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# Barriers and motivations for solar photovoltaic (PV) adoption in urban Nigeria

**Anthony Ifeanyi Ugulụ***

*Department of Construction Management and Quantity Surveying, Faculty of Engineering and the Built Environment (FEBE), University of Johannesburg, Auckland Park Campus, 2006, Johannesburg, South Africa.*

**ABSTRACT:**

For decades, Nigerian households have endured unreliable national electricity supply which have stifled economic growth and socio-economic development. As nations shift to green electricity adoption and a commitment to lowering their carbon footprint, opportunities arise for developing countries like Nigeria to improve supply using solar PV for power generation. At over 50% private power systems ownership, the majority of urban Nigerian households rely on self-generation using expensive petrol and diesel-powered generators. With PV generated electricity increasingly becoming more cost-competitive with conventional sources due to technological learning and support policies, this paper investigates the barriers to and motivations for PV adoption in urban Nigeria. Using interviews, data were gathered on key barriers to and motivations for PV adoption and results analysed. Findings indicate that the major barriers are high capital costs and lack of finance. The key motivation for PV adoption was power outages, energy cost-savings including generator use fuel fraud, awareness and access to finance. The results point to the need for regulatory and political intervention. Effective PV awareness creation campaigns and promotional strategies would also be necessary in the changing face of electricity supply in Nigeria.

***Keywords:***

Solar PV electricity;
Adoption;
Barriers;
Motivations;
Urban households;
Nigeria;

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## 1. Introduction

Promoting green energy technologies and energy efficiency are the two core tenets of the transition to a low-carbon future. The goal is to advance renewables and encourage resource-use efficiency particularly in the built environment which constitutes the bulk of energy use and emissions globally [1]. It is generally accepted that following this path would ensure the security of vital energy systems via the use of more sustainable energy sources. This is because conventional fossil-based sources are environmentally harmful. Heavy reliance on combustible fuels contributes to climate change which causes global warming. A situation that many nations globally now seek to mitigate due to the adverse consequences linked to a warming globe.

As part of this initiative, the UN Sustainable Development Goal (SDG) 7 is aimed at increasing the use of clean energy systems with the goal to make it affordable by 2030 [2]. While the targets may not be binding for Nigeria [3], it is important to put various policy measures in place to diversify the national energy portfolio and promote renewable energy technologies (RETs). Nigeria also has its own nationally set targets for clean energy aimed at improving electricity supply, increase access as well as reduce environmental pollution. In the long term, it is projected that solar PV will provide 13 GW by the year 2030 [4]. This figure excludes solar PV streetlighting, solar refrigerators and solar hot water systems.

Ranging between 12.6 MJ/m$^2$/day to 25.2 MJ/m$^2$/day (3.5–7.0 kwh/m$^2$/day), Nigeria has an ideal solar

[1]Corresponding author - e-mail: anthonyugulu@yahoo.com; aiu30@hw.ac.uk.

radiation base. using Artificial Neural Networks (ANN), Fadare [5] mapped the entire country to arrive at average solar radiation intensity for all urban areas with lagos receiving between 12.6 MJ/m$^2$day to 19.5 MJ/m$^2$/day (3.54 –5.43 kwh/m$^2$/day). Recently, in their assessment of solar potential in cities in Nigeria, Ozoegwu [6] demonstrated similar. As a city, Lagos has the added advantage of being in a coastal area where PV performance is generally better than in excessively hot climates or locations. This is why, despite low overall solar insolation in a location like Ireland, improved module performance was recorded [7]. In their study examining Lagos and Ibadan, Fagbenle et al. [8] reported the technical feasibility of using PV in such urban locations. Despite this the uptake of PV in Nigeria has been slow with the current installed PV capacity estimated to be less than 1 MW [9].

Presently in Nigeria, the operational grid network is undersized at 6000 MW [10], commensurate to the 185 million population [11] it is intended to serve. The under-capacity of the grid infrastructure has frequently led to power outages with electricity rationing and load shedding commonplace for most households. At the present operating capacity, the grid network is only able to meet 31% of the energy necessary for minimal use [12]. For this reason, for years, the supply and demand gap has been filled by households using private power generators making them ‘experienced’ own-power generators. As a result, approximately half of the electricity produced in Nigeria is generated off-grid [13]. But the price of petroleum products for these generators have risen sharply. Similarly, following the removal of state electricity subsidies electricity tariffs have increased by over 80% [14] making modern renewables like solar PV more competitive.

The Nigerian government has recognized the scale of the electricity sector problems and the crucial role the private sector and energy end-users would play towards improving the electricity situation. This is because the cost of grid expansion for 100% connection runs into millions of dollars making it unaffordable for the government [13]. Given the exorbitant electricity tariffs, high petroleum prices, suitable solar resource of between 12.6 MJ/m$^2$/day to 25.2 MJ/m$^2$/day (3.5–7.0 kWh/m$^2$/day) [5] and the constantly declining costs of PV modules, this paper investigates the barriers to and likely motivations for residential solar photovoltaic (PV) adoption in cities in Nigeria.

Although there are studies on the necessity of including RETs such as solar in the energy portfolio in Nigeria, most focus on rural electrification programmes [15] which has not been successful in many studies [11, 12]. When focused on urban electrification, the existing studies emphasize centrally supplied electricity [13, 14]. For decades, this focus on large central power approach has failed hence the current national power predicament. Only Fagbenle et al. [8] researched the potential of adopting PV in cities using ANN and found it to be technically viable. But their focus was on commercial buildings. No known study has approached the electricity provision challenge directly from the viewpoint of the electricity end-users, the households.

Analysis of these studies revealed opportunities for improvement in the PV promotion agenda. This study contributes to the debate from a demand-oriented perspective. It proposes a solution based on the ‘experienced’ power-generating households. This paper therefore investigates the barriers to and motivations for urban households PV adoption in Nigeria, and how uptake can be accelerated through this group. This paper is structured as follows. Section 2 discusses the background, status quo of electricity generation, energy consumption and challenges in Nigeria. In section 3, the theoretical framework that underpins the study are explored. Section 4 focuses on the method of enquiry. In section 5, the results are presented. Section 6 discusses the key findings in relation to existing studies. Section 7 concludes the paper by suggesting some policy recommendations based on the findings.

## 2. The status of electricity and energy generation in Nigeria

In Nigeria, electricity is jointly produced using thermal power plants and hydropower with the thermal plants generating a bulk of the supply at 81% [19]. The undersized operational grid infrastructure of 6000 MW implies that there is always an imbalance between demand and supply which households and other energy end-users have to bridge using private power generators. Nigeria is also rich in crude oil and natural gas and is one of the largest exporters of this resource. Crude petroleum sales represent over 75% of the government’s revenue bringing in close to \$100b per year from 2011–2013 [17, 18]. To emphasize, daily crude oil production in Nigeria up until 2014 constantly averaged 317,974 cubic metres (2.0 million barrels) [22].

However, in recent years, the oil revenues have been on the decline due to fall in oil prices to below \$80 for 0.1589 cubic metres (per barrel) for the first time since 2014. Also, the discovery of shale gas in the United States of America which was Nigeria's largest export market [23] has resulted to a reduced source of revenue for the Nigerian economy. Figure 1 represents the decline in demand for the Nigerian crude oil over a period of 10 years. Such revenue drop is another reason for wanting to divest from fossil fuels and moving to cleaner energy sources which are subject to lesser market fluctuations. Nigeria is also one of the largest gas flaring countries in the world. A practice that is not only wasteful but environmentally degrading. While this has reduced in recent years, it is still amongst the top five natural gas flaring country. Figure 2 details. The Nigerian government has now set targets for renewables with 13 GW of electricity expected to be generated from solar PV by 2030 [4].

