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Solar energy applications and development in Nigeria: Drivers and barriers

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ABSTRACT

In this study, current perspectives of solar energy utilization as a renewable energy option in Nigeria are examined and discussed from the standpoint of sustainable development. The country being a world crude oil and natural gas producer, is over-dependent on these energy sources for electricity generation and other energy applications. This has currently put the country at a risk of impending energy crises in view of the fast diminishing fossil reserves, inadequate refining capacity to meet domestic consumption and serious cases of energy insecurity in restive regions where exploitations exist. In spite of the vast fossil based energy reserves, a meager electricity production capacity that is put at 4517.6 MW as at December 2012 is generated to support the economy of a teeming population of approximately 170 million people. Nigeria is naturally endowed with abundant deposit of renewable energy resources of which solar energy from the Sun (being the world's most abundant and permanent energy source) has for decades been enjoying very high level utilization by rural dwellers for agricultural processings in the country. It is vastly deposited with an estimated 17,459,215.2 million MJ/day of solar energy falling on the country's 923,768 km^2 land area (approximate range of 12.6 MJ/m^2/day in the coastal region to about 25.2 MJ/m^2/day in the far north). The different applications to which solar resources have been put and the extent of utilization (including details of existing projects) in the country were thoroughly investigated and discussed. The possible motivations for extensive development of solar energy conversion systems in Nigeria are also discussed and some of the barriers and challenges are presented. Steps and policy measures to overcome the barriers and facilitates the utilization of this resource are suggested.

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1. Introduction

The Sun can be a singular solution to our future energy needs [1] since almost all renewable energy sources originate directly or indirectly from the Sun. It delivers more energy per hour than the earth uses in one year, it is free from pollutants, greenhouse gases and very secure from geo-political constraints and conflicts. The amount of solar energy reaching the Earth′s surface is about 100,000 TW [2]. The total global primary energy consumption in 2012 is 12,476.6 million tonnes of oil equivalent or 145,103 TWh [3]. From the BP Statistical Review of World Energy [3], it is very glaring that the global annual energy consumption can be supplied by solar energy in every 88 minutes or about 6000 times total annual energy consumption yearly. It is the world′s most abundant and permanent energy source that shows different appearances depending on the earth′s surface topography [4]. In esssence, solar energy is expected to play a very significant role in the future global energy needs and most especially, in developing countries. The global cumulative installed capacity of solar power is shown in Fig. 1. It is shown from this figure, that the global cumulative installed capacity increased rapidly from 1400 MW in 2000 to about 102,156 MW in 2012 [5]. In terms of installed cumulative solar power, the top four countries are Germany, Italy, China and USA with installed capacity of 32509, 16987, 8043 and 7665 MW respectively. The installed solar power capacity in Germany alone (a country located in a temperate region), is seven times more than the highest peak total electricity generated from all sources in Nigeria, being 4517.6 MW as at December 2012 [6].

Nigeria with her location on the equator is within a high sunshine belt where solar radiation is fairly well distributed [7–9]. It was estimated that the annual daily average of total solar radiation varies from about 12.6 MJ/m^2/day (3.5 kWh/m^2/day) in the coastal region to about 25.2 MJ/m^2/day (7.0 kWh/m^2/day) in the far north, thus making her to have an estimated 17,459,215.2 million MJ/day (17.439 TJ/day) of solar energy falling on its 923,768 km^2 land area. Provided there is an estimated average of 18.9 MJ/m^2/day (5.3 kWh/m^2/day) over a whole year, an average of 6,372,613 PJ/year ($\approx$ 1770 thousand TWh/year) of solar energy is estimated to fall on the entire land area [7,8]. In spite of this potential, solar energy is yet to find its foot in the country′s total energy mix even though the territory has good and viable potential for solar applications ranging from stand-alone pico units to large scale grid connected applications.

The solar radiation distribution in Nigeria is shown in Fig. 2. From this map, three different solar radiation zones can be defined viz: zones I, II and III with each zone having different radiation levels that may be needed for a particular project selection and sizing. Table 1 gives the irradiation range for each zone as distributed among the 36 States of the federation. Zone I comprises of all the states in the North-East geo-political zones.

