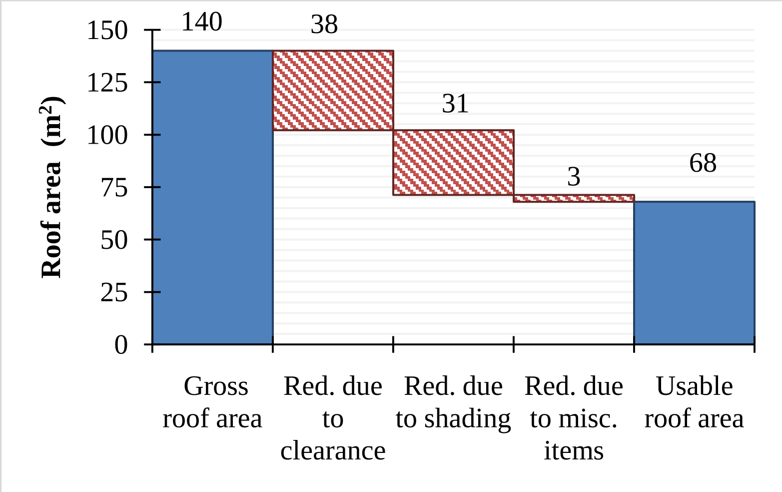

Figure 6. Reduction from gross roof area to usable roof area.

As depicted in Figure 6, a typical urban residential building has a gross roof area of 140 m^2. Out of this, 37.9 m^2 is required for clearance (27% of the gross roof area), the area allocated to shading is 30.8 m^2 (22% of the gross roof area) and 3 m^2 roof area is needed for other domestic miscellaneous items which is equivalent to 2% of the gross roof area. In sum, the net available roof area for PV installation in a typical urban residential building in Nigeria is 68 m^2 which is about 49% of the gross roof area. Thus, the available roof area for the entire urban residential buildings of Nigeria is estimated as product of the net available roof area for PV installation in a typical urban residential building and total number of suitable urban rooftops which is equal to 796 km^2. This value represents about 5% of the total urban land area and less than 1% of the entire land mass of Nigeria.

From Eq 7, the technical potential of rooftop solar PV for the residential urban buildings of Nigeria has been estimated at 124 GW_p. This value is about ten times the current electricity generation capacity in the country (12.52 GW) [23]. Although solar PV has lower capacity utilization factor as compared to conventional power plants, still electricity generation from the estimated technical potential of rooftop PV would be significantly higher than the current electricity supply in Nigeria. Thus, this result suggests that Nigeria has a relatively huge potential for rooftop solar PV electricity. The estimated potential will further increase if rural households are also accounted for. Hence, even if a small fraction of the estimated technical potential of rooftop solar PV of urban buildings in Nigeria is harnessed, it is possible to substitute diesel and gasoline generator sets which are used by households as a backup for the unstable power supply from the central utility. Moreover, since the total number of households has been determined from the total population, it is expected that with increase in population and urbanisation, as well as with the development of more advanced technologies, this value will increase in the near future. Further, rooftop solar PV can facilitate multiple utilisation of land which is a very scarce resource especially in urban areas.

With respect to energy yields, the highest energy yield was obtained in Kano with 16540 kWh/year while the lowest energy yield was obtained in Port Harcourt with 10637 kWh/year. On average, a typical urban residential building in Nigeria can generate about 13049 kWh/year from rooftop solar PV. The complete results are shown in Table 9. The LUCE of rooftop solar PV for the selected cities are also analysed from Eq 8 and the results are presented in Table 9. Results show that the value of LUCE varies from 37.52 ₦/kWh (Kano) to 58.35 ₦/kWh (Port Harcourt).

Table 9. Energy yield and LUCE of rooftop solar PV in different cities of Nigeria.

