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Suburban Housing Development and Off-Grid Electric Power Supply Assessment for North-Central Nigeria

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ABSTRACT

Energy infrastructures in North-Central Nigeria are inadequate and grid electricity is unable to meet suburban housing electricity demand. The alternative power-supply options proposed by governments in the region require appropriation analysis for selection. Four public housing estates in suburban Abuja are selected for electricity demand analysis under conventional and energy-efficient lighting scenarios; then techno-economic parameters of two off-grid electric power supply systems (PV and Diesel-powered generation) to meet these electricity demands are evaluated. An energy techno-economic assessment methodology is used. The study determines the energy-efficient lighting system is appropriate with 40% energy savings relative to the Conventional Lighting Systems. The diesel generator alternative power-supply option has Life Cycle Costs almost 4 times those of the PV option. The study established the PV-energy-efficient lighting system as the most feasible off-grid electric power supply alternative for implementation.

Keywords:

Electric power supply;
Off-grid electric power systems;
PV systems;
Diesel generator systems;

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1. Introduction

This introduction provides background information on electricity generation in Nigeria, the rationale behind the study/statement of the problem, the study area (North Central Nigeria and Abuja, FCT), and the objectives of the study.

1.1. Electricity generation patterns in Nigeria

Nigeria is a country richly endowed with energy resources including petroleum, natural gas, coal, wood and hydroelectricity [1]; however the country is faced with acute electricity problems, demand far outstrips supply and more often than not, the supply is epileptic in nature. The acute electricity problems are in part because of mismanagement in the government agency overseeing energy production [1, 2, 3, 4].

Access to electricity is particularly crucial to human development as electricity is, in practice, indispensable for certain basic activities (such as lighting, refrigeration and the running of household appliances) and cannot easily be replaced by other forms of energy [5]. The access to electricity by individual citizens is one of the most clear and un-distorted indications of a country's energy poverty status [6].

Nigeria's national electricity demand is estimated to be in excess of 10,000 MW at peak demand, however total installed electricity capacity is less than 7,000 MW [3, 4], and electricity availability is usually only about half the installed capacity (between 2,500–3,000 MW)

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and power outages [i]frequently occur [3, 4]. A wide gap between the installed capacity and available electricity capacity started emerging in 1978 and has increased significantly ever since [3, 4]. The acute electricity problems noticed in Nigeria have been attributed to several problems including very poor management capacity by the former government agency overseeing electricity production and distribution, theft of electric power equipment, poor gas supply to power turbines, non-installation of purchased electric power equipment, very poor maintenance of power equipment, high prevalence of accidents and incidents at electric power facilities, limited funding of the sector, and very low human capabilities and capacity utilisation for power generation, amongst others [2, 3, 4, 5, 6].

Electricity in Nigeria is provided from two major sources–conventional thermal power plants (which provide 48% of electric power) and hydroelectric power plants (which provide 52%) [7, 8]. However, only a small percentage of the country's potential hydroelectric capacity has been developed [3]. Thermal power generation for the national grid is dependent on gas supply from the Niger Delta region [3]. Off-grid power generation is almost wholly dependent on petrol/diesel generators, as other sources of power are negligible in the national energy mix [6]. Petrol generators tend to be used at single housing units with low power demand, diesel generators tend to be used in industrial settings and housing estates which have considerably large power demands [9].

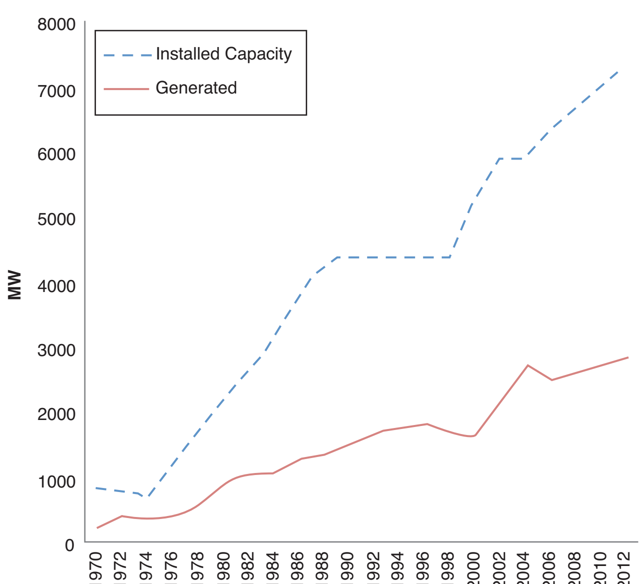

Figure 1: Electricity Availability in Nigeria (1970 to 2012) Source: Atoyebi et al. [20]

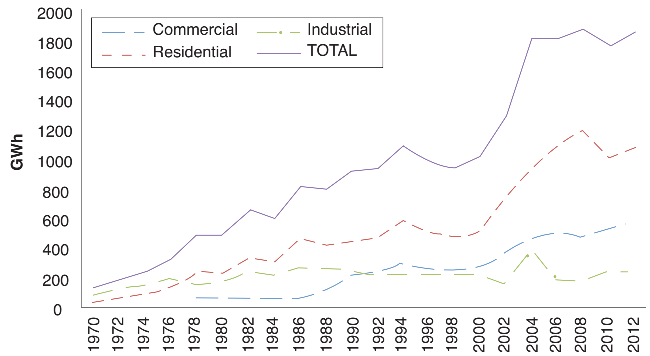

Figure 2: Sectoral Electricity Demand in Nigeria Source: Akinwumi et al. [3]; Atoyebi et al. [10]

Figure 1 illustrates installed capacity and total generation of electricity in Nigeria from 1970 to 2012. A wide gap between the installed capacity and actual maximum electricity generation capacity started emerging in 1978 and has increased significantly ever since [10].

Only about 40 percent of Nigerians have access to public electricity [11, 12]. This is shared between three key sub-sectors (see Figure 2) – the residential sector (59.6 per cent of total electricity supplied), the commercial sector (29.1 per cent) and the industrial sector (11.3 per cent) [6, 10, 12]. It is estimated that based on total electric power demand in the country, the national power infrastructure can only supply uninterrupted power to the whole nation for just 50 minutes per day [13]. To compensate for power outages, these sectors are increasingly using privately operated petrol/diesel generators for power supply [14].

1.2. Rationale for the study

The provision of adequate and affordable energy, being a critical component of sustainable national economic planning in Nigeria has had a number of government policy roundtables, seminars, conferences and policy researches carried out for its successful actualization. In the aftermath of the Science, Technology and Innovation (STI) Policy developed in 2012, and the drive for the realization of the National Development Agenda, the Federal Government of Nigeria produced various energy masterplans and policy documents including the Renewable Energy Masterplan (2013) and the National Renewable Energy and Energy Efficiency Policy (2014) [15]. The objectives of these energy initiatives include guaranteeing the development of Nigeria's renewable energy resources, guaranteeing adequate, reliable and sustainable supply of energy at appropriate costs and in an environmentally friendly manner to the various sectors of the economy for national development, amongst others. Several policy and political risks confront reliable energy provision in the country and some of them include non-adoption of outlined policies; policy inconsistencies, instability and contending interests in Government; the risks of inadequate policy implementation; lack of continuity of government policies; and socio-cultural conflicts [16].

State governments in Nigeria have not been left out of the development of appropriate Science & Technology (S&T) policies for the economic development of their various states, or the development of policy initiatives for sustainable energy solutions [17]. In spite of all efforts, the provision of adequate and affordable alternative energy solutions in the country has been difficult to achieve [6, 7, 8, 9]. The State Governments in North-Central Nigeria have interest in developing renewable energy solutions to address their energy challenges, and have taken into cognizance the high solar irradiation (Figure 3) in the region to focus on the - PV option as an appropriate alternative energy source [6, 8, 9]. Traditionally, off-grid electric power is generated using petroleum products like petrol and diesel [11, 12, 13].

