

University of Nottingham
UK | CHINA | MALAYSIA

Department of Architecture and Built Environment

IMPLEMENTATION AND APPLICATION OF SOLAR ENERGY IN NIGERIA

Benedictta Ifechukwude Dibia

Thesis submitted in partial fulfilment of the requirement leading to the award of Doctor of Philosophy

April 2019

STATEMENT OF ORIGINAL WORK

I declared that l have read the student's code of conduct in accordance with the academic regulation as described in the student handbook of University of Nottingham.

This PhD thesis represents my original work except where materials, ideas/words from previous authors borrowed for emphasis and these l have duly acknowledged in the study.

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ABSTRACT

Nigeria is an exporting country and the electricity sector depends on gas, diesel and hydropower sources. Currently, the hydropower has replaced gas as the main source of energy due to climate change. Presently, the fossil fuels are expensive and limited due to scarce generation. This resulted into a power supply shortage that created a huge gap between the energy supply and demand. However, a new alternative energy source is required to complement the existing shortfall in supply of electricity in the country. Solar energy is a potential resource with huge availability for small and large-scale off-grid and grid-connected systems to be utilized in Nigeria. However, the high cost of Photovoltaic (PV) systems is one of the major problems identified and the current energy uses have limitations due to climate change. It affects conventional energy, hydropower and biomass which result to deforestation, desertification and water shortage/drought. This study focusing on economic, policy and technical perspectives investigated the possibility of using solar PV system to address challenges of electricity shortage and the affordability in order to meet electricity consumption with over 180 million populations and reduce the tendency of depending on diesel-fuel generators in the future in Nigeria. However, this study involved use of questionnaire method for data collection to understand the population perception about solar energy use with PV systems. The off-grid case studies were selected to determine the electricity generation, consumption and the payback period with mono and polycrystalline silicon PV types for the electricity generation. The RET Screen simulation software was adopted to analyse the amount of electricity output generated and the amount of emission reductions due to PV efficiency and accuracy. The innovative financing (PAYG) model was used to assess energy budget to ascertain energy consumption per user against blind decision due to cost based on the financial resource availability. The simulation results reveal more of electricity generation with the installed PV system at angle 15^0 degree. The monthly bills due to increased energy supply from the installed off-grid PV systems reduced from the utility grid electricity. The payback time for installed PV systems based on financial viability analysis shows reasonable, affordable, profitable and rewarding. In addition, the electricity cost from installed PV system generation and presently without subsidy is lower than the grid electricity

based on cost of outages. Finally, the results based on proposed grid-connected PV power system, putting economic factor into consideration can be more feasible.

Keywords: Solar Radiation, PV technologies, Off-grid and Grid-connected applications, Electricity generation, Economic implication, GHGs emission reduction and RET Screen Simulation Software.

PUBLISHED AND PRESENTED PAPERS BASED ON THIS RESEARCH WORK

Dibia Benedictta Ifechukwude, Jie Zhu, Gan Guohui and Blaise Mempouo 2018, Checkmate Climate Change Using Affordable PV System Technologies in Nigeria: 17th International Conference on Sustainable Energy Technologies (SET2018) 21st-23rd August 2018, Wuhan, China.

Dibia Benedictta Ifechukwude and Jie Zhu, 2017, Renewable Energy Policies for Investment Option: 19th International Conference on Solar Power (ICSP 2017) 24th- 25th April 2017 London UK.

Dibia Benedictta Ifechukwude and Jie Zhu, 2016, Innovative Financing Models for Solar Systems (Solar TR 2016) 6th - 8th December 2016, Istanbul Turkey.

DEDICATION

This PhD thesis dedicated to the Almighty God whom I serve through Christ Jesus for the gift of life and provider of substance necessary to complete the study.

My sincere gratitude to my partner Charles Chukwu with financial support and love I would not be who I am today. Your knowledge contribution made much impact to the study.

I also dedicate this work to my late parents Charles Chukwudobe and Gladys Patricia Dibia. I would not be who I am today without the love and support of them although our time together was brief and their contributions to my life will be felt forever. May your gentle souls continue to rest in the Lord, Amen.

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ACKNOWLEDGEMENTS

This thesis accessed various government agencies, research organisations, financial institutions, and private sector' companies, academic colleagues and individuals with significant contributions with time spend and information shared.

I would like to use this opportunity to express my gratitude by thanking my supervisors' Dr (s) Jie Zhu and Gan Guohui for guidance and direction in my PhD research study. My primary supervisor, your selfless time and attention helped me while the critics, corrections and feedback contributed a lot to improve my research work.

I specially want to thank staff of PDTF for the top-up support programme rendered for the completion of my academic research work. I take this opportunity to express gratitude to all the Department and Faculty members in the University of Nottingham and my colleagues for their help and support with necessary materials for the research. I am very grateful to Dr (S) Siddig Omer, Prof Saffa Riffat, Auwal Dodo, Ameen, Twaha, Daniel Gomez etc. I would like to thank my close colleagues and other academic colleagues for their support contributed to the finish of this thesis.

I would like to thank my loving and wonderful family for their prayers, care and encouragement. They are always there during difficult and trying times. My most senior brother Ignatius Dibia for the care and valuable ideas to this academic work and always there for the family. I like to thank my family friends who deserve my special appreciation, Fidelis Ayah and Winfred Morgan for sharing their knowledge willingly. Also, to Lina Morgan, Bunmi Babatunde, Branda and Mic Dacosta, Peniel and Francis Garuba, Claire and Lucy for your care and kindness, prayers and encouragement and others for your contributions to the completion of my academic research. Thank you all.

LIST OF ABBREVATIONS AND ACRONYMS

Acronym	Definition
AC	Alternating Current
AD	Aggregate Demand
ACP	Alternative Compliance Payment
AEF	Alternative Energy Fund
BIPV	Building Integrated Photovoltaic
BNCC	Backup Supplement of National Control Centre
BOI	Bank of Industry
BOS	Balance of system
BP	British Petroleum
BPE	Bureau of Public Enterprises
BTU	British Thermal Units
CBN	Central Bank of Nigeria
CDM	Clean Development Mechanism
CO_2	Carbon Dioxide
CREB	Clean Renewable Energy Bonds
CSI	California Solar Initiative

CPV	Concentrating Photovoltaic
CSP	Concentrating Solar Power
DC	Direct Current
DECC	Department of Energy and Climate Change
DISCO	Distribution Company
DNI	Direct Normal Irradiance
DOE	Department of Energy
NECN	National Electricity Corporation of Nigeria
ECN	Energy Commission of Nigeria
ECOWAS	Economic Community of West African States
EE	Energy Efficiency
EERE	Energy Efficiency and Renewable Energy
EIA	Energy Information Administration
EMSL	Electricity Management Services Limited
EPBB	Expected Performance-Based Buy-Down
EPPS	Electric Power Policy Statement
EPS	Electricity Power Stations
EPSR	Electric Power Systems Research
EPSRA	Electric Power Sector Reform Act

ERA	Environmental Rights Action
ESPR	Electric Power Sector Reform
ESI	Electricity Supply Industry
EU	European Union
FCT	Federal Capital Territory
FDCA	Federal Capital Development Authority
FEC	Federal Executive Council
FEN	Friends of the Earth Nigeria
FGN	Federal Government of Nigeria
FIT	Feed in Tariff
FME	Federal Ministry of Environment
FMOP	Federal Ministry of Power
FRN	Federal Republic of Nigeria
GDP	Gross Domestic Product
GENCO	Generation Company
GHGs	Green House Gases
GHI	Global Horizontal Irradiance
GIZ	Gesellschaft fur Internationale Zusammenarbeit GmbH
GND	Gross National Domestic Product

GRA	Government Reserved Area
GSM	Global Service Mobile
GTP	Gas Thermal Plant
IEA	International Energy Agency
IEDN	Independent Electricity Distribution Network
IEEE	Institute of Electrical and Electronics Engineers
IEJ	International Energy Journal
IEO	International Energy Outlook
IIED	International Institute for Environment and Development
IISD	International Institute of Sustainable Development
ILO	International Labour Organization
IMF	International Monetary Fund
IPCC	Intergovernmental Panel on Climate Change
IPO	Independent Power Operator
IPP	Independent Power Producer
IRENA	International Renewable Energy Policy
IRJES	International Referred Journal of Engineering and Science
ISO	Independent System Operators
JAMB	Joint Admissions and Matriculation Board

JICA	Japan International Cooperation Agency
Km^2	Kilometers Square
kW	Kilowatt
kWh	Kilowatt hour
LCDA	Lagos Island Council Development Area
LCOE	Levelized Cost of Electricity
LFN	Laws Federation of Nigeria
MAN	Manufacturers Association of Nigeria
MDA	Ministries Department and Agencies
MEF	Major Economies Forum
MJ	Mega Joule
MMOP	Modelling Measures of Performance
MO	Market Operation
MOE	Ministry of Environment
MOU	Memorandum of Understanding
MPPT	Maximum Power Point Tracking
Mtoe	Million Tonnes of Oil Equivalent
MW	Megawatt
MWh	Megawatt hour

MYTO	Multi Year Tariff Order
NA	National Assembly
NAEE	Nigerian Association of Energy Economist
NAPTIN	National Power Training Institute
NASA	National Aeronautics and Space Administration
NBET	Nigerian Bulk Electricity Trading
NBS	National Bureau of Statistics
NBTE	National Board for Technical Education
NCC	National Control Centre
NCERD	National Centre for Energy Research and Development
NCP	National Council of Privatization
NCS	National Council of State
NDA	Niger Dams Authority
NDGSPR	National Domestic Gas Supply and Pricing Regulations
NDPHC	Niger Delta Power Holding Company
NDRC	National Development Reform Commission
NEC	National Economic Council
NELMCO	Nigeria Electricity Liability Management Company
NEP	National Energy Policy

NEPA	National Electric Power Authority
NEPD	National Energy Policy Document
NEPP	National Electric Power Policy
NER	Nigerian Energy Reform
NERC	Nigerian Electricity Regulatory Commission
NES	Nigeria Economic Summit
NESI	Nigerian Electricity Supply Industry
NESCO	Nigeria Electricity Supply Company
NESP	Nigerian Energy Support Programme
NESREA	National Environmental Standards and Regulations Enforcement Agency
NETS	Nigerian Electricity Transmission System
NFG	Nigerian Federal Government
NGN/N	Nigerian Naira (Currency)
NGO	Non-Governmental Organization
NIPP	National Integrated Power Project
NO	Nitrogen Oxide
NOAA	National Oceanic and Atmospheric Administration
NPC	National Planning Commission
NPO	Non-Profit Organizations

NPSR	New Power Sector Roadmap
NPTI	National Power Training Institute
NREEEP	National Renewable Energy and Energy Efficiency Policy
NREL	National Renewable Energy Laboratory
NREMP	National Renewable Energy Master Plan
OECD	Organization for Economic Cooperation and Development
OPEC	Organization of Petroleum Exporting Countries
PACP	Presidential Action Committee on Power
PAYG	Pay As You Go
PBI	Performance-Based Incentive
PEF	Power Emergency Fund
PHCN	Power Holding Company of Nigeria
PIB	Petroleum Industry Bill
PPA	Power Purchase Agreement
PPP	Public Private Partnership
PSRB	Power Sector Reform Bill
PRB	Population Reference Bureau
PTFP	Presidential Task Force on Power
PV	Photovoltaic

PWD	Public Works Department
R&D	Research and Development
RE	Renewable Energy
REA	Rural Electrification Agency
REAP	Rural Energy for America Program
REF	Rural Electrification Fund
REMP	Renewable Energy Master Plan
REP	Renewable Energy Policy
RES	Renewable Energy Sources
RET	Renewable Energy Technologies
RISE	Research Institute for Sustainable Energy
RO	Renewables Obligation
ROC	Renewable Obligation Certificates
ROI	Return on Investment
ROW	Right of Way
RPS	Renewable energy portfolio standard
RTO	Regional Transmission Organization
SDN	Sustainable Democracy Network
SE4All	Sustainable Energy for All Initiative

SEI	Solar Energy International
SELF	Solar Electric Light Fund
SELCO	Solar Electric Light Company
SERC	Sokoto Energy Research Centre
SET	Solar Energy Technologies
SHS	Solar Home Systems
SMG	Solar Micro-Grids
SO	Service Operator
SREC	Solar Renewable Energy Credit
SSA	Sub-Saharan Africa
STA	Solar Trade Association
STC	Standard Test Condition
TCN	Transmission Company of Nigeria
TDF	Transmission Development Fund
TGC	Tradable Green Certificate
TMY	Typical Meteorological Year
TSP	Transmission Service Provider
UNCED	United Nations Conference on Environment and Development
UNEP	United Nations Environment Programme

UNDP	United Nations Development Programme
UNIDO	United Nations International Development Organization
UNN	University of Nigeria Nsukka
USA	United States of America
USAID	United State Agency for International Development
VAT	Value Added Tax
WAPP	West African Power Pool
WB	World Bank
WCED	World Commission on Environment and Development
WEO	World Energy Outlook
WEF	World Economic Forum
WHO	World Health Organization
WRE	World Renewable Energy

CHAPTER 1: INTRODUCTION

Nigeria also called "The Giant of Africa" is over 180 million population with a land area of about 923,770 Km^2 (FRN Commission, 2010) and blessed with abundant non- renewable and renewable natural energy resources. Nigeria is located in the south coast of West Africa named after River-Niger, shares a border with Benin (west), Cameroon and Chad (east) and Niger (north). It remained a federal government after independence in 1960 with multi-ethnic and various religious denominations. The farmland primarily located in the middle belt and Sub-Sahel zone is largely untouched due to lack of irrigation capacity (ECN, 2006). The total cultivated farmland is less than 50% with low agricultural productivity due to lack of modernization, and mechanized farming system despite the agricultural potential (Ibitoye and Adenikinju, 2007). Figure 1-1 represents the Nigeria geographical population distribution.

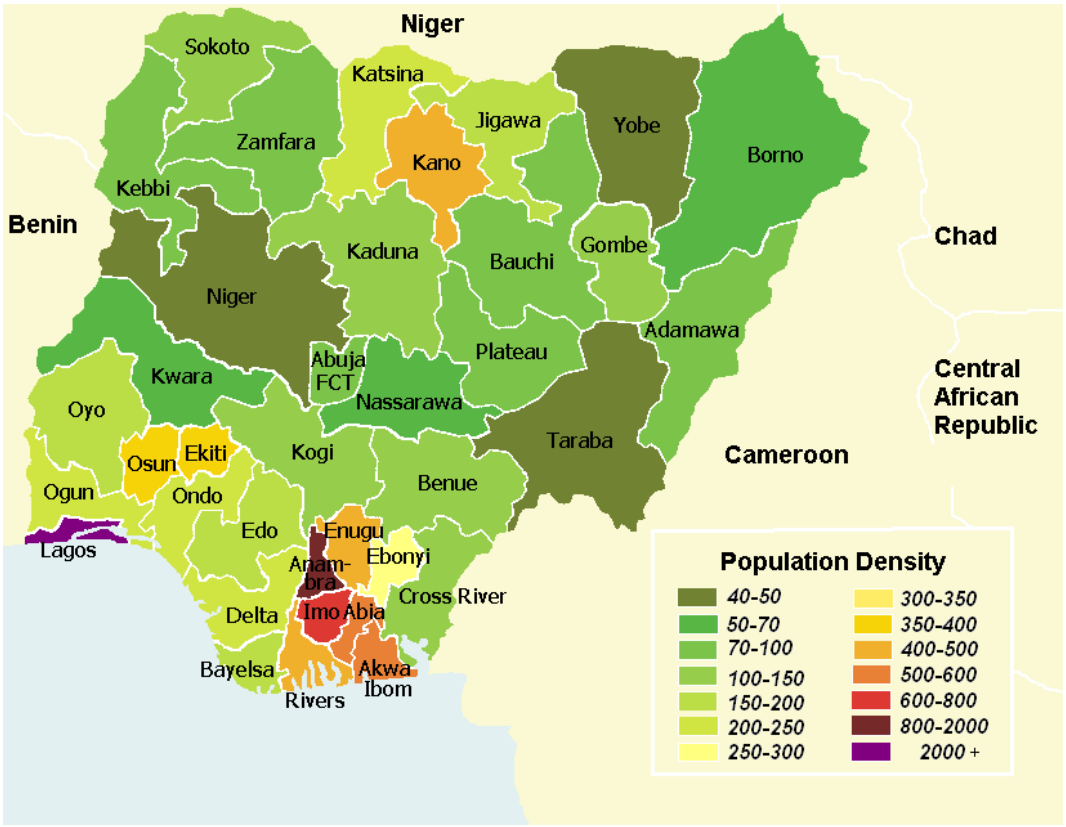


Figure 1-1*:* Nigeria Map for Geographical Location and the Population Distribution (Source: FRN, 2016 and FGN, 2010).

The economic indicators for energy productivity of the country include the total energy consumption of about 1,259TWh/annum, the total electricity production of 19.78TWhr/annum, the electricity consumption of 18.05TWh, and the per capita energy consumption of about 8.1 MWh. The national electricity access is 54% while rural electricity access is 28%. The gross domestic product (GDP) is about GBP1.8 billion (US$262.6 billion) with 7% average growth in the last three years (NBS, 2012c; Asaju and Adagba, 2013). The energy industry support is more than GBP6.9 billion (US$1 trillion) and equivalent to 7.7% of the U.S national economy gross domestic product (GDP) in 2012 (WEF, 2012). The gap between energy supply and demand is significantly wide and still needs to be addressed using renewable resources. Figure 1-2 demonstrates the interaction between man, energy and environment.

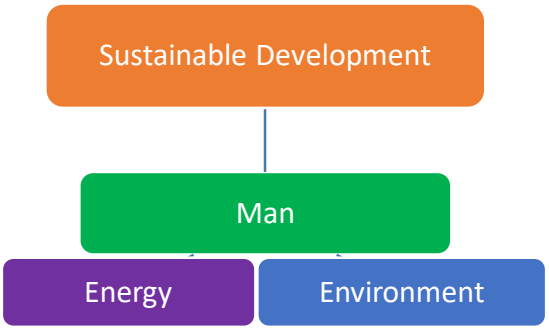


Figure 1-2: Interaction of Man, Energy and Environment for Sustainable Development.

The interaction between man, energy and environment is connected to necessities in the modern society. Energy is a major ingredient for socio-economic growth and development and highly associated with the environment. (Tallapragada, 2009). In today's world, RE technology is a current factor that facilitates sustainable development to enhance resource efficiency. Studies found that "Sustainable development is a development to meet the needs of the present without compromising the ability of the future generation to meet their own needs" (Brundtland and IISD report, 2016). This has two key concepts such as essential needs for the world's poor with limitations imposed by the state of technology and social organization with the environmental ability to meet present and future needs (Barkemeyer et al., 2014).

According to the 2002 World Summit on Sustainable Development for 'People, Planet and Prosperity' at Johannesburg, the energy sector plays a pivotal role in achieving sustainable development, balancing socio-economic developments and protection of the environment from encapsulated 'strapline' (IEA, 2016b and 2016a). In today's Nigeria, climate change has a huge effect on the existing resources that have led to a scarcity of electricity supply with lack of electricity access in remote rural areas (Chukwueyem, 2015). Solar energy application cannot be ignored, particularly for those without grid-connection, and this can be achieved mainly with the application of PV systems in the country (Babatope et al., 2013).

1.1 Nigeria Energy Background

The conventional methods for electricity production used in Nigeria include hydro and gas thermal plants set up in the 1970s, and later introduced coal and oil-gas fired stations (Okoro and Madueme, 2004). The gas production recently take over from hydro use to reduce pollution and improve water supply, mitigate climate change issues as well as to enhance the capacity of electricity generation (Olayinka Oyedepo, 2012 and Oseni, 2011). In Nigeria, the enormous scarcity of energy for decades largely contributes to poverty in the country.

After the first commercial oil production between the 1950s and Mid-1980s, the country suffered the problem of inadequate energy supply. It affected commercial activities that lead to the collapse of the nascent manufacturing sector. For instance, the car assembly and tire industries collapsed. The manufacturers since then have been deploying large capacity generators for electricity supply to address the long-time electricity scarcity gap without considering the negative effects on the environment.

The result of power outages, a financial loss which is about GBP311 million (N126 billion) equivalent to (US$984.38 million) from the report estimates by the Council for Renewable Energy of Nigeria (Oyedepo, 2012). The constant use of diesel generator sets is an open exposure to the amount of carbon emissions in different household and business locations. According to the report, the country is underdeveloped due to a high percentage of the

population living under the poverty line and more than 80% Nigerians live on less than a dollar per day (Ball and Vlaicu, 2012). Despite the yearly growth rate of 3-7%, the majority of the people are poor when compared to other Africa countries (Chauhan-Pole; Bloomberg, 2016). Figure 1-3 indicates the typical power distribution line, which is part of the national grid in Nigeria.



Figure 1-3: National utility grid-connected electricity (Source: Shewa, 2016).