S. No.	Cities	Annual energy yield (kWh/year)	LUCE (₦/kWh) 10kW$_p$
1	Kano	16540	37.52
2	Maiduguri	16480	37.66
3	Zaria	16215	38.27
4	Bauchi	15964	38.88
5	Abuja	13658	45.44
6	Suleja	13516	45.92
7	Ilorin	13182	47.08
8	Ogbomoso	12772	48.59
9	Awka	12347	50.27
10	Asaba	12265	50.60
11	Onitsha	12259	50.63
12	Owerri	11991	51.76
13	Lagos	11945	51.96
14	Benin	11829	52.47
15	Uyo	11389	54.49
16	Calabar	11140	55.71
17	Aba	10750	57.73
18	Port Harcourt	10637	58.35

Sensitivity analysis is also conducted for the city of Port Harcourt (which has lowest energy yield and highest LUCE) to study the impact of changes in financial parameters on the LUCE of rooftop solar PV. Capital cost of rooftop solar PV can change as a result of market competition and development of new and cheaper technologies. Discount rate can also change due to changes in inflation rate, while operation and maintenance cost is also expected to change when local skilled man-power is available. These uncertainties will consequently have an impact on the LUCE of rooftop solar PV. The result of the sensitivity analysis is shown in Figure 7. LUCE of rooftop solar PV is seen to be most sensitive to capital cost followed by discount rate. LUCE shows less sensitivity for Operation & maintenance cost and useful lifetime.

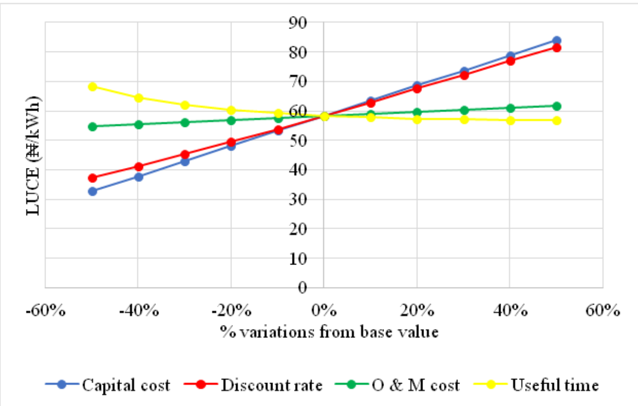

Figure 7. Sensitivity analysis for LUCE of rooftop solar PV with respect to key parameters for Port Harcourt city.

The Nigerian Electricity Regulatory Commission (NERC) is the government agency in charge of regulating and fixing electricity prices. It considers and approves the electricity prices provided by the Distribution Companies (DISCOs) for different category of households. There are eleven electricity DISCOs in Nigeria and their electricity tariff for end-users varies across the country. The DISCOs have classified residential consumers into R1, R2S, R2T, R3 and R4 categories based on their sources of supply and same has been done for fixing their respective tariffs. For 2017, the tariffs of the respective DISCOs that are franchised in the sample cities are shown in Table 10.

Table 10. 2017 Tariffs for residential consumers in selected cities [66].