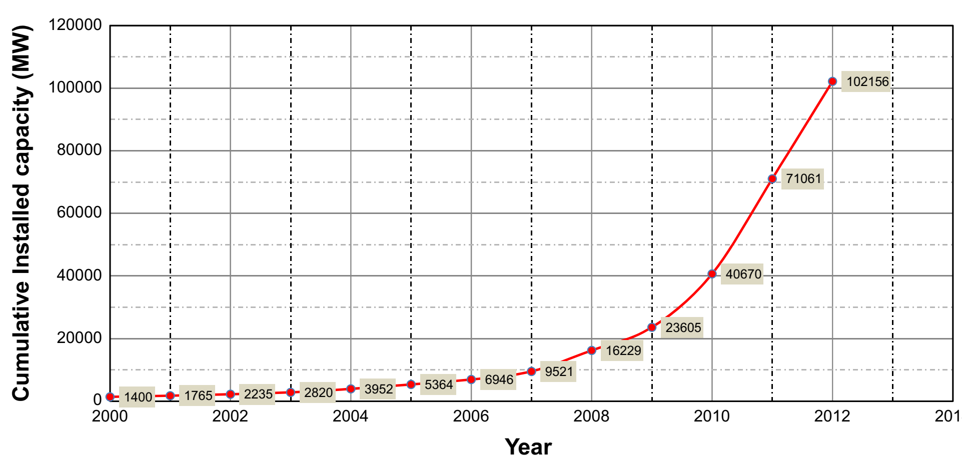

Fig. 1. The global PV cumulative installed capacity 2000–2012 [5].

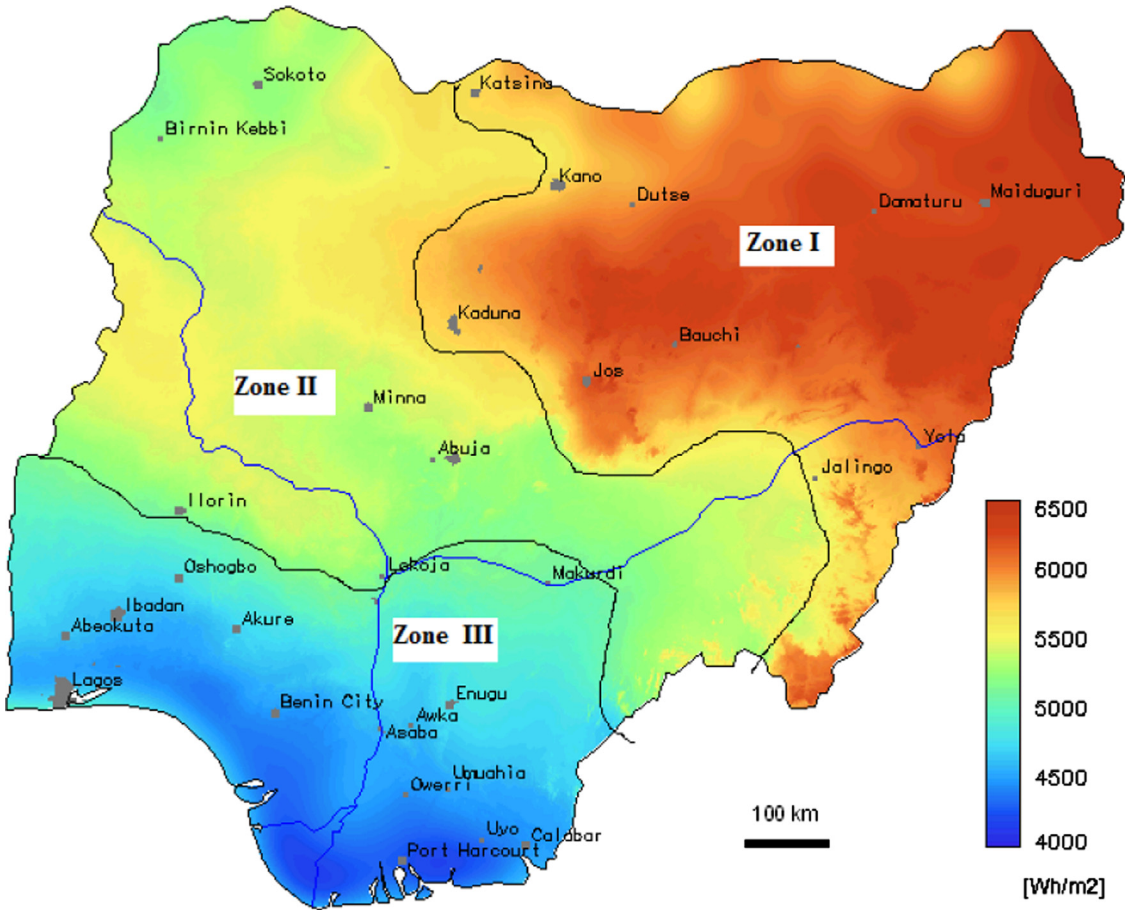

Fig. 2. Solar radiation map of Nigeria [10].