In Nigeria, solar energy development has been a slow pace, compared to other countries in the developing world. Main barriers for solar energy exploitation, include lack of political will, weak regulatory framework, corruption, lack of commitment to funding, and incentives, high upfront solar energy costs, purchasing power, limited research and development for solar energy application, lack of awareness of solar systems by the people, poor operation and maintenance of the solar systems and intermittency of solar energy systems (Sambo, 2009b). In particular, most individuals in Nigeria cannot afford the initial cost of the solar system without subsidies, tax exemptions as well as without other financial support/schemes from the governments or other private organizations (Okonkwo, 2007).

1.2 Technical Perspective

Solar energy technology can ensure flexibility and long-term operational stability with high-efficiency Photovoltaic (PV) energy system and higher-flexibility with Building Integrated PV (BIPV) will reduce barriers to applications. According to IEEE, the installation of large-scale PV plants has become a sustainable solution to achieve energy sufficiency mostly in the developing countries where the economies depend on a higher level of energy importation (IEEE, 2017). However, these technologies applied in the developing countries can be apply in

the urban and remote rural areas in Nigeria through solar energy development schemes by the government.

1.2.1 Photovoltaic Technology and Types

Solar PV systems convert solar energy into electricity when installed in a certain location (DOE, 2005). A typical solar PV system consists of the mounting structure, charge controller (or dc-dc converter), and inverter for efficient performance (IEEE, 2017; Timilsina et al., 2011). Table 1-1 represents the historical development of PV technology.

Table 1-1: Photovoltaic Historical Development

Year	Name of Observer	Energy Conversion	Source
1838	Alexandre Edmond Becquerel	Electricity generation by chemical reactions when exposed apparatus to sunlight that increased the electrical energy produced.	(Strong and Scheller , 1987)
1887	Heinrich Hertz	PV system for direct conversion of sunlight into electricity with Photovoltaic effect use of semiconductor material.	(Rigden, 2005)
1905-1950s	Albert Einstein	This conversion explained in 1905 and the practice commenced in the 1950s.	
1954	Scientists	Silicon produced solar cells with 4 percent conversion of direct sunlight to electricity and powered spaceships and satellites at Bell Laboratories. "Solar battery" with 6 percent PV cell converted solar radiation into electricity at Bell Laboratories.	(NREL, 2007); (Deshmukh and Venkataraman , 2006) (Bernstein, 2006)

1960s 1970s		PV power generation technology improved in demand. Serious effort commenced when the PV panel started to provide cheaper solar power.	(Kurtz, 2012)

(Source: NREL, 2007).

The typical PV type is the monocrystalline silicon of good efficiency (13-17%) for a single crystal with thin layers of cells and more expensive than the other types but saves space. The polycrystalline silicon type crystallized small particles on square cell has a conversion efficiency of 11-15%, slightly cheaper than the monocrystalline PV type (Lechuga, 2011). The amorphous silicon PV non-crystalline silicon cells have a dark grey appearance that operates in low diffuse light with 6-8% conversion efficiency (Kleissl, 2013 and Monari et al., 2011). The Hybrid PV type is coated in an amorphous layer with PV crystalline cell for PV systems utility grid-connected. It can also operate on stand-alone BIPV or on the ground-mounted large-scale grid-connected system (Myers, 2013 and IEA, 2010b). These are four identified PV types.

1.2.2 Off-grid Vs Grid-connected Applications

The Off-grid also called stand-alone is an independent operation design, directly connected to direct current (DC) load without electrical energy storage (i.e. batteries) from PV module/array as a DC output. The critical part of designing a well-performing stand-alone system is the matching of the electrical load from PV array for maximum power output. The load only operates during sunlight hours making the design suitable for common applications like ventilation fans, water pumps including small circulation pumps for solar thermal water heating systems. The off-grid systems and an inverter, directly connected to consumer alternating current (AC) appliance types. In many off-grid PV systems, the batteries are energy storage used at night when there is no sunlight to generate energy from the PV systems are suitable for rural-remote areas application in Nigeria.

The dc-dc converter with maximum power point tracker (MPPT), helps to utilize better available panel maximum power output (Rekioua et al., 2014; Alsadi and Alsayid, 2012). According to research studies, the RE off-grid systems are being utilized for the power needs of the world poor, and a prerequisite for the development (Wiemann and Ling, 2014). The grid extension is not a feasible option for rural areas, often characterized by remoteness and low population density (Scott and Seth, 2012). Figure 1-4 represents a typical off-grid PV system with battery storage used for supplying direct current (DC) and alternating current (AC) loads.

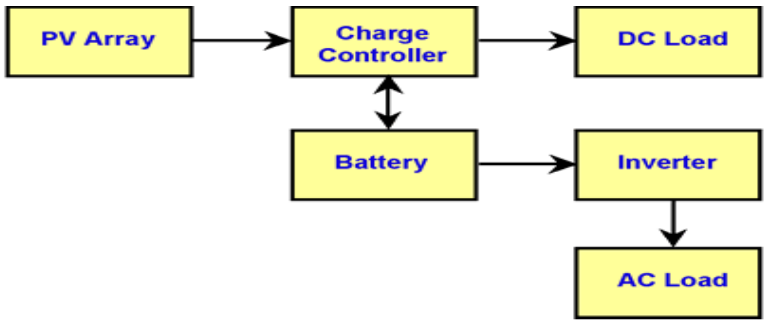


Figure 1-4: Diagram of Stand-alone PV system.

The grid-connected PV system as a utility-interactive design operates in parallel, interconnected with the electric utility grid. The primary component for grid-connected PV systems is the inverter or power conditioning unit (PCU) with consistent voltage. A well-designed PV system with robust converter converts the generated DC power into AC power more effectively with no energy storage losses (Sharma and Chandel, 2013), particularly for large-scale applications. In addition, the PV grid interconnected system has a bi-directional interface between the PV system AC output and the electric utility network for on-site distribution panel (Kaundinya et al., 2009).

On one hand, this allows the AC power either generated from the PV system to supply electrical loads on-site or feedback to the grid when the PV system output is greater than load demand on-site. It, however, requires a safety feature called anti-islanding component for all grid-connected PV systems to ensure the PV system cannot continue to operate or feedback

into the utility grid when due for service or repair (Giraud and Salameh, 2001). Figure 1-5 indicates the grid-connected PV power system for large-scale utility design application.

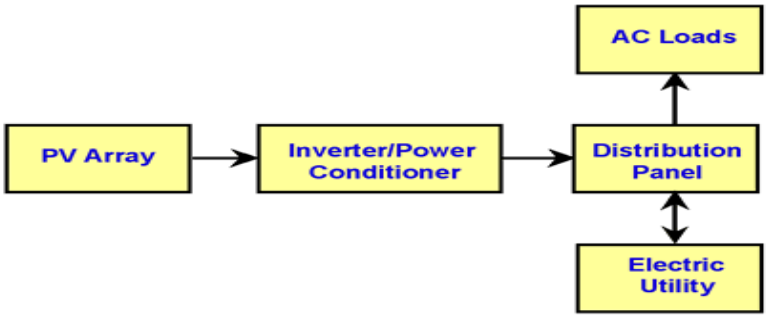
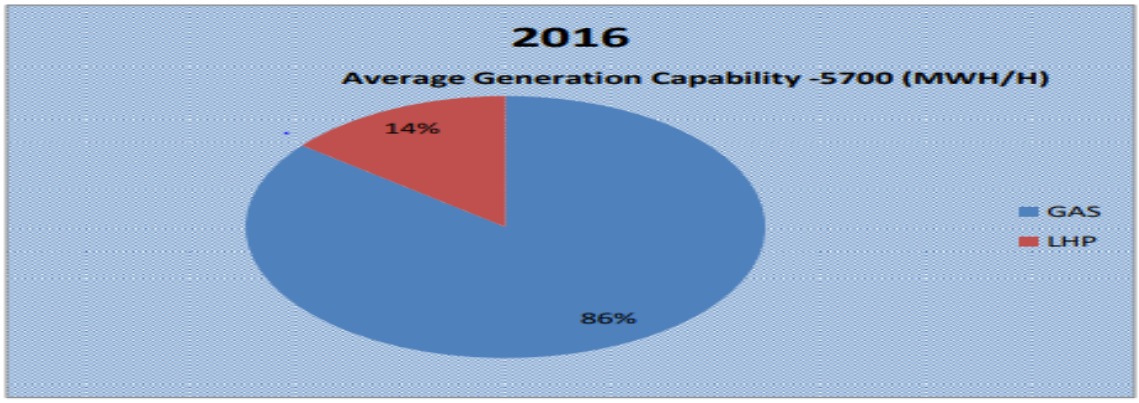


Figure 1-5: Diagram of Grid-connected power supply PV system.

1.2.3 Energy Sector Situation

Energy is an important factor for the country's economic sector growth which directly associated with per capita energy consumption and the people's standard of living (Olayinka, 2012). Nigeria faces extreme electricity shortage with multi-faceted challenges such as financial, structural, and social-political problems for many years (Oyedepo, 2012a). The recent world's energy crisis has emanated out of the rapid population growth, with increased living standard in the societies (Bristow and Kenndy, 2010). Nigeria huge energy crisis contributed to poverty and paralyzed industrial activities for decades (Onochie et al., 2015). The country's infrastructure for electricity generation faces a huge gap between demand and supply and the energy demand is currently estimated to be about 17,520 MW against 5,700 MW peak generation power for the population. Figure 1-6 represents the energy mix for generation utilization capacity.



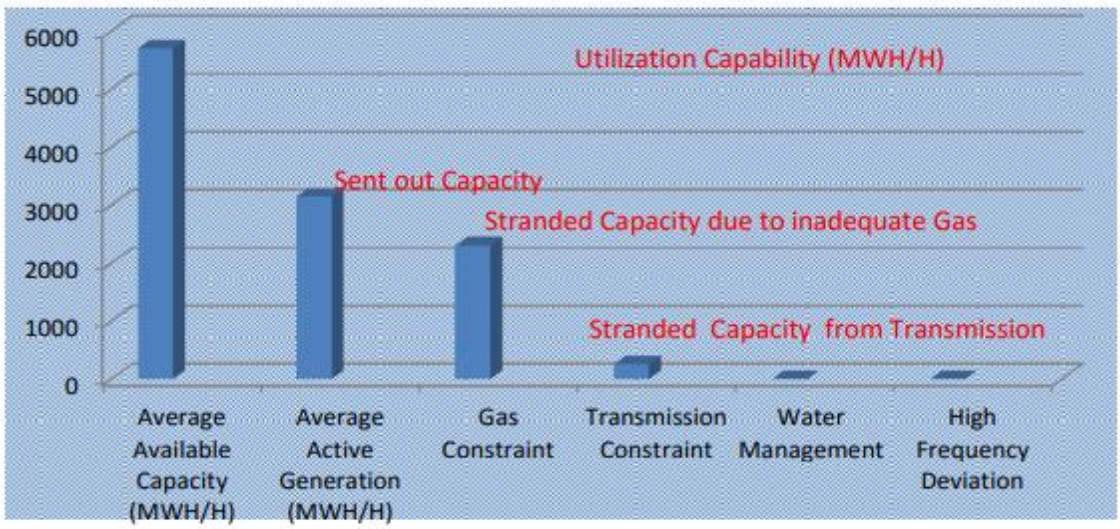


Figure 1-6: The present and current energy mix (MW)-generation average utilization capacity (Source: FGN DRAFT, 2016).

In 2013, the total installed capacity generation was about 10,396.0 MW for 23 grid-connected generating plants, with 6,056 MW available operation capacity. Apart from the general deteriorating state of energy infrastructure, Nigeria experiences underinvestment in the energy sector for lack of maintenance, mismanagement, ineffective execution, and timing of reforms as well as factors affecting generation, transmission, and distribution. The national grid with poor voltage networks has a limited control infrastructure, overload transmission lines, the high technical, and non-technical losses and poor maintenance of generation stations (David-West, 2014 and Ogunleye, 2017).

Nigeria's electricity supply is a major factor for the country's development and effective industrialization (Olayinka, 2012). The availability of electrical power is a major pillar of wealth creation and a driving force for the growth of all sectors of the economy. The country currently has 11 electricity distribution companies (Discos) owned by a consortium of larger state governments in Abuja, Benin, Peko, Enugu, Ibadan, Ikeja-Lagos, Jos, Kaduna, Kano, Port Harcourt, and Yola states (Vincent and Yusuf, 2014) and the population consumes 58,000 tonnes of LPG per annum (UNIDO, 2014).

As already noted, the majority of the areas are not connected to the utility grid especially rural-remote areas of the country. About 90% of the Nigerian population is not connected to the grid (World Bank, 2017) and 50% are without access to electricity (Kumar, Sudhakar & Zarma, 2006) rely on fuel-wood for cooking. However, the grid extension is not economically sustainable, due to the high cost of constructing the transmission infrastructure (Report, 2015). Besides, the urban areas connected to the grid do have recurrent blackout issues, and load shading continues to pose serious constraints to economic development (Agbongiarhuoyi, 2015b). Figure 1-7 represents Nigerian households without access to electricity in the country.

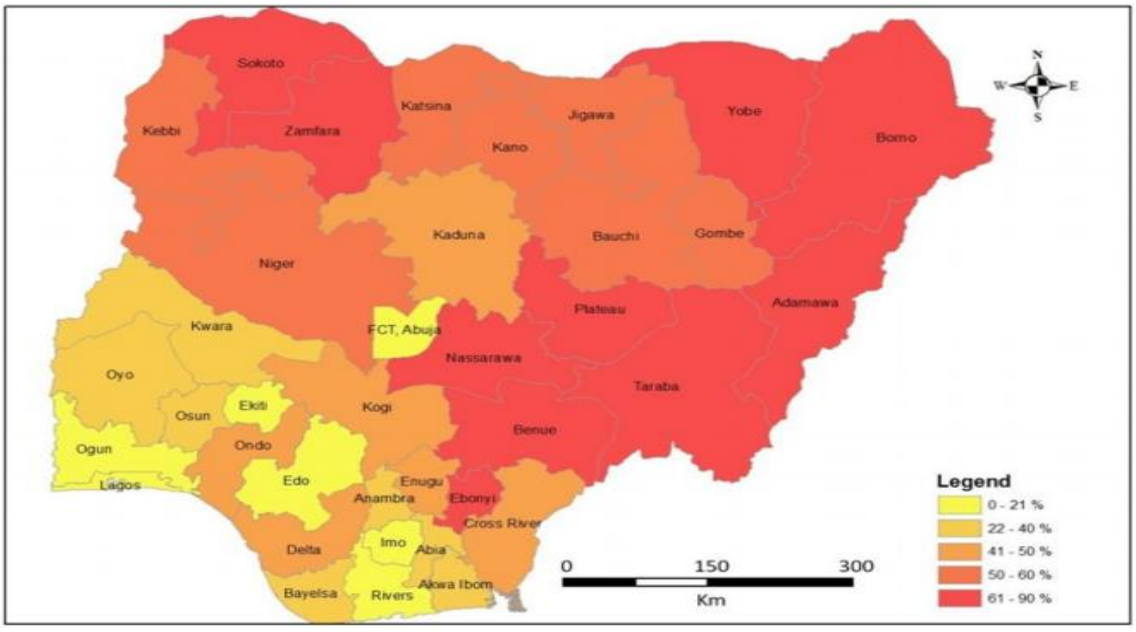


Figure 1-7: Households without electricity access in different states of Nigeria (Source: National Bureau of Statistics, 2009 & 2012).

This study aims to justify the possibility of utilizing solar energy systems to meet the gap between demand and energy supply mostly the remote-rural areas that are not connected to the national grid. Figure 1-8 represents the non-electricity population clustered in each state of the country.

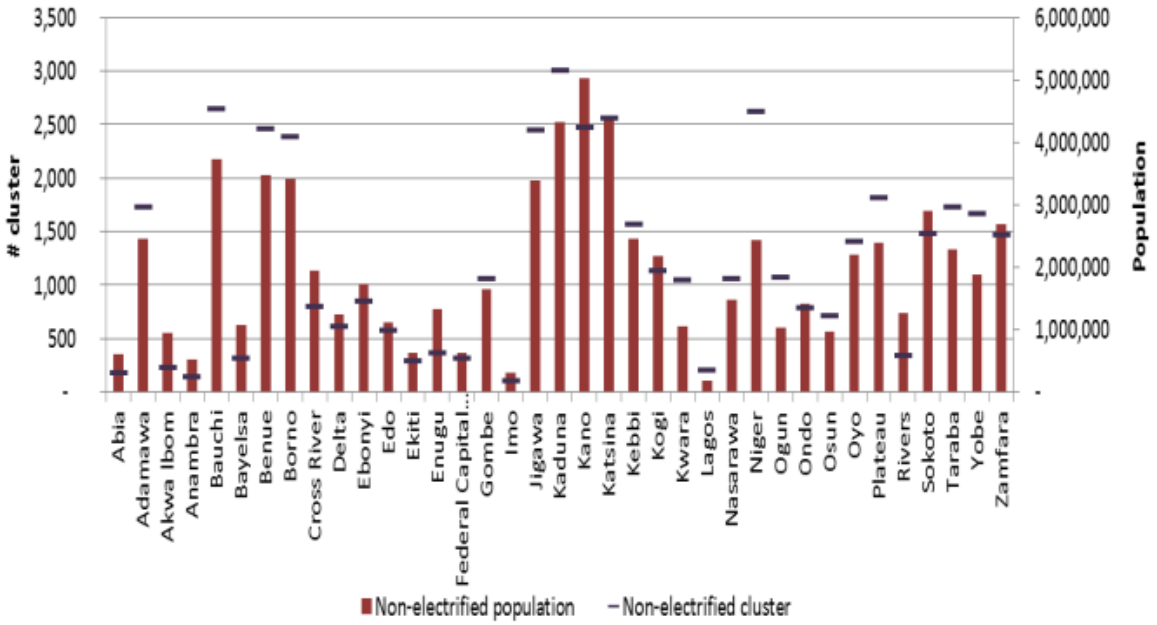


Figure 1-8: Nigeria Statistics of Non-Electrification Population Clusters per state.

1.2.4 Nigeria Solar Resource Situation

Nigeria's renewable energy resources include solar, biomass, hydro and wind (Fashola A. , 2016). These are solutions to address the existing power shortages and promote federal government drive for power generation to increase the installed capacity by 2030 and beyond. The early use of solar energy in the country has been limited to the drying of crop production, fuelwood for cooking, frying and heating, and the wind energy has been utilized for winnowing process (Sambo, 2010 and 2009a). The solar energy potential is abundant, reliable, and well distributed across the country to support the power sector development (Vincent and Yusuf, 2014).

The resource development primarily depends on resource availability because the daily annual average sunshine is between 3.5 and 7.0 hours with the average solar radiation of 5.25

kWh/m^2/day in the coastal areas and between 8 and 12 hours with average solar radiation of 7.0 kWh/m^2/day in the far northern boundary (Osueke and Ezugwu, 2011). Nigeria's annual daily average solar radiation generally varies between 3.5 kWh/m^2/day and 7.0 kWh/m^2/day and available sunshine is from 4-8 hours/day (Kafayat and Abraham, 2014; NERC-UDUS, 2015). According to IPCC, the global renewable potentials are substantially higher than both the current, and future projected energy demands (Policy & Finance, 2011). Figure 1-9 depicts Nigeria's solar potential for global horizontal irradiance in the country.

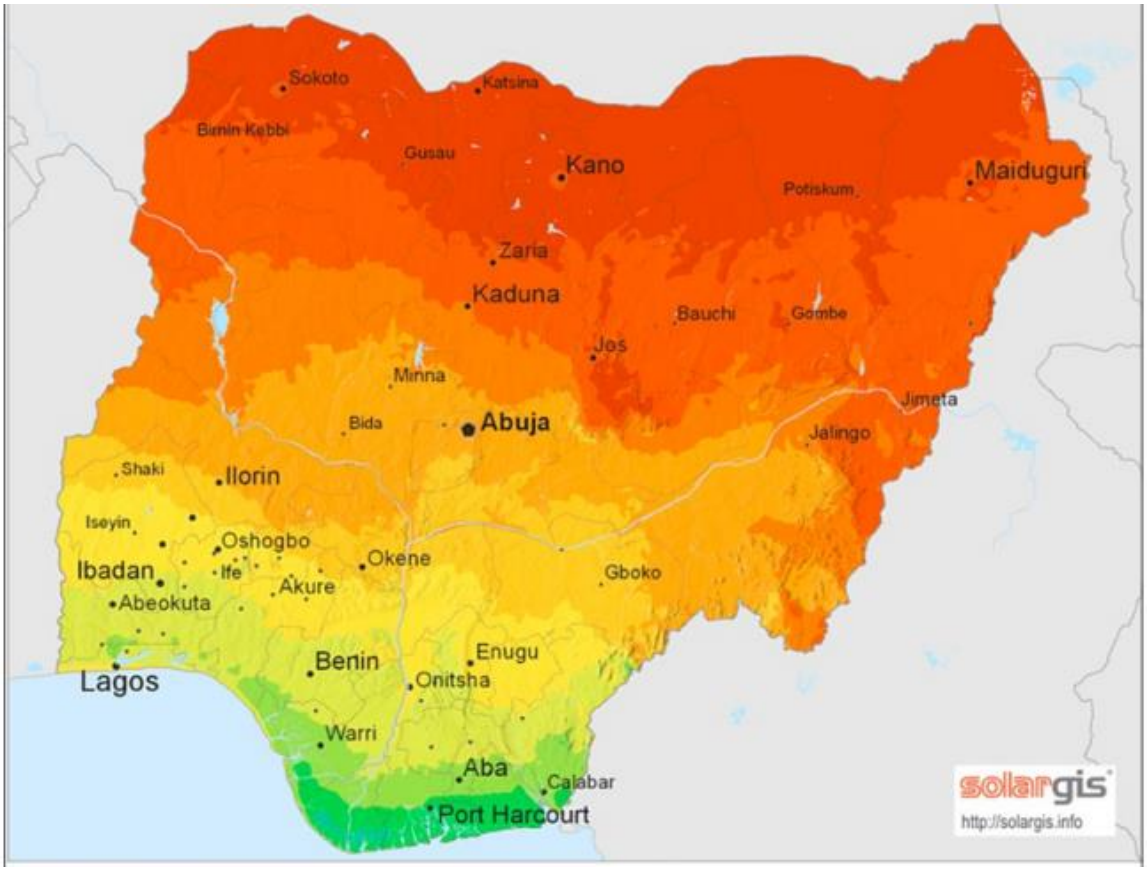


Figure 1-9: Nigeria's Solar Potential (Sources: FGN DRAFT, 2016; GIZ, 2015, Fagbenle et al., 2014 and Solargis, 2011).