S. No.	Cities	Franchised electricity distribution companies	Residential end-user tariff (₦/kWh)				
			R1	R2S	R2T	R3	R4
1	Kano	Kano Disco (KEDCO)	4.00	22.50	29.61	42.63	42.63
2	Maiduguri	Yola Disco (YEDC)	4.00	25.73	28.17	51.46	N.A
3	Zaria	Kaduna Disco (KED PLC)	4.00	27.40	32.33	42.74	48.77
4	Bauchi	Jos Disco (JED PLC)	4.00	29.81	29.81	45.76	45.76
5	Abuja	Abuja Disco (AEDC)	4.00	24.30	24.30	47.09	47.09
6	Suleja	Abuja Disco (AEDC)	4.00	24.30	24.30	47.09	47.09
7	Ilorin	Ibadan Disco (IBEDC)	4.00	24.97	24.97	44.66	44.66
8	Ogbomoso	Ibadan Disco (IBEDC)	4.00	24.97	24.97	44.66	44.66
9	Awka	Enugu Disco (EEDC)	4.00	30.39	34.28	48.12	46.08
10	Asaba	Benin Disco (BEDC)	4.00	31.27	34.40	40.46	40.46
11	Onitsha	Enugu Disco (EEDC)	4.00	30.39	34.28	48.12	46.08
12	Owerri	Enugu Disco (EEDC)	4.00	30.39	34.28	48.12	46.08
13	Lagos	Eko Disco (EKEDC)	4.00	22.34	28.39	29.18	29.18
		Ikeja Disco (IKEDC)	4.00	21.10	21.73	35.68	36.11
14	Benin	Benin Disco (BEDC)	4.00	31.27	34.40	40.46	40.46
15	Uyo	Port Harcourt Disco (PHED)	4.00	30.23	30.23	48.39	50.76
16	Calabar	Port Harcourt Disco (PHED)	4.00	30.23	30.23	48.39	50.76
17	Aba	Enugu Disco (EEDC)	4.00	30.39	34.28	48.12	46.08
18	Port Harcourt	Port Harcourt Disco (PHED)	4.00	30.23	30.23	48.39	50.76

Note: N.A.—Not Applicable. Yola Disco (YEDC) (Maiduguri) has no tariff for R4 category.

From Table 10, R1 consumers represents those on lifeline (50 kWh and below), R2S single phase, R2T three phase, R3 LV maximum demand and R4 HV maximum demand (11/33 KV). It is observed that some cities are served by the same DISCO (for example, Uyo, Calabar and Port Harcourt are served by the Port Harcourt Disco (PHED), while the city of Lagos is served by two different DISCOs due to the large number of consumers there. The Eko Disco cover areas like Lekki, Apapa, Victoria Island etc. whereas, the Ikeja Disco cover areas such as Ikeja, Ikorodu, Surulere etc. It is also observed that Yola Disco (YEDC) (Maiduguri) has no tariff for R4 category and consumers tariff varies from 4.00 ₦/kWh for R1 category to 50.76 ₦/kWh for R4 category across all DISCOs. The R2S tariff is the range 21.10 ₦/kWh (Ikeja Disco)—31.27 ₦/kWh (Benin Disco), R2T 21.73 ₦/kWh (Ikeja Disco)—34.40 ₦/kWh (Benin Disco), R3 29.18 ₦/kWh (Eko Disco)—51.43 ₦/kWh (Yola Disco) and R4 29.18 ₦/kWh (Eko Disco)—50.76 ₦/kWh (Port Harcourt Disco). Moreover, it is worthwhile to note that the National Electric Power Policy and Electric Power Sector Reform Act of 2005 mandated that the tariff for low income households should be the same across the country [65]. In view of this act, the NERC has set 4.00 ₦/kWh for all households in R1 category for all the distribution companies.

From Tables 9 and 10, it has been observed that the LUCE of rooftop solar PV is lower than the tariffs of the DISCOs in Kano, Maiduguri, Zaria, Bauchi, Abuja and Suleja for the R3 and R4 categories of consumers. This can be attributed to the high amount of solar irradiance in these cities and the billing system of the franchised DISCOs.

BE_{Crsp} of rooftop solar PV has been estimated from Eq 10 and the results are presented in Table 11. As expected, with variation in solar radiation for different cities, break-even capital cost also varies. Our analysis shows that BE_{Crsp} in R1, R2S, and R2T categories of consumers across all selected cities are less than the present capital cost of 375000 ₦/kWp for rooftop solar PV system (Table 8), while in the R3 and R4 categories, BE_{Crsp} in some cities is seen to be higher than the capital cost of rooftop solar PV, which essentially mean that for these categories, rooftop solar PV system is already financially viable. For example, in R4 category of Zaria, investment in rooftop solar PV would be financially viable even if capital cost increases to 477828 ₦/kW_p. However, for Port Harcourt R1 category, investment in rooftop solar PV will be financially feasible only when capital cost reduces to the level below 25709 ₦/kW_p. Thus, support in terms of financial/fiscal incentives are still needed most especially for those in R1, R2S, and R2T categories to promote rooftop solar PV in the country.