Table 1
Solar radiation zones (global horizontal irradiation) Ref. [10].

Zones	kWh/m²	h/d	kWh/m²/yr	States
Zone I	5.7–6.5	6.0	2186	Borno, Yobe, Jigawa, Kano, Kaduna, Bauchi, Gombe, Adamawa, Plateau and Katsina
Zone II	5.0–5.7	5.5	2006	Sokoto, Zamfara, Kebbi, Niger, Abuja, Nassarawa, Taraba, Kwara, some section of Plateau and Katsina
Zone III	< 5.0	5.0	1822	Oyo, Osun, Ekiti, Kogi, Benue

With the high solar radiation incident on the horizontal surface, the country has excellent and viable potential for large scale solar photovoltaic (PV) especially in the semi-arid region. Zone II consisting of the North-West and North-central belt of the country, also have viable solar radiation that may be required for most solar projects. Low potential of annual global solar radiation exist in zone III (comprising all locations in the South region of the country including the coastal region); zone III can be suitable for stand-alone PV systems. Furthermore, some states/locations in the South-West and South-East regions can readily support decentralized solar energy projects.

Despite the abundant solar energy deposit in Nigeria, it was found that applications and utilization of the resource is majorly limited to small-scale and isolated applications. The aim of this work is therefore to: (i) present an overview of status of solar energy development in Nigeria, (ii) discuss the possible motivations for the development of this resource together with the current obstacles to large-scale development of solar energy conversions systems (SECs) in Nigeria and (iii) suggest some steps and policies needed to be taken into consideration in order to accelerate the development of solar energy in Nigeria.

2. Status of solar energy development in Nigeria

For decades, solar thermal has been constantly enjoying very high level utilization by rural dwellers for agricultural processings in purposes including drying of agricultural products such as grains, cassava (tubers or marsh), yam flakes, meat, fish, fruits, kernels, drying of manure, hides and skins, cooking and frying of agricultural products which are not preserved or sold raw. Other areas of solar energy utilizations include heating and lighting of animal pens, pumping of water and irrigation, food and vaccine storage [11]. In addition to these, solar energy has also found wide usage in Nigeria viz: solar street lightings, solar refrigerators, solar cookers, solar-powered water pumps, etc; different applications exist in the form of solar thermal and solar PV.

Solar energy devices (mainly solar thermal) have been designed, built or adapted by research institutes and tertiary institutions across the country. Notable among the products in existence locally is the built 1000-litre capacity solar water heating system at the Usman Danfodiyo University Teaching Hospital, Sokoto in 1998 by the Sokoto Energy Research Centre (SERC), solar driers, solar chick brooders and solar absorption refrigerators developed at the National Centre for Energy Research and Development (NCERD). Solar PV found widespread usage in street lighting, but other pilot projects including water pumping, vaccine refrigerators, community lighting and few stand-alone mini grids installed and scattered across the country by the government or any of its agency like the Energy Commission of Nigeria (ECN), Federal Ministry of Power (FMoP) and the Federal Ministry of Science and Technology (FMoST) also exist. List of some solar projects as carried out by ECN is given in Table 2. However, synergy does not exist among all the major energy players (ECN, FMoP, FMoST, other private donors and state parastatals that are involved in energy projects), hence, no comprehensive project database exist for renewable projects in the country. Furthermore, all existing projects are either off-grid light applications of few kWp or stand-alone mini-grid at the moment; off-grid hybrid or grid connected solar projects do not exist across the country.

Table 2
List of some energy projects in existence in Nigeria.
Source: (i) Energy Commission of Nigeria (http://www.energy.gov), Ref. [29].
(ii) *61: Ref [30].