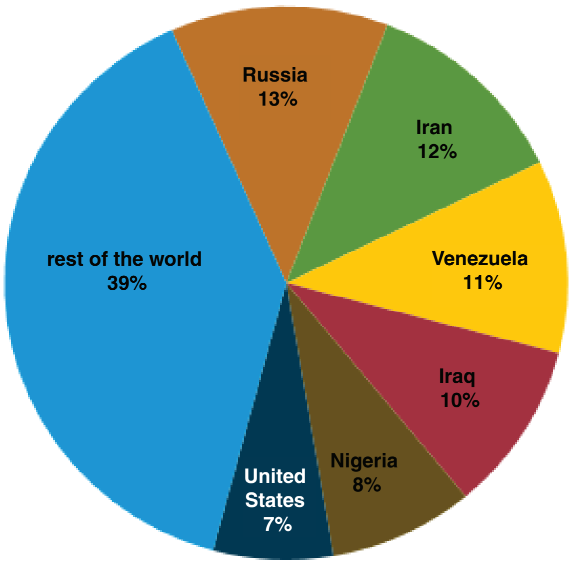


Figure 2: World's top five natural gas flaring countries as at 2014, Source: IEA, 2017

## 2.1. Patterns of electricity consumption in Nigeria

Electricity demand in Nigeria is broadly grouped into residential, industrial, and commercial sectors. Demand from the residential sector has in the past decades taken up the largest proportion of total electricity production [24]. Figure 3 illustrates. This is in sharp contrast with

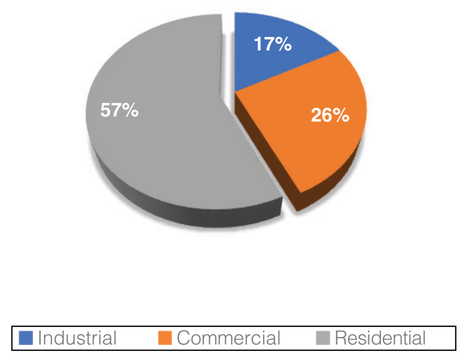


Figure 3: Electricity demand by sector in Nigeria 2000 to 2011 Source: Author using IEA data

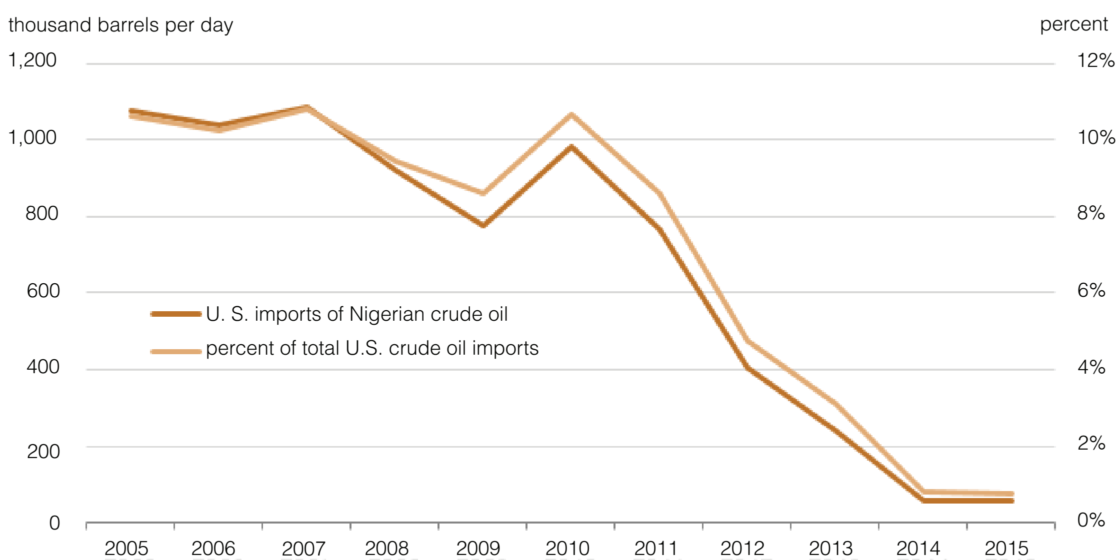


Figure 1: US crude oil net imports from Nigeria from 2005–2015 Source: EIA, 2017

South Africa where industry represented the largest total electricity consumed for the same period. [25].

### 2.2. Challenges of the electricity sector in Nigeria

Urban households generally use electricity for lighting, use of appliances and sometimes for cooking. Due to the power supply shortages, many urban dwellers use Liquefied Petroleum Gas (LNG) for cooking. This electricity supply and demand imbalance has meant that the average per capita electricity consumption in Nigeria is still small relative to many locations in Africa [4], including other oil resource-rich regions. In 2010, the electricity consumption per capita in Nigeria was 136 kWh/cap while that of South Africa was 4510 kWh/cap. As at end 2012, it rose to 156 kWh/cap for Nigeria. Though that of South Africa fell for period end 2012, it was greater 4000 kWh/cap. Figure 4 details. Although Ghana has oil deposits, it is not an oil-rich country. It was included in the graph for the sake of emphasis.

Based on to the latest available data, the world average electricity consumption per capita for 2014 was 3217 kWh/cap [26]. A figure that South Africa surpasses at 4198 kWh/cap for same year despite a fall compared to 2012 levels. However, for Nigeria, per capita electricity consumption dropped in 2014 by approximately 6% and have been fluctuating between 130 kWh/cap to 156 kWh/cap in the past 14 years without any significant improvement [25].

Using data from urban locations in Southwestern Nigeria (including Lagos state), the Minimum Energy Poverty Line (MEPL) for urban Nigeria should be at least 3068 kWh/cap [12]. The MEPL is the minimum energy that is required to meet the subsistence needs of urban households per/year [12]. This level of electricity demand can be easily generated using a good-sized PV. A 4 kWp PV system was able to generate 4000 kWh/year in the UK meeting the annual energy needs of the average UK household [26]. Such a PV device can generate more in locations with better solar intensity as long as it is properly designed, installed and maintained. The next section discusses the grounded theories on technology adoption, innovation diffusion and barriers and motivations linked to RETs uptake.