The states in the North-Central region of Nigeria are within the distribution zones of three electricity distribution companies, namely, Abuja Electricity Distribution Company Ltd, AEDC or Abuja DISCO, for Niger, Kogi, Nassarawa States and the FCT; Jos Electricity Distribution Company Ltd, JEDC or Jos DISCO, for Plateau and Benue States; and Ibadan Electricity Distribution Company Ltd, IEDC or Ibadan DISCO, for Kwara State [18, 19]. Despite past investments in expanding the electricity infrastructure, demand in the Discos' service zone far exceeds supply [18, 19]. Increasing population continues to add to that demand. The new electricity tariff introduced by the Nigerian Electricity Regulatory Commission (NERC) under the Multi-Year Tariff Order (MYTO) 2015, became effective on the 1st of February, 2016. Under the new power tariff regime, electricity consumers in residential customer category (R2) class, pay approximately \$0.12 per kWh in Abuja and Ibadan, and \$ 0.13 per kWh in Jos [18].[2]

The North Central region of Nigeria, just like other regions, has witnessed rapid population and socio-economic expansion over the last two decades, and municipal infrastructure (including housing and power provision) have been found inadequate to meet the huge population demand [19, 20, 21, 22]. Housing estates in the suburbs of the major cities in the region have been

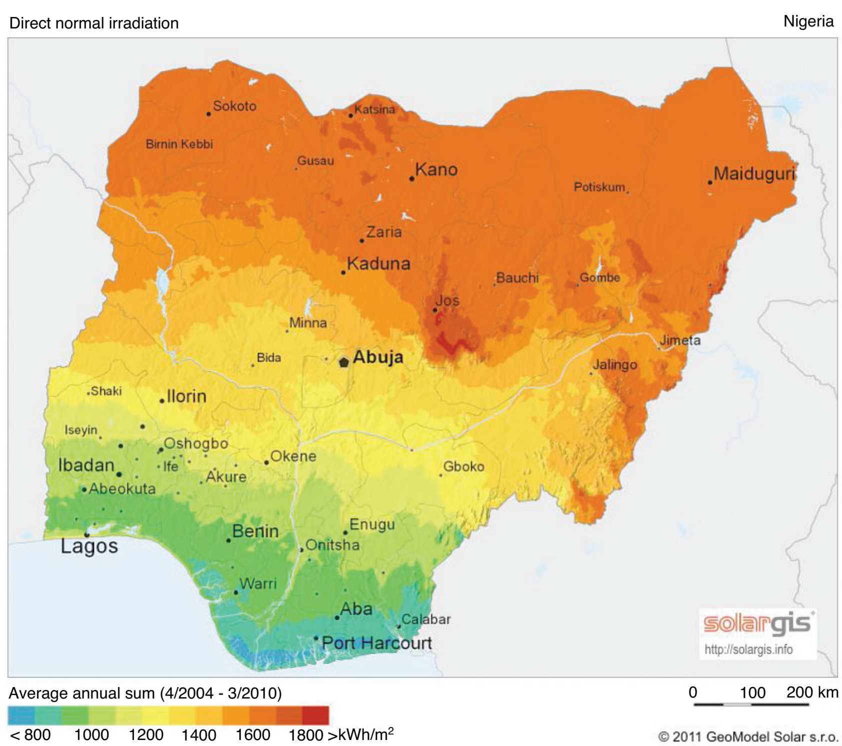

Figure 3: Map of Nigeria showing direct normal irradiation Source: Sambo [9]

2 The study utilized an exchange rate of ₦200 = US\$1, obtained from the CBN as at March 1, 2016

constructed or encouraged for construction by respective public and private concerns (federal and state governments as well as private housing consortiums) to meet the housing demand [23, 24, 25]. However grid electric supply has been found inadequate to meet the suburban housing electricity demand, and suburban housing residents have resorted to using environmentally-polluting diesel and petrol generating plants to meet their housing and commercial electric power demands [26]. The Regional Development Strategy of establishing environmentally-friendly, and energy-efficient suburban housing estates has had limited implementation. Many of these suburban housing developments have been based on the design of existing housing estates in the suburbs of Abuja, FCT.

1.3. Statement of the problem

Various alternative energy options have been advocated for states in the region as appropriate solutions for suburban residential estates (including the PV option and the energy efficiency lighting option), and in several system combinations [27, 28, 29]. State policy on appropriate power-supply system development and adoption in the region has however been ineffectual, and alternative-lighting plans and projects in the region have had very limited success [15, 16]. This limited capacity has been attributed to the non-availability of an appropriate techno-economic assessment of the existing power-supply system, and the viability determination of the alternative options. This techno-economic assessment is critical, being an appropriate evaluation tool for the selection of government alternative-lighting plans in the region. This study provides a viable assessment using selected suburban housing developments in Abuja, FCT as case study.

1.4. Objectives of the study

The specific objectives of this study are to:

i. Determine the electricity consumption in the housing estates under two energy consumption scenarios (conventional and energy efficient electric lighting systems).
ii. Determine energy savings (if any) between the two energy consumption scenarios.
iii. Calculate techno-economic specifications of photovoltaic (PV) and diesel generator systems as off-grid electric power supply options for the energy consumption scenarios.
iv. Establish the viability of PV system adoption as the off-grid electric power supply option.

2. Perspective on solar energy utilization in Nigeria

The utilization of solar energy as a renewable energy source in Nigeria has been widely reported, with studies on solar energy availability in Nigeria, its potential for sustainable energy development and the constraints to its use as a sustainable energy source, and its adoption in rural communities in the country [9, 10, 16, 27, 28, 30, 31]. Identified solar energy projects in the country include street lighting in Ekiti State, village electrification and TV viewing in Enugu, Jigawa and Sokoto States, water pumping schemes across the geographical Northern regions, solar rice and solar forage dryers in Enugu and Kebbi States, and solar farms in Katsina and Bauchi States [32, 33]. These projects were aimed at reducing the acute energy poverty in Nigeria, reduce greenhouse gas emission from use of diesel generators, and enhance sustainable energy use in Nigeria.

Oparaku [34] analysed the costs of the photovoltaic, diesel/gasoline generator and grid utility options of rural area power supply in Nigeria and determined that the PV option was more viable than the diesel/gasoline generator option. Akinpelu and Eng [35] also determined the PV option as more viable than the diesel generator option as energy supply in Nigeria's telecoms industry. Jesuleye et al [16] reported that contributions of the PV option in the energy mix of rural areas of Nigeria was very low (about 14% of the total lighting requirement and less than 2% of the total requirement for energy services) in spite of the best efforts of government, while Ukwuoma et al [15] acknowledged the viability of the PV option in Nigeria, but noted the limited adoption of the technology in industrial and domestic situations on the country. They attributed this to the huge cost of PV acquisition and deployment. In evaluating the demand management based design of residential solar power systems in Nigeria, Oladokun and Adeshiyan [36], determined reduced costs of designing and installing solar power systems by as much as 62–65% by adopting an integrated demand management approach. Atoyebi et al [10] however observed that most PV – diesel/petrol generator – grid utility comparison studies in Nigeria were conducted based on energy demand in single housing units or single infrastructural projects, with very little reportage of comparison analysis based on multiple housing or infrastructural sites. They argued for these analyses, noting the limited development of various public and private residential housing projects in the country due to the challenge of providing appropriate analysis and advice on acceptable off-grid power supply options. Momodu et al [44] pointed out that the adoption of energy efficient lighting in residential buildings in Nigeria could reduce national electric power demand by as much as 6,000 MW, which is almost twice the electricity supply in the country. Regional development initiatives in Nigeria generally, and the North-Central region in particular, have been less than successful in incorporating energy efficiency schemes in multiple housing or infrastructural sites [29, 36].