S/N	PROJECT	LOCATION	STATE
1	Solar based rural electrification	Oproma, Ekawe	Bayelsa
2	Solar based rural electrification	Oproma, Ekawe	Bayelsa
3	Solar based rural electrification	Ekowe	Bayelsa
4	Solar based rural electrification	Egwuma	Benue
5	Solar based rural electrification	Okokolo	Benue
6	Solar based rural electrification	Ogbanlu	Benue
7	Solar based rural electrification	Ekwo	Benue
8	Solar based rural electrification	Enungba	Benue
9	Solar based rural electrification	Ojantele	Benue
10	Solar based rural electrification	Ikobi	Benue
11	Solar based rural electrification	Adiga	Benue
12	Solar based rural electrification	Usha	Benue
13	Solar based rural electrification	Egwuma,	Benue
14	Solar based rural electrification	Ikobi	Benue
15	Solar plant	Evwreni, Ughelli North LGA(II)	Delta
16	Solar plant	Evwreni, Ughelli North LGA	Delta
17	Solar based rural electrification	Ibuza	Delta
18	Solar based rural electrification	Ibuza	Delta
19	Solar based rural electrification	Ibuza	Delta
20	Solar based rural electrification	Ibuza	Delta
21	Solar based rural electrification	Ibuza	Delta
22	Solar based rural electrification	Ibuza	Delta
23	Solar based rural electrification	Ibuza	Delta
24	Solar based rural electrification	Filin-dabo, Abuja	FCT
25	Development of farm for bio fuel production	Abuja	FCT
26	Solar pilot project	Malam Inna	Gombe
27	Solar based rural electrification	Laya	Jigawa
28	Solar based rural electrification	Sakura	Jigawa
29	Solar based rural electrification	Sharhori	Jigawa
30	Solar based rural electrification	Tudun Wada	Jigawa
31	Solar based rural electrification	Dubau	Jigawa
32	Solar based rural electrification	Kurmin sata, Chikun,	Kaduna
33	Solar based rural electrification	Kasuwan Daji Igabi,	Kaduna
34	Solar based rural electrification	Gubuci	Kaduna
35	Solar based rural electrification	Kudan	Kaduna
36	Solar based rural electrification	Makarfi	Kaduna
37	Solar based rural electrification	Hunkuyi	Kaduna
38	Solar based rural electrification	Panladan by Railway, Sokoto Rd Zaria	Kaduna
39	Solar based rural electrification	Panladan by Railway, Sokoto Rd Zaria	Kaduna
40	Solar based rural electrification	Kano – Kafur Rd Malumfashi	Katsina
41	Solar based rural electrification	Galadima Sallau,Tunai Dudi,Shawai Rd,Malumfashi,	Katsina
42	Solar based rural electrification	Galadima Abu, BCGA-Dan Murubo Rd, Malumfashi,	Katsina
42	Solar based rural electrification	Borin Dawa Muntari Abubakar Rd Malumfashi	Katsina
43	Solar based rural electrification	Danbilagu Unguwar Makera, Malumfashi	Katsina
44	Solar based rural electrification	Danbilagu Unguwar Makera(II), Malumfashi	Katsina
45	Solar based rural electrification	Birnin Kogo, Faskari	Katsina
46	Solar based rural electrification	Sirika B, Dutsi LGA	Katsina
47	Solar based rural electrification	Galadima Abu, BCGA-Dan Murubo Rd, Malumfashi	Katsina
48	Solar based rural electrification	Birnin Kogo, Faskari	Katsina
49	Wind energy for electric power generation	Kebbi	Kebbi
50	Wind energy for electric power generation	Yauri	Kebbi
51	Solar based street lighting	Adeyemi Street Ogun Oloko, Mafoluku Oja	Lagos
52	Solar based rural electrification	Old Muri and Environs,	Taraba
53	Solar based rural electrification street light	Palace way to Comprehensive Sec. Sch, Behind SSS Office Jalingo	Taraba
54	Solar based rural electrification	Tella village	Taraba
55	Solar based rural electrification	Tella village	Taraba
56	Solar based rural electrification	Old Muri and Environs	Taraba
57	1.565 kWp Solar-powered borehole and street lighting	Malarin Gamma Village, Malam Madori LGA	Jigawa State
58	1.820 kWp Rural solar electrification project	Gui, AMAC	FCT
59	2.85 kWp solar based electrification	Centre for Mentally Ill Destitutes, Itumbuzo	Abia
60	1.75 kWp solar based electricity and street lighting	Ini LGA Secretariat	Akwa Ibom
*61	7.5 kW centralized solar power plant	Oduduwa Road, University of Ibadan	Oyo State

According to Sambo [12], solar PV installations are growing in Nigeria. A survey in Bala et al. [13] on PV installations in over ten Northern states of Nigeria, showed that the distribution in application by type includes: water pumping (57%), rural-clinic (for refrigeration and lighting (24%)), communications (television and radio (10%)), village and domestic lighting/TV viewing (8%) and experimental room air conditioning occupying 1%. All these have increased in recent years due to the appalling power situation in the country. In addition, low-powered solar appliances in kWp (solar lanterns, solar battery chargers and other solar-powered home appliances) can be seen on retails across the country.