## 3. Technology adoption and innovation diffusion theories

Most of the conceptual models deployed in PV adoption and diffusion studies from the end-user's perspective are predominantly based on social psychological perspectives [27]. Fewer studies are embedded in economic principles [28]. The economic model is founded on the classical economic theory of utility. It is centred on rational choice. It assumes that given capital constraints consumers make consumption decisions based on least cost and welfare maximisation. It further views the performance of any

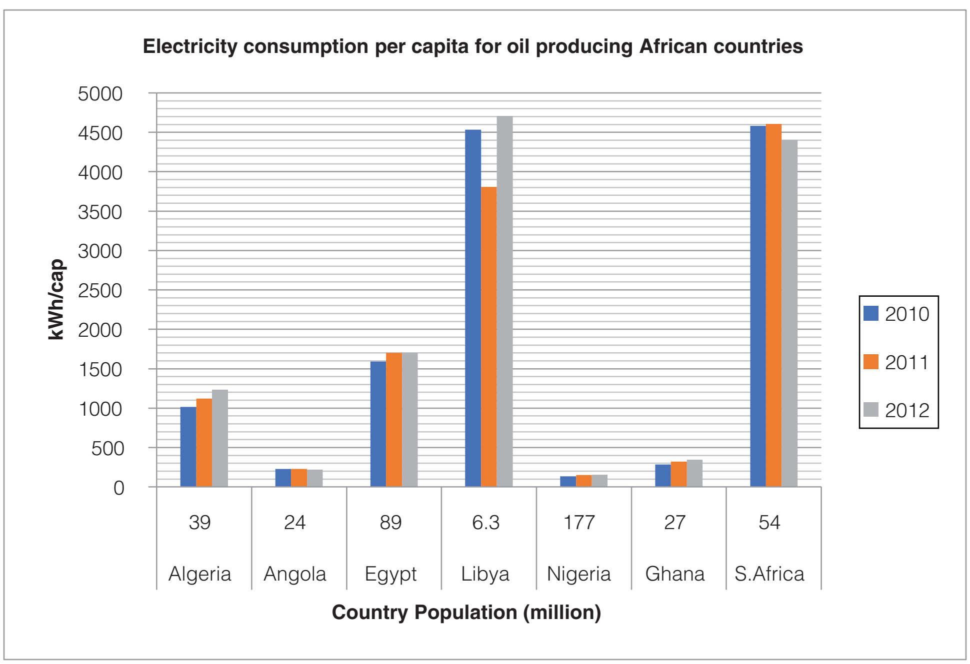


Figure 4: Electricity consumption per capita of select oil rich African countries Source: Author

purchase behaviour as a reflection of an individual's underlying needs. This need is driven by the quest to maximise the satisfaction gained from consuming the product or service concerned. Thus, for any demand for a good or service, there is a conflict with an alternative good or service, as the scarce financial resource faces stiff competition from both desired goods [28].

A key aspect of PV technology's profile which impacts uptake is its high upfront costs and long payback time [29]. High initial costs of PV systems discourage uptake. Due to the initial cost implications of PV as at the time of purchase, it yields negative outcomes, while some desirable outcomes are postponed. Thus, PV is said to represent a high involvement purchase for most individuals [30]. For households in developing countries in particular, low income and purchasing power would mean that the capital-intensive PV becomes unaffordable for many.

Aside capital cost as a deterrent to PV adoption, the influence of payback time (PBT) has been shown [31]. PBT can be important in technology adoption decisions [32]. In general, consumers tend to prefer shorter PBT for their investments. But PBT is only a part of a bigger consumer barrier or motive. An example of PBT not making much of a difference has been shown in the UK, where lower PBT for wall insulations did not result in increased investments [33]. This means that there are other factors necessary for consumer uptake beyond economic factors. The rational choice theory has been criticised mainly by behaviourists, who argue that consumers do not make decisions solely on economics, but also as a result of ethical and environmental worldviews [27].

Studies have shown that altruism and concern for the environment can influence the adoption of green energy technologies [34]. Some other common factors that determine adoption decision include prior knowledge or awareness [35], output limitations, availability of technical support [16] and availability of fiscal support incentives [28]. Aside, the socio-cultural, technological, environmental and economic factors impacting solar PV adoption decision, the key role of regulation and supportive institutions have been repeatedly referenced[26, 32].

As a social psychological perspective, the theory of planned behaviour or reasoned action [37] is one of the most frequently cited in technology adoption and innovation discourses. It has been hugely successful in explaining and predicting consumer behaviours and has found application in many fields. The theory of planned behaviour proposes that attitudes (such as, perceived reputation of utility suppliers), subjective norms (e.g. concern for environment) and perceived control (e.g. technology affinity) drive behaviour. Attitudes, norms and perceived control impact intention and subsequently behaviour [34].

Ajzen's theory also suggests that aside norms, knowledge is also crucial in the formation of consumer attitudes including the formation of 'green' attitudes [30]. This theory is vital in that it helps to reveal the major factors and the characteristics of households who want to generate their own power sustainably. In terms of meeting home energy needs, households must make PV adoption decisions based on a number of factors including: cost, reliability, values, attitudes, energy use behaviour, income, household size and availability of government subsidies etc. This long list of considerations adds to the complexity of the decision-making which can pose a barrier to adoption.

Few studies in Nigeria have explored the power sector challenges in Nigeria and solutions using solar [8, 36] and general renewables [9, 10]. As pointed out earlier, Fagbenle et al. [8] were the first to investigate the feasibility of using PV on buildings in cities and found it to be technically viable. However, they revealed that the investment costs remained a barrier and recommended that carefully designed financial support schemes be used to facilitate uptake. Note that this research was conducted over 15 years ago. Over this time, PV module costs has greatly reduced. Aliyu et al. [9] and Adhekpukoli, [10] researched electricity sector challenge proffering generic solutions that included the addition of renewables to the energy mix, use of support incentives and the importance of private sector participation.

Most importantly, as relates to this particular research, Ohunakin et al. [36] detailed how high capital costs, low level of awareness, absence of incentives and poor-quality control of products has posed a barrier to PV adoption. They also described how favourable government policy can lead to increased adoption. They further opined that solar PV usage is practical in every part of Nigeria including grid-tied urban areas with highly unreliable grid power network. While their study gave insightful details as to the drivers and barriers it was more exploratory based on expert opinion of the sector. In other words, it can be described as a general prescription in the search for electric sector solutions in Nigeria.

This present study takes the electricity sector challenge and solution debate further by examining the electricity and energy end-users, the households. This study therefore investigates the barriers to and likely motivations for domestic PV adoption in urban Nigeria. The goal is to understand why despite a fall in PV module costs from about $30/Wp three decades ago to less than $1/Wp currently, uptake has been slow [4]. Gaining such an insight would help create effective support mechanisms to boost uptake and eventual diffusion. Most importantly, it is argued that private sector PV adoption would help to ease the national electricity supply deficit in cities as well as extend access to the unconnected rural areas.

## 4. Research Methodology

A total of 14 solar PV users from urban households were interviewed with most taken from Lagos state, a key city with one of the most diverse population in Nigeria. Other respondents were taken from Abuja, Delta and Edo states. The reason for drawing respondents from these other states was because of the small number of users initially found in Lagos willing to participate in the survey. The decision to stop at 14 respondents was based on reaching saturation. At saturation point, conducting further interviews would no longer be value adding. This is a known quality control process. Bahaj and James [38] did a comparable study in Southampton, UK using 9 households, while Sommerfeld et al. [39] used 22 Australian PV adopters in their qualitative study.

The interview was primarily designed to understand the barriers that has prevented electricity and energy consumers from adopting the technology when the prices of conventional fuels have been on the rise. It was also designed to gain an understanding from the few early PV adopters the reasons for adoption, challenges faced and how uptake can be accelerated. The gathered data are based on the views and experiences of the heads of households who would have overseen the adoption decision. The impact of human factor in green power technology adoption decisions were also examined.