According to the report, the Northern part of Nigeria experiences more solar irradiation (Gesellschaft fur Internationale Zusammenarbeit GmbH, 2015). For example, the Northern zone found to be the best option due to the long hours of sunshine throughout the year that exceeds 2200kWh/m2/year solar energy potential. This qualifies the location for proposed solar PV power plants and the feasibility studies for solar power plant investment in locations

with the highest solar energy potential (Akinyele et al., 2015). The southern part also has a solar energy potential.

The solar energy systems market is growing rapidly with a reduction from the cost of solar PV systems in the country. However, the solar power moving into a competitive stage requires more players to participate in making solar systems ultimately more popular to drive cost down in Nigeria. For example, a privately owned piece of land with the preliminary design of 5 MW solar power project has been proposed between Latitude 7°53‟42” N and Longitude 9°47‟59E on a land area of 2,250,000m2 (1.5 x1.5km) at Wukari town in Taraba state. The same capacity is proposed between latitude 9° 52‟ 20” N and longitude 6° 16‟ 98” E that covers 1.8 x 1.8 km (3,240,000m2) area about 8 Km from Bida – Lemu road in Niger State. The projects are expected to use a monocrystalline type of solar modules technology (Akinyele et al., 2015 & 2016).

1.3 Economic Perspective

Solar energy emitted from the sun is cost-effective (affordable) for electricity generation to meet the basic social needs and the economic activities in the country. The solar PV potential is economically viable in harnessing energy from sunlight at a competitive price. According to prior reports, the global cost of PV system investment is rapidly decreasing due to technology improvements and the economics of scale (UNEP, 2012 & 2013). Nigeria established over 65% medium and large manufacturing industries is the most competitive and effective market in West Africa for solar energy (Ogunleye, 2017). As stated by the IEA, the cost of investment was estimated at least about GBP2.4 (US$ 3.5 billion) for electricity generation per annum including the cost of other parts of the supply chain such as fuel to power infrastructure, transmission, and distribution in 2016.

In Nigeria, this requires a large investment to achieve the required energy supply capacity (Ogunleye, 2011). The projection of 13% growth rate requires about GBP103 (US$150 billion) investment by 2020 with additional 100,000MW generation to attain full requirement for industrialization of the economy (Chukwueyem, 2015 and ECN, 2003). The planned generation capacity that projected for future electricity is estimated to cost an average of

GBP1.3 (US$1.5 million), and the energy sector investment estimated at GBP1.2 trillion is equivalents to $1.8 trillion each year to attract clean energy due to sharp fall of upstream oil and gas investment.

1.3.1 High Initial Cost of Investment

The initial cost of a PV system is a major barrier slows the penetration pace of PV system installation, and the RETs development faces a financing challenge and lack of subsidy to support, and this making solar electricity application uncertain. In addition, renewable energy found to be a high-risk investment, sometimes scare away potential investors and developers in Nigeria (Ottinger and Bowie, 2015). Government incentives to reduce short-term costs for the long-term benefits are required because this will support PV investment to boost solar energy deployment, making solar PV project relatively cost-effective (DOE, 2010; IEA-PVPS, 2007) in Nigeria.

On one hand, the government short-term financial support will expand PV systems deployment because the populations are in need of electricity. On the other hand, the price of installation of solar systems, in the long run, will decrease. It is similar to the case of a global system for mobile (GSM) communication systems, which started with a high investment cost and after a few years become attractive with low running costs in Nigeria. The solar system, the best option for alternative electricity benefit, modern power service access to overcome irregular electricity supply, and reduce diesel generator use in the country.

The Nigeria solar system pilot projects show evidence of success and failure. In 2001, Jigawa state, obtained funding assistance from the Japanese government for full-scale rural electrification project, and an additional funding assistance (USAID and DOE, 2001). The Solar Electric Light Fund (SELF) Company implemented and maintained the solar project to touch every villager's house in the state, which is a successful and remarkable project that other states look forward to adopting something similar (JICA, 2007). This provided villagers without access to the national grid, the benefit of modern energy services access (Freling and

Ramsour, 2010). Figure 1-10 represents the Northern solar electrification in Jigawa village of Nigeria.



Figure 1-10: Jigawa Village Solar electricity in Northern Nigeria (Sources: PV Magazine, 2013 and SELF, 2001).

The solar electrification pilot project sponsored by the Lagos state government at Bishop Kodji in Onisowo Village, provide an example of unsuccessful projects (Omisore, 2011). According to the Kadri Hamzat report (2006), the state government installed at two sites 300 watt PV panels (Okereke, 2017). Boyo and Olagunju stated that this project was financed through Rural Electrification Fund out of the GBP187 million ($272 million) fund from World Bank to support the privatized electricity in 2005 (Omisore, 2011). In terms of financing, Nigeria's opaque bureaucracy without outside institutions, governments' involvement is difficult in obtaining and verifying specific information (Freling and Ramsour, 2010). This project happened to be cost-effective, failed to function properly after 5 years of installation. Figure 1-11 shows the failed solar electrification project at Onisowo village in the Lagos state of Nigeria.



Figure 1-11: Solar Bishop Kodji Onisowo village in Lagos State (Source: Obebe, 2006).

In addition, a solar PV system installed at Oke-Agunla Village during government pilot projects in Akure local government of Ondo State also expected to benefit the community use of the system. However, the project is vulnerable due to some functional and non-functional performance (Jesuleye et al., 2012). The results from an assessment conducted by interviewing the village people confirmed inadequate PV facilities, untrained technicians with improper use of facilities resulted in complications, and poor maintenance of the facilities. The ineffectiveness for a 4.5 kW solar installed PV systems project due to lack of technical know-how, poor maintenance and the inability of project contractors to take these factors into consideration (Ismail et al., 2012).

Jigawa scheme experienced more risk with bigger goals and greater results with the sum of GBP309, 000 ($450,000) than Bishop Kodji. The amount invested is five times more than the amount spent at Bishop Kodji solar electrification. The Jigawa state scheme shows proper management with high investment cost and better quality delivery when compared to Bishop Kodji projects. In the case of Oke-Agunla project, a proper training of the technical team aims to avoid a system failure in the future.

1.4 Policy Perspective

The Nigeria energy sector has undertaken reforms to achieve a series of transformation through investment to bridge a huge deficit in electricity demand and supply in the country. Based on 2005 Electricity Power Sector Reform Act (EPSRA), the federal government power sector's reform and privatization programme was set up as a solid foundation (NERC, 2012). However, the reform contributed to liberalization and commercialization of national utility company known as the National Electricity Power Authority (NEPA) and later changed to Power Holding Company of Nigeria (PHCN). The agencies and institutions include the established National Electricity Regulatory Commission (NERC), the Nigerian Bulk Electricity Trading (NBET) and Rural Electrification Agency (REA) are the key tools used to drive core objectives of the reform programme.

This enables electric power industry corporatization to increase access and power delivery capacity, optimize the costs of the power industry and increase the efficiency and the share

of RE generation to minimize the environmental damage (Ebohon, 2005). Nevertheless, the reforms may not yield the desired result if current end-users inefficiency is not controlled. Furthermore, Nigeria's electric power sector required substantial reforms to realize economic development and poverty alleviation (Ebohon and Ikeme, 2005). The generation, distribution assets, and transmission system are privatized to private operators. Figure 1-12 displays the structure of power sector reform after privatization.

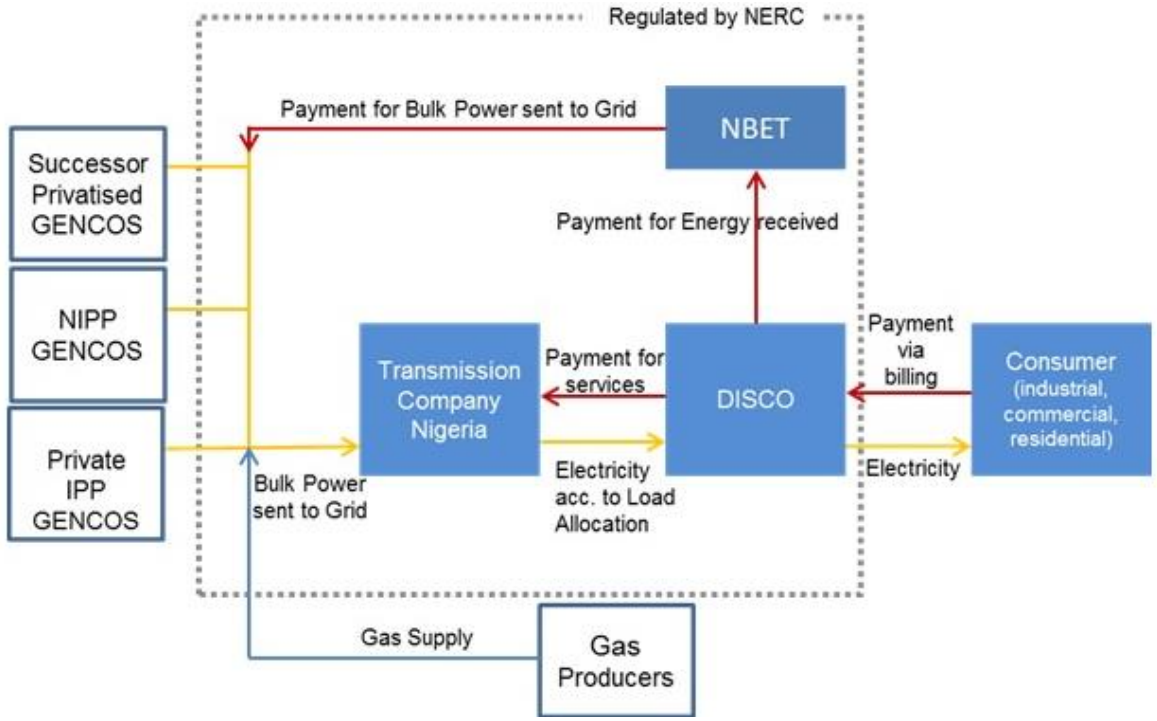


Figure 1-12: Structure of Power Sector Post-Privatization (Source: FRN Draft, 2016).

The post-reform structure of the power sector as shown in Figure 1-12 made the sector change from government ownership/management of assets to a private sector in line with 2005 EPSR Act driven by Nigerian Electricity Supply Industry (NESI) (Onochie et al., 2015). The electricity sector fully privatized into three major subsectors as follow: The generation, (Gencos) to optimize production cost with a competitive offer for sale of power in the operating environment. The distribution companies (Discos) to purchase power from Gencos based on choice. The TCN (Transco), an independent power operator (IPO) and third subsector is energy transporter with the responsibility of ensuring bilateral contracts between Discos and Gencos (Ismail and Victor, 2013). However, the federal government laid a

significant solid foundation for Nigeria power sector with 2005 EPSRA act, the privatization programme, and reform initiatives, the introduction of Independent Power Producers (IPPs) and setting up of National Integrated Power Projects (NIPPs) among the existing power plants (Adeakin, 2016 and Sambo, 2010).

1.4.1 Management and Political issues

Nigeria lacks adequate infrastructure for electricity generation because of dilapidated facilities with poor maintenance and lack of expansion to meet the growing demand. Presently, government commitment efforts are not encouraging because of the delay to implement renewable energy projects. This is due to the problem of funding, weak or almost non-existence of legal and institutional framework towards Renewable Energy Master Plan (REMP). According to the report, policy implementation is yet to be passed into law notwithstanding the interest and effort so far shows poor percentage contribution to the achievement (ECN, 2012). In addition, the power sector suffers policy problems caused by frequent administrative changes including bureaucracy, and corruption where new administration comes with new policies instead of continuing with the previous administration policies.

1.4.2 Environmental Problem

The problem of gas flaring due to use of fossil fuels leads to rapid deforestation, local urban air, and water pollutions, oil pollution to the water, loss of arable land and rapid urbanization. However, these problems are against international agreements to biodiversity, climate change, endangered species, hazardous wastes, the law of the sea and marine, dumping, marine life conservation, ozone layer protection, and wetlands (IEA, 2010a).

1.4.3 Renewable Energy Master Plan (REMP)

In 2006, the Nigerian government road map vision supported by UNDP in order to increase the use of RE, recognizing RE sources potentials to achieve sustainable development established off-grid generation/distribution plants in form of pilot project. These projects

demonstrations for electricity supply, employment creation and income generation will help remove import duties on RE products provide tax credits, capital incentives, and preferential loan opportunities for RE projects with FITs in respect to solar energy, wind power and small hydro in the country. The REMP is driven by an increasing share of RE and encouraging a shift from fossil economy to RE. This was instigated by FME to increase RE contribution to 10% of total energy consumption by 2025 (NREEEP, 2015); (Sambo, 2009a).

1.4.4 Nigeria Energy Policy Framework

Public policy has been the most powerful driving force for RE consumption due to pressure to combat climate change (EIA, 2009). Nigerian federal government due to energy constraints, set up targets for the country's energy mix to exploit the potentials from coal, solar, wind, biomass, large and small hydroelectric power generation and make the electricity supply less vulnerable to disruption, more affordable, available, and reliable (Adejumo, 2018 and Fashola, 2016a). Consistent with Sambo and IEA report, Nigeria with financial instruments such as incentives, taxes, and grants will support and encourage solar PV systems deployment to reduce dependence on fossil fuels (Sambo, 2008); (IEA, 2009).

In 2015, the nation planned to intensify efforts to increase the percentage of solar energy in the present energy mix with RET targets such as small-hydro with 600 MW to 2,000 MW, solar PV with 500 MW, biomass-based power plants with 50 MW to 400 MW and wind with 40 MW electrification (NESP, 2015). Figure 1-13 represents the average generation capacity with the energy mix targets. Table 1-2 represents the approved draft energy policies targets for harnessing energy potentials in Nigeria.

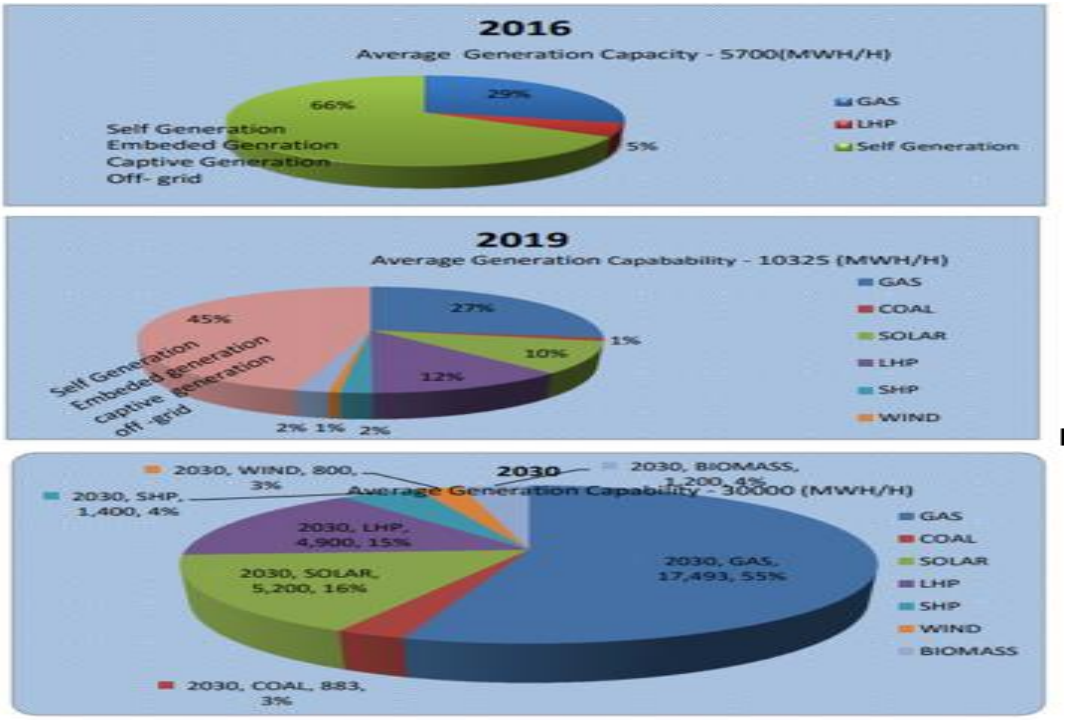


Figure 1-13: Average Generation Capacity and Energy Mix Target (Source: FGN DRAFT, 2016).

Table 1-2: Nigeria Approved Draft Energy Policies Targets

Approve National Energy Policies	Draft Energy Policies
National Electric Power Policy (NEPP) – 2001	Renewable Energy Master Plan (REMP) 2013
Nigeria Energy Policy (NEP) - 2003	National Renewable Energy Action Plan (NREAP) 2015
Electric Power Sector Reform Act (EPSR) – 2005	National Energy Efficiency Action Plan (NEEAP) 2015
Rural Electrification Policy Paper (REPP) – 2009	Sustainable Energy for All - Action Agenda (SE4All-AA) 2015
The Roadmap for Power Sector Reform 2010	
Nigeria Electricity Management Services Act - 2015	

Policies	Regulations	Institutions	Target S2030
Unsolicited Projects	Bulk Procurement Regulation	NBET	10,000 (FF+RE)
Competive Procurement	Bulk Procurement Regulation	NBET	10,000 (FF+RE)
REFIT	REFIT Regulation	NBET/DisCo	3,000 (RE)
Mini-grid (Off-grid)	Mini-grid Regulation (draft)	REA/SREA	13,000 (FF+RE)

(Source: FMOP, 2014 and Fashola, 2016).

1.5 Aims and Objectives of Study

This study has two main aims. The first is to review the relationship between solar energy potential currently available in Nigeria with the performance of PV systems for electricity generation in an affordable and environmentally clean way. The second is to consider the quantity of electricity that needs to be generated within Nigeria in the context of the financial resources available for promoting PV installation use to minimize the gap between energy demand and supply in the country.

The study objectives are to:

- Review PV systems as a source of additional electricity generation at various locations in Nigeria. Such a review might usefully assist the development of government policy in promoting or assisting in the installation of the PV system.
- Assess how successful or unsuccessful renewable energy policies have been in meeting energy demand and in reducing the cost of installation in the context of available financial support and incentives.
- Assess the level of access to solar energy in all areas including remote/rural areas. Additionally, public awareness of solar potential energy is considered.
- Evaluate PV electricity generation in relation to emission reduction (hence pollution reduction) and costs associated with the energy budget of Nigerian consumers.

1.6 Significance of the Study

The content in relation to these aims is crucial because Nigeria energy production from all sources is less than 6,000 MWh and almost all derived from fossil fuel combustion. This is unsustainable in the current global context of reducing CO_2 emissions, while the PV system technology based on energy from the sun is of enormous potential and significant. In the current context of reducing global CO_2 emission, solar PV energy system is crucial for the future of the country. However, this study is important because it aims to understand solar energy potential with the PV system and the relationship between the quantities of electricity

generated associated to cost in Nigeria. In this study, the findings therefore, will be significant in the following ways:

Solar energy is a unique renewable energy source that can be utilized by PV technology for electricity generation because application of PV technology is a reliable decentralized solution and better future energy supply to the household, commercial, industry and agriculture sectors in Nigeria. It can also be used to reduce costs for households and businesses as well as increasing sustainability for the local community and economy.

The Nigerian Electricity Regulatory Commission (NERC) recommended cost of energy charged but relatively high despite that consumptions are assessed by meter reading in Nigeria. However, the energy policy-makers (NERC and ECN) proposed assessment framework might improve the regulatory power if implemented with more accurate approach than the haphazard overarching presently in place. It may also help to prevent exploitation by providers.

The regulators through effective action and financing mechanisms might help improve policy decision in administration to achieve the policy implementation. They have the opportunity for reducing Green House Gas emissions (GHGs) to improve health and socio-economic development as well as meeting the energy needs. In addition, help to strengthen the grid system with RE electricity as well as bridge the gap between demand and supply of electricity in the country.