3. Drivers and barriers to solar application and development

To meet up with the energy need by considering the escalating population growth and socio-economic activities, the planned Vision 20:2020 envisaged an increase in the country's electricity production from 4000 MW that had been attained since 2007 to 35,000 MW in 2020. The contribution target from renewable resources by the FMoP for 2020 is 1000 MW of capacity installed and expected mostly from large scale hydro power development (Vision 20-2020 [14]). This actually shows government's desire to increase electricity generation and also the incorporation of renewable resources into the country's energy mix. Solar energy development can bring major benefits for economic and social development especially in rural areas through the different range of applications. The development of solar energy conversion systems can thus be driven by many factors as discussed in Section 3.1. However, solar energy development also faces many obstacles in Nigeria. Some of these obstacles or barriers are presented in Section 3.2.

3.1. Motivations or drivers for solar power development

Apart from the advantage of good solar radiation and its abundance across the country, several other drivers propelling solar energy development in Nigeria are as discussed below:

3.1.1. Power sector reforms law

The enactment of the Electric Power Sector Reform Act (EPSRA) Cap E7 LFN 2004 in March 2005, made provision by law for an individual to construct, own or operate an undertaking for generating electricity not exceeding 1000 kW in aggregate at a site without a license and/or own or operate an undertaking for distribution of electricity with a capacity not exceeding 100 kW in aggregate at a site without a license [15,16]. This exemption to holding a license favours energy generation from renewable resources. This law empower individual or group of individuals to invest in stand-alone or off-grid power generating systems [16]. The legislation also made way for the establishment of the REA whose major objectives are to: (i) extend the national grid (ii) facilitate independent off-grid systems (iii) generate renewable energy power and (iv) coordinate renewable electricity activities among the state and federal agencies. Solar energy will thus play a major role in achieving these objectives in both the grid-connected and independent off-grid systems because of the abundance of solar radiation in this country.

3.1.2. Reduction of CO_2 footprint

Climate protection is one of the major drivers for solar energy development in Nigeria. Nigeria has a coastline that is 800 km long, sea level rise of about 0.2 m will inundate approximately 3400 km sq. of the coastline; several kilometers of arable lands have also been found to be lost annually to desert encroachments. Rise in sea level and desertification are consequences of changing climate as propelled by rapid greenhouse emissions. Solar applications produce no emission thus meeting or exceeding emission standards around the world. Energy generation through various solar applications will thus reduce the industry's carbon footprint and will also be an excellent means of reducing carbon dioxide (CO_2) emission thereby mitigating climate change across the country. The lowering of the water table in the North through desertification will continue to also make solar water pumps a relevant choice in water supply.

3.1.3. Energy demand

Population projection of Nigeria was expected to grow from 115.22 million in 2000 to 268.81 million by 2030 at an average annual rate of 3.86% between 2000 and 2030. Population growth is a major driver of energy demand while its most important determinant is the level of economic activity measured by the total GDP alongside with its shares by the various sectors and sub-sectors of the economy [17]. The rapidly growing demand for energy will create opportunities for solar energy development because conventional energy sources will not be enough to meet the need of the ever increasing population in a flexible manner. Furthermore, the expanding economic opportunities in the rural areas will also demand an aggressive deployment of renewable energy options (most especially the vast solar resources) due to grid non-availability needed to evacuate generated conventional power to the respective primitive locations [8].

3.1.4. Energy security and access for rural electrification

It was estimated that only 10% of the rural population in Nigeria have access to electricity services [8]. Even in semi-urban and urban areas, there is also an 80% demand-supply gap in electricity in the country making most businesses to run on self-generated electricity using diesel- or gasoline-powered generators. In addition, the transmission network is overloaded resulting in a poor voltage profile on most parts of the network. There are occurrences of frequent system collapse and exceedingly high transmission losses [15], often in the range of 30–35% [16]. However, the official transmission losses are reported as less than 10% [17]. Particular issues identified include stagnated power generation capacity growth, inadequate maintenance procedures, and a lack of human capacity development. Currently, power mix in the country is dominated by fossil fuel based generating plants. Since the off-grid power needs are enormous in Nigeria, stand-alone PV and solar thermal systems thus constitute a safe, reliable and to a large extent an affordable alternative to the widely spread self-powered generator sets. Every part of the country (as shown in Fig. 2) is very relevant for modern off-grid solar products, even in grid-urban areas that are characterized by a highly unreliable network. Solar energy is thus a stabilizing factor for the energy supply system in Nigeria; energy generation through various solar energy developments will therefore be a high potential source for diversifying energy sources and increasing the share of domestic energy supply in the country, thereby meeting the objective of security of supply.