Following purposive sampling technique, the scheduled interviews were carried out between January to June 2014. Under this type of sampling, the researcher's judgment is relied upon based on study rationale and interest [40]. Purposive sampling is a generally acceptable technique in qualitative studies [41]. The respondents were primarily PV households, installers and module component distributors with varying degrees of experience with using the system. Three of the adopters were recruited following a questionnaire survey of a different study while the remainder were from referrals[1]. In most cases, adopters knew someone else using solar PV and may have had their panels installed by the same technician. This method of referral is also referred to as snowball sampling [31].

The format of the interviews was open-ended and semi-structured to allow the respondents the freedom to say the unexpected which is recommended in qualitative studies. In other words, the interview was flexible but with researcher control. The interview questions format took the order of the opening questions, the intermediate and the final questions. The opening questions centred on how they became aware of PV, the PV system size owned and duration of ownership. The intermediate questions focused on barriers faced by the adopters and potential adopters', the motives for uptake, the adopter's user experiences and their perception of the PV module compared to petrol and diesel-powered generators and national grid electricity. The final questions examined the difficulties (technical, financial and otherwise) faced prior to installing PV and in the course of utilizing PV and respondents' suggestions for dealing with such challenges. All the interviews were recorded with a tape recorder and the data transcribed and analysed using a computer assisted qualitative data analysis software. Table 1 represents the summary of the analysis process followed. Table 2 is a profile of the surveyed adopters while Figure 5 is the Map of Nigeria highlighting the 4 cities from where the adopters were drawn.

## 5. Results and analysis

The barriers to PV adoption as identified in this study were found to be socio-cultural, technical, economic and regulatory as Figure 6 shows. In order of importance, the top three barriers are high capital costs, installer dishonesty and use of sub-standard products and lack of government incentives and regulation. These barriers are discussed next.

[1] A situation where an interviewed adopter refers the researcher to other users

**Table 1: NVivo analysis process, Adapted from O'Neil [42]**

| NVivo analysis phases | Steps taken at each phase |
|---|---|
| **1. Descriptive Phase** | Interview transcript review |
| | Inputting sources |
| | Assigning attributes |
| | Creating values |
| | Creating classifications |
| **2. Topical Phase** | Identifying key themes |
| | Creating initial nodes |
| | Creating memos |
| | Preliminary coding |
| **3. Analytical Phase** | Merging nodes into hierarchies |
| | Text search/word frequency queries |
| | Final coding/matrix coding queries |
| | Creating models and relationships |
| **4. Conclusions** | Cross verification |
| | Validation and theory development |

## 5.1. High investment costs and lack of finance

As shown in Figure 4 and representing 60% of the responses, the high investment cost of a PV system was cited as the foremost impediment to uptake. Although most found the modern power technology appealing and beneficial, the high capital outlay prevented consumers from paying for the system. Collectively, high investment costs and lack of finance accounted for about 80% of responses. As some of the adopting respondents acknowledged,

> Purchasing power is still a key problem. Not many people can afford it due to the high upfront cost. Most people tend to withdraw because of the high cost. - B.C.

The cost of acquiring it is the problem. So, people prefer to continue using the generators they have and be spending maybe like £8–£12 everyday instead of putting in about £3000 or thereabout for good-sized panels. My panels, I actually got it from a distributor friend who agreed that I pay by instalment which made it easier for me. - F.I.

The high capital cost would mean that not many Nigerian households can easily pay for a sizeable PV module. Although there seemed to be an interest in this modern renewable power technology, this interest does not readily culminate in uptake as a result of this barrier. When it did, the outcome was that individuals ended up installing under-sized systems incompatible with their

**Table 2: Profile of the interviewed PV Adopters**

| Adopter | Age group | Education | Tenancy | State | PV size | Time of ownership | Period of use | PV use | Occupation |
|---|---|---|---|---|---|---|---|---|---|
| B.C | 35–44 | Degree | Renting | Delta | 350 Watts | 8 months | > 6–12 months | Business | Electrical Engineer |
| D.T | 35–44 | Degree | Renting | Lagos | 1.2 kWp | 4 years | > 2–4 years | Business | Electrical Engineer |
| D.S | 35–44 | Degree | Owner occupied | Lagos | 1.6 kWp | 4 years | > 2–4 years | Home | Other services |
| D.F | 55–64 | Degree | Owner occupied | Abuja | 5.2 kWp | 1 year | 1–2 years | Business | Other services |
| D.B | 25–34 | Secondary | Renting | Lagos | Unknown | 1 year | 3 months | Business | Other services |
| F.I | 45–54 | Degree | Renting | Lagos | 6 kWp | 1 year | 1–2 years | Both | Semi-professional |
| F.F | 35–44 | Secondary | Renting | Lagos | 4 kWp | 3 years | > 2-4 years | Business | Semi-professional |
| J.A | 35–44 | Degree | Owner occupied | Lagos | 2.5 kWp | 2 years | 1–2 years | Home | Electrical Engineer |
| L.S | 35–44 | Degree | Renting | Abuja | 4 kWp | 2 years | 1–2 years | Home | Other services |
| R.C | 55–64 | Degree | Owner occupied | Abuja | 8 kWp | 18 months | 1–2 years | Home | Other services |
| B.R | 45–54 | Degree | Owner occupied | Edo | Unknown | 2 years | 6 months | Home | Other services |
| S.A | 35–44 | Secondary | Owner occupied | Edo | 3.5 kWp | 6 months | > 6–12 months | Both | Other services |
| S.I | 25–34 | Degree | Owner occupied | Abuja | 2.8 kWp | 4 years | > 2–4 years | Both | Electrical Engineer |
| S.B | 45–54 | Degree | Renting | Lagos | 2 kWp | 1 year | 1–2 years | Business | Semi-professional |