This study will expose solar energy service providers to a more profitable and proper acceptable approach for better service provision due to off-grid installed PV system performance with adequately-generated electricity to the benefit of the end-users. It also demonstrated short payback from both generation and consumption. Similarly, this could provide service providers with a quick return on investment to encourage investment increase and more jobs in the economy.

The investors will have the opportunity to offer financial support through leasing, loans and selling electricity directly to customers with power purchase agreements (PPAs) because

more people investing in using a PV system for generating environmentally free energy will equally benefit the environment rather than fossil fuels that emit GHGs. In addition, the economic cost for PV components replacement can be low when compared to conventional hydropower/gas generation in Nigeria. This environmentally does not require laying of pipelines through communities in respect to gas turbines and less community agitation can best serve Nigeria.

The customers/end-users will profit by paying less over a shorter period by having more disposable income to use for expanding PV use or other ventures. Thus, increase the level of PV system use and reduced the level of energy and abject poverty in Nigeria as one of the overarching aims in turn, improve people's standard of living and promoting renewable energy application in the society.

This study could benefit individuals and group activists who advocate for increased, democratized and equitable use of alternative energy sources. The findings may be useful for increasing public awareness about renewable development and decentralized application of RE projects in turn, electricity access to rural areas for economic, social and environmental benefits for electricity generation using PV systems in Nigeria.

This may provide researchers and students the opportunity to replicate the study in other contexts. This type of research suggests other areas of further research that could be extended to educational institutions and industrial aspects because it does not cover every aspect except selected locations in Nigeria.

1.7 Thesis Outline

This study focuses on the technical, economic and policy perspectives for solar energy use with a PV system, for electricity generation in Nigeria. This research adopts a software simulation tool to assess the PV performance and innovative financing model approach to determine the appropriate solutions for economic problems. The study scope covers literature review, case study, questionnaire and the use of RET Screen computer simulation software for technical performance analysis. The payback period with PV installation is

manually computed. The conclusions summarized solar energy system for policy implementation with suggested possibilities. However, the thesis structure is divided into eight chapters:

Chapter 1 introduces the Nigerian power sector and its challenges, the solar energy significance, the technical, economic and policy rationale for PV potential benefits to Nigerian people and the economy.

Chapter 2 presents the literature review to identify the research gaps by reviewing the PV system based on technical, socio-economic and environmental aspects. It presents the local literature review due to electricity generation capacity and consumption. In detail, identifies the relevant challenges within the existing energy sector regarding generation and consumption of electricity. It reviews some design models such as computer software tools, innovative financing model and regression analysis for PV systems development. It describes the technical characteristics of RE projects applications and the factors affecting solar radiation. It reviews PV system performance, cost, and GHG emission reductions.

Chapter 3 describes the research methodology used for data collection based on multiple sources. It explains the used quantitative and qualitative research methods. It also shows the used primary sources (questionnaire, interview and case studies, RET Screen and PAYG models). The secondary sources from journals and article publications including internet-websites.

Chapter 4 analyses the results by comparing the major energy sources in terms of comparative advantage, cost and energy projections particularly for solar energy potential targets as well as the capacity projection towards generation and consumption of energy sources in Nigeria.

Chapter 5 focuses on analyses of results from the questionnaires as well as the specific feedback obtained.

Chapter 6 assesses 11 case studies carried out on different locations based on overview generalization with off-grid PV system installation performance. The component specifications include PV system types, the efficiency, capacities, area cover, PV tilt angle, inverter and batteries including the electrical coefficient characteristics. This chapter adopts RET Screen model which was used with PV system to evaluate the electricity generation capacity and GHG emission reductions as well as to examine innovative financing model (PAYG) design for off-grid installation in the country.

Chapter 7 evaluates the policy frameworks in consideration of RE policy objectives and strategies for the promotion of PV technology development in Nigeria. It also presents a proposal to encourage policy implementation for rapid PV development in generating sufficient electricity to meet energy demand in Nigeria.

Chapter 8 summarises key findings and offers conclusions and recommendations.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

This chapter reviewed PV system based on technical, socio-economic and environmental aspects and presented the local literature review of electricity generation capacity and consumption as well as the relevant challenges within the existing energy sector for the generation and consumption of electricity. It also reviewed some design models such as computer software tools; innovative financing models and regression analyses for PV systems development and factors affecting PV system performance.

2.2 Technical Aspect

Energy plays a crucial role globally in any country for industrialization. In addition, energy in global economies is an "oxygen" and life-blood for growth in any nation. Electricity at every facet of human life has been an important source of energy and the basic developmental services for food, pipe borne water and provisions for industrial activities, health care, conducive abode, telecommunications, and quality education among others (Oseni, 2011 and Oseni, 2012b). Electricity according to Mankiw et al model (1992) is an explicit factor of production and economic development in the 1990s, which resulted in improved wellbeing of citizens, particularly among emerging economies. Nigeria electricity sector production presently experiences an energy crisis which relates to climate change and environmental pollutions from GHGs (Adeyemo, 2013) despite that electricity is an important element for consumption from energy production (Acemoglu et al., 2011 and Bernanke, 2001). The centralized electricity supply depends on thermal gas and hydro generating stations above 100 MW high capacity (Sambo et al., 2012). During the military regime, the power infrastructure faces a major setback where most of the hydro-electric dams decayed with the obsolete transmission, distribution and equipment lines (Sambo, 2008b).

The Nigerian government has been solely responsible for power generation, transmission and distribution (Bloomberg, 2012). The electricity supply rate has been less than 2 hours per day and 60 percent of the population is connected to power grid whereas 40 percent without

access to the national grid in the rural-remote areas (Sieminski, 2014; DOE, 2005). The problem is identified to be limited access to the infrastructure and low connection rate; inadequate power generation capacity; inefficient usage of capacity; lack of capital for investment; ineffective regulation; high technical losses and vandalism; insufficient transmission and distribution facilities; inefficient use of electricity by consumers; inappropriate market structure and industry including unclear delineation of roles and responsibilities (Okoro and Madueme, 2004a).

The study reported that absence of reliable-clean energy services access imposes disease burden and impedes prospects for the development of low-income populations in the country. Furthermore, the current patterns of fossil-fuel use, causes substantial ill-health from air pollution, occupational hazards and the impending climate change threatening health mainly driven by the energy use (Haines et al., 2007). According to Sunday Oyedepo's report, climate change and limited availability of fossil fuel reserves have become urgent to deploy renewable energy for electricity generation (Oyedepo, 2012).

2.2.1 Photovoltaic Module Performance

Solar energy that reaches the earth is found as the most obvious choice of RES and predictable source of energy throughout the year for daily electricity generation (Ren21, 2011). The Photoelectric effect is the function of semiconductor composition, intensity and wavelength on the available solar radiation with PV device used to produce the amount of electricity (Damascelli et al., 2003). The devices in the world recently record to have steadily increased conversion efficiency to about 43.5 percent due to research and development advances (Jan Kleissl, 2013; McCulloch and Neuhaus, 2001). Solar PV has been one of the fastest-growing RETs in today's world and expected to play a major role in global electricity generation mix in the future (Abe and Adetan, 2008). The modular sizes are the most "democratic" renewable factor within the reach of individuals, co-operatives and small-scale businesses that requires owning generation facilities to power and lock-in electricity prices (Ogunleye and Awogbemi, 2011).

The solar electric PV system with several PV cells known as solar PV Networks, the PV cells usually produces about 1-2 watts. The PV cells are connected together to form large units called modules in boosting power output and further connected to larger units which are called array (Tripathy et al., 2016). The PV education reported that special electrical property of the PV cell provides a voltage that drives current to an external load such as light bulb appliance (Education, 2013). Figure 2-1 represents the solar PV cells being a solid block on each efficiency performance.

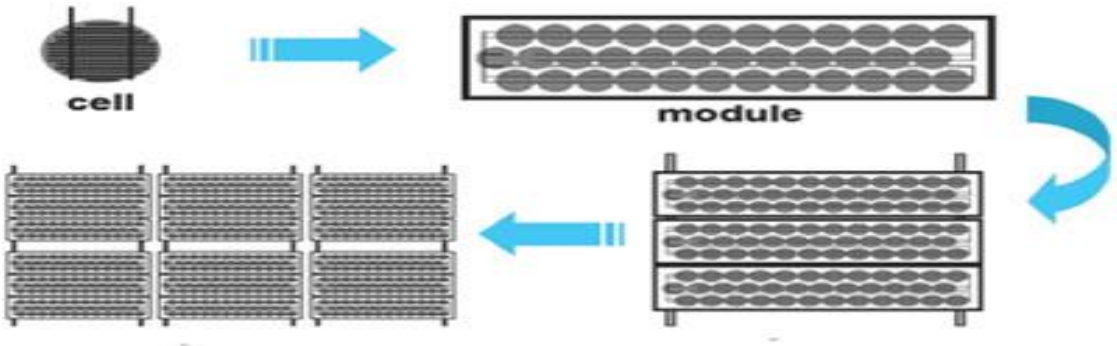


Figure 2-1: PV cells, modules or panels and arrays (Source: PV-Education, 2013).

The PV module performance is measured in peak watt (Wp) rating to determine maximum power under the laboratory standard test conditions (STC). The measurement rating includes PV module operating temperature (25^0c/77 F), level of solar irradiance (1000 W/m^2) and Air mass spectral distribution (1.5 AM) and this may or not be how PV module/array typically operate in a location (Myers, 2013). The actual performance of PV modules is extremely safe and reliable from 85-90 percent due to STC rating with minimal failure rates. The PV lifetime projected service in maintaining a high percentage of initial rated power output is from 20-30 years with more years' warranty. The researchers in selecting PV modules advise looking for product listing (UL) on qualification testing and warranty information through manufacturer's module specifications (EERE, 2013).

The solar energy technologies are divided into two broad categories, solar PV and solar thermal technologies (CSP). They easily and readily convert primary energy source into a

renewable form for electricity and heating. The solar PV panels convert solar radiation into a direct electric current (DC) and through an inverter into alternating current (AC). The solar thermal type according to Carnot's Cycle Principle provides direct conversion of solar radiation into heat that turns the electric turbine. The concentrating solar power (CSP) using mirror receives sunlight and heats a fluid to achieve high temperature, drives the turbine for generating electricity for local large or small-scale level (Energy, 2016b). In addition, these plants play an important role in the rising of renewable energy sources (RES) shares due to the possibility of storing thermal energy. It also allows electricity exports to Europe to gain importance even after 2030 (Boie et al., 2016) and to achieve higher temperature using different types of concentrators such as Fresnel lenses, parabolic mirror, etc. The solar PV systems have a lower risk compared with wind or liquid gas turbines (LNG) (Zelya, 2016 and Zelaya-Angel et al., 1995). Figure 2-2 represents systematically the structures of solar PV and thermal technologies.

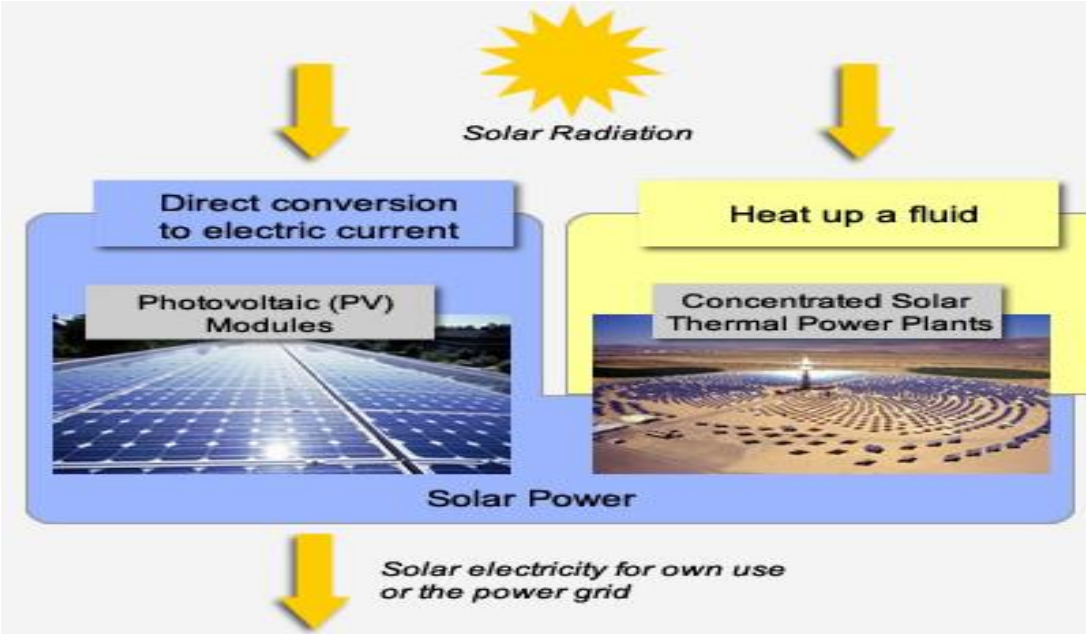


Figure 2-2: A systematic work of the solar PV and thermal technologies (Source: Energy, 2016).

The PV efficiency is the ratio between the electrical power generated and the amount of solar energy received, as well as the main indicator of PV cell modules performance. The PV cells connected in series and parallel for production of high voltage as high as several kilovolts. The

monocrystalline is more efficient but expensive in supply than polycrystalline and others. The second-generation PV systems include thin-film PV types for early market deployment (distribution) including the amorphous (a-Si) such as micro-morph silicon (a-Si/µc-Si); Cadmium-Telluride Cd-Te); Copper-Indium-Selenide (CIS) and Copper-Indium-Gallium-Diselenide (CIGS) (Fthenakis et al., 2009b; Fthenakis, 2009). The third-generation PV system such as concentrating PV (CPV) or (CSP) and organic PV cells under demonstration is yet to be widely commercialized with other new ideas under development (Kleissl, 2013 and Jungbluth et al., 2009). Figure 2-3 represents the prospects and photovoltaic technology status.

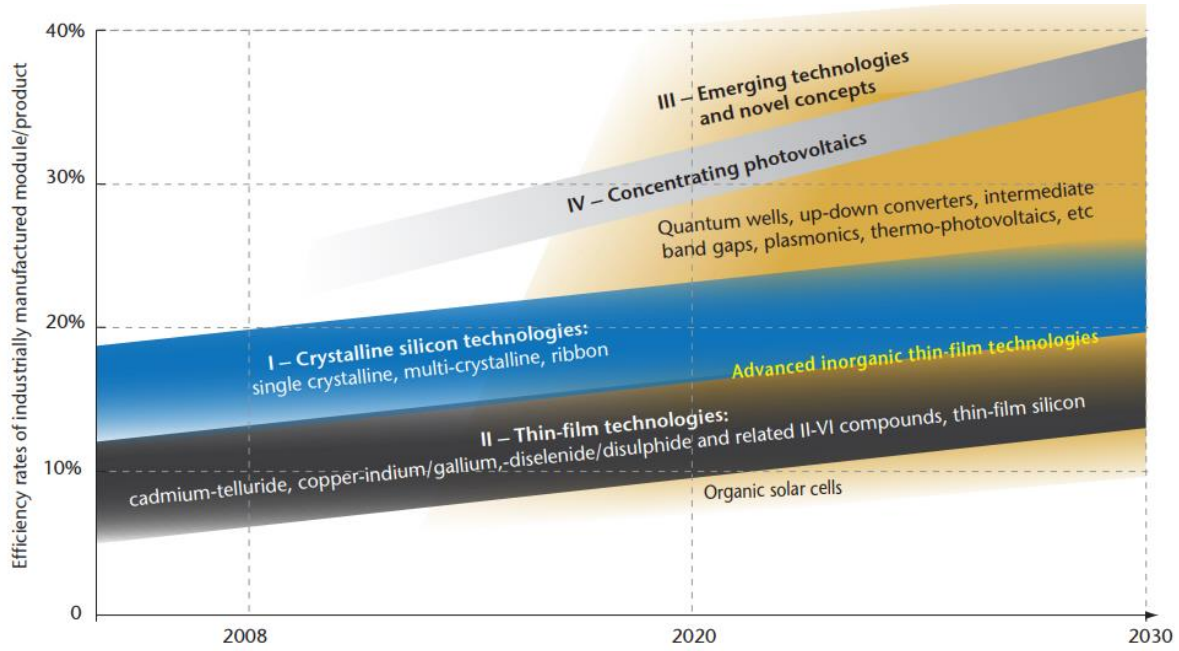


Figure 2-3: The Photovoltaic Technology Status and Prospects (Source: IEA/PVPS, 2009).

Silicon found to be most commonly used for commercial PV system applications and material for deployment in most countries of the world (Ngo and Natowitz, 2009). Table 2-1 represents the different PV module efficiencies. Figure 2-4 represents future improvement expectation of PV system efficiency.

Table 2-1: Efficiencies for different PV Modules types

Wafer-based c-Si		Thin-film		
Sc-Si	mc-Si	a-Si;(a-Si/µc-Si)	CdTe	CIS/CIGS
14-20%	13-15%	6-9%	9-11%	10-12%

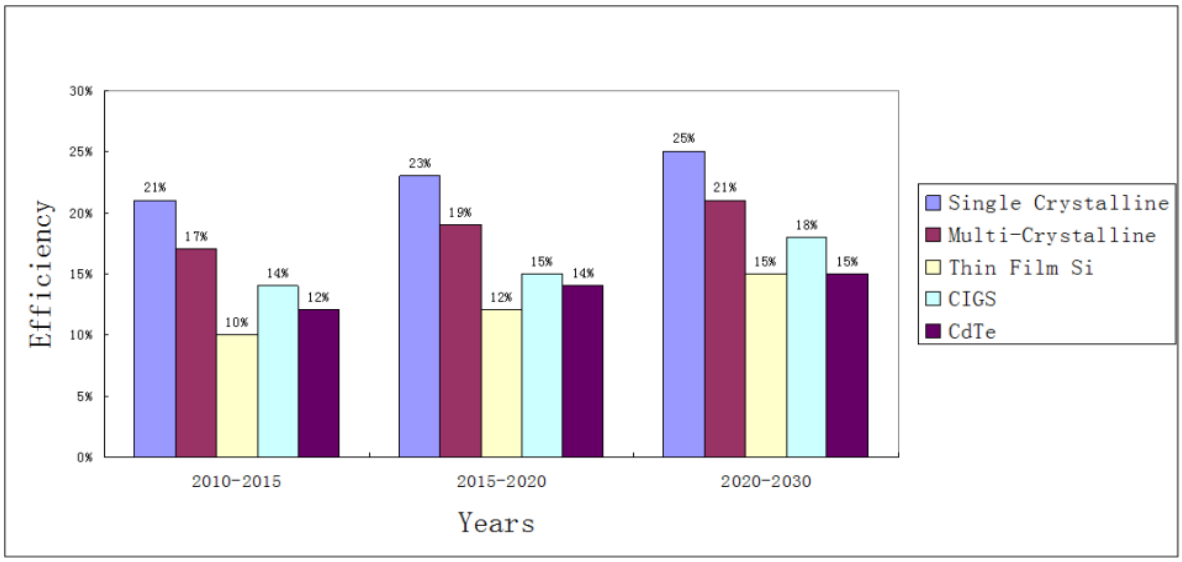


Figure 2-4: Future PV system expectation for efficiency improvement (Source: IEA, 2010).

Many studies have confirmed solar energy technologies to be reliable power generation with a useful lifetime not limited to 20-25 years based on an assumption (Arthur, 2009). BP solar reports according to Wohlgemuth (2008:2003), providing 25-year crystalline silicon modules with extensive testing excellent field results with 10 years' warranty. However, the PV cell is a solid-state building block device without moving part makes the technology highly reliable and long-lived. The open-circuit voltage (Voc) decreases with temperature. Honsberg Christian reported that the temperature depends on current ampere (Isc), and the current and voltage are affected by weather condition (Christian, 2013). The effect of temperature clearly displays PV panel current and voltage curves and this shows different combinations of voltage and current produced by a given PV panel under existing conditions (Article, 2016). Figure 2-5 represents the current-voltage curve and temperature effect for PV efficiency performance.