2.1. The North-Central region of Nigeria

The North-Central region of Nigeria (or the Middle Belt as it is commonly called) is a human geographical area covering 242,425 Km_2 comprising six states (Kwara, Niger, Nassarawa, Plateau, Benue and Kogi) and the Federal Capital Territory (FCT) stretching across the country longitudinally (Figure 4) [19]. The region is made up of largely minority ethnic groups like the Nupe, Ibira, Idoma, Tiv and the Gwari people, although there are Hausa and Yoruba ethnic groups present [20]. Major towns include Ilorin, Minna, Lokoja, Jos, Makurdi, Lafia, and Abuja [19]. The total population is estimated to be 25.4 million people [21]. Although the region forms the agricultural centre of the nation and its major occupation is farming, there are considerable commercial, manufacturing, and transportation activities [20]. Abuja, Nigeria's federal capital located in the FCT is the region's central settlement [20]. Some twenty years ago, the population of the region was only an estimated 12 million people [22]; the huge population growth over the years (from 12 million to 25.4 million) is not unconnected to the massive influx of people into Abuja and the neighbouring states for economic reasons [21].

2.2. Abuja, Federal capital territory

Abuja, the capital city of Nigeria, is a planned city located in the centre of Nigeria, within the FCT [23]. The city was built mainly in the 1980s and officially became Nigeria's capital on 12 December 1991, replacing Lagos, which remains the country's most populous city and economic capital [23, 37]. The city is located in a relatively undeveloped, ethnically neutral area. A large hill known as Aso Rock provides the backdrop for the city's government district, which is laid out along three axes representing the executive, legislative, and judicial branches. Government agencies began moving into the new capital in the early 1980s, as residential

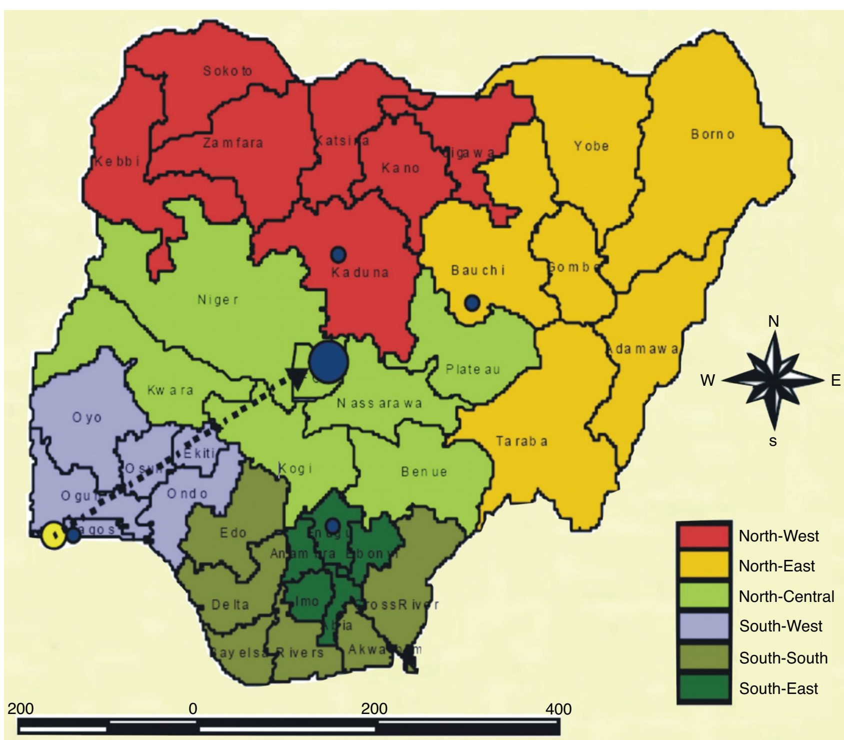

Figure 4: Map of Nigeria Showing the North-Central Region Source: National Population Commission [22]

neighbourhoods were being developed in outlying areas [37]. Abuja has experienced huge population growth, as much as 20 – 30% per year. In 1991, the population was about 380,000; in 2006 it was an estimated 1,406,239, making the city one of the top ten most populous cities in Nigeria at that time [24]. The huge influx of people into Abuja has led to the rapid emergence of satellite towns, squatter settlements and other suburban districts such as Nyanya, Karu, Kubwa, Jabi, Suleja, Gwagwalada, Lugbe, Mpape and Kuje to which the planned city is fast sprawling towards and in which about 75 percent of residents reside [24, 37, 38]. Jibril and Garba [25] estimated that that the Abuja metropolitan area would have a population well over three million, making it the fourth largest urban area in Nigeria after Lagos, Kano and Ibadan.

2.3. Housing and power infrastructure deficits in Abuja, FCT

The Abuja City Master Plan made provision for the development of residential estates for the city's residences [25]. Initially, due to the desire to encourage people to move in and settle in the new City, the Federal Government took up the responsibility of developing residential houses. By the early 1990s, after clear and significant private sector interests and investments in real property development, the Federal Government withdrew from direct involvement in housing development and the responsibility shifted to the private sector [25, 39]. Many private housing estate developments have sprung in the city and its suburbs to cater for the ever growing population; however, after more than twenty years of huge influx of people into the Abuja metropolitan area these private sector investments have been overwhelmed and there is a huge deficit in housing in the city and its suburbs [25, 39].

Similarly, electric power demand to the FCT far outweighs the supply. The shortage of power supply in FCT has been attributed to load shedding from the national grid. The FCT is reported to require about 400 to 500 MW for the residents to enjoy uninterrupted power supply, but what is being released for distribution is between 200 and 300 MW only[18, 19, 40]. Thus, as the private sector has striven to provide houses for the residences through the development of suburban housing estates, they have also striven to provide alternative power supply to these estates in the form of off-grid electric power devices and energy efficient technologies [18, 19, 40].

3. Methodology

Four public housing estates in the suburbs of the Abuja metropolitan area are considered for the study. Each housing estate consists of 400 housing units built as a single development. Each housing unit is a 4-bedroom apartment and the electrical load demand in each of the housing units is assumed to be the same. The housing estates are government approved, and duly registered with the Abuja Municipal Area Council (AMAC). Residents in the housing estates are predominantly middle-income public servants, who are well-educated (with at least the Master's degree), and have maximum family size of four children per family.

NOTE

1. The energy planning is based on maximum possible electric power demand. Thus, the maximum possible electric appliance daily time use of 24 hours is assumed in the housing units in the estates. The Nigerian scenario is quite unique as most housing units are not metered, and the power distribution companies tend to issue arbitrary, estimated electricity bills which do not necessarily reflect actual power consumption as determined by meter reading, but by the approved revenue targets set by the firms. These bills have been noted to be based on a 24-hour per day, maximum possible electric power consumption template. Consequently, Nigerians have developed the inclination for indiscriminate use of electricity as they know they will pay very high bills, whether they use the power or not. Nigerians tend to leave their electric appliances on to use up as much electric power as possible when they do have grid electricity. Electric power demand planning is therefore based on maximum power demand, rather than actual power demand. Furthermore, as most Nigerian residents generate their own power through the use of petrol/diesel generators, there is very little cautiousness to limit electric power usage.
2. The public housing estates have matching designs, and identical basic electric appliances installed in each housing unit.
3. 10 housing units in each estate were randomly visited to affirm the authenticity of matching housing designs and basic electric appliance installations.

To achieve objective i, an energy audit of the housing estates is conducted. This entails three steps: (a) walk-through audit entailing appliance inventorizing, (b) detailed appliance wattage measurement, and (c) appliance time of use measurement. Under the conventional scenario, 60W incandescent bulbs are utilized in the housing estates while under the energy efficient scenario, the 60W bulbs are replaced with 15W compact fluorescent lamps (CFL).

To achieve objective ii, the power rating and energy consumption data for the housing estates under the energy efficient scenarios are tabulated and compared with each other, and energy savings determined by calculation.