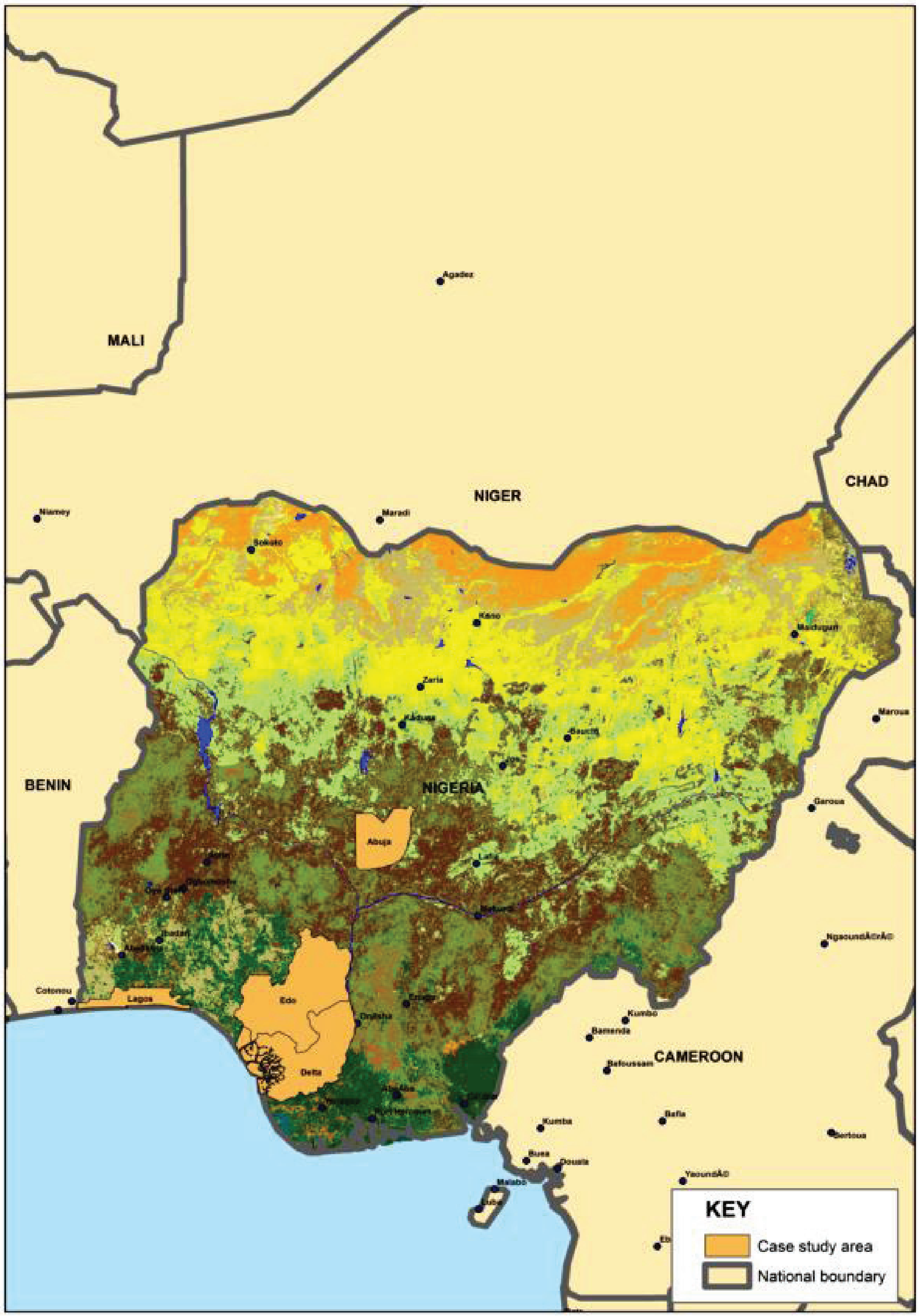


Figure 5: Country map of 4 cities from where the PV adopters were drawn Source: Author

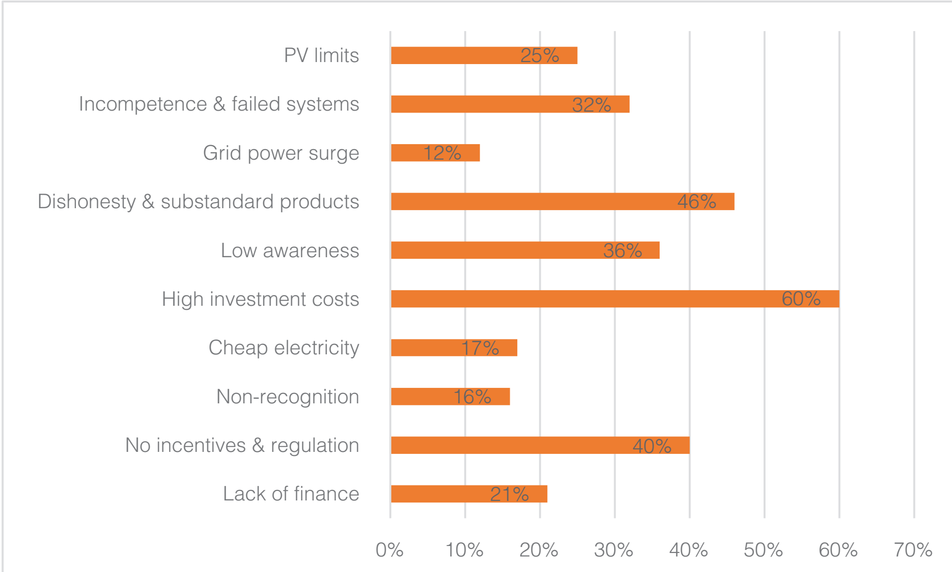


Figure 6: Barriers to PV adoption in urban Nigeria

energy demand, leading subsequently to system failures as described by one respondent here:

> It would have turned out to be a good investment if I had money to pay for a suitably-sized system. - B.R.

Some described how not having sufficient funds and the lack of PV knowledge led them to purchase 8 batteries rather than the 16 batteries recommended by his installer. Another adopter said,

> You know, when I installed my PV, I wasn't having much money and I was doubtful of the technology so I didn't want to invest too much money on something I was not sure of. - S. A.

This high investment cost is further compounded by the need to utilise energy efficient appliances which are generally more expensive than their conventional equivalent. PV efficiency limits which has to do with the well-known capacity factor issues also means that households who opt for it would have to incur further expense in the form of purchasing low energy appliances in order to enable the module operate optimally. Thus, when potential adopters weigh the whole cost estimates, some decide to continue using gasoline engines.

### 5.2. Dishonesty, incompetence and substandard PV products

Representing 46%, dishonest module distributors and installers have hampered widespread PV adoption and diffusion in Nigeria. As emphasized by the interviewed respondents who use PV in their homes and those that installed it for running their businesses, the presence of dishonest and low-skilled technicians and the prevalence of poor-quality modules, inverters and batteries all contribute to the low rate of uptake. Remarks about incompetence ranked 32% of the responses. When combined, issues related to incompetence, and the prevalence pf sub-standard products represented 78% of responses. Relevant comments include

> There was a time I had problem with my panels and I was asked to change the batteries. I did but the new ones that I got were not actually new. The batteries were actually 150 watts; they now changed the labels to 200 watts. You know these guys that install the systems; they play a lot of tricks. I also discovered that some installers don't have the required knowledge. That is why some people tell you that solar panels don't work. - F.I.
>
> A key problem we usually have is that, you know in Nigeria, they bring in sub-standard products. That's why sometimes; you find that a battery that was okay at the start, after six months, the battery will not be able to back up the user again. - D.T.

The remarks made towards incompetence were found interesting. Some improperly installed PV systems as

Figure 7: Shaded streetlight, Ikeja Lagos

Figure 8: Abandoned streetlight in Lekki, Lagos

well as abandoned systems the researcher saw during the field trip support the claims. Examples of this can be seen from Figure 7 where a system was installed under a tree which mostly shaded it from the requisite daylight necessary for its proper function. Figure 8 is an image of a failed PV streetlight module which was subsequently abandoned.

### 5.3. Absence of Government financial incentives and regulation

The third most cited barrier to uptake was the lack of Government support in the form of incentives and policies to protect the emerging industry. The absence of this sort of support received 40% of the responses. For many, it was a key reason why the industry seemed to be struggling to take off. Most of the major problems that the adopters reported are in one way or another connected to competition in an unregulated market. Since PV uptake has been largely market-oriented in Nigeria, the role of governance towards legislation and consumer protection becomes increasingly important. Some of the adopters shared how without the financing they received, it would have been difficult for them to obtain a PV device. While other adopters' criticised Government inaction on people who through their bad practices bring the industry into disrepute. Key comments with respect to this view include,

> If Government can help to regulate the market, it will bring about a reduction in the number of poor-quality systems we see in the market today which has affected consumer confidence in PV. - D. T.

> If Government can subsidise PV and make it readily accessible and cheaper for consumers, it will encourage uptake. We import all our systems. Government should create an environment where there will be an outlet for manufacture of PV systems and components. - S. I.