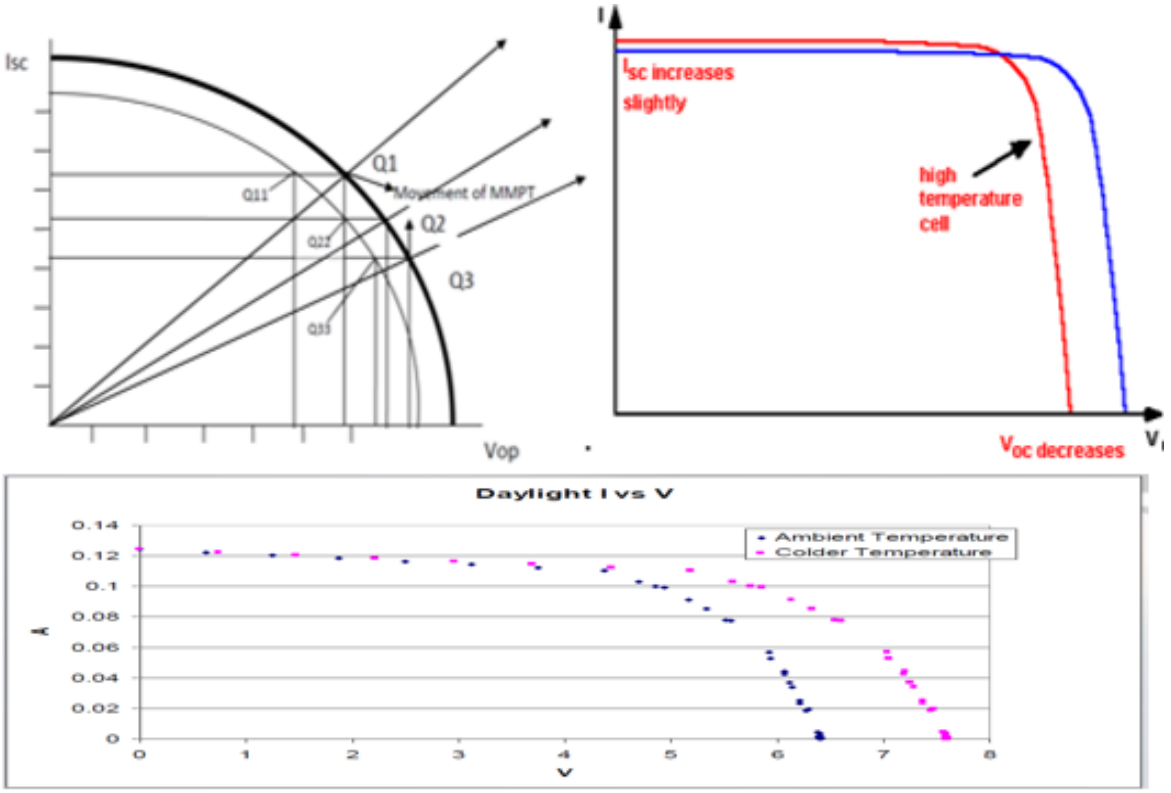


Figure 2-5: I-V characteristic curve with temperature effect on solar module voltage (Source: PV-Education, 2014).

The Isc represents short circuit (Amps), and the Voc represents open circuit (volts). The efficiencies at Q1, Q2 and Q3 and Q11, Q22 and Q33 represent solar module maximum power point tracking. The temperature according to report depends on voltage output that becomes greater due to solar cell increased temperature, and mostly affects the open-circuit voltage (Cindy, 2013). Studies confirmed solar cells to be sensitive to temperature because increasing temperature reduces the band gap of the semiconductor, which affects most of the semiconductor material parameters. The band gap of a semiconductor decreases with temperature and increases electrons of the material. The energy band according to report reduces band gap and the increased temperature reduces the band gap (Bowden, 2013). The measurement of the system reliability according to DOE report focuses not only on PV cell but on the whole system modules and the effect on one panel can affect others (Akhil et al., 2013).

The length of sunlight received is an important factor for the solar panel's power production. The operating temperature affects the PV panel strength, high temperature and other environmental factors reduce PV efficiency that lower the power output. For example, UK field experiment shows the temperature that reached over 42^0 C (107^0 F) and 1.1 percent peak output drops per degrees Celsius. Nigeria laboratory experiment carried out in 2008 at River State University of Science and Technology in Port-Harcourt have similar results. The solar panel energy production drops steadily when the panel temperature reaches 44^0 C (111^0 F). The efficiency according to report drops to 87-91 degrees Fahrenheit in the temperate climate during summer hour's daytime than in the equatorial nations (Cindy, 2013).

Nigeria temperature has narrow variation by regional differences and relatively high in seasonal diurnal. The weather has two seasons, the rainy season from April to October and the dry season from November to March (Ozor et al., 2012). The dry season comes with Harmattan wind between December and February with a chilly dry spell but the lower temperature transports dust from winds blowing through Arabian Peninsula across the Sahara (FCDA, 2014; Africa, 2012). Historically, the proper weather-climate condition from February to March is the hottest yearly temperature from 33-380C that comes with the highest aridity in the Northern part of Nigeria (Abdussalam, 2014). Figure 2-6 represents the Harmattan condition in Nigeria environment.



Figure 2-6: Harmattan image view across Nigeria (Source: NBS, 2014).

Solar energy intermittency according to NASA in 2014 report is a major constraint contributor to energy mixture and intermittent nature of most renewable sources has become an

important issue for electricity storage. In addition, the dynamic overshadowing effect presented on the building surfaces determines the reduction of solar radiation availability and significantly can affect solar energy potential use. According to the study, the intermittency problem can be solved by integrating PV with compressed air energy storage (CAES) or/and extending the thermal storage capability to CSP (Fthenakis et al., 2009).

2.2.2 Solar Balance of System (BOS)

The BOS is the functional and operational requirements of the PV system. The major components include DC-AC power inverter, battery bank and charge controller. The auxiliary energy sources sometimes specify the electrical load use of appliances. The BOS hardware based on DOE report includes wiring with surge protection; disconnect devices, and other processing equipment. The modules combination with BOS components create the entire PV system needed to meet energy demand for powering appliances such as lighting, water pumping (Gevorkian and Gevorkian, 2008). Figure 2-7 represents complete solar PV systems operation combination.

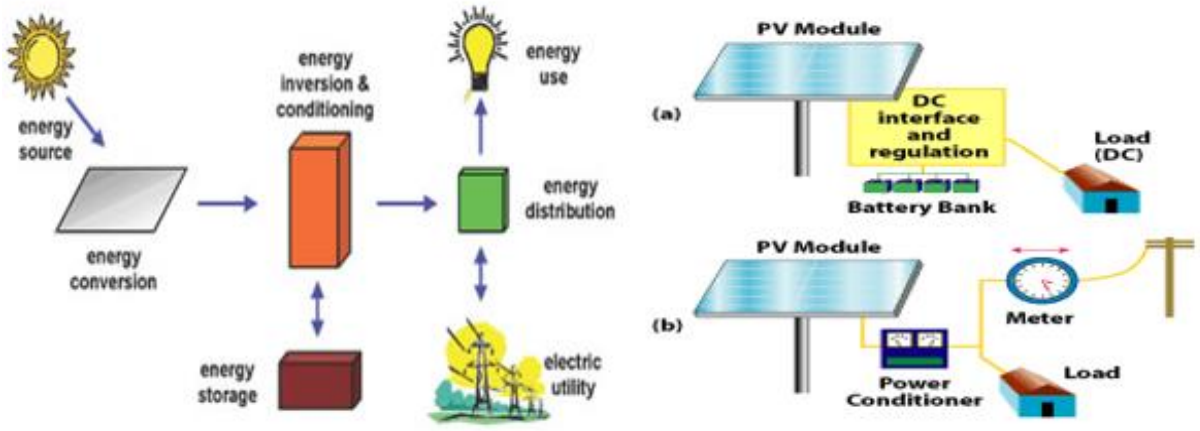


Figure 2-7: Solar PV systems complete operation combination.

PV technologies divided into three subsystems are 1) PV cells and modules/arrays from the generation side for conversion. 2) BOS-the entire PV system for the proper functioning of PV power output generation including mounting structure, PV module/arrays, and power-

conditioning equipment point components towards the sun for direct current. The inverter converts DC electricity to AC load but does not determine how PV modules/arrays operate in the field. The battery use for energy storage during the day for night-time generally is considered effective for reducing intermittency during solar PV systems electricity generation. 3) The Load as the third subsystem from the consumption side uses the PV electricity generated (EERE, 2013).

In 2013, the storage solutions based on integrated PV-battery systems investment are reported to be economically viable for small PV systems. Additionally, a model with a large number of different PV storage capacities economically determines the optimal configuration of system size. The model assumption based on optimal size for residential PV systems and battery storage will significantly rise in the future (Hoppmann et al., 2014). The Lead-acid batteries, for example, have been a suitable technology for on-site storage of micro-generated electricity. The effective use of storage can increase the versatility of a micro-generation system in satisfying a highly variable electrical load of individual dwelling and changing usage patterns on the national grid (Jenkins et al., 2008a).

Electricity production through micro-generation with suitably sized storage can reduce export with over 90 percent and substantially with 70-72 percent typical efficiency in a location and developed model takes account of losses in battery storage. The study found that a developed model estimating the performance of a system allows various design parameters of the PVT unit to vary and the influence on overall system performance can be studied (Herrando et al., 2014). The ability of lead-acid battery storage in capturing AC and DC power generated from PV cells can combine heat power and wind turbines with an appropriate temporal resolution of data (Jenkins et al., 2008b). However, the new energy storage technologies greatly could increase the role of renewables (Heal, 2009).

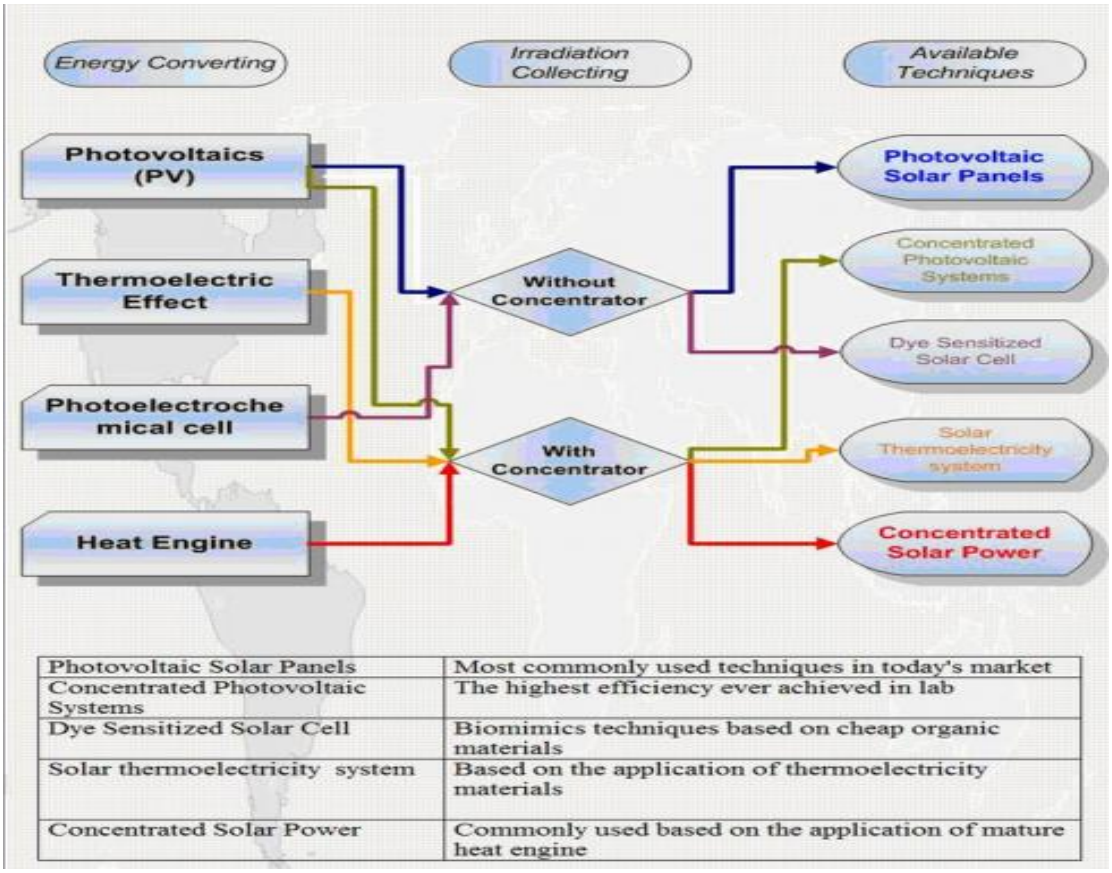
Solar PV technology with the advantage of the photoelectric effect can produce electricity to power domestic and commercial properties. The solar PV collects free energy emitted from the sun for electricity in operation of the electrical appliances. The PV conversion technically driven by weather varies in quantity with time and the location (Myers, 2013). The solar

panels fitted to rooftop or ground mounted create free electricity from the sunlight and the three components mainly used to create free electricity from the sunlight are a solar panel, inverter and generation meter. The electricity generated is converted from DC output to AC in roof space (Maehlum, 2015b). This according to RSPI report, this can equally feed into the commercial electrical grid or used by the local off-grid electrical network to reduce energy bills. Table 2-2 and Figure 2-8 represent Solar PV Technologies Conversions.

Table 2-2: Comparison of Solar PV Technologies Conversion

Characteristics		
Use	Direct and diffuse sunlight	Direct sunlight
Size	from Watt to MW	10 MW to a few hundred MW
Installation:	everywhere (roof etc.)	flat unused land
Capacity:	700 – 2000 full load hours	2000 – 7000 full load hours
Reserve capacity:	External	Internal (fossil operation)
Proofed life time:	> 20 years	> 20 years
Annual production (2004)	>25 000 GWh	> 2 500 GWh
LEC (today)	0,20 – 0,35 €/kWh	0,15 – 0,25 €/kWh

(Sources: Robert Pitz-Paal and DLR, 2004).



Photovoltaic Solar Panels	Most commonly used techniques in today's market
Concentrated Photovoltaic Systems	The highest efficiency ever achieved in lab
Dye Sensitized Solar Cell	Biomimics techniques based on cheap organic materials
Solar thermoelectricity system	Based on the application of thermoelectricity materials
Concentrated Solar Power	Commonly used based on the application of mature heat engine

Figure 2-8 : Solar Technologies Conversions (Source: GENI, 2011).

The common applications for non-concentrating technologies are all the passive solar applications, stand-alone PV panels, and rooftop solar water heaters or solar air heaters (Bradford, 2006 and 2008). The buildings that generate power using RES can reduce demands on traditional utility generators and overall emission gases due to climate change (Church and White, 2011). Table 2-3 represents solar energy technologies classification.

Table 2-3: Classification of Solar Energy Technologies

	Active Solar			Passive Solar
	Solar PV	Solar Thermal		
Centralized (>200 kW)	Concentrating PV arrays (CPV) Utility scale PV	Concentrating Solar Thermal (CSP)	District water heating	
Large-scale distributed (>20kW)	Commercial building PV		Commercial hot water systems	
Small-scale distributed (<20kW)	Small commercial & residential building PV		Residential water heating systems	Heating and cooling
Off-grid applications	Stand-alone systems for remote applications, solar home systems			Day lighting

The accurate solar energy forecast and resource assessment according to Jan (2013), can equally reduce the risk of selecting a project location in designing appropriate solar energy conversion system (NREL, 2012 & 2007). Solar energy based on a PV system, solar thermal and Building Integrated Photovoltaics (BIPV) systems applications can be a design for the purpose of telecommunications, rural development vaccine refrigeration, military, water pumping, commercial grid-tie systems, oil and gas, lighting, railroad signal, and traffic signal applications. PV technologies use a variety of collector designs such as flat plate panels on fixed position or tilt. Tracking can be used for BIPV where sun following trackers are integrated into building designs and the CPV/CSP systems (Tripathy et al., 2016).

BIPV system is an integrated PV module into building coating roof or façade and serves as building envelope material for the power generator. It provides savings in materials, reducing electricity costs from fossil fuels use and emissions and adds architectural interest to the

building (Tripathy et al., 2016). Rise reported that power production benefits utility associated with transmission, distribution due to losses (Rise, 2014), grid support and consumer savings at the point of use for lowing electric bills due to peak sharing i.e. matching peak production with periods of peak demand, and most of the systems available for utility grid can be used in stand-alone/off-grid systems. The BIPV grid-tied systems have a benefit to the cooperative utility storage system with 100 percent efficient, which essentially free and unlimited in capacity. The contribution reduces energy costs for the building owner and the solar electricity export helps support utility grid during greater demand time (Raugei and Frankl, 2009). Figure 2-9 represents the building integrated PV system for on grid-connected benefit in Nigeria.



Figure 2-9: Building Integrated Photovoltaic (BIPV) System (Source: Rise, 2014).

The Hybrid PV is a connection of two or more sources of energy system where energy from grid connects auto-generating set, solar or wind turbine for the purpose of generation supply of electricity to consumers (end-user). Secondly, when the PV system is connected with other energy supply sources such as wind, hydro, gas and nuclear serve public utility for supplying power to consumers and the operation uses different types of PV technology cells. For example, Sanyo hybrid PV cell system comprises of the monocrystalline PV cell, which covered by ultra-thin amorphous silicon PV layer. This type of cell performs well at high temperature

with over 18 percent high efficiency than conventional silicon PV cells with the high cost(Rekioua et al., 2014).

South Korea, for example, depends heavily on oil imports composed a hybrid system of RE with the existing grid system and diesel generator on Jeju Island (Chang et al, 2014). The Korean administration currently implemented energy policies such as smart grids with the diffusion of renewable energy generation sources to improve energy infrastructure with reliable systems for stable energy supplies (Yun et al, 2014). Figure 2-10 represents combination of more than one infrastructural design for more output generation of electricity.

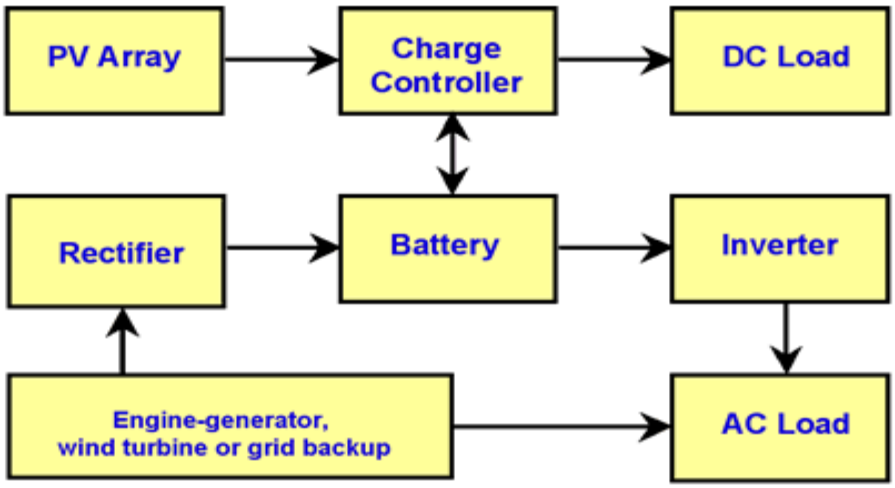


Figure 2-10: Diagram of PV Hybrid System (Source: Online.com, 2008).

The decentralized power according to report is characterized by the generation of power nearer to demand centre mainly for meeting local energy needs (Ohunakin et al, 2014). This power system functions either in the presence of a grid feed of surplus generated power to the grid or independent/stand-alone/isolated system exclusively for meeting local demands in remote locations (Kaundinya et al., 2009). The feasibility of PV power plant considers monthly average daily global solar radiation data in project locations (Khalid and Junaidi, 2013). The decentralized renewable energy solutions are a better alternative to alleviate energy poverty due to cost-effectiveness over the system's lifetime, easy-to-deploy, install

and maintain as well as a design that tailored according to individual needs (Kaundinya et al., 2009). Currently, the industrial growth engines are “Green Growth" and "Sustainability".

2.2.3 Nigeria Energy Sector Production

The Nigerian national transmission grid for power sector operates at 132 KV and 330 KV. The current transmission system capacities are from 5,523.8 - 6,680 km for 330kV lines with 10,238 MVA substation transformer capacity and 6,801.49 - 9,161 km for 132 kV lines with 11,721 MVA substation transformer capacity. The present total transmission wheeling capacity equals to 5,300MW against 6,600MW capacity (Uzoma et al., 2012 and Nnaji, 2011). The specific transmission infrastructure on super-grid operates at 760 KV for transportation of power to major load centre of the country.

The replacement installed from aging substation transformers equals to 150 MVA with 330 KV and 132 KV lines are new construction in Lagos and Kano. The on-going construction of 3rd Benin-Onitsha with 330 KV line. The Load location centres are in Lagos state, Ibadan, Aba-Port-Harcourt axis, Benin-Warri axis, Enugu-Onitsha axis, Abuja-Kaduna axis and Kano. The National Control Centre (NCC) is at Oshogbo in Osun state, Backup Supplement of National Control Centre (BNCC) is at Shiroro in Niger state. The three regional control centres (RCC) are at Ikeja West (RCC1), Benin (RCC2) and Shiroro (RCC3) control the central transmission grid. The national grid network has 9500 km total length with 330 KV lines, and 9700 km with 132 KV lines (Vincent and Yusuf, 2014). The entire grid power load with wheeling power capacity about 16,852 MW is equivalent to 7886 MW with 330 KV lines and 8986 MW with 132 KV lines. Figure 2-11 represents the existing power infrastructures in Nigeria locations.