3.1.5. Conflict neutral energy sources

One of the major problems of fossil-fuel plants in Nigeria is the lack of/or irregular supply of gas for the gas-powered plants. In most cases, the problem is due to sabotage and destruction by the youth restive groups (militancy) and oil pipeline vandalism in the Niger Delta region of Nigeria [18]. Solar technologies do not incorporate conflict relevant materials. The resource is abundant and inexhaustible, and will not give rise to conflicts about using rights. This may serve as an important pushing factor for solar technologies, more so that it addresses the same market segment in the country as fossil plants.

3.1.6. Increasing demand for local added value

Solar technologies will support the needs of developing countries like Nigeria through added local values. Only about 30% of the entire Nigeria population are connected to the national grid and the majority (mostly rural dwellers) are left to the use of biomass and fuel wood for their energy needs. Most of solar applications can be developed locally by the rural dwellers for energy in various forms (solar cookers, solar chicken brooders etc). Majority of solar based applications belong to technologies with a high potential for local added value; some have a little fraction of high-tech components substituted with other parts that easily subject themselves to local fabrication. This will promote socio-economic stability, skill acquisitions and employment generation.

3.1.7. Job creation

Promotion of solar technologies across the country will contribute immensely to poverty reduction through local communities benefiting from employment opportunities, skills development, investment opportunities and technology transfer. Many renewable energy pilot projects in developing countries give anecdotal evidence of the role that renewable sources can play in energy-poor communities [19–21]. Therefore, increased investment in solar applications will lead to the development of indigenous expertise in repairs, installations and manufacture of the various solar devices across the country and in particular the rural, off-grid communities thus leading to vast job creation.

3.2. Barriers

Solar application in Nigeria is actually experiencing a lot of challenges despite the (i) good solar radiation availability across the country, (ii) inherent advantages and motivations as discussed (Section 3.1) and (iii) market opportunities created by the numerous dwellings/inhabitants without or with limited access to electricity. A number of barriers to the development of solar energy in Nigeria include:

3.2.1. Variability and intermittency of radiation

Solar energy is a variable resource and its availability as an energy source fluctuates. Sunshine duration in Nigeria ranges from a minimum 4 h in the South to 9 h/day in the Northern part of the country [8]. As a result, electricity output from solar power plants across the country will vary accordingly while its demand does not follow similar pattern. Grid connected and hybrid solar electricity can only be realizable in the North where solar insolation is highest whereas off-grid solar applications (solar lantern, solar battery charger etc) can be a viable option in the Southern part of the country. However, this shortcoming can be overcome by the development of appropriate solar energy storage technologies for storage purposes when solar energy is available, and then re-use when the energy is not available.

3.2.2. Grid unreliability

This portends a barrier for grid-connected solar power. Currently, the transmission grid in Nigeria operates at 132 and 330 kV with a coverage that is limited to about 30% of the populace that are mostly spread in the urban/semi-urban regions of the country. The transmission network is found to be a weak link in the electricity supply chain in the country. The current transmission capacity of the national grid is less than 6000 MW [17]. Most of the transmission equipment across the country are aged, obsolete, poorly maintained and the construction of new lines is not in view thus making the operational transmission capacity to be presently below 5000 MW. In addition, utility-scale solar power plants are often located more remotely than fossil-fuelled plants due to the requirement for wide land area in primitive locations with no grid access. At the moment, the country's national grid is not designed to handle intermittent electricity generating system; therefore, grid connected solar applications will require the construction of new and expensive transmission lines which have hitherto been proving very difficult in Nigeria due to the associated cost.

3.2.3. Lack of awareness and information

The level of awareness about the immense socio-economic and environmental benefits derivable from solar energy among the citizens and decision-makers at different political and administrative levels is very low in Nigeria. The current flow of information about the development, various applications, dissemination and diffusion of solar energy resources and technologies are also inadequate. There is inadequate and insufficient education of consumer/solar applications users. Solar projects (mainly solar street lights) across the different states of the country had been executed by inexperienced technicians/practitioners using substandard solar products; most of the facilities are therefore no longer functional. This has established poor confidence of the technology among the public, private and financing sectors on the adoption of SECs in the country.