> Government has been too lenient. Even most street-light projects the Government contracted out, after three months, the system dies off. When such happens, it becomes difficult to convince people again. - S. B.

Although related to the lack of Government incentives, particular mention was made with reference to dearth of a recognition and appreciation for PV users. Non-recognition accounted for 16% of the responses on obstacles to uptake and in combination with the absence of incentives represents 56% of consumer concerns. This group of adopters were very aware of their contribution towards emissions reduction and environmental sustainability.

> If government can encourage people by maybe letting them pay less tax or paying them for not polluting the environment. Since I am using PV systems, if there is any way I can benefit from doing this, it would serve to encourage people. We need something to make people see that their uptake of alternative energy sources is recognised and rewarded. - F. I.

Representing 36% of responses, low awareness of PV technology appeared to be a barrier to adoption. The link between level of awareness, knowledge and education on PV uptake has long been demonstrated [28]. This is the reason adoption levels tend to be higher in richer and more developed countries [29]. Also, education is also crucial in the acceptance of novel technologies due to its links to level of consumer awareness and general knowledge. Results showed a strong correlation between education and adoption decision. Highly educated consumers had a more positive allure for PV than the less educated. Perhaps, this is to do with the fact that more educated people are more likely to spend the time to search for information and research a technology to aid their decision-making. This finding on the effect of education is in line with that of other researchers [25, 26, 39].

Furthermore, the respondents did not consider PV power limits a hindrance to uptake. PV power limits has to do with the intermittency of solar radiation as an energy source and PV module capacity factor issues which places limits to its power output. This is often cited as a barrier in studies [36]. An explanation for this not having an impact on the respondent's perception of PV is the fact that most installations come with battery power storage helping to balance demand when production is low due to reduced insolation.

### 5.4. Motivations for solar PV adoption in urban Nigeria

The motives for PV adoption in Nigeria were broadly found to be socio-economic and environmental. The most significant motive was households' need for reliable electricity supply. In other words, frequent power outages were driving the demand. Others are energy cost savings and familiarity with PV generated power. They are explained accordingly.

### 5.5. Reliable supply

Frequent electricity outages and the need for a more reliable supply source represented 80% of the motivations for PV adoption as Figure 9 indicates. All the interviewed found PV to be very reliable and better than grid electricity and petrol and diesel-generated electricity. Even more impressive was that adopters whose systems failed after a duration of 3 and 6 months held this same optimistic view. They attributed the failures to not being able to afford the number of required batteries and using insufficient number of modules. Overall, the opinions were positive.

### 5.6. Energy cost savings

Representing about 60%, energy cost savings was the second most important motive for PV uptake. This finding was surprising because of the widely acknowledged high initial cost of PV modules. Most of the adopters clearly thought that in the long-run, PV generated electricity was more economical than private generators and grid distributed electricity, with some specifically given a breakdown of the cost-savings. A notable point made in the interview regarding PV was that its installation turned out to be a mechanical solution to the problem of generator-use fuel fraud. An adopter narrated how his PV installation helped curb being defrauded by his employees. They said,

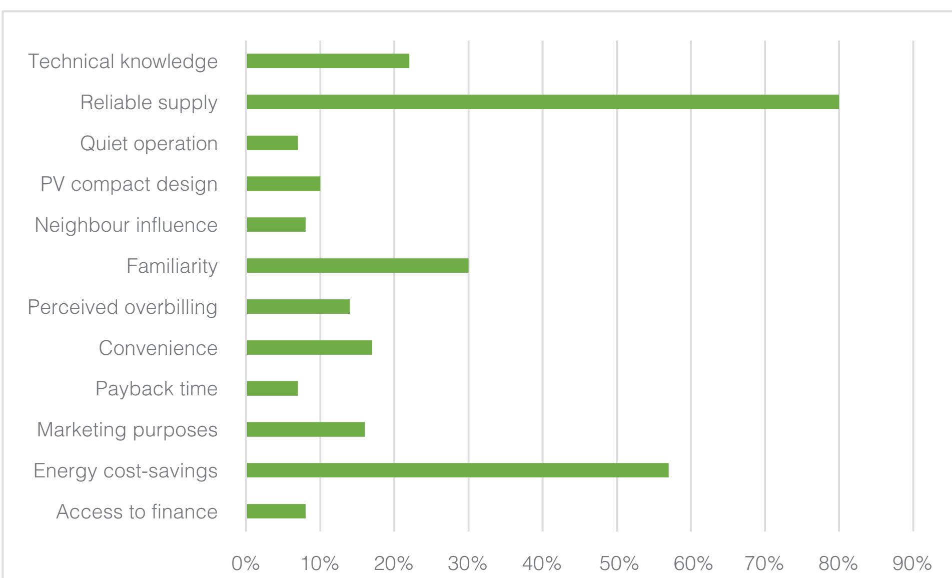


Figure 9: Motivations for PV adoption in Nigeria

> I tell you something. In my shops when I am away, I have been having this issue where my staff members do not buy fuel for generator use but tell me that they did buy fuel. There might have been central electricity supply and they will say oh there was no *light*[2]; that they bought fuel when they didn't buy fuel. So, I have used my PV installation to cut them off. It is actually saving me a lot of money. They can tell you that they bought fuel and they used generator from morning to night when they didn't use it. -F. I.

The above described scenario was made possible because the PV adopter made use of a switchover connection allowing the system to switch automatically to grid electricity when central power was restored and vice versa. Therefore, depending on how the connections are made, PV can help safeguard adopters and users from being defrauded by employees and family members.

### 5.7. Awareness, technical knowledge and familiarity of PV

As identified in studies, awareness comes before uptake in the adoption decision. Not only the awareness of the technology but also some basic technical knowledge about electricity. Sovacool et al. [44] pointed out how basic electricity literacy was very low even in the United States. Familiarity represented about 30% of views. Many adopters said that they deliberately made certain electrical connections in their dwellings to accommodate such modern energy systems like PV. Awareness and familiarity also meant that some adopters were able to question the quality and number of modules, batteries and general work before deciding whether to go ahead with the installation. While the role of marketers influenced PV uptake as well as perceived overbilling from grid supplied electricity distributors was a driver of the change, they were less significant. Understandably, payback time was the least of the motives. This is expected for consumers who suffer frequent power outages and its associated inconvenience.

## 6. Discussion

The results from this study is largely in agreement with established research locally and internationally, but with some new findings. Sociodemographic profile, environment, technological, socio-economic and political factors have been previously shown to impact the adoption of PV and other green energy technologies. Sociodemographic factors such as age [28, [29], income [31] education and homeownership [34] although important, are often less significant factors compared to the technological and socio-economic determinants. Environmental factors as drivers were not significant in this study. There is evidence that altruism or environmental concerns can sometimes be exaggerated even in advanced nations [29].

Technological and socioeconomic factors were greater influences in this study. These finding are shared with many established studies. For example, Sovacool et al. [16] demonstrated how in Papua New Guinea, issues of low-quality products affected PV adoption. Tillmans and Schweizer-Reis [17] gave similar accounts in their Ugandan study. Likewise, unfamiliarity and lack of awareness were also found to be barriers just as technology affinity was shown to drive uptake [39]. In this particular research, dishonest installers using low-quality products were found to be barriers to adoption.