To achieve objective iii and iv, data on Life Cycle Costs (LCC) over a 25-year period for the two off-grid power systems are obtained from primary and secondary sources. The first step entailed designing the stand-alone PV system for the electrification of the estate. The peak power of the design of the PV generator is determined from the estimated total energy consumption per household. Other parameters for the calculation are obtained from literature. The next steps are to determine the size of the battery, the size of the charge regulator, and finally the size of the inverter. Similarly, for the diesel electric generator, the maximum demand on the generator and generator set ratings are calculated from the estimated total energy consumption per housing unit, the diversity factor, and the power factor. The associated costs of the components of the stand-alone PV system and the diesel generator are obtained from electric power vendors and these costs are fed into the LCC formulae to determine the LCC of each power option. The cost evaluation of the energy supply systems are determined by the following formulae:

Life Cycle Cost Analysis

Capital cost: These are the one time fixed cost of purchasing and installing the plant

Non Recurring cost: This is a form of fixed cost used for replacement of parts and may be referred to as Life Replacement Cost

$$\mathrm{LRC} = \sum \left[\mathrm{IC} \times \left(1 + \left(\frac{1+\mathrm{G_e}}{1+\mathrm{D_r}} \right)^{\mathrm{Ry}} \right) \right] \quad (1)$$

Where LRC is the Non-recurring costs (Life Replacement Costs), IC is the cost of the item, G_e is the general escalation value and is 10.8% as at December 2015 [46], D_r is the Discount rate and is 4.25% as at December 2015 [46] and R_y is the item replacement year which is 10 years.

Recurring Cost: These are the regular cost which account for fuel cost and servicing cost

$$\mathrm{LFC} = \mathrm{AFC} \times \left[\left(\frac{1+\mathrm{F_e}}{\mathrm{D_r}-\mathrm{F_e}} \right) \times \left(1 - \left(\frac{1+\mathrm{F_e}}{1+\mathrm{D_r}} \right)^{\mathrm{P}} \right) \right] \quad (2)$$

Where LFC is the life cycle fuel cost, F_e is the fuel escalation which is assumed to be 25% per year because the fuel price has increased by approximate 25% per year over the last 3 years and p is the life cycle of the PV system which is 25 years.

$$\mathrm{LMC} = \mathrm{AMC} \times \left[\left(\frac{1+\mathrm{G_e}}{\mathrm{D_r}-\mathrm{G_e}} \right) \times \left(1 - \left(\frac{1+\mathrm{G_e}}{1+\mathrm{D_r}} \right)^{\mathrm{P}} \right) \right] \quad (3)$$

LMC is the life cycle maintenance cost and AMC represent annual maintenance cost.

Life Cycle Costs are determined by the equation:

$$\mathrm{LCC(\$ / KWh)} = \frac{cc + LFC + LMC + LRC}{Period \times 365 \times kwh / day} \quad (4)$$

The costs and GHG emissions for the housing estates using the two power system options were computed and comparative analysis used to determine the viability of the PV option relative to the diesel generator option.

3. Results

The calculations of the study are presented in this section. The study is based on 24-hour power supply as has been explained in the methodology. Evidence is available that the power distribution companies bill customers by the highest maximum possible demand per 24 hours. This affects energy planning in Nigeria as there is a dearth of research on energy billing in the Nigerian market. Electricity planning and billing in Nigeria is on the 24-hour power supply template and thus is used in our study.[3]

[3] It is important to note that the researchers have had to install personal alternative energy systems in their homes (generator sets, on-grid inverter and battery systems, and solar panel+inverter+battery systems in order to guarantee 24 hours uninterrupted power supply in their homes).

3.1. Electricity consumption in the housing estates under two energy consumption scenarios (conventional and energy-efficient electric lighting systems)

Electricity consumption in the housing estates under conventional lighting scenario shows that the total power rating per housing unit would be 2630 W while energy consumption would be 40,120 Wh/day (14.64 MWh/year) based on certain assumptions (Table 1). Table 2 depicts that total energy consumption per estate would be 16,048 kWh/day (5,856 MWh/year) while total energy consumption for the four estates would be 64,192 kWh/day (23,424 MWh/year).

Under the energy-efficient lighting scenario (Table 3), the power rating per housing unit was determined to be 1955 W while energy consumption calculated to be 23,920 Wh/day (8.73 MWh/year). Total energy consumption per estate would be 9,568 kWh/day (3,492 MWh/year) while total energy consumption for the four estates would be 38,272 kWh/day (13,968 MWh/year (Table 4).

3.2. Energy savings using energy efficient lighting system in place of conventional lighting system in the housing estates

The energy savings determined by using energy efficient lighting points in place of conventional lighting points are shown in Table 5. Power rating savings are 675 W, 270 kW and 1080 kW per house, per estate and for the four estates respectively. Similarly, estimated energy consumption savings are 16.20, 6480 and 25920 kWh/day per house, per estate and for the four estates respectively. Furthermore, the Conventional Lighting System (CLS) has an estimated power rating 1.35 times that of the Energy-Efficient Lighting System (EELS). CLS also shows energy consumption 1.68 times that of EELS.

Table 6 shows the estimated on-grid maximum energy costs and cost savings using conventional and energy efficient lighting in the Abuja suburban housing estates from the projected electricity consumptions in the housing estates. Under the CLS, on-grid energy costs from AEDC were estimated to be $ 4.85 per housing unit, $ 1,940 per estate, and $ 7,760 for the four estates.

Table 1: Energy consumption per house using conventional lighting

No of items	Electrical Appliances	Power Rating/Unit (W)	Total Power Rating (W)	Daily Use (h)	Energy Consumption (Wh/day)
3	Fans	65	195	24	4680
15	Lighting units	60	900	24	21600
2	TV set	45	90	24	2160
1	Pressing iron	1000	1000	1	1000
1	Sound system	45	45	24	1080
2	Fridge/freezer	200	400	24	9600
			2630		40,120

Table 2: Total energy consumption in the estates using conventional lighting

	Energy Consumption per Housing Unit	Energy Consumption per Estate	Energy Consumption for the 4 Estates
Daily (kWh)	40.12	(40.12*400) 16,048	(16,048*4) 64,192
Yearly (MWh)	(0.04012*365) 14.64	(14.64*400) 5,856	(5,856*4) 23,424

Table 3: Energy consumption per housing unit using energy-efficient lighting

No of items	Electrical Appliances	Power Rating/Unit (W)	Total Power Rating (W)	Hourly Consumption (h)	Energy Consumption (Wh/day)
3	Fans	65	195	24	4680
15	Lighting units	15	225	24	5400
2	TV set	45	90	24	2160
1	Pressing iron	1000	1000	1	1000
1	Sound system	45	45	24	1080
2	Fridge/freezer	200	400	24	9600
		1,370	1955		23,920

Table 4: Total Energy consumption in the estates using energy efficient lighting points

	Energy Consumption per Housing Unit	Energy Consumption per Estate	Energy Consumption for the 4 Estates
Daily (kWh)	23.92	(23.92*400) 9,568	(9,568*4) 38,272
Yearly (MWh)	(0.02392*365) 8.73	(8.73*400) 3,492	(3,492*4) 13,968

Table 5: Energy savings using energy efficient lighting system in place of conventional lighting system in the housing estates

	Power Rating			Energy Consumption		
	Per Housing Unit (W)	Per Estate (kW)	For the Four Estates (kW)	Per Housing Unit (kWh/day)	Per Estate (kWh/day)	For the Four Estates (kWh/day)
Conventional Lighting Systems (CLS)	2630	(2.630*400) 1052	(1052*4) 4208	40.12	(40.12*400) 16,048	(16,048*4) 64,192
Energy Efficient Lighting Systems (EELS)	1955	(1.955*400) 782	(782*4) 3,128	23.92	(23.92*400) 9,568	(9,568*4) 38,272
Energy Savings	675	270	1080	16.20	6,480	25,920
CLS:EELS	1.35:1	1.35:1	1.35:1	1.68:1	1.68:1	1.68:1

Table 6: Estimated on-grid maximum energy costs and cost savings using conventional and energy efficient lighting systems in the abuja suburban housing estates (AEDC Energy Costs = $ 0.12/kWh)

	Housing Unit $	Estate $	Four Hostels $
Conventional Lighting System (CLS)	4.85	1,940	7,760
Energy Efficient Lighting System (EELS)	2.90	1,160	4,640
Cost Savings	1.95	780	3,120
CLS:EELS	1.68:1	1.68:1	1.68:1

Adopting the EELS gives estimated on-grid energy costs from AEDC to be $ 2.90 per house, $ 1,160 per estate, and $ 4,640 for the four estates. Energy costs saving are estimated to be $ 1.95 per housing unit, $ 780 per estate, and $ 3,120 for the four estates. These calculations show a 40.4% costs reduction by replacing the CLS with EELS in the estates.