Table 11. Break-even capital cost for rooftop solar PV in different cities of Nigeria.

S. No.	Cities	Break-even capital cost (₦/kW_p)				
		R1	R2S	R2T	R3	R4
1	Kano	39976$^-$	224864$^-$	295921$^-$	426042$^+$	426042$^+$
2	Maiduguri	39831$^-$	256212$^-$	280509$^-$	512423$^+$	N.A.
3	Zaria	39190$^-$	268454$^-$	316756$^-$	418749$^+$	477828$^+$
4	Bauchi	38584$^-$	287545$^-$	287545$^-$	441397$^+$	441397$^+$
5	Abuja	33010$^-$	200537$^-$	200537$^-$	388613$^+$	388613$^+$
6	Suleja	32667$^-$	198452$^-$	198452$^-$	384573$^+$	384573$^+$
7	Ilorin	31860$^-$	198885$^-$	198885$^-$	355715$^-$	355715$^-$
8	Ogbomoso	30869$^-$	192699$^-$	192699$^-$	344651$^-$	344651$^-$
9	Awka	29842$^-$	226722$^-$	255743$^-$	358996$^-$	343776$^-$
10	Asaba	29644$^-$	231738$^-$	254934$^-$	299844$^-$	299844$^-$
11	Onitsha	29629$^-$	225106$^-$	253921$^-$	356437$^-$	341326$^-$
12	Owerri	28981$^-$	220185$^-$	248369$^-$	348645$^-$	333864$^-$
13	Lagos (Eko)	28870$^-$	161239$^-$	204905$^-$	210607$^-$	210607$^-$
	Lagos (Ikeja)	28870$^-$	152290$^-$	156837$^-$	257521$^-$	260625$^-$
14	Benin	28590$^-$	223500$^-$	245872$^-$	289185$^-$	289185$^-$
15	Uyo	27526$^-$	208030$^-$	208030$^-$	332999$^-$	349309$^-$
16	Calabar	26924$^-$	203482$^-$	203482$^-$	325719$^-$	341672$^-$
17	Aba	25982$^-$	197397$^-$	222665$^-$	312562$^-$	299311$^-$
18	Port Harcourt	25709$^-$	194294$^-$	194294$^-$	311012$^-$	326244$^-$

Note: N.A.: Not applicable; $^+$Financially viable; $^-$Not financially viable.

5. Conclusions

An initial attempt towards the estimation of the technical potential of rooftop solar PV in urban residential buildings of Nigeria has been presented in this paper. Based on our analysis, it may be concluded that there is a huge potential of rooftop solar PV in the country. However, it is expected that this potential will be reduced when the economic/market potential is quantified. We analysed the energy yields of rooftop solar PV and can infer that it has a major role to play towards energy security in the Nigerian residential sector. We found that LUCE of rooftop solar PV is higher than the average electricity tariffs of DISCOs in most parts of Nigeria. We also found that investment in rooftop solar PV is not yet financially attractive for the R1, R2S, and R2T categories of households in Nigeria. Therefore, robust fiscal/financial incentives are still needed to encourage mass deployment of rooftop solar PV in the country.

The results of this study suggest that the present initial capital cost may hinder the deployment of rooftop solar PV in Nigeria, particularly for R1, R2S and R2T categories of residential consumers. In order to accelerate the deployment of rooftop solar PV in Nigeria, we suggest that capital subsidy for rooftop solar PV should be provided by the Nigerian government. Countries like India, Italy and Japan have been providing capital subsidies for rooftop solar PV projects and have recorded successes. Thus, the government of Nigeria can learn from their experiences and consider providing a certain percentage of the total solar PV investment costs in the form of grants in initial stage.