3.2.4. High initial investment cost

A basic barrier to the development of solar energy technology in Nigeria as a developing country lies in the high initial costs, including high installation costs with long payback times. High initial costs may also reflect high-risk perceptions of investors and a general lack of financing instruments as well as fragmented or underdeveloped financial sectors [21,22]. There is also lack of incentives on import or local manufacturing of solar devices in the country. Import duties are not allowed on solar PV in Nigeria; when the PV to be imported into the country forms a part of the complete solar device including battery storage, it attracts a 21% import duty. This has forced the initial investment cost of solar devices to tower high above other conventional energy sources (such as diesel generators whose duties are stable, regular, and the products readily available when needed). This challenge further becomes more pronounced in the country because of the high transaction costs since most solar projects are decentralized and within the small scale range. The solar energy projects thus become too costly in the long-run for local banks in Nigeria to consider for financing. The banks are always in a haste to recover funds and hence contemplate long-term solar projects too risky to finance. Furthermore, with the view that most of the populace belong to the low-income range, it is thus generally difficult for an average individual to invest in solar energy systems.

3.2.5. Operation and maintenance costs

Solar technologies have been viewed as the energy supply option for the remote and rural poor areas in the country. At the moment, the operation and maintenance costs are appreciably high in the country, due largely to lack of technically skilled personnel. Hence, potential users of the technologies (occupying largely the remote locations) may be prevented from the adoption of SECs due to fear of failure in the absence of technical supports.

3.2.6. Government policy and incentives

Policies instituted by the government have not supported the profitable exploitation of renewable energy resources (generally and particularly solar energy) for any intending investors. High supports in the form of subsidies are given to encourage energy generation from conventional energy sources leading to a fall in their prices and thereby creating an unfair competitive environment for solar energy exploitation; this has led to a slow in the growth demand for solar energy devices. Furthermore, production of electricity in developed countries from solar resources is largely driven by Feed-in-Tariffs (FiT) (France, Germany, Spain, etc.) and government personal income tax credit solar PV-targeted tax incentives (e.g., in the USA and Australia) [23]. For instance, the

German government in 1991 introduced the Electricity Feed Act in Germany, which regulates the feed-in to the grid of electricity generated from renewable resources. This Act made it mandatory for utility companies in Germany to purchase electricity generated from renewable resources at set rates (feed-in tariffs). Due to this Act, the PV installed capacity has increased from about 90 MW in 2000 to 17370 MW in 2010 in Germany and similar trend was reported for countries with favorable government policies [23]. The proposed FiT incorporated into energy policies in Nigeria is not attractive for investors and this must be reviewed to encourage private investment into solar infrastructures. The proposed FiT ranges from 68 NGN/MWh (US$0.4366) to 93 NGN/MWh (US $0.5970) between 2012 and 2016 for solar plant in the country; this is very high to allow for profitable investment by any intending investor.

3.2.7. *Ineffective quality control of products*

Absence of national technical standards and effective quality control units in the country were identified as a major institutional challenge to the adoption of renewable energy in households. This absence is due to lack of appropriate training and personnel. Most of the solar products are imported from China through various nation's borders into the market. There are no existing standards and specifications regulating these products; products are also without trademark certificates and certificates of analysis from manufacturers (most of the products in the market have no brand name). These led to the influx of large quantities of substandard/poor quality of solar components; systems and services are also poorly installed by technicians with inadequate expertise. Confidence reposed on the technology has thus been undermined since the high initial cost of investment into these products cannot be justified.

3.2.8. *Insecurity of solar plant infrastructure*

Most locations that are very suitable for the development of solar energy system in the country had played hosts to militant insurgency in the past. Insecurity has affected power plants constructions and other infrastructures through kidnaps and killing of workers in various parts of the country. General insecurity of solar infrastructures especially in the northern region of the country where there are abundant solar insolation can be a potential threat that will stall future investment in large scale grid-connected solar infrastructure.

3.2.9. *Competition with land uses*

Land issues may be very complicated especially when the intending project to be sited on such land, is non-governmental. There may be a major challenge in siting and securing of permits for solar power plants in new locations. Most land in rural communities are for agriculture being the major occupation of the inhabitants; ownership of such piece of land may also belong to families or communities. Most communities are preventing foreigners from owning land for fear of total destruction of their heritage (e.g. Niger Delta oil spillage that has destroyed aquatic lives). Since solar projects on a large scale will involve private participation, prohibiting foreigners from owning land will constitute barriers to their involvement in bilateral solar project development and hence may be a major barrier to solar applications especially solar PV on a large scale.