3.3. Comparative techno-economic specifications of the off-grid photovoltaic (pv) and diesel generator power supply options

In this section, the design specifications of the PV system are determined.

3.3.1. Design of the PV for electrification of the estate

There are 400 housing units in the estate, and 1.25 is thus diversity factor [47, 48]. The total required power in the estate based on their load is $\frac{2620 \times 400 \times 1}{1.25} = 838{,}400$ W

The total energy consumption in the estate is 40120 * 400 = 16,048 kWh/day

3.3.2. Designing a stand-alone PV system for electrification of each housing unit in the estate

The peak power (Wp) of the PV generator (P_{pv}) for a household is obtained from the following equation:

$$P_{pv} = \frac{EL \times Sf}{nR \times nI \times PSH} \quad (5)$$

Where P_{pv} = Peak power of PV,

E_L is the daily electricity consumption in each housing unit and is equal to 40.12 kWh,

PSH is the peak sun hour duration in Nigeria which is approximately 6 hours [49]

S_f is the safety factor, for compensation of resistive and PV-cell temperature losses = 1.15

n_R is the efficiency of charge regulator = 0.92

n_I is the efficiency of Inverter = 0.9.

Substituting these values in equation (5), the peak value of the PV is obtained as:

P_{pv} = 9.974 kW, approximately 10 kW

To install this power, a polycrystalline-60 rectangular cells module type CS6-P-230-P of a 1.61 m^2 cross sectional area, rated at 12 VDC, and peak power of P_{mpp} = 230W is selected.

The angle/direction of installation in Nigeria is estimated to be 20 – 28°S [48, 49]

The number of PV modules ($No._{pv}$) is obtained as:

$$No._{pv} = .\frac{Ppv}{Pmpp} \quad (6)$$

$No._{pv}$ = 43.37 modules, approximately 44 modules

Selecting the voltage of the PV generator to be *V nominal* = 96V, the numbers of the PV modules in series is given as:

$$No._{pvs} = \frac{V_{pv}}{V_{oc}} \quad (7)$$

(V_{pv} and V_{oc} are the nominal voltage and the open circuit voltage of the PV respectively). The open circuit voltage and the short circuit current of CS6-P-230-P at standard condition are: V_{oc} = 29.6V, I_{sc} = 8.34A respectively.

$No._{pvs}$ = 3.24 ≈ 4, thus 4 modules will be connected in series in order to build 9 strings in parallel. The actual number of PV generator modules is 4 * 9 = 36 modules.

The open circuit voltage and the short circuit current for the array can be obtained as:

$V_{oc} = 4 \times 29.6V = 118.4V$

$I_{sc} = 8.34A \times 28 = 233.52A$

Therefore, the maximum actual power obtained from this PV array is 27.65 kW

3.3.3. Determining the size of the battery

A large storage capacity is required for this PV arrays system. Thus, a special lead-acid battery (block type) with long lifetime (more than ten years) and higher capability of deep discharge period is selected for this design. The Ampere hour capacity (C_{Ah}) of the block battery, necessary to cover the load demands of each building for the period of 1.5 days when there is no sun [51] is calculated as:

$$C_{Ah} = \frac{1.5 \times EL}{VB \times DOD \times nB \times nI} \quad (8)$$

Where DOD is the depth of discharge of a cell and is 0.75, V_B is 96V and n_B and n_I are the efficiency of battery and efficiency of inverter respectively and are 0.85 and 0.9 respectively. Substituting these values, the ampere hour capacity of the battery block is obtained as:

$$C_{Ah} = \frac{1.5 \times 40120}{(96 \times 0.75 \times 0.85 \times 0.9)}$$

C_{Ah} = 1092.6 Ah and the watt-hour capacity is calculated as:

$$C_{Wh} = C_{Ah} \times V_B \tag{9}$$

$C_{Wh} = 1092.6 \times 96 = 104{,}889.6$ Wh

Installing this capacity required 62 battery blocks in series (each rated at 2V/1000 Ah) in order to build a battery block with an output rated voltage 124 VDC/1000Ah.

3.3.4. Determining the size of charge regulator

The charge regulator is used to normalize the output of the PV generator going to the inverter and also protect the battery against overcharge and deep discharge. The rating of the charge regulator is determined by output of the PV array and its nominal voltage.

The V_{input} is equal to V_{oc} which has a range from (4×12) to (4×29.6)

Thus the range of V_{oc} is 48 to 118.4 VDC

The rated power of the charge regulator is equal to the peak power of PV and is equal to 9.974 kW. In this case the appropriate size of the charge regulator is 10 kW.

3.3.5. Determining the size of inverter

The power of the inverter is determined from the total required power in the household and this should match the battery block voltage. The required power in each building is $P = \frac{1415 \times 1}{1.25} = 1132$ where 1.25 is the diversity factor

This is estimated to 1.415 kVA at 0.8 power factor. For this design the appropriate rated power of the inverter is 1.8 kVA

3.3.6. The diesel electric generator

The Diesel generator is the combination of an electrical engine called alternator and the diesel engine to generate electrical energy. In Nigeria, diesel generators are widely used to supply electrical energy to the villages without connection to the power grid. Sizing of the generator is critical to avoid low-load or shortage of power. The power rating of the diesel generator is determined by the size of the load. The estimated connected load of the each housing unit in the estate is 2630 W as shown in Table 1.

Applying the diversity factor of 1.25, the demand/connected load is thus estimated as:

Maximum Demand= 2630 W × (1/1.25)

Maximum demand = 2104 W

Percentage loading = 70%

Therefore, the generator set rating

$$= \frac{maximu.Demand}{Percentage\ Loading} = 3005.7\text{W}$$

At 0.8 power factor, the diesel set rating is 3.75kVA.

3.3.7. LCC for the PV system

Capital cost = $ 12,485

Annual maintenance cost is 2% of capital cost = $ 249.70

Using equation 10 above, LMC = $ 15,159.03

Non-recurring cost of PV system

Capital cost of replacing batteries, inverters and charge controller = $ 4120

Annual replacement cost is 30% of capital cost = $ 1236

LRC = $ 11945

Therefore, Life Cycle Costs (LCC) for the PV System are:

$$\text{LCC}_{\text{SPVC}}(\$ / \text{KWh}) = \frac{cc + LFC + LMC + LRC}{Period \times 365 \times kWh / day}$$

The load demand per housing unit is 40.12 kWh/day

LCC_T for PV per housing unit = $ 0.11/kWh

Table 7: The Associated Costs of Stand-alone PV System

Item	Components	Quantity	Unit price ($)	Life time (Years)	Total price $
1	PV module(CS6P-23 0-P)	10000 W	1.16/W	25 yrs	11600
2	Inverter	1	160	10	160
3	Battery 2v 1000Ah	62	60	10	2880
4	Charge controller	1	240	10	240
5	Circuit breaker and switches	1	100	5	100
6	Installation materials				75
7	Installation cost				250
	Total system cost				12485

Note: The associated costs for the stand-alone PV system and the diesel generator are obtained from energy systems vendors in the FCT.

LCC_T for PV per estate of 400 houses = \$ 44/kWh

LCC_T for PV for the four suburban housing estates = \$ 176/kWh

3.3.8 . LCC for the diesel generator

The generator considered in the study is the Firman FPG 3800 E2 3.8 KVA Diesel generator with capital cost of \$ 475

The Recurring Costs are the Fuel Costs and the Maintenance Cost

The Life Fuel Cost (LFC)

Fuel cost: The system is designed at 24hrs/day as the generator duty cycle and the fuel consumption is 1.1 litres/hr

Therefore, the cost of fuel/year = \$ 7057

Assuming the fuel escalation of 25% per year over 3 years.