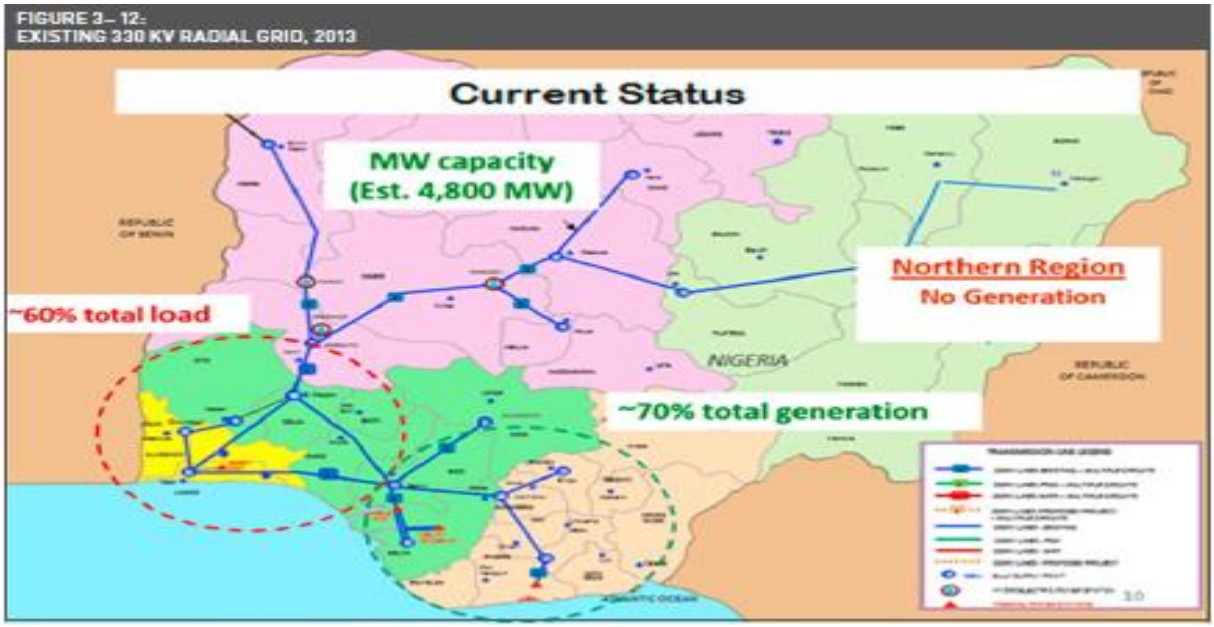


Figure 2-11: Existing 330 KV Radial Grid (Source: TCN, 2013).

In 2016, the study estimated Nigeria electricity demand at 12,800 MW. The historic gap between power demand and available grid electricity led to widespread of self-generation power where many individuals and businesses in commercial, industrial and residential sectors own generators to compensate the lack of access to grid energy supply (Watkins, 2016). The large population of Nigerians with over 170 million has the available installed capacity of 10,400 MW against 4,300 MW available generation capacity when compared to the South Africa population of 52 million with 31,880 MW available installed capacity. The current electricity generated and supplied from the national grid that powers the entire country found equivalent to the UK Liverpool and Manchester power supplied (David-West, 2014 and Ogunleye, 2017) covers one percent of Nigeria's population. According to Power Africa by Obama, "Access to electricity is described as a fundamental opportunity for children studying in this age because power allows an idea to transform into a real business that requires Africa plugging into global grid economy for power.

McKinley reported that NBET negotiated eight of PPAs with solar power developers projects in different phases in 2015 (Asaju and Akume, 2010). Since privatization, the power sector elicited high investment interest and many developers secured generation licenses from NERC but none of the Greenfield IPPs has commenced operations due to varying reasons in

securing finance (Kuta, 2009b; ECN, 2009). Figure 2-12 represents Nigeria current IPPs in different locations across the country.

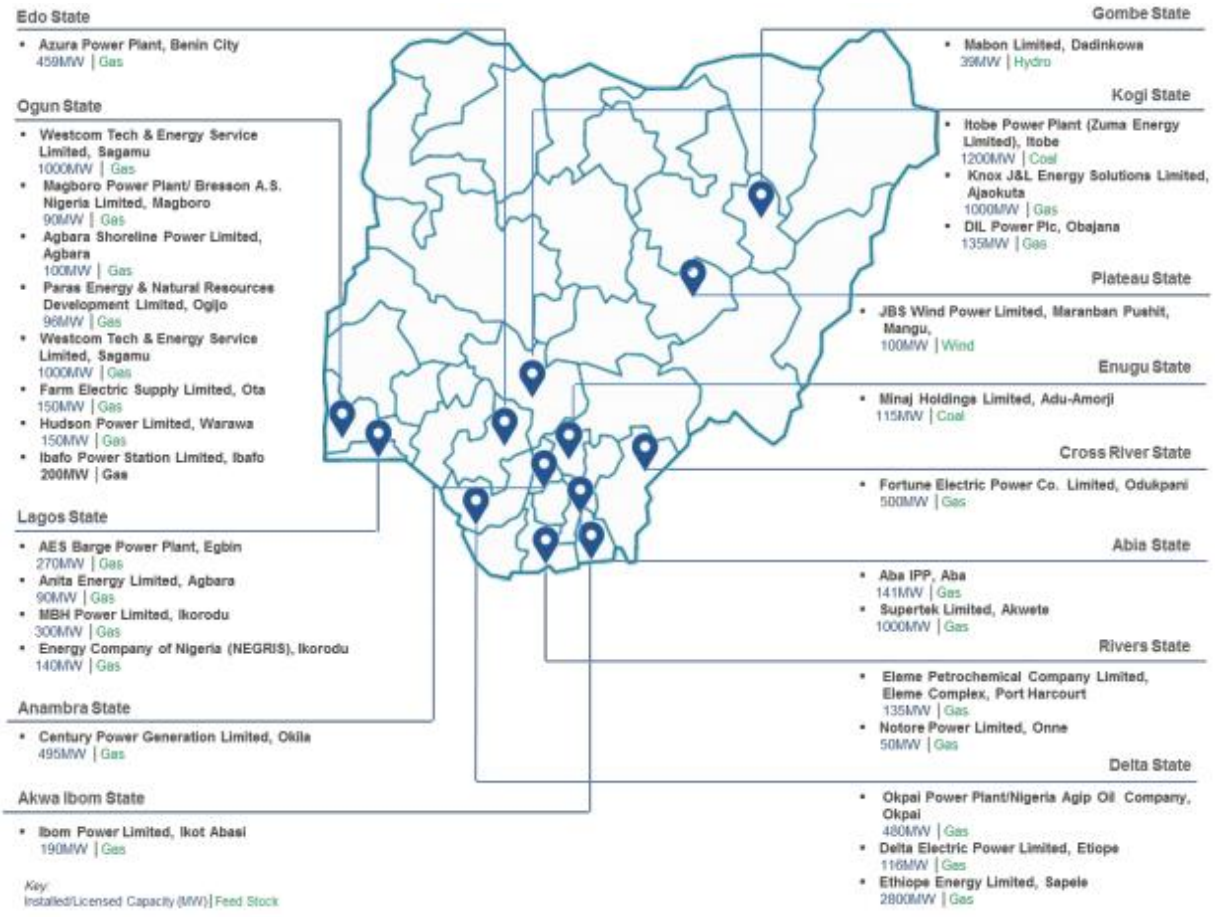


Figure 2-12: Current IPPs in Nigeria (Source: NERC, 2016).

2.2.4 Nigeria Solar Photovoltaic Power

Solar energy potentially vast in abundance is about 120,000 times more than annual average energy generated by PHCN in Nigeria (Chineke and Igwiro, 2008). Nigeria global solar radiations for high, medium and low zones monthly annual mean about 22.88MJ/m ^{2} /day, 18.29MJ/m ^{2} /day and 17.08MJ/m ^{2} /day. The sunshine durations for high, medium and low zones are 12.06 hour/day, 12.04 hour/day and 12.03 hour/day respectively (Abdussalam, 2014). The country is well distributed with solar radiation that lies within a high sunshine belt. The total annual average varies between 12.6 MJ/m2 -day (3.5 kWh/ m2 -day) in the coastal

latitudes and 25.2 MJ/ m 2 -day (7.0 kWh/ m2 /day) in far north whereas the annual average solar energy intensity about 1,934.5 kWh/m2/year. The solar energy falling on the entire land area can provide an average of 6,372, 613 PJ/year approximately 1, 770 thousand TWh in a whole year (Adewole et al., 2015). The amount of solar energy radiation that reaches the earth's surface is reliable and available in the most country of the world and the variation depends on the geographical location, time of day, season, local landscape and the weather condition (EERE, 2013).

Some off-grid PV power supply systems developed to power office appliances made of the photovoltaic array, mounting frame, storage device, inverter, charge controller and wiring system from an alternative source of power to the government own unreliable and epileptic utility power supply (Babatope et al., 2013). For example, a solar power system in Akure tested with Latitude $7.15N^0$ showed good performance of the system (Aina et al., 2013) and the functional output between 10.00 and 16.00 hours with high solar radiation period coincides with office hours. The office total load of appliances by the system 290 watts for 334-watt average solar power output from the test carried out (Adejuyigbe et al., 2012).

Solar energy with PV system has powered motorbike called Keke-Marwa to help reduce energy, health and foreign exchange costs for environmental improvement in Nigeria (Ebele and Okeyika, 2016). In addition, solar system powered car from Ebonyi state in 2016 and Volkswagen Beetle scraps (off-road vehicle) by Mojeed Sanni and Segun Oyeyiola in Nigeria. According to Minister of Environment (MOE) and Niger-delta Permanent Secretary, during the 10th National Council on Environment workshop at Lafia in the Nasarawa state of Nigeria, African continent enjoys about 3,700 clean development mechanisms (CDM) projects worldwide and only 1.4 percent (Usman, 2016). The Keke Marwa powered by solar energy has been a shred of evidence to continue attracting foreign direct investment in renewable (Ebele, 2016 and Bergstresser, 2017).

The study reported that renewables led to the transformation of the power sector over power market design and electricity security. In 2006, the world energy output examined more stringent decarbonization options and the 450 consistent Scenario with 50 percent chances

of limiting global warming to 2 °C as well as further pathways to limiting warming (PVPS, 2016). In today's energy use, CO2 emissions threaten the climate and this led to G8 call on IEA in providing guidance for a decision on how to bridge the gap that needed be done to build a clean, clever and competitive energy future from what is happening (IEA, 2012). In addition, the world needs increasing energy supplies due to energy resources under pressure to sustain economic growth and development. The numerical radiation algorithms with GIS tools found to be the pathway to evaluate those complex effects (Reed and De Freitas, 2015).

2.3 Economic Aspect

Solar energy due to cost constraint has been the major contributor to energy mixture. The recent drastic cost reductions pave way for PV production in becoming cost competitive for energy generation to fossil fuel. The right incentives can bring cost competitiveness with grid prices by 2020. Despite the subsidy burden, the cost has been falling for renewables growth, Europe leads and China has the largest source of growth. For example, North America leads with the falling cost of renewables for the new grid-scale power generation costs (Energy Outlook, 2014). Figure 2-13 represents the renewables falling cost by 2035 reference case.

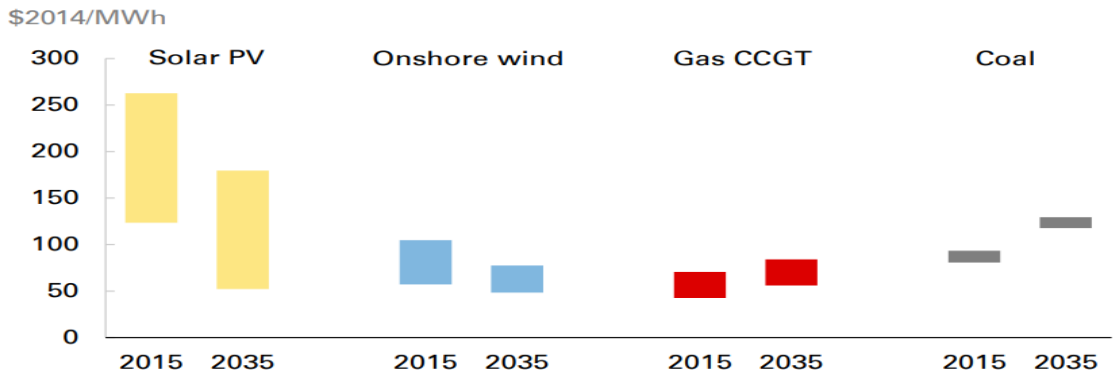


Figure 2-13: Falling cost for Renewables by $ per megawatt hour for 2035 Reference case MWh (Source: Energy Outlook, 2014).

The burden of policy support has become a constraint for renewables growing in volume and costs of renewable power needs to keep falling to maintain rapid growth and per unit power but required reducing the subsidy. BP energy reported the expected renewables cost to significantly fall due to continued technological advances, learning by doing and economies

of scale (BP energy outlook , 2013). For example, the best location for onshore wind power even without subsidy for grid integration costs can compete increasingly with new conventional fossil power plants. Solar PV according to BP report in 2014 is expected to become competitive across a number of increasing market niches and requires PV grid-scale carbon price to compete with efficient gas combined cycle generation by 2035 (British Petroleum, 2014). Figure 2-14 represents the renewables growth in share of power generation from 2013-2035.

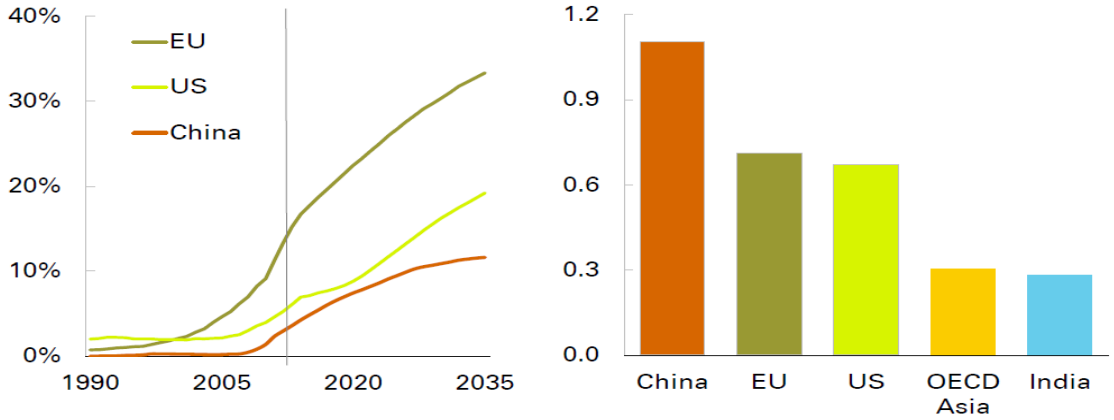


Figure 2-14: Renewables growth from 1990 to 2035 Thousand TWh (Source: BP PLC, 2015).

The falling costs of renewables in Europe have continued to gain share with the spread of renewables to other regions. The EU led the way in promoting renewable power with the ability of grid systems handling intermittent sources of power in a number of EU markets add a technical constraint to renewables growth rate. According to the BP report, the scaling up renewables outside EU and USA may not reach the current EU level of renewables penetration until 2030 and would be longer for China (British Petroleum, 2016). The EU growth in volume between 2013 and 2035 will scale up renewable deployment while China growth in volume surpasses and matched the United States.

2.3.1 Solar Economic perspective

Electricity supplied price for home rooftop PV solar cells found to have fallen below the retail price of grid electricity in some areas. The residential households have economic incentive to

install rooftop PV systems and reduce the electricity purchases from the grid. The costs incurred by a significant portion of utility companies fixed must be recovered even though consumption falls and electricity rates must increase for utility companies to recover fixed costs from shrinking sales. The increasing rates have resulted to even more economic incentives for customers to adopt PV rooftop (Cai et al., 2013). According to the report, the objective of human activity and economic growth are two casual chains potentially important instrument to human development and the achievement of human development critically contributes to economic growth based on activities. In addition, the national resource allocation contributes to human development and helps to increase the national income (Stewart and Ramirez, 2015).

In the UK, solar PV market has grown from zero to 5GW-installed capacity. The rapid growth propelled the UK into the top ten global markets for the solar PV system. The significant deployments contributed to significant economic benefits and robust business including job creation for industries that supply the components and labour to achieve the rollout. The recent changes to the solar industry with the financial support available particularly for large-scale solar PV installations threaten economic potential viability of the industry and the benefits of solar PV to continue to deliver to the UK economy (CBER, 2014).

The high upfront cost has been a critical barrier for clean infrastructure technologies investments in the developing countries (Huenteler et al., 2016a). For example, the case study of Thailand's electricity sector, created realistic estimates with relative contributions of local and global technological learning in reducing cost in the future (Huenteler et al., 2016b). The renewable electricity technologies locally developed a global share source of goods and services are based on the local effects and the global learning implementation of Thailand's renewable energy targets by 2021.

The results show that the largest potential for aggregate cost reduction lies in enabling local learning such as a skilled workforce and a stable regulatory framework. The establishment of sustainable business models has a more significant impact on the cost of renewable energy in developing countries than global technology learning curves (Qazi, 2016) and the

importance of local and global learning relatively differs and significantly by technology. The country characteristics need local context framework conditions to reap full benefits of technological learning across a wide range of clean technologies, and considering global perspective for international support (Huenteler et al., 2016a).

Solar PV technology market prices around the world receive growing attention among key stakeholders by gaining coherent shifts across the industry value chain. The PV supply chain complexity involves a large number of manufacturing processes; the balance of system (BOS) and installation costs which associated with complete systems, choice of different distribution channels and the differences between regional markets within PV deployed locations (Mills and Wiser, 2010). For example, stakeholders from fifty industries on BOS costs offered uneven and complex industry chances for collaboration on strategies to reduce installed BOS costs for commercial and small utility systems apart from San Jose California experts (Wiser and Bolinger, 2011). In addition, many opportunities potentially identified could reduce BOS costs from GBP0.61-0.41/watt ($0.90 to $0.60/watt) about 45-65 percent reduction with current best practices in less than five years' time frame (Bony et al., 2010).

In 2010, the RMI proposed a number of industrial activities to support BOS cost reduction in achieving low-carbon, more efficient physical system designs, to streamlined business processes and rapid industrial scaling. Dedicated industry and wide effort will help accelerate cost reduction opportunities. During the U.S second quarter in 2012, the BOS costs twice and more expensive for the average price of residential installed PV system than Germany (Bony et al., 2010). Recent studies found that accurate value for the solar system may not relatively be easy for new real estate market but can often recover 100 percent of the original cost due to property value increase by a substantial amount (Nevin, 2010). In research & development, more than GBP6.9 ($100 billion) has been invested in new renewable energy capacity through global milestone for manufacturing plants in 2007. In recent years, RE rapidly changes due to the reality of its significance and perceptions whereas increasing conventional energy worldwide lagged behind (Richards et al., 2012).

2.3.2 Solar PV Economic Assessment and Reductions

The most important barrier to solar PV power system deployment in today's world has been management. BOS is the sum of module costs, mounting structures, inverters, cable and total system costs and sensitive to economies of scale that vary substantially depend on the type of application. The costs of different module technology types vary per watt, which is less significant while taking technology efficiency need and land-use into consideration (NREL, 2012). The leading market prices for utility-scale about GBP2749/kW equivalent to (USD 4000/kW) and GBP4124/kW (USD 6 000 /kW) for residential small-scale applications (WEC, 2016). The PV capital cost possibly will continue to decline (IEA, 2010). Figure 2-15 represents the capital cost of PV system now and by 2025.

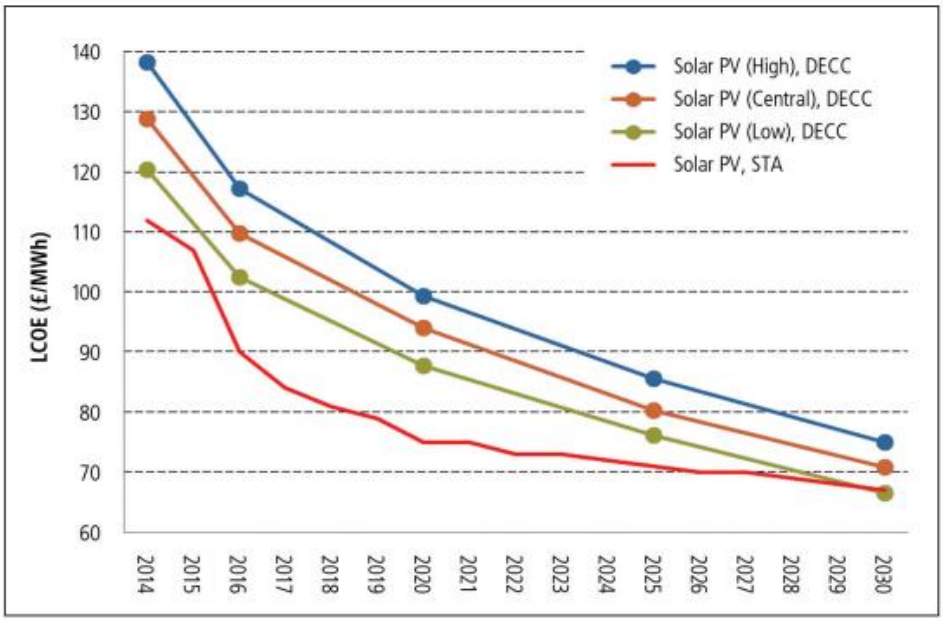


Figure 2-15: Solar PV Capital cost based on LCOE projection (Sources: DECC and STA, 2014).