The private sector also has a role to play towards making rooftop solar PV financially attractive in the country. For instance, the third-party ownership model which is now common in USA can as well be introduced to Nigeria by private investors. In this scheme, a commercial firm installs and manages the rooftop solar PV for the building owner. This model can be in the form of Solar Leasing (SL) or Solar Power Purchase Agreement (SPPA). In the SL model, the building owner leases the PV system to the firm for a given period in which the building owner pays in instalments and consumes the power generated by the rooftop solar PV system at a price which is usually lower than the central utility price. While in the SPPA model, the building owner buys electricity from the firm at a price agreed upon during the project development for a given period. These two models can go a long way to reduce the upfront cost of solar PV for the already overburdened poor Nigerian masses, as well as reduce the responsibility of the government.

To make rooftop solar PV viable in the country, soft loans and interest subsidies may also be provided for the citizens when investing in rooftop solar PV. In this scheme, a certain percentage of the total capital cost is provided in the form of loan in which the interest is below the official commercial rates. The difference between the official interest rate and subsidised rate will be borne by the government. This will help to reduce the loan repayment period for the R1, R2S and R2T categories of residential consumers and as such reduce the LUCE of rooftop solar PV.

Another incentive to be considered by policy makers is the solar investment tax credit (ITC). In this, a certain fraction or all expenses involved in rooftop solar PV development is charged from taxable income of the investors. This policy can help to lower the capital cost of rooftop solar PV project. Accelerated depreciation benefit policy can also be implemented in Nigeria. This method is used to deduct the cost of assets in greater manner in the first few years of the project. Thus, this policy instrument can help to reduce the total cost of rooftop solar PV projects during the first few years and as such, reduces the income tax liability of Nigerians.

Furthermore, the present Feed-in Tariff (FiT) in the country does not provide good encouragement for investment in rooftop solar PV. It does not provide any recompense for energy that is generated but can't be sold and as such has no room for electricity generation from rooftop solar PV. FiT should be considered as one of the major steps towards unlocking the potential of rooftop solar PV in Nigeria. It is therefore only pertinent for Nigeria government to reassess the present FiT scheme with the view of including power generation from rooftop solar PV. Given the fact that the price of solar PV has been projected to continue declining in the future while the technology continues to improve, Nigeria can later adopt the corridor concept of Germany. This policy allows the market forces to determine the level of FiT. In a nutshell, to make rooftop solar PV viable in Nigeria, the government of Nigeria need to develop and implement policies that makes rooftop solar PV more financially attractive than the conventional sources of electricity.

While reducing the cost of rooftop solar PV in Nigeria is needed, deploying rooftop solar PV in the country is expected to have certain implications on the electricity grid given the current state of the country's power supply sector. The present grid system can only transmit around 6000 MW which is far below the current installed generation capacity and the total electricity demand of Nigeria. Another problem is that the present grid is very weak and is characterised by high transmission losses. Hence, a complete refurbishment and capacity expansion is needed in order to incorporate large-scale renewables such as the rooftop solar PV systems. Also, to account for the exchange of information and power between the power producers and consumers, a smart grid technology is needed in the country. Smart grid provides a framework for handling electricity demand in a reliable and cost-effective manner.

This paper provides a methodology that could be used to estimate rooftop solar PV potential in other developing countries where data is very limited. We suggest going further with this study by estimating the technical potential of rooftop solar PV in the rural households of Nigeria as well as the economic potential for the same. The findings of our paper will be beneficial to electricity system operators, households who want to invest in rooftop solar PV, and policy makers. The estimated technical potential will help utilities predict future electricity generation for planning purposes. The annual energy yield analysis will help homeowners to determine the amount of electricity that can be supplied by rooftop solar PV systems. Through our economic analysis, policy makers can know the type of households that require financial support and the enabling conditions required for private investors to thrive in the rooftop solar PV space of Nigeria. This will go a long way to inform logical and incentivizing policies and programs required for mass deployment of rooftop solar PV in the country.

Conflict of interest

The authors declare no conflict of interest in this research.

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