LFC = \$ 27,168.17

LFC over 25 years = \$ 244,513.50

The Life Maintenance Cost (LMC)

Annual Maintenance Cost (AMC): \$ 50

LMC = \$ 152.30

LMC over 25 years = \$ 1,370.70

The Non-Recurring Cost (LRC)

$LRC_{minor\ overhaul}$ = \$ 436.05

$LRC_{major\ overhaul}$ = \$ 536.09

Generator replacement = \$ 8592.75

LRC_{Total} = \$ 9564.89

Therefore, Life Cycle Costs (LCC) for the Diesel generator are:

$$LCC_{DG}(\$ / KWh) = \frac{cc + LFC + LMC + LRC}{Period \times 365 \times kWh / day}$$

The load demand per housing unit is 40.12 kWh/day

LCC_T for Diesel generator per housing unit = \$ 0.7/kWh

LCC_T for Diesel generator per estate of 400 housing units = \$ 280.00/kWh

LCCT for Diesel generator for the four suburban housing estates = \$ 1120/kWh

Table 9 represents the life cycle costs (LCC) of the two off-grid power supply options under the various energy consumption scenarios. Taking the CLS scenario in perspective, under the PV option, LCC were estimated to be \$0.11/kWh per housing unit, \$44/kWh per estate, and \$176/kWh for the four estates. For the diesel generator

Table 8: Associated Costs of Diesel Generator

No	components	Quantity	Unit price \$	Life time	Total price \$
1	3.8 kVA Diesel generator	1	475.00	2,3/4.years	475
2	Diesel fuel	10 Litres	0.73/L	9 hours	7,057/yr
3	Engine oil	2 Litres	5/L	1 month	120/yr
4	Diesel filter	1	7.50	500 h	45
5	Air filter	1	3.50	2500 h	7
6	Maintenance/overhaul	1	50	1 year	50

Note: The diesel generator fuel consumption is estimated to be 1.1 litres/hour using a fuel consumption calculator [50] and actual observation using a brand new diesel generator[4].

Table 9: Life Cycle Costs of Off-Grid Power Systems and Energy Consumption Scenarios in the Four Estates

	(Conventional Lighting System) \$/kWh			(Energy Efficient Lighting System) \$/kWh		
Off Grid Power System	**Per Housing Unit**	**Per Estate**	**The Estates**	**Per Housing Unit**	**Per Estate**	**The Estates**
PV	0.11	44	176	0.07	28	112
Diesel Generator Cost	0.70	280	1120	0.42	168	672
Differences	0.59	236	944	0.35	140	560
PV: Diesel Gen	1:6.36	1:6.36	1:6.36	1:6	1:6	1:6

4 A new 3.8 kVA diesel generator was purchased. The estimated connected load of each housing unit in the estate (2630 W) was applied to the generator. 10 litres of diesel was poured into the fuel tank and the diesel generator was switched on and operated over time. After operating for 9 hours, the generator ran out of diesel. This process was carried out once a day for 5 days with the same result. Thus the diesel generator fuel consumption was established to be 1.1 litres per hour.

option, LCC were estimated to be $ 0.70 per housing unit, $280 per estate, and $1120 for the four estates. Similarly, LCC under the EELS scenario were estimated. Under the PV option, LCC were estimated to be $0.07 per housing unit, $ 28 per estate, and $112 for the four estates. For the diesel generator option, LCC were estimated to be $0.42 per housing unit, $168 per estate, and $672 for the four estates. Diesel generator LCC is approximately 6 – 6.36 times the LCC for the PV system.

4. Discussion on the results

The inability of the Nigerian State to provide uninterrupted electric power for the use of the nation's citizenry is well documented. The ineffectual alternative energy planning by state governments in Nigeria's North-Central region has been attributed in part to the inadequacy of the planning premises and energy consumption profile of the housing estates in the region. Tables 1–4 show that the maximum estimated power consumptions in the suburban housing estates under the CLS should not be less than 40.12 kWh/day per housing unit, 16,048 kWh/day per estate, or 64,192 kWh/day for the 4 estates. Under the EELS, it should be 23.92 kWh/day per house, 9,568 kWh/day per estate, or 13,968 kWh/day for the 4 estates. These therefore become the upper limits for the energy planning framework for the suburban housing developments in the North-Central region.

The adoption of EELS relative to the CLS shows power rating energy savings of 45W. This translates to 18kW over the 400 houses in the estate, and 72kW over the four estates. These results show a 3% reduction in power ratings. The energy savings calculated for energy consumption in the suburban housing developments by using EELS in place of CLS (16.20 kWh/day per house, 6,480 kWh/day per estate, and 25,920 kWh/day for the four estates) show a 40.4% reduction in energy consumption. This energy consumption reduction is significant and not only justifies the switch over from CLS to EELS, but offers critical information to benchmark planning criteria for this switch-over. The results further provide critical empirical corroboration to the arguments of Momodu et al.[44], Jesuleye et al. [16], Akinwale et al. [43], and Akinwale et al. [44], that the adoption of energy-efficient lighting would enhance Nigeria's energy mix. Table 6 shows the estimated maximum energy costs in the Abuja Area from the projected electricity consumptions in the housing estates. These costs are critical to energy planning development and implementation in the estates. None of the state governments in the North-Central region of Nigeria have reported determining these maximum energy costs to residents in the estates. It is not expected that any household would actually have such high electricity bills, but that these figures would provide the benchmarks for planning and regulation. The results further provide empirical evidence for electricity end-users to switch from conventional lighting systems to energy-efficient lighting. An agglomeration of energy-efficient light system adoption in Nigeria could drastically reduce the need to build huge power generation systems for the country as pointed out by Momodu et al [44].

Diesel generating sets are the most dominant central off-grid power supply systems in Nigeria's housing developments [16]. The decision to choose diesel generators is mostly dependent on the cheaper purchase costs in the short term relative to other central off-grid power supply systems like PV systems. The long term financial and environmental effects however are not taken into consideration in this energy supply system purchase decision-making process. This is not ideal. Sovacool [41] has reported that diesel generators have lifecycle greenhouse gas (GHG) emissions of 778gCO_2/kWh while a PV system made from polycrystalline silicon emits 32gCO_2/kWh. Thus, the diesel generator has lifecycle GHG emissions more than 24 times the PV system. This huge difference is critical for planning on the appropriate alternative energy system to adopt in the housing developments in the area.

Adopting the Life-cycle cost analysis (LCCA) method for alternative power systems selections, requires looking at the long term financial and environmental effects in decision making. The results showed that the diesel generator option LCC costs were approximately 6 times those of the PV option. The consequent calculations define the project parameters the North-Central regional governments need in determining the appropriate alternative-energy option for their suburban housing developments. Table 7 showed quite clearly that adopting the PV option under the Energy efficient lighting system had the lowest costs of the four possible options and should be selected for the housing developments. This indicates regional governments have the ability to improve overall efficiency of an energy system of a metropolitan area with its suburbs by the high penetration of the PV option under the Energy efficient lighting system [42].

5. Summary, conclusions and recommendations

This study examined alternative lighting systems and off-grid electric power options for suburban housing developments in North-Central Nigeria, and paid attention to estates in Suburban Abuja, FCT, which were being considered as templates for housing suburban developments in the rest of the North-Central region. Four housing estates in suburban Abuja consisting of 400 housing units each were examined to determine their electricity consumption and energy savings under two energy consumption scenarios (conventional and energy efficient electric lighting systems). The techno-economic specifications of two off-grid electric power supply options (photovoltaic (PV) and diesel generator systems) were calculated in order to establish the viability of the PV system relative to the diesel generating system as the off-grid electric power supply option.

The study determined electric power demands of 40.12 kWh/day/housing unit, 16,048 kWh/day/estate and 64,192 kWh/day/4 estates for the conventional lighting scenario and 23.92 kWh/day/housing unit, 9,568 kWh/day/estate and 38,272 kWh/day per the 4 estates for energy efficient lighting scenario respectively. These power demands are to serve as decision benchmarks for policy-makers in the States in Nigeria's North-Central region.