According to the Department of energy and climate change (DECC) and Solar trade association (STA). The comparison of LCOE percentage reduction analysis is based on LCOE values when compared with DECC high, central and low costs. These are lower all years from 2014-2030 even lower than the DECC low-cost scenario (STA, 2014). In January 2016, drop occurred due to anticipated removal of the EU-China anti-dumping tariff. However, the rate of cost reduction will be steeper by 2020 and flatter from 2020-2030 when compared to the DECC

scenarios. In addition, the percentage will drop from 2014-2020 (27%) for DECC and (35%) for STA and from 2020-2030, it will drop according to DECC (25%) and STA (11%) for large-scale solar PV (Bloomberg, 2014).

Study found that PV BOS costs for commercial and residential smaller-scale systems to be higher than utility-scale systems in percentage (McGinn et al., 2013) and the RE costs falling are based on market and technology improvement (IRENA, 2016 & 2014) that compensates fuel and health cost savings for using less fossil fuel (Elliott, 2015).

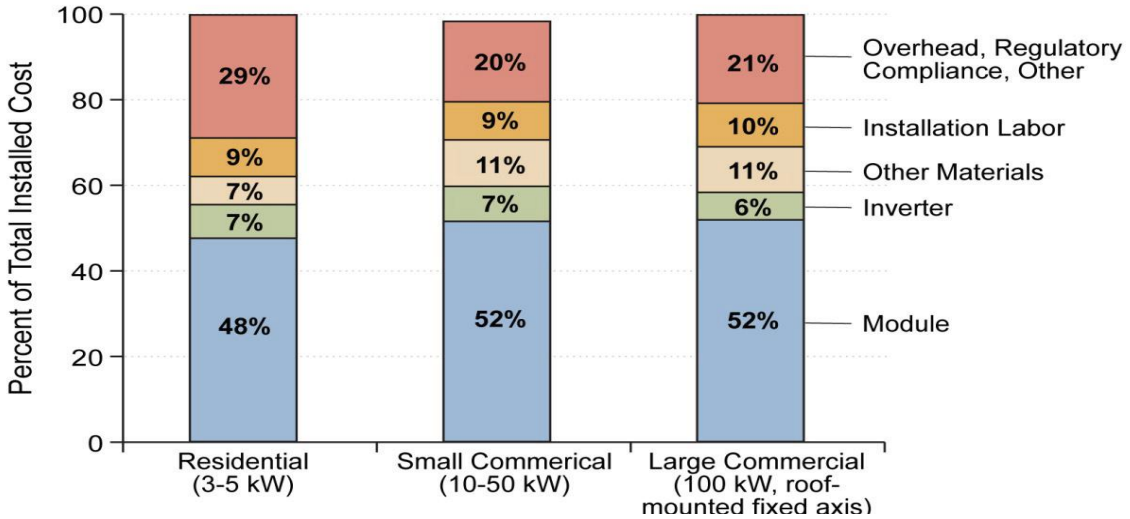


Figure 2-16: PV system component contribution to the total costs (Source: Wiser et al., 2009).

BSW reported that the average costs for large commercial rooftop systems in Germany and Italy respectively in 2012. The BOS cost for residential systems in Germany is about USD 1 to USD 1.4/W (BSW, 2012). The Levelized Cost of Electricity (LCOE) for c-Si residential PV systems without battery storage is between USD 0.28 and USD 0.70/kWh in 2010. In 2011, the c-Si module prices declined in the range of USD 0.25 and USD 0.65/kWh (Photon Consulting, 2012). The LCOE for small-scale systems in the second quarter fell lower than most residential tariffs in Germany but the cost can still be competitive for large commercial rooftop installations.

The installed costs for example between GBP0.16 and GBP0.34/kWh are equivalent to USD 0.23 and USD 0.50/kWh in U.S and second quarter higher in Germany for residential systems. The latest LCOE for utility-scale projects increases the competitive due to cost reductions for residential systems (IRENA Renewable Cost Database , 2013). The LCOE values for utility-scale projects in Germany fall between GBP0.11 and GBP0.15/kWh. The LCOE for a small number of projects in Latin America varies from GBP0.08-0.21/kWh (Griffith-Jones et al., 2017). The typical projects in China are about GBP0.24/kWh and other Asia regions between GBP0.10 and GBP0.38/kWh. The South Korea projects are most expensive with high capital costs and low capacity factors (Mauleón, 2015). Figure 2-17 represents the global current price of different PV system technologies.

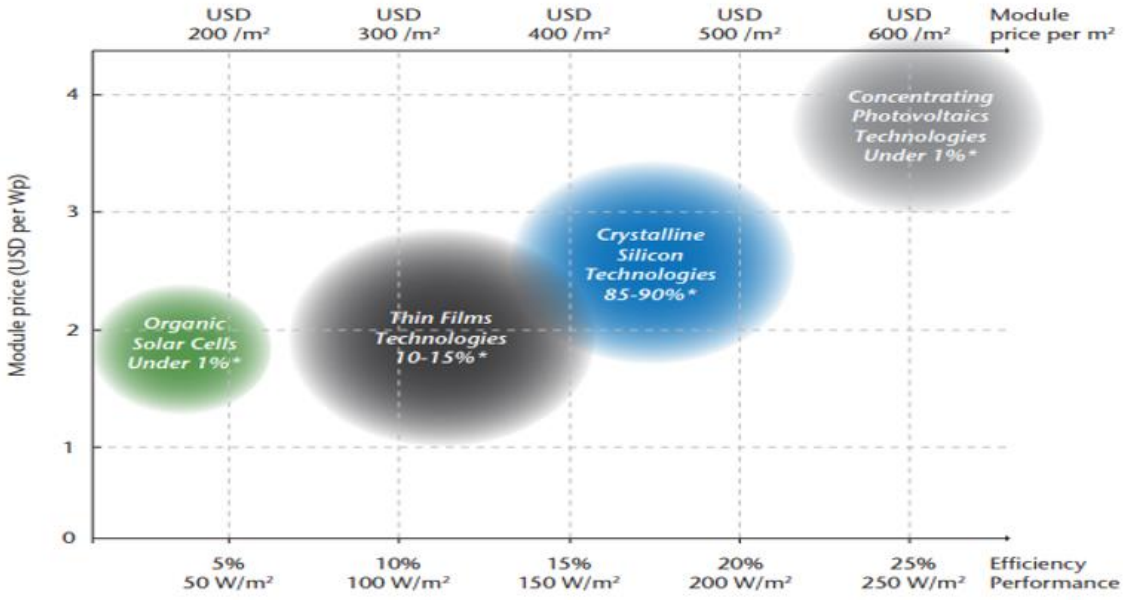


Figure 2-17: Different PV module technologies with current price performance (Source: IEA-PVPS, 2008-2009).

The Levelized cost of electricity PV system (LCOE) generation depends heavily on two factors: the yearly amount of sunlight (i.e. associated capacity factor) and interest/discount rate (Myers and Kleissl, 2013). In 2008, the maximum prices for small-scale BIPV systems are less-mature PV. The price from IEA countries with larger interest rate and the best system price is lower than GBP2, 062. The cost of PV electricity generation according to (Hernández-Moro

and Martínez-Duart, 2013) for utility-scale applications is GBP165/MWh with very high radiation capacity factor in the location.

Solar PV cost has drastically come down for power production will become halve from three to five years without subsidies (Abubakar, 2007). In 2013, a pioneering factory innovation (G24) breakthrough with affordable solar cell technology production at Cardiff in Wales confirmed solar energy harnessing within the United Kingdom. For example, the new cell materials produced the fifth version of silicon-based for commercial use in the developing countries. According to the report, a tenacious US-based environmental activist cited that IEA has a 50 percent cost reduction of solar photovoltaic from 2001 to 2020 (Nader, 2013). According to U.S report, America could meet the entire energy needs by covering 1.6 percent land area with solar cells and such enormous opportunities have a very large role to play in the alternative energy mix for most countries in the coming decade (DOE, 2010); (Atiku, 2007).

The solar panel price falling represents better value for money and some people suspected that solar power with incentives become more competitive to existing fuels in the next ten years. Secondly, the cost has been a determining factor for household consumer/business switching except with major incentives such as low-cost loans. The FITs could make the change and reasonable for household level although incentives are not without risks (Newsom, 2013). Nigerian businesses face much higher costs from grid power and generator use going by the unreliable state of the national grid and enough incentive can meet the difference with about GBP0.10/kWh (N40/kWh) tariff. The RE electricity should be about GBP0.18-0.34/kWh ($0.26-0.50/kWh) per unit power cost and grid electricity about GBP0.069-0.10/KWh ($0.10-0.15/kWh) per unit cost in 2013.

The Europe experience ‘grid parity’ makes renewable solar-PV power cost equal/less than conventional grid retail. The cost savings from the solar-PV project in today’s grid energy recently range from GBP0.03-0.048/KWh in Spain. FITs for solar PV is currently less than 30 kW capacity on the rooftop with GBP0.38/kWh (0.43€/kWh). Between 30 kW and 100 kW rooftop capacity for GBP0.36/kWh (0.41€/kWh). Between 100 kW and 1MW rooftop capacity

for GBP0.35/kWh (0.39€/kWh). The freestanding rooftop capacity units are greater than one MW for GBP0.29/kWh (0.33€/kWh) and each tariff for every kWh of electricity generated is eligible to 20 years fixed price payment in Germany (IEA, 2011). The Germany's FIT assessment technique is currently on a "corridor mechanism" (Greenpeace, 2011; Bhandari and Stadler, 2009). Figure 2-18 represents Nigeria solar PV cost per kWh from 2005-2031 for electricity projection to conventional energy.

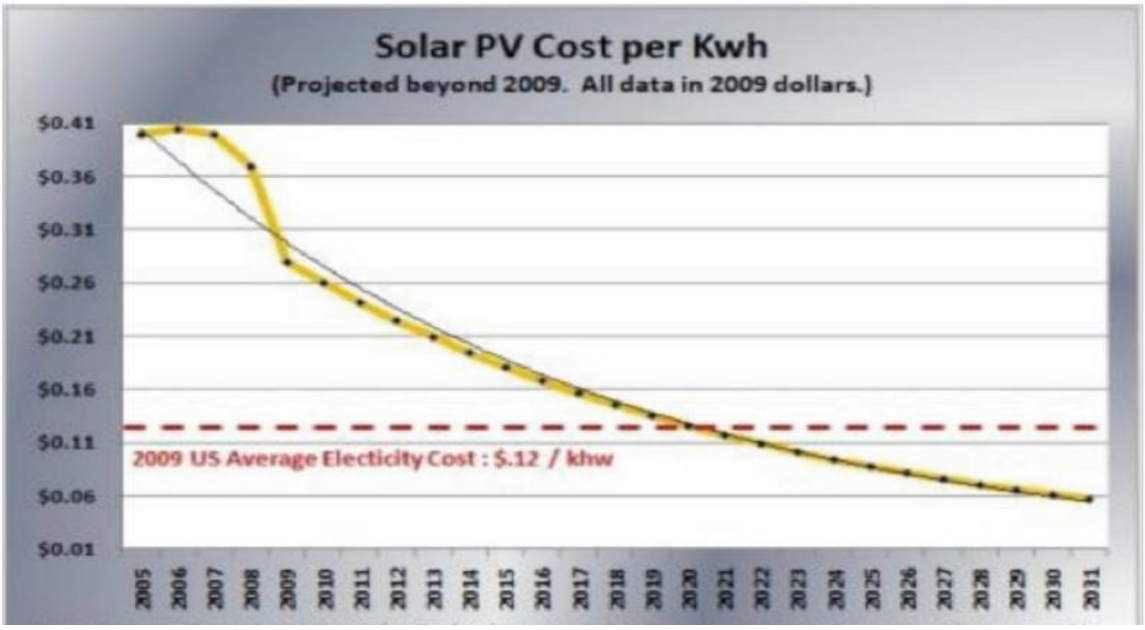


Figure 2-18: Projected costs of solar PV versus conventional electricity 2005-2031 (Source: Nigeria Low Carbon Plan & Power Sector-Interim Presentation, 2011).

The renewable energy costs have continued to fall annually with some projects which credibly claiming 'grid parity' in Europe (PV-Tech, 2012). The study found Conergy's pilot project to have achieved grid parity where renewable solar-PV power costs the same or less than retail conventional grid (Bhandari and Stadler, 2009). A study found it is important to lower cost of renewables in Nigeria to become similar to the level enjoyed in Europe for wider foster of renewables market in reducing business costs of RE companies and the barrier to import tariffs. The 'standby' cost per unit of electricity from generator or kerosene is greater than GBP0.34/kWh (Newsom, 2013). The study also revealed that a decline in the cost of the system has been for wider acceptance of solar as well as the significant decrease in rising prices of solar electricity cost in the past three years. Since 2009, the average cost of solar PV

systems has decreased by 50 percent and the oil prices has risen by 36 percent. In 2012, the solar industry worth GBP4.5 billion and the current cost roadmaps clearly position the energy source for continuous improvement in competitiveness (Bhandari and Stadler, 2009).

2.3.3 Levelized Cost of Electricity (LCOE)

The natural gas electricity faces high price due to Levelized cost of simple cycle gas turbine technologies and much higher to other conventional technologies because only utilities dispatch the technology when other technologies are not available results to small capacity utilization factor (Colpier and Cornland, 2002). The natural gas in some places is a major source for electricity generation. The base load renewable energy power plant lowers Levelized electricity cost (Bazilian et al., 2013). Equation 2-1 represents electricity generation cost formula for different energy sources.

$$\text{LEC} = \quad \sum_{t=1}^{n} It + Mt + Ft/(1+r)t \quad / \quad \sum_{t=1}^{n} \frac{Et}{(1+r)t} \qquad 2\text{-}1$$

Where,

LEC is average lifetime Levelized electricity generation cost; It is investment expenditures in the year; Mt is operations and maintenance expenditures in the year; Ft is fuel expenditures in the year; Et is electricity generation in the year; r is discount rate; n is a life of the system.

The LCOE commonly as a measure is used to compare different power sources. The level of penetration per kWh value of PV generation in regional electricity market depends on many features. For instance, more PV capacity has less valuable increment for the generation in a given online market (Zamalloa et al., 2011). In addition, the government guaranteed the loan for CSP commercial-scale project with the less mature PV system, experience large risks. Directing payment to renewable generators can be more efficient than tax credits and subsidies (grants/aids/supports). It provides better incentives for producing power because PV can be deployed very rapidly from expectations of price-based subsidies (Schmalensee, 2015a).

Solar radiation with higher direct/diffuse level lowers solar PV system's LCOE operation (Schmalensee, 2015b). The PV system in area location with higher solar resources usually has minimized the cost of electricity by the annual mean (kWh/m2/year or kWh/m2/day). The economic competitiveness of solar electricity relating to other generation technologies in a particular power market depends on cost and the output of the value sold.

2.3.4 Nigeria Energy Investment Assumptions

Nigerian electricity market provides 15-year wholesale and retail prices as end-user tariffs path for the electricity industry. NERC introduced Multi-Year Tariff Order (MYTO) in 2012 and amended to MYTO 2 in 2014 with minor reviews each year with parameters such as inflation, exchange rate, and gas prices. The major tariff reviews expected all stakeholders and investors input every five years. The current wheeling charges amended ("TCN Tariff" MYTO 2.1) to GBP 6.78 (N2, 743) per MWh. The NERC published a new set of tariffs in 2015 for 2015-2024 distribution companies with effect from 1st February 2016. This requires end-users in different locations to pay different amounts for each kWh with the following principles. The assumptions include cost recovery/financial viability; signals for investment; certainty and stability; efficient use of the network; allocation of risk; simplicity and cost-effectiveness; incentives for improving performance and transparency/fairness (David-West, 2014).

Nigeria average cost for generating, transmitting and distributing per kWh is about GBP51.00 (N20, 655) per MWh tariff (N20.66) for electrical energy use by the consumer in 2014. The electricity price for utility grid-connected is less than self-generation. The private investor may be discouraged considering investing in repair and upgrades from the existing infrastructure to the building of new facilities without increasing consumer tariff (Vincent and Yusuf, 2014). Nigeria electricity price has increased in 2016 to GBP0.06 (N18-N24.30) for household consumption and GBP0.13 (N54) for commercial consumption.

Nigeria belongs to the group of countries with the lowest electricity consumption when measured in per capita income and the nation's prosperity (Olayinka, 2012). Despite being 12th world's highest producer of oil with about 2 million barrels per day and 9th largest

proven reserves of natural gas with about 182 tetra cubic feet (TCF) still ranked the poorest among countries in the world (Ibitoye and Adenikinju, 2007). Nigerian power market has to reach stability for the willing-buyer and willing-seller to ensure all aspects and NESI stakeholders are working together to deliver quality, reliable and efficient electricity to consumers at reasonable prices (McKinley, 2014) based on long-term goals in 2015 and beyond. To continue to increase available capacity with the aspiration of 40 GW by 2020 will assume 2.6 percent population growth per annum and 80 percent load factor plants approximately 4.3 GW for the new capacity per annum for much more stable socio-economic position. Figure 2-19 represents the power growth plan to achieve 40 GW by 2020.

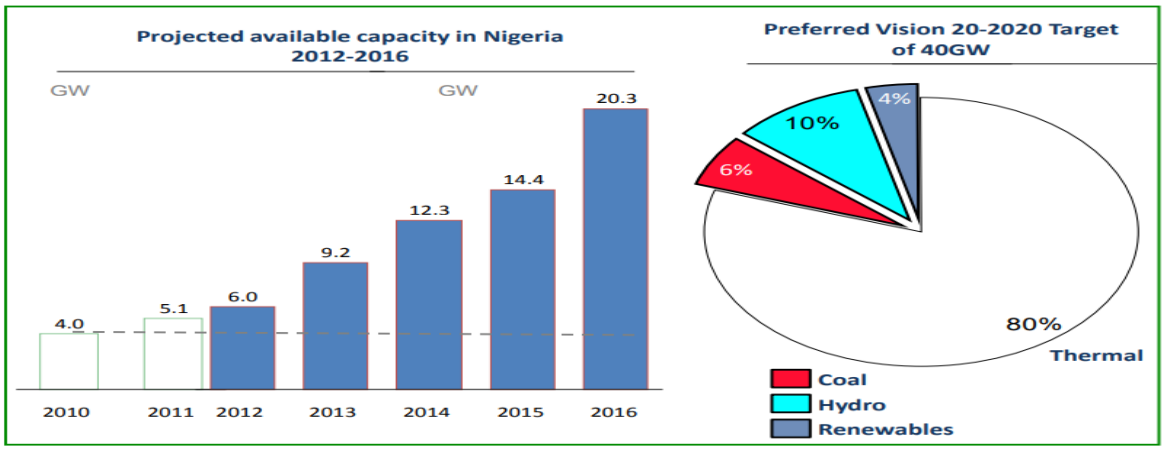


Figure 2-19: Power Growth Plan for increasing availability Capacity (Source: NERC and McKinley Analysis, 2009).

NERC is an independent federal regulatory agency and a decision maker for grid-connection electricity services that has the following key aspects: the technical and economic regulation through tariff regulation, approval of capacity expansion plans and regulated company business plans, oversight of capacity, tendering, competition, standards, quality of service and service obligation. The issuing of licenses to companies that operate in the electricity supply industry, monitor and enforce economic and technical regulation of the sector with separate licenses for transmission (Dispatch), generation, distribution including retail sales as well as decisions on regulatory approval for wholesale and retail electricity tariffs prices. In Nigeria presently, there is no operating grid-connected renewable energy project except for hydropower.

Renewable energy financing is a crucial element in realizing the federal government's policy thrust on renewable electricity. The financing long-term involves foreign and domestic resources and foreign investment capital that provides a greater proportion of funds needed. The government providing guarantees and financial frameworks are required for stimulating renewable electricity market expansion due to risk element in financing renewable electricity projects.

The federal government continuously improves conditions to enhance funding of renewable electricity through equity, debt financing, grants, and microfinance. Ignoring financing costs when comparing other investment against the conventional source of energy will bias evaluation against EE and RE investment. According to (Yogi Goswami and Frank Kreith, 2016) report, financing is described as the amount financed, the loan period and interest rate and usually are assumed to be a uniform payment schedule. The financing of energy investment can alter economic viability of such investment particularly for energy efficiency (EE) and RE investment with large initial capital investment costs returns that spread over time.

The study found innovations to be the latest affordable rural electrification solutions with a unique focus on Africa due to sustainable benefits to the local people. The international stakeholder has recognized the need and renewable energy potential for business evolution with the involvement of strong wide diversity from the public sector to donors in Africa. The modern energy services are crucial to human well-being and the country's economic development. According to IRENA report, 1.2 billion people are without access to electricity and more than 47 percent of these people live in Africa and 60 percent with additional generation capacity expected to reach off-grid universal electricity access by 2030. The North African (NA) countries, for example, possess vast RE resources whose electricity supply largely dependent on fossil fuels. The cost analysis conducted to optimize deployment of RES scenarios in five (5) North African countries by 2030 and 2050 confirmed high RES shares close to 100 percent in North Africa and possibly by 2050.