In terms of economic influences, as found in this study, high initial costs and lack of finance have been shown to be one of the most important factors that hinder uptake [16, 36], while the desire to reduce energy bills was revealed to be a driver [29, 39]. In their Greek study, Sardianou and Genoudi [28] showed that such economic influences play a role. The negative effect of long payback time (PBT) was described by Saleki [32] who studied solar PV and wind energy in Iran. They suggested that financial aids should be used as incentives. PBT was not a strong determinant in this present study hence contrasts with Saleki's [32]. However, it agrees with the finding by Schelly [31] who researched households in the United States of America.

In Nigeria, Ohunakin et al. [36] who investigated solar energy application barriers and drivers enumerated barriers that included capital intensiveness, low level of awareness, absence of incentives and poor control of substandard products that gets into the market. They suggested that government support would be necessary to stimulate uptake. Also, in Nigeria, researchers Aliyu et al. [9] concluded that market-based policies and support incentives such as feed-in-tariffs (FITs) would be necessary to facilitate uptake and diffusion of decentralised PV.

[2] Note that in Nigeria and most of Africa, electricity is generally referred to as "light."

Lastly, a key contribution of this study is the finding that PV by its design can be a mechanical solution to the problem of fuel theft. This finding has economic connotation. PV enabled users to bypass the problem of not having any way of knowing how much petroleum that has been used by their family members or staff in the operation of their petrol or diesel generators. PV can therefore help users save money on total electricity costs and bills. This finding can be used by the Nigerian government to promote PV for well-off large households and SMEs who frequently have to buy petroleum products for their generators. It would also be a useful investment and promotional strategy for donor agencies and governments seeking to promote PV in Africa and countries with similar power sector challenge. As would be reasonably expected, the economic case or benefits would yield far better response from the households and businesses than an environmental argument. Such benefits should be harnessed.

## 7. Conclusions and recommendations

This paper contributes to the green power promotion and carbon emissions reduction debate by shedding light on the barriers and motivations for urban PV uptake in urban Nigeria. The findings reveal that high capital costs, lack of finance, poor technical manpower and use of substandard products were major barriers. Payback time was not a significant barrier. Similarly, while it prevented the use of some appliances, PV power limitations was not a major barrier. Awareness and knowledge of electricity and PV systems would be required to increase so that households grasp the workings of electricity supply better. This could help in not just the PV adoption and diffusion agenda but also in conservation and efficiency matters.

The key drivers of PV adoption in Nigeria are the frequent national power outages and the need for regular power. Also, households' intention to reduce their energy bills drives adoption. The rise in fuel and electricity prices in Nigeria following the recent removal of subsidies has led the 'experienced' self-generating households to seek green power. In terms of reliability, the adopters found PV to be the best power supply technology and would recommend it. There is also indication that the cost of PV has been steadily declining in the last 10 years. The identified motives for PV uptake in this paper provides evidence of the vital role of the private sector towards transforming the power sector in Nigeria and similar countries. Like Adhekpukoli [10] pointed out in his paper on the democratisation of power, meaningful change can only come in the Nigerian power sector when it is decentralised and handed back to the people. Until, the end-users are seen as a key part of the power supply and demand process, the lingering electricity issue will remain unsolved.

As the Nigerian Government seek out ways to combat the electricity supply problems it will be imperative to seriously ponder the opportunities PV electricity presents. Barriers to uptake can be slowly removed with adequate political, regulatory and institutional support. In many countries, there are incentives to help stimulate private sector uptake of renewables such as the feed-in tariffs (FITs) and net metering depending on level of grid maturity and electricity markets liberalisation. Finally, despite the high initial cost, in the long run, PV offers greater cost savings over grid power and auto-generation as previous studies have demonstrated with zero direct emissions. There is an urgent need to regulate the nascent PV industry to ensure that only quality modules are imported and used in Nigeria. The presence of monetary and non-fiscal incentives would encourage potential adopters and adopters who by their actions are contributing to carbon reduction. This would also help support businesses as well as grow the economy as new markets are created. As a public good that creates net environmental benefits, PV will be instrumental for transforming the Nigerian power sector.

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## References

[1] UNEP, "Renewable Energy: Renewables on the rise.," *United Nations*, 2018. [Online]. Available:https://www.unenvironment.org/explore-topics/energy/what-we-do/renewable-energy. [Accessed: 29-Jul-2018].

[2] UN, "Sustainable development goals 7: Clean Energy," *United Nations*, 2018. [Online]. Available: https://www.un.org/sustainabledevelopment/energy/. [Accessed: 19-Jul-2018].

[3] Momodu A.S. "Energy Use: Electricity System in West Africa and Climate Change Impact," *Int. J. Sustain. Energy Plan. Manag.*, vol. 14, pp. 21–38, 2017. https://doi.org/10.5278/ijsepm.2017.14.3

[4] Ozoegwu C.G, Mgbemene C.A and Ozor P.A. “The status of solar energy integration and policy in Nigeria,” *Renew. Sustain. Energy Rev.*, vol. 70, pp. 457–471, Apr. 2017. https://doi.org/10.1016/j.rser.2016.11.224

[5] Fadare D.A. “Modelling of solar energy potential in Nigeria using an artificial neural network model,” *Appl. Energy*, vol. 86, no. 9, pp. 1410–1422, Sep. 2009. https://doi.org/10.1016/j.apenergy.2008.12.005

[6] Ozoegwu C.G. “The solar energy assessment methods for Nigeria: The current status, the future directions and a neural time series method,” *Renew. Sustain. Energy Rev*., vol. 92, pp. 146–159, Sep. 2018. https://doi.org/10.1016/j.rser.2018.04.050

[7] Ayompe L.M, Duffy A, McCormack S.J and Conlon M. “Measured performance of a 1.72 kW rooftop grid connected photovoltaic system in Ireland,” *Energy Convers. Manag*., vol. 52, no. 2, pp. 816–825, Feb. 2011. https://doi.org/10.1016/j.enconman.2010.08.007

[8] Fagbenle R, Oladiran M.T and Oyedemi T.I. “The Potential Generating Capacity of PV-Clad Residential and Commercial Buildings in Nigeria,” no. 36762. pp. 519–526, 2003. doi:10.1115/ISEC2003-44232

[9] Aliyu A.S, Dada J.O and Adam I.K. “Current status and future prospects of renewable energy in Nigeria,” *Renewable and Sustainable Energy Reviews*. 2015. https://doi.org/10.1016/j.rser.2015.03.098

[10] Adhekpukoli E. “The democratization of electricity in Nigeria,” *Electr. J.,* 2018. https://doi.org/10.1016/j.tej.2018.02.007

[11] World Bank, “Nigeria: Population as at 2016,” *World Bank*, 2016. [Online]. Available: https://data.worldbank.org/country/nigeria?view=chart. [Accessed: 17-Jun-2018].

[12] Chidebell-Emordi C. “The African electricity deficit: Computing the minimum energy poverty line using field research in urban Nigeria,” *Energy Res. Soc. Sci.,* vol. 5, pp. 9–19, Jan. 2015. https://doi.org/10.1016/j.erss.2014.12.011

[13] ESMAP, “Assessing low-carbon development in Nigeria: An analysis of four sectors,” *ESMAP Technical paper*, 2013. [Online]. Available: http://documents.worldbank.org/curated/en/2013/01/17977719/assessing-low-carbon-development-nigeria-analysis-four-sectors#.