The energy savings calculated for energy consumption in the suburban housing developments by using EELS in place of CLS (16.20 kWh/day per housing unit, 6,480 kWh/day per estate, and 25,920 kWh/day for the four estates) show a 40.4% reduction in energy consumption. Comparing household electricity bills also showed a 40.4% reduction in the bills if the Energy-efficient lighting system was adopted over the Conventional Lighting System. The diesel generator alternative power-supply option had Life Cycle Costs approximately 6 times those of the PV option. These calculations indicate that the PV option is a more viable off-grid power supply option compared to the diesel generator option. Furthermore, the calculations in the study provided the project parameters the North-Central regional governments need for the planning and development of appropriate alternative-energy options for their suburban housing developments.

Finally, the study showed that adopting the PV option under the Energy-efficient lighting system provides the lowest techno-economic costs and would be considered the most viable option for off-grid alternative-energy system for suburban housing developments in the North-central region of Nigeria.

It is recommended that suburban housing developers in Nigeria's North-Central region be encouraged to invest in the development and deployment of PV and energy efficient lighting systems in the region as they have been found to be more techno-economically viable relative to diesel generator and conventional lighting systems.

References

[1] Akarakiri, J.B. Wood Energy in Nigeria. Energy, vol. 16, No.5, 1991; pp 875-678.

[2] Akinbami, J-F.K. Renewable energy resources and technologies in Nigeria: present situation, future prospects and policy framework. Mitigation and Adaptation Strategies for Global Change. 6 (2), 2001, 155-182. http:// citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.200.783&rep=rep1&type=pdf.

[3] Akinwumi, I.O., Moses, R., and Akinbami, J-F.K. "Electric power supply strategies and productivity in selected manufacturing industries in Nigeria". Resources, Energy, and Development, 3(2), 2006; 107-128. http:// content.iospress.com/articles/journal-of-resources-energy-and-development/ red120034 http://www.i-scholar.in/index.php/jred/rt/capture Cite/90295/0')

[4] Ibitoye, F., and Adenikinju, A.: Future demand for electricity in Nigeria; Applied Energy, Volume 84, Issue 5, (2007), Pages 492–504

[5] Iwayemi, A. Investment in Electricity Generation and Transmission in Nigeria: Issues and Options, International Association for Energy Economics, (2008), pp 38–42 , https://www.iaee.org/documents/newsletterarticles/Iwayemi.pdf

[6] Sambo, A.S. Matching electricity supply with demand in Nigeria. International Association for Energy Economics (IAEE) Newsletter, Fourth Quarter, 2008, https://www.iaee.org/documents/newsletterarticles/408sambo.pdf

[7] Olaopa O., Ogundari, I.O., Awoleye, M., and Siyanbola, W.O. (2009): "The politics and policies of oil deregulation in Nigeria: Implications and policy suggestions". Contending Issues in the Niger Delta Crisis of Nigeria. JAPSS Press Inc, Houston, 203-256. http://www. academia.edu/4182495/ Chapter_IX_The_politics_and_policies_of_oil_deregulation_in_Nigeria_Implications_and_policy_suggestions._Olawale_Olaopa_Ibikunle_Ogundari_Mike_Awoleye_and_Willie_Siyanbola

[8] Adegbulugbe A. O. and Adenikinju A. Energizing Vision 20:2020 in A. Iwayemi, W. Iledare, and A.. Adenikinju (eds.) Proceedings of the 2010 NAEE Conference (2011) Book Merti Publishers, Ibadan.

[9] Sambo, A.S.: "Renewable Energy for Rural development: The Nigerian perspective". ISESCO: Science and Technology Vision, Vol. 1, May, 2005, http://www.isesco.org.ma/ISESCO_Technology_Vision/NUM01/doc/A.S.Sambo.pdf

[10] Atoyebi, A., Ogundari, I.O., and Akinwale, O.Y. Comparative techno-economic analysis of a grid and off-grid electric power supply for a new housing estate development in North Central Nigeria". Seminar presented at the National Centre for Technology Management (NACETEM), Federal Ministry of Science and Technology (FMST), September, 2013.

[11] Babatunde, M.A. and Shuaibu, M. I. The demand for residential electricity in Nigeria: A bound testing approach, 2008, http://www. africametrics. org/documents/conference09/papers/Babatunde_Shuaibi.pdf

[12] Ogundari, I.O., Akinwale, O.Y., Olaopa, O.R., Akarakiri, J.B. and Siyanbola, W.O. An Analysis on Electric Power Supply, Electricity Sectoral Allocation and Off-Grid Power Supply Technologies for Sustainable Development in Nigeria. A paper presented at the 6th Annual NAEE/IAEE International Conference held at Sheraton Hotel, Lagos, from April 22–23, 2013.

[13] Ogundari, I.O., O.R. Olaopa, O.A. Jesuleye, I.G. Nwosu, W.O. Siyanbola, An Analysis on Electric Power Requirements for Techno-Economic Development in Nigeria. A paper presented at the 2011 National Solar Energy Forum 'NASEF 2011' of the Solar Energy Society of Nigeria, Sokoto Energy Research Centre, Usman Dan Fodio University, Sokoto, November 14–18, 2011.

[14] Iwayemi, A. "Nigeria's dual energy problems: Policy issues and challenges". International Association for Energy Economics, 2008; pp 17-21, https://www.iaee.org/en/publications/newsletterdl.aspx?id=53

[15] Ukwuoma O., Ogundari I. O., Akinwale Y. O, and Adepoju A. O (2015): "Harnessing Renewable Energy Resources for Sustainable Economic Development in Nigeria". In Oluwasogo, Ogungbenro, Nwoye and Kulla (Eds). Proceedings of the 5th Annual & International Conference by the Renewable and Alternative Energy Society of Nigeria (RAESON) at Gregory University, Uturu, Abia State.

[16] Jesuleye, O. A., Siyanbola, W. O., Ilori, M. O., Akinbami, J-F. K. and Ogundari, I. O.: "Solar Photovoltaics Contribution to Energy Services in Selected Remote Villages in Nigeria". Nigeria Journal of Solar Energy, Volume 23, 2012; pp 49-6

[17] Siyanbola, W. O. Addressing the Centrality of Science, Technology and Innovation (STI) Policy in the Economic Transformation Process: Key Issues and New Directions. A paper delivered at: the 3rd Technology Management Forum For Directors of Science, Technology Held 20 August 2012 At NACETEM South-South Office, Bayelsa State, Nigeria.

[18] Nigerian Electricity Regulatory Commission (NERC). Review of Basic Assumptions for Semi-Annual Review Of MYTO-2, May 2014. http://www.nercng.org/index.php/nerc-documents

[19] Federal Ministry of Power, Works and Housing (MPWH). Daily News Monitoring, Press and Public Relations Unit. http://www.power.gov.ng/Press%20Reviews/PRESS%20REVIEW%20WEDNESDAY%20FEBRUARY%2010TH%202016.pdf

[20] Falola, T. The History of Nigeria. Greenwood Press, 1999; ISBN 0-313-30682-6, https://www.cambridge.org/core/journals/journal-of-african-history/article/div-classtitlenigeria-a-history-the-history-of-nigeria-by-toyin-falola-the-greenwood-histories-of-the-modern-nations-series-london-and-westport-ct-greenwood-press-1999-pp-xviii269-2795-isbn-0-313-30682-6-div/1AA2A1BCA6D66F310EA3FF8D2F59BF55

[21] National Centre for Technology Management (NACETEM), Harnessing Science, Technology and Innovation (STI) for Development in North Central Nigeria: Policy Issues, Challenges and Agenda for Action. NACETEM Seminar, July 1, 2012.