4. Steps and policies to overcome barriers to solar energy development

In order to overcome the above barriers and accelerate the development of solar energy applications in Nigeria, there will be the need for favorable policies and strong political will from the government at all levels (Federal, State and local). However, the removal of one or more barriers may not be sufficient to encourage and/or increase investment in solar energy as such actions may even be in conflict with other government policies. For instance, some land areas or regions may be designated for large scale farm in order to improve food security in the country and using such regions for solar energy development can lead be a threat to food security in such locality. To accelerate solar energy development, the following steps and policies are suggested:

4.1. *Mitigate political and regulatory investment risk*

The development of essential reform processes in political, economic and societal structures that will be needed to manage corruption, establish standards of transparency in public administration and enforcing established laws are essential in reducing the fundamental barriers of the political and regulatory risk of the country. There is also need for political will and determination to address security related issues, as previously discussed.

4.2. *Cost reduction measures*

Solar energy development is economically viable in Nigeria but project finance is not readily available. Financial institutions can be encouraged to offer loans to retailers of solar technologies at rates that are more favorable than commercial terms. Retailers will thus have access to capital needed for procurements of SECs (e.g. solar PV) in bulk. It may also be essential to provide soft loans with low interest rates for solar energy projects. In addition, micro-lending schemes adopted by microfinance institutions should be encouraged and promoted. Micro-credit linked to micro-enterprise has proven highly successful in promoting renewable energy and reducing poverty in some countries [24]. Currently, the federal government made economic incentives (such as tariffs waivers, subsidies) available to encourage energy investments through fossil sources. These incentives are not open to renewable resources projects; switching these subsidies from fossil fuels to fund the required incentive mechanisms for renewable energies development will surely accelerate the development of these resources (especially, solar energy) in Nigeria. This will create a level playing ground between the energy sources (conventional and renewable); through this means, the risk-return profile of renewable energy relative to conventional energy will be improved [25].

4.3. *Favorable government policy*

Favorable policies are fundamental to long-term sustainability of solar energy development. The lifetime and crediting period of large scale solar projects will exceed the democratic duration of any government in Nigeria. Ensuring that laws are stable and enforced is very vital as potential investors will need reasonable certainty that key legislative provisions put in place for solar activities will remain stable, unambiguous and enforced, thus allowing the continuity of investment into the future. In addition, the current electricity tariff is low; the tariff is not market reflective for profitable investment in power generation even with the existing fossil fuel energy sources and hence will not encourage any transactions into solar applications by any potential investor. However, increasing the tariff regime may be counter-productive considering the fact that larger portion of the population belong to the low-income level.

4.4. *Consistent awareness creation*

Large scale implementation of renewable energy applications can only be undertaken successfully with the understanding and support of the public [21,26]. Hence, increased awareness into the benefits and opportunities associated with the development of

SECs and the inherent advantage for climate change mitigation is vital to rapidly and significantly improve the desire and interest among the public across the country. Awareness is also found to be an important ingredient needed to help in specific solar project identification and will also assists in tackling the problem associated with insecurity of solar plant infrastructures. Awareness can be accomplished through various promotions and dedicated communication efforts primarily through workshops and media (television and advertisement) and community meetings/forums. These meeting and advertisement will need financial support of the government and non-governmental organizations.

4.5. Competition with land uses

Large-scale solar projects (PV solar farms, CSP farms etc) are often associated with trade-offs related to competing uses of large pieces of land. Most arable lands in the country are for agricultural purposes in rural communities. Land use issues arising from commercial scale energy crops are another area of increasing attention [21,27,28]. Government should establish economic compensations scheme policy which can be offered to affected populations for possessing their source of income (land) for solar energy development and educate/train them on skill acquisitions in solar technologies to provide alternative job opportunities.

4.6. Establish and enforce quality standards for solar energy equipment

A lot of setbacks due to poor-quality solar systems had been suffered with some solar energy projects in this country. The Standard Organization of Nigeria (SON) and other government agencies such as ECN need to establish suitable manufacturing standards and specifications and to strictly enforce them. Policy instruments and incentives could be introduced to encourage local production of solar devices. The failure of solar energy equipment and associated appliances are due to poor sizings and designs, resulting from lack of quality solar and other meteorological data.

5. Concluding remarks

In this paper, solar energy resources, its current applications and the extent of utilization in Nigeria are presented. Motivations and obstacles to solar applications and developments together with measures needed to overcome the identified barriers were suggested. In order to extensively develop solar energy resources in Nigeria, good and enforceable policies with strong political will are necessary in the following areas:

i. Manpower training with skill knowledge on solar energy technology.
ii. Financial support for research in solar data collection and analysis.
iii. Financial and subsidy incentive to individual, communities as well as private organizations to invest in solar energy development.
iv. Financial compensation and training for individual and communities whose land are acquired by government and/or investors for the development of the solar energy project.
v. Encouragement of community participation/ownership of solar energy projects for security and infrastructure protection.

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