[14] Financial Times (FT), “Nigeria power rates to rise up to 88%’.,” *Financial Times*, 2015. [Online]. Available: http://www.ft.com/cms/s/0/78b805ec-5586-11e1-9d95-00144feabdc0.html#axzz3meyF6HX7. [Accessed: 20-Mar-2012].

[15] Ohunakin O.S. “Energy utilization and renewable energy sources in Nigeria,” *J. Eng. Appl. Sci*., 2010. http://eprints.covenantuniversity.edu.ng/id/eprint/7420

[16] Sovacool B.K, D’Agostino A. L and Jain Bambawale M. “The socio-technical barriers to Solar Home Systems (SHS) in Papua New Guinea: ‘Choosing pigs, prostitutes, and poker chips over panels,’” *Energy Policy*, 2011. https://doi.org/10.1016/j.enpol.2010.12.027

[17] Tillmans A and Schweizer-Ries P. “Knowledge communication regarding solar home systems in Uganda: The consumers’ perspective,” *Energy Sustain. Dev.*, vol. 15, no. 3, pp. 337–346, Sep. 2011. https://doi.org/10.1016/j.esd.2011.07.003

[18] Shaaban M and Petinrin J.O. “Renewable energy potentials in Nigeria: Meeting rural energy needs,” *Renew. Sustain. Energy Rev*., vol. 29, pp. 72–84, Jan. 2014. https://doi.org/10.1016/j.rser.2013.08.078

[19] Nigerian Integrated Power Project (NIPP), “Nigerian Electricity Market,” *Government*, 2014. [Online]. Available: http://www.nipptransactions.com/. [Accessed: 31-Jul-2014].

[20] BBC News, “Nigeria forced to revise budget as oil prices remain low,” 2014. [Online]. Available: https://www.bbc.com/news/business-30518956. [Accessed: 07-Aug-2015].

[21] BBC News, “Buhari’s battle to clean up Nigeria’s oil industry,” *2016*, 2016. [Online]. Available: https://www.bbc.com/news/world-africa-35754777. [Accessed: 07-Dec-2016].

[22] Central Intelligence Agency (CIA), “The World Fact book, Nigerian Economy: Overview,” 2014. [Online]. Available: https://www.cia.gov/library/publications/the-world-factbook/geos/ni.html. [Accessed: 17-Nov-2014].

[23] Energy Information Administration (EIA), “US imports of Nigerian crude oil,” 2017. [Online]. Available: https://www.eia.gov/beta/international/analysis.php?iso=NGA. [Accessed: 10-Jun-2018].

[24] IEA, “Electricity and heat for 2012,” 2013. Available: http://www.iea.org/statistics/statisticssearch/report/?country=Nigeria&product=electricityandheat.

[25] World Bank, “Energy and Mining: Electricity consumption per capita for select oil rich African countries,” *World Bank*, 2018. [Online]. Available: https://data.worldbank.org/topic/energy-and-mining?locations=NG-DZ-EG-LY-GH-ZA. [Accessed: 01-Aug-2018].

[26] Energy Saving Trust, “‘Solar panels: Generate cheap, green electricity from sunlight.,’” *Energy Saving Trust*, *UK*, 2018. [Online]. Available: http://www.energysavingtrust.org.uk/renewable-energy/electricity/solar-panels. [Accessed: 23-Jun-2016].

[27] Claudy M.C, Michelsen C and O’Driscoll A.“The diffusion of microgeneration technologies - assessing the influence of perceived product characteristics on home owners’willingness to pay,” *Energy Policy*, 2011. https://doi.org/10.1016/j.enpol.2010.12.018

[28] Sardianou E and Genoudi P. “Which factors affect the willingness of consumers to adopt renewable energies?,” *Renew. Energy*, vol. 57, pp. 1–4, Sep. 2013. https://doi.org/10.1016/j.renene.2013.01.031

[29] Balcombe P, Rigby D and Azapagic A. "Motivations and barriers associated with adopting microgeneration energy technologies in the UK," *Renew. Sustain. Energy Rev*., 2013. https://doi.org/10.1016/j.rser.2013.02.012

[30] Rundle-Thiele S, Paladino A and Apostol S.A.G. "Lessons learned from renewable electricity marketing attempts: A case study," *Bus. Horiz*., vol. 51, no. 3, pp. 181–190, May 2008. https://doi.org/10.1016/j.bushor.2008.01.005

[31] Schelly C. "Residential solar electricity adoption: What motivates, and what matters? A case study of early adopters," *Energy Res. Soc. Sci*., vol. 2, pp. 183–191, Jun. 2014. https://doi.org/10.1016/j.erss.2014.01.001

[32] Saleki S. "Introducing Multi-Stage Qualification for Micro-Level Decision-Making (MSQMLDM) Method in the Energy Sector – A case study of Photovoltaic and Wind Power in Tehran," *Int. J. Sustain. Energy Plan. Manag*., vol. 17, pp. 61–78, 2017. https://doi.org/10.5278/ijsepm.2018.17.6

[33] Sauter R and Watson J. "Strategies for the deployment of micro-generation: Implications for social acceptance," *Energy Policy*, vol. 35, no. 5, pp. 2770–2779, May 2007. https://doi.org/10.1016/j.enpol.2006.12.006

[34] Leenheer J, de Nooij M and Sheikh O. "Own power: Motives of having electricity without the energy company," *Energy Policy*, 2011. https://doi.org/10.1016/j.enpol.2011.04.037

[35] Komatsu S, Kaneko S, Ghosh P.P and Morinaga A. "Determinants of user satisfaction with solar home systems in rural Bangladesh," *Energy*, vol. 61, pp. 52–58, Nov. 2013. https://doi.org/10.1016/j.energy.2013.04.022

[36] Ohunakin O.S, Adaramola M.S, Oyewola O.M and Fagbenle R.O. "Solar energy applications and development in Nigeria: Drivers and barriers," *Renew. Sustain. Energy Rev*., 2014. https://doi.org/10.1016/j.rser.2014.01.014

[37] Ajzen I. "The theory of planned behavior," *Organ. Behav. Hum. Decis. Process*., vol. 50, no. 2, pp. 179–211, Dec. 1991.

[38] Bahaj A.S and James P.A.B. "Urban energy generation: The added value of photovoltaics in social housing," *Renewable and Sustainable Energy Reviews*. 2007. https://doi.org/10.1016/j.rser.2006.03.007

[39] Sommerfeld J, Buys L and Vine D. "Residential consumers??? experiences in the adoption and use of solar PV," *Energy Policy*, vol. 105, no. May 2016, pp. 10–16, 2017. https://doi.org/10.1016/j.enpol.2017.02.021

[40] Creswell J.W. "Research Design: Qualitative, Quantitative and Mixed Method Aproaches," *SAGE Publ*., 2007.

[41] Robson C. *Real World Research: A Resource for Social Scientists and Practitioner-Researchers*. 2002.

[42] O'Neill, "The NVivo Toolkit," *Na*, 2013.

[43] Crossland A.F, Anuta O.H and Wade N.S. "A socio-technical approach to increasing the battery lifetime of off-grid photovoltaic systems applied to a case study in Rwanda," *Renew. Energy*, vol. 83, pp. 30–40, Nov. 2015. https://doi.org/10.1016/j.renene.2015.04.020

[44] Sovacool B.K. "Rejecting renewables: The socio-technical impediments to renewable electricity in the United States," *Energy Policy*, 2009. https://doi.org/10.1016/j.enpol.2009.05.073