[22] National Population Commission. National Census Figures, 2006; http://www.population.gov.ng/files/nationafinal.pdf

[23] Jibril, I.U. Resettlement Issues, Squatter Settlements and Problems of Land Administration in Abuja, Nigeria's Capital. Promoting Land Administration and Good Governance, 5th FIG Regional Conference, Accra, Ghana, March 8-11, 2006. https://www.fig.net/resources/proceedings/fig_proceedings/accra/papers/ts18/ts18_01_jibril.pdf

[24] Ndubueze, O.J. Urban Housing Affordability and Housing Policy Dilemmas in Nigeria. Unpublished PhD Thesis, Centre for Urban and Regional Studies, School of Public Policy, The University of Birmingham, U.K., 2009. http://humanitarianlibrary.org/sites/default/files/2013/08/Ndubueze09PhD.pdf

[25] Jibril, I. U. and Garba, K.T. The Challenges of Housing Development and Needs in Abuja, Nigeria". FIG Working Week Rome, Italy, 6-10 May, 2012. http://www.fig.net/pub/fig2012/papers/ts06c/TS06C_jibril,_garba_5915.pdf

[26] V.O. Oladokun and S.A. Adeshiyan Demand management based design of residential solar power supply system: a techno-economic evaluation, American Journal of Scientific and Industrial Research © 2012, Science Hu?, http://www.scihub.org/AJSIR, ISSN: 2153-649X doi:10.5251/ajsir.2012.3.1.21.26

[27] Oghogho, I., Sulaimon, O., Adedayo, B.A., Egbune, D., Kenechi, A.V., (2014). Solar energy potential and its development for sustainable energy generation in Nigeria: a road map to achieving this feat. International Journal of

Engineering and Management Sciences (2014), 5(2), 61. http://scienceandnature.org/IJEMS-Vol5(2)-Apr2014/IJEMS%20Vol5(2)-2.pdf

[28] Nwofe, P. A. Utilization of Solar and Biomass Energy- A Panacea To Energy Sustainability in A Developing Economy, International Journal of Energy and Environmental Research, (2014) Vol.2, No.3,pp.10-19. http://eajournals.org/wp-content/uploads/Utilization-of-Solar-and-Biomass-Energy-A-Panacea-to-Energy-Sustainability-in-A-Developing-Economy.pdf

[29] Bala, E.J., Ojosu, J.O., and Umar, I.H., (2000). Government Policies and Programmes on the Development of Solar PV Sub-sector in Nigeria. Nigeria Journal of Renewable Energy. 8(1&2), 1.

[30] Owolabi I.E., "Solar Photovoltaic power technology: Prospects and challenges for socioeconomic empowerment in Nigeria." Technical Paper presented to the Nigerian Society of Engineers (NSE) Ado-Ekiti branch. Pg 3-5, 2008.

[31] Ogunleye, I.O. and Awogbemi, O., "Constraints to the use of solar photovoltaic as a sustainable power source in Nigeria." American Journal of Scientific and Industrial Research, Vol. 2(1): 11-16, 2010. http://www. scihub.org/AJSIR/PDF/2011/1/AJSIR-2-1-11-16.pdf

[32] Chendo, M.A.C., . Factors Militating Against the Growth of the Solar-PV Industry in Nigeria and their Removal, Nigerian Journal of Renewable Energy. (2002) 10(1&2),151.

[33] Awogbemi, O., and Komolafe, C.A., (2011). Potential for Sustainable Renewable Energy Development in Nigeria. Pacific Journal of Science and Technology. 12(1), 161, http://www.akamaiuniversity.us/PJST12_1_161.pdf

[34] Oparaku, O. U. Rural Area Power Supply in Nigeria: A Cost Comparison of the Photovoltaic, Diesel/Gasoline Generator and Grid Utility Options. Renewable Energy, (2003), 28: 2089 – 2098. http://fulltext.study/preview/pdf/303236.pdf

[35] Akinpelu E. O., and Eng, M. Sizing and Cost Assessment of Solar PV System for Energy Supply in the Telecommunication Industry in Nigeria. Journal of Engineering and Applied Sciences (2011), 6 (2): 130–134.

[36] Federal Ministry of Science and Technology (FMST). The Nigerian National Science, Technology and Innovation Policy, 2012. http://www. scienceandtech. gov. ng/docs /STI_POLICY.pdf

[37] Nuhu, M.B. Compulsory Purchase and Payment of Compensation in Nigeria: A Case Study of Federal Capital Territory (FCT) Abuja. Nordic Journal of Surveying and Real Estate Research, Special Series 3, 2008; 102-126, http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.611.3700&rep=rep1&type=pdf

[38] Umoh, N. Exploring the Enabling Approach to Housing through the Abuja Mass Housing Scheme. Unpublished MA Thesis, Department of Urban Studies and Planning, MIT, USA. 2009. https://dspace.mit.edu/handle/1721.1/73831

[39] Olotuah, A.O. and Bodaoye, S.A. Sustainable Housing Provision for the Urban Poor: A Review of Public Sector Intervention in Nigeria." The Built and Human Environment Review, 2009; 2:52-63 http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.468.935&rep=rep1&type=pdf

[40] Federal Capital Territory Administration (FCTA) (2012): Energy Demand in the Federal Capital territory. Memoranda to the Science, Technology and Innovation (STI) Policy Review Initiative.

[41] Sovacool, B.K. Valuing the greenhouse gas emissions from nuclear power: A critical survey". Energy Policy, Vol. 36, 2008; p. 2950, http://www.grid.unep.ch/FP2011/step1/pdf/003_Sovacool_2008.pdf

[42] Prina, M. G., Cozzini, M, Garegnani, G., Smart Energy Systems Applied at Urban Level: The Case of the Municipality of Bressanone-Brixen, International Journal of Sustainable Energy Planning and Management Vol. 10 2016 33-52, (1225–5287-1-PB.pdf) http://dx.doi.org/10.5278/ijsepm.2016.10.3

[43] Akinwale, Y. O., Ogundari, I. O., Ilevbare, O. E., and Adepoju, A. O.: "A descriptive analysis of public understanding and attitudes of renewable energy resources towards energy access and development in Nigeria". International Journal of Energy Economics and Policy. 4(4), (2014); Pp 636 – 646.

[44] Akinwale, Y. O., Ilevbare, O. E., and Ogundari, I. O.: "Utilising renewable energy technologies for electricity poverty reduction in South-West Nigeria: technology adoption and psychosocial perspectives", Int. J. Renewable Energy Technology, Vol. 6, (2015); No. 3, pp. 224–244. http://www.inderscience.com/offer.php?id=70149

[45] Momodu, A.S., Abraham, O.E. Ogundari, I.O., Jesuleye, O.A., Sanni, M., Ibuoye, T.F., and Siyanbola, W.O. Cost-benefit analysis of promoting energy efficiency diffusion in Nigeria's residential and commercial buildings. Nigeria Journal of Solar Energy, Vol. 22, 2011; pg 105–119

[46] Otasowie, P. O. and Ezomo, P. I. (2015), Life Cycle Cost Analysis for the Economic Validity for Solar and National Grid for Powering BTS, Journal of Energy Technologies and Policy, 5(3):49-56. www.iiste.org/ Journals/index.php/JETP/article/download/.../21186

[47] Indradip Mitra and S. P. Gon Chaudhuri, "Remote Village Electrification Plan through Renewable Energy in the Islands of Indian Sundarbans", homerenergy.com webcastdownloads ises-remic2-v2.pdf. downloaded 13/09/2016.

[48] SEIAPI/PPA, Off Grid Pv Power Systems System Design Guidelines, guidelines have been developed by the Sustainable

Energy Industry Association of the Pacific Islands in Collaboration with the Pacific Power Association, Issue 1 September 2012, http://www.irena.org/ documentdownloads/ events/2013/march/palau/8_offgrid_designguidelines.pdf

[49] Boyo, A. O., Correlation of monthly average daily global radiation and relative duration of sunshine for south-western cities in Nigeria, Journal of Engineering Applications, 3(2), (2003), pp 79-84. http://www .ijier.net/index.php /ijier/article/ download/401/377

[50] Global Power Supply LLC, Power Generation Calculators, (2016), www.globalpwr.com. Accessed 27/10/2016

[51] Masa Bote, D., Photovoltaics electrification in off-grid areas, In Case studies for developing globally responsible engineers, (GDEE) (eds.) Global Dimensions in Engineering Education, Barcelona. (2015) https://gdee.eu/ index.php/ resources.htm