2.3.5 Photovoltaic Market

Germany, Japan, the United States, and Spain are countries that dominated and sustained PV market. They all experience spurts of growth that contributed to overall worldwide cumulative capacity (Bathelt and Schuldt, 2010). Germany, Czech Republic, and Italy accounted for 4.75GW new installations. The U.S and Japan accounted for 500MW each in 2009 and among the countries that dominated the markets significantly over 15 years are India, China, Australia, Canada, and France (Buzz, 2010).

Many developing countries lacked access to modern energy services despite how important it is for economic development, improving peoples' livelihoods and promoting sustainable development (Rehfuess and Organization, 2006). Studies estimated approximately 1.3 billion people as a fifth of the world's population that lacks access to electricity at home and the vast majority in Sub-Saharan Africa (SSA) and South Asia rural areas. About 81 percent of the population in these regions relies on traditional biomass for cooking and heating despite several disadvantages from the traditional use. The usage according to reports mainly associated with women and children depend on the amount of time significantly spent on fuel-wood collection, indoor air pollution, deforestation, and soil degradation (WEO and IEA, 2015). According to 2009 projection, number of people relying on traditional biomass will increase 10 percent from 585 million to 645 million by 2030 from the business scenario and the electricity connection rate may not keep pace with the population growth (Chirambo, 2016). Figure 2-20 represents percentage of the population-deprived access to electricity in the developing countries.

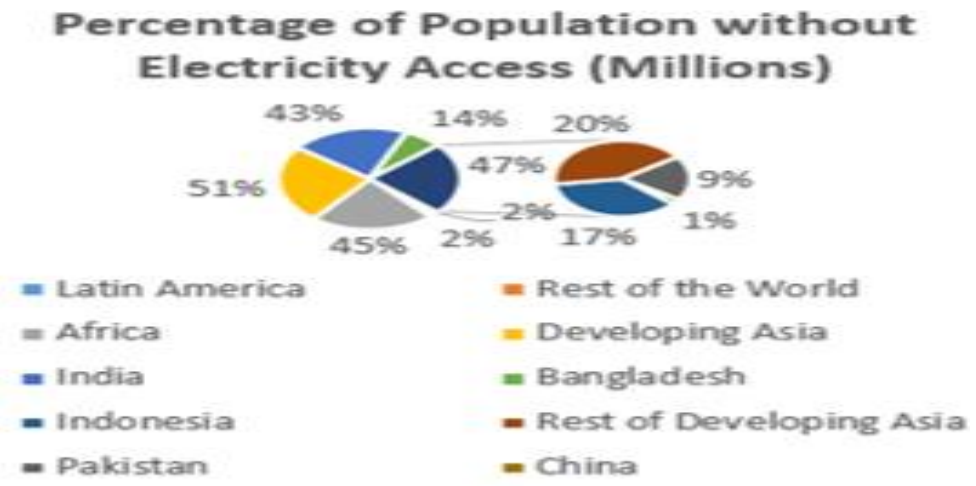


Figure 2-20: 2009-2030 percentage projection for developing countries without access to Electricity.

Studies revealed 587 million Africans in 2009 lacked access to electricity (IEA, 2011a) even though energy access very important to income and poverty alleviation. Modern energy access virtually rises from zero to 70 percent. For example, some countries have access to electrification programmes and many rural populations remain deprived of electricity. More than half of the population among 41 countries in Sub-Saharan Africa has no electricity access and average electrification rate will barely rise from now till 2020 (Shyu, 2014 and Monari, 2011).

Sustainable energy globally for all multi-stakeholder partnership initiative has three interlinked objectives to ensure universal access to modern energy services to double the global rate of energy efficiency improvement (Ki-Moon, 2012). Among the governments, the private sector and the civil society, the RE has shared in the global energy mix by 2030 (Bazilian et al., 2014) that requires substantial financial and technological investments in achieving the goals which far exceed historical levels. The general perception is that the region contributes very little to global GHG emissions with few opportunities in reducing emissions to attract climate finance projects (Chirambo, 2016). In 2009, the projection confirmed million people in developing countries will continue to lack access to electricity by 2030 (IEA, 2011b).

Modern energy access is a social and economic priority for the rural population due to direct socioeconomic and environmental benefits because energy is indirectly an important input factor for growth and Millennium Development Goals (MDGs) benefits. Finance is found to be the main barrier for many rural families that have little expendable capital in Nigeria (Chirambo, 2014). The off-grid photovoltaic (PV) deployment by combining the market, energy use and socioeconomic elements with existing support mechanisms and incentives is a new solution for promoting sustainable energy for remote-rural areas in developing countries (Groth, 2012).

The electricity generation, transmission, and distribution are capital-intensive activities that require huge resources with funding capacity because the adequate power supply is an unavoidable prerequisite for any nation's development. The theories debate that "agile energy systems" are where regions, cities, and communities must have combinations of on-site or distributed energy generation such as combined heat and power (CHP) along with central grid power generation (Clark and Lund, 2007). In addition, infrastructures with a sustainability record may evolve over time lock-in waste handling and collaboration with institutional, technical, cultural, and material for the emergence of more sustainable urban infrastructures with a program to unlock urban infrastructure (Corvellec et al., 2013).

Solar energy awareness increased in the last decades and several efforts increased the diffusion, making solar competitive in the energy market. In 2010, PV module efficiency increase and the manufacturing cost reduction with strong public support are favourable incentive schemes, which generated a significant rise in the installed power exceeding 40 GWp in the PV sector. The global trend for the PV sector is positive and different among countries due to local peculiarities and evolutions with national support policies.

The study found net present value, payback capital budget, and national support strategies; technical, environmental, economic and financial parameters to be the most important factors affecting PV system economic feasibility. The PV system profit in each country potentially based on the installation feature (configuration). The national support strategies to the PV sector still play a key role for most of the countries whereas Germany, Italy and

Spain present the most favourable conditions for a profitable installation of PV systems. Furthermore, the initial investment heavily affects the plant profitability of all the studied scenarios and returns to scale which significantly lead to the increased installed power plant. However, the high rated power plants generally outperform the smaller ones (Bortolini et al., 2013).

The theory of innovation found the attitude towards the decision to accept or reject implementation which starts from the decision to confirmation with the following stages: Knowledge exposure to the understanding of how it functions (e.g. the technology) through media (TV, Newspaper, radio, handbills, colleagues, study/research, internet and training (Lor, 2015). The persuasion can be favourable or unfavourable attitude towards innovation where people become more knowledgeable about the technology cost, users review, features and keen interest on how it works. The decision based on weighing the benefits, cost, trade-off advantage and disadvantages. The implementation considers more information about the technology with the technical evaluation in meeting expectations to enhance usage. The confirmation proves integration of the technology seeks reinforcement through innovation decision actions.

Payback period is related to cash inflows and outflows, timing and investment. The small business capital often with budgeting decisions relies heavily on payback period as a criterion (Encyclopaedia, 2016b; Bhandari, 1986). However, investment costs that recover soon/quickly enable funds available for further use. The shorter payback time is less risky compared to longer payback with greater risk (Schmidt, 2002). It is a method for appraising investment proposals that calculates the time taken for net cash-flows to payback and a measure of risk (Encyclopaedia, 2016a). For example, a company can undertake no major expenditure that couldn't pay itself at least for 3 years (Schmidt, 2016).

The dramatic growth of PV systems in the last century generated the need for sophisticated tools, the mathematical models to assess PV systems electricity generation capacity and economic benefit. For example, HOMER, Energy Plus, RET Screen and others are tools that have a similar basis for determining the amount of electricity generation in a given area for a

given technology (EPIA, 2011). The similarity includes meteorological components such as solar radiation, wind speed, monthly and yearly generation, temperature and number of hours of daylight. Across the globe, all models calculate the amount of energy generated to determine the economic feasibility of the system in use by the majority of planners and academic institutions.

Solar Micro-Grids according to Reja report, developing rural market offers the possibility of providing improved electricity services within a much larger share. For example, the solar micro-grids that recently emerged provide many features for solar household systems (SHSs) in India. This effectively can eliminate the possibility of individual system theft and greatly reduce the system maintenance burden for the subscribers (Amatys, 2015). Scaling up solar PV main problem engages a sustainable process for socio-economic development due to a vicious circle of energy poverty in developing countries. However, energy services must be available, accessible and affordable in breaking the circle, technologists and entrepreneurs use design, manufacturing and business knowledge to address paying attention to solar applications (Paulo, 2008). The programs to support serious efforts need by the developed country's governments and international community supports to develop and commercialize novel solar applications at all scale (Anderson and Ahmed, 1995).

The study reported that UNCED Agenda 21 held 14 June 1992, requested the International Community's comprehensive programme for action in achieving global environmental improvement by the government's development agencies, UN, and independent sector groups. In 1992, UNCED highlighted the need to promote greater awareness and wider application of indigenous knowledge (Morin-Labatut and Akhtar, 1992) in conjunction with Rio de Janeiro Declaration on the environment including development for sustainable management of ecosystems during UN conference at Earth summit (e.g. forests) (Mackay and Probert, 1995).

According to UN report, countries are mandated with 17 set goals: no poverty; affordable and clean energy; climate action; zero hunger; decent work and economic growth; life below water (i.e. ecosystem/fish). It also includes good health and well-being; industry innovation

and infrastructure; life on land; quality education; reduced inequalities; peace justice and strong institutions; gender equality; sustainable cities and communities; partnership goals; clean water and sanitation; responsible consumption and production. This new sustainable development agenda for all is helping to end poverty, protect the planet and ensure prosperity with specific targets to be achieved by 2030 (Meara et al., 2015). In addition, everyone needs to play a part such as the government, private sector, civil society and people in reaching these goals toward a sustainable future.

Solar power is revealed to become the cheapest form of electricity in many regions of the world and expected future annual sunshine power cost to become 4-6 ct/ kWh by 2025 and 2-4 ct/kWh by 2050. The financial and regulatory environments remain the key to reducing the global market cost of hardware source irrespective of the local conditions significantly in the future. In addition, inadequate regulatory regimes increase the cost of power to 50 percent through higher cost of finance whereas the better local solar resource can over-compensate the effect. In most scenarios, global/regional power system modelling for future domestic usage (PVPS, 2016) foresees only a small contribution of solar power (Johannes et al., 2015). Solar energy is revealed to play a significant role in expansion plans for the developing country utilities notwithstanding the high initial cost and intermittency nature of PV system due to starving low-cost baseload capacity (Schmalensee, 2015a).

Solar energy with PV technologies globally and significantly is used for transportations, electricity generation, and storage and business entrepreneur by world countries. For example, Morocco has commenced two solar plants for CSP and PV systems with an 800MW capacity (Yala; Palestine and Masen, 2017). In East-Africa, solar entrepreneur drives east-African women business to flow in Tanzania at Bunambiyu in Shinyanga remote village using solar power lantern light for sewing customers' cloth when darkness falls and ordinarily, the tailoring shop would have closed (PV.tv, 2017). In the UK, a magnificent sun-powered luxury yacht run solely on solar power without the need of stopping for days to refuel with unlimited potential range indefinitely in seas sail (Finance, 2017).

2.4 Policy Aspect

The governments found promoting RE as a key component to combat climate change, which is based on price condition, and solar energy system deployment might not be significant without major policy incentives. The renewables rapid growth depends on policy support in most markets, and policies to promote access to non-polluting and sustainable sources of energy have great potential to improve public health and mitigate climate disruption. In addition, the barriers for change include vested interests, political inertia, inability to take meaningful action, profound global inequalities, weak technology-transfer mechanisms and knowledge gaps which needed an address and transform the global markets (Haines et al., 2007).

2.4.1 Government Perspective Instruments

Many governments introduced incentive schemes to attract investment in new technologies for electricity. Millions of populations are without electricity access in Africa and Eastern Europe/Eurasia. According to World Bank report, RETs wholesale and retail levels are yet competitive to conventional energy commodities and a large number of governments decided to increase solar energy development through a range of instruments including fiscal, regulatory, market and others (World Bank , 2011). In 2015, the developed and developing countries launched energy and climate strategies during major economic forum (MEF) to help political leadership generate resources necessary to achieve a successful outcome from annual UN climate negotiations to increase the supply of clean energy and for cutting GHG emissions. The participated countries include Australia, Brazil, Canada, China, the European Union, France, Germany, India, Indonesia, Italy, Japan, Korea, Mexico, Russia, South Africa, United Kingdom, and the United States.

In the absence of a more comprehensive policy, the rationale is to encourage the use of low-carbon technology for mitigating GHGs carbon tax without cost-effective incentives for mitigation choices. The investment's expansion helps to drive down costs of technologies through economies of scale and learning-by-doing (Nerlove and Arrow, 1962). It is a powerful

force to stimulate economic development and subsidize small-scale PV off-grid and other RES in bringing electricity to remote-poor areas. However, most developed and developing economies employed a range of policies and practices with varying degrees of success in overcoming the barriers. According to the report, the experiences led to enhanced approaches and goal setting to guarantee effective action on climate change (MEF, 2008).

RE solution is a key element for rural electrification roadmaps and the working programmes in Africa support local business creation, improve water irrigation and sanitation systems including new opportunities for public health, education, and gender equality. It is vital to develop young rural electrification markets to achieve the global challenge of universal clean, reliable and sustainable electricity services in the current international policy agenda. The Sustainable Energy for All (SE4ALL) is a strong drive for energy access and one of the main priorities for development agenda at the local and international level (Wiemann; Ling, 2014 and Scott and Seth, 2012).

The promoted sustainable energy policies are to spur economic growth and environmental protection in reducing GHG emissions from climate change in a global context. The growth experienced energy-related CO2 emissions mainly due to 1.8 percent global economic improvement on energy intensity and the trend is bolstered by gains from energy efficiency, which expanded worldwide use of cleaner energy sources mostly renewables (IEA, 2015).

Nigerian federal government in 1998 initiated efforts to end NEPA's monopoly for electricity generation, transmission and distribution sales due to the problems identified, adopted a holistic approach to restructuring electricity sector by privatizing NEPA in 2000. The Reform Act established NERC with some responsibilities due to problems facing the electricity sector. The Nigerian government and its agencies require promoting RE policies for electricity supply to meet energy demand in the country. Figure 2-21 represents the global renewable energy deployment for electricity generation.

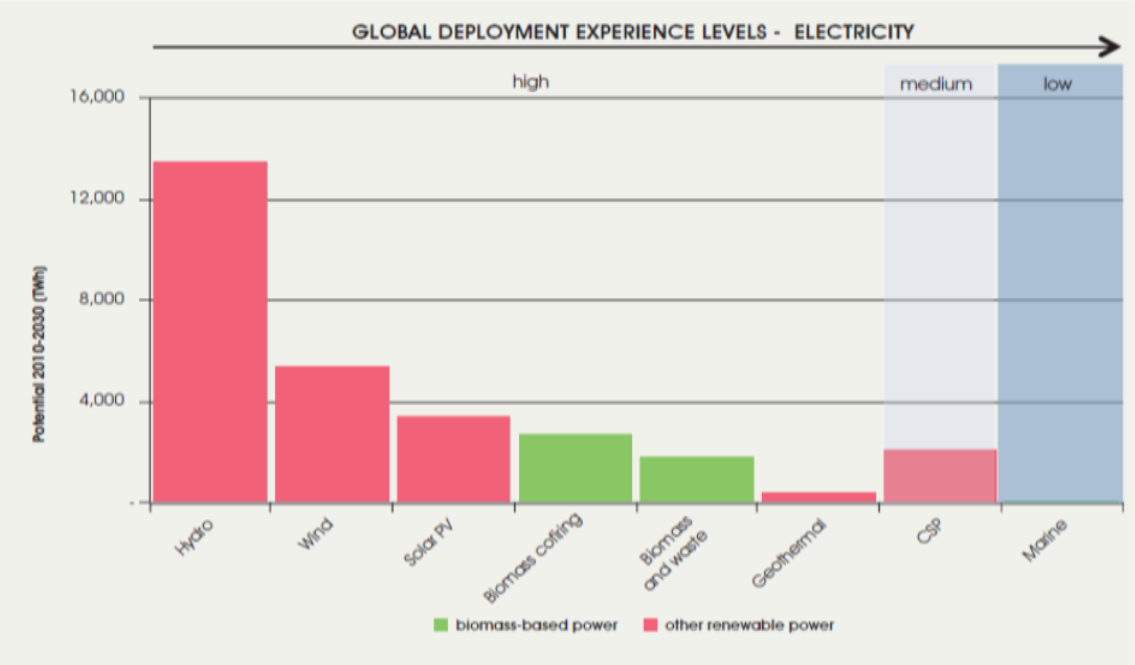


Figure 2-21: Global renewable energy deployment in electricity generation.

The UK government proposed more than 50 percent PV installation reduction for generation tariff due to the consultation on a comprehensive review of solar PV tariffs. In April 2010, the introduction of FITs rapidly increased deployment of PV technologies for small scale. The policies centrally offer guaranteed prices for fixed periods to enable a greater number of investors. For instance, Cornwall in the UK proposed and performed two real-life installations on domestic PV system under 4 kW to determine the impact on FIT cuts and the possibility of a healthy return on Investment (ROI). The result shows future installations focus on offsetting electricity from the national grid with the long-term push for true sustainability than subsidized schemes. The profitability of future installations features with in-service and end-of-service considerations such as FIT, module efficiencies and end-of-life disposal associated with implications of costs (Cherrington et al., 2013).

The different EU-states implementation increase share of RET and the ambitious targets increasingly recognized social acceptance that forms the factor constraining expansion of implementation and use (Moula et al., 2013). In today's world, different circumstances exist between developed and developing countries. The developed part of the world has specifically formulated case studies including general frameworks for applications. In

developing countries, the existing challenges include economic, social, security and political stability. However, some barriers and drivers of renewable technologies distribution are the same in the world (Eronini, 2014). In the developed countries, instruments used are feed-in tariffs, direct subsidies, tax credits and the instruments for solar energy development primarily are investment grants and soft loan payments.

In the developing countries, the instruments mostly used include public investment, feed-in tariff, financing facilitation, investment tax credit, net metering and clean development mechanism (CDM). However, CDM is the most implemented mechanism that supported and promoted solar energy development. The key instruments generally employed in developed and developing countries include feed-in-tariffs, investment tax credits, direct subsidies, favourable financing facilitation, mandatory access and purchase, renewable energy portfolio standards (RPS), net-metering, public investment, and other government regulatory provisions (D'Agostino et al., 2011).

2.4.1.1 Feed-in Tariff (FITs)

FITs is a premium payment for the new and renewable energy technologies for electricity generation relatively expensive but competitive with conventional technologies because the cost of electricity-produced comes with reasonable ROI to the generator and reduces the potential investors risk for long-term investments. In early 2010, more than 75 authorities implemented this policy around the world such as UK, Australia, EU countries, Brazil, Canada, China, Iran, Israel, the Republic of Korea, Singapore, South Africa, Switzerland, and the Canadian Province of Ontario with some states in the United States (REN21, 2010). The policies implemented covered all the solar energy technology types from small residential rooftop PV to large-scale CSP plants. FITs have been the key driver for the recent growth of solar power grid-connected. Studies with several concerns identified that FITs put upward pressure on electricity rates and significantly scales up the technology's deployment in the medium term in the USA.

The changing payment levels increase investors, political pressure, uncertainties and holding down the increased payments by overall market risk. For example, Germany had political

pressure to cap policy or speed the rate of decline (Frondel and Schmidt, 2008). This to an extent posed a challenge for balancing tariff purpose and increasing utilization of beneficiary technologies which fiscal cost authorities considered appropriate tariff adjustments (Cory et al., 2009). The FIT policies guaranteed grid interconnection regardless of grid location and increased transmission costs for far sited projects from load centres or existing transmission/distribution lines (Couture and Cory, 2009). Periodical studies revealed that FIT policies add an adjustment to change of technology costs and market prices over time (Couture and Gagnon, 2010).

The UK government April 2002 supported the development of renewable energy and the main mechanisms that encourage the uptake were FITs and Regulation Obligation (RO) (Wicks, 2009; DECC, 2009). In 2015, the electricity suppliers licensed to source for specific annual electricity supply with a 3 percent increase target of renewable sources in 2003, 10 percent in 2010 and 15 percent (Muhammad-Sukki et al., 2013). The generators of renewable electricity received renewable obligation certificates for each MW of electricity generated or sale to suppliers to fulfil the obligation (UK Renewable and DECC, 2010). In 2010, the introduction of 2009 EU renewable directives made 15 percent target progress in the UK. The energy consumptions from renewable sources with 4.2 percent and 5.2 percent between 2012 and 2013. The renewable electricity experienced significant growth contributions along with renewable heating and transportation rise. The UK accounted for 5.41 percent from 2013-2014; onshore wind lead the technology with (38) percent capacity at end of 2013 and offshore wind (19) per cent, solar photovoltaics (14) per cent and hydro (8.6) per cent, bioenergy represented (20) percent capacity, Biomass (9.9) percent as main component plant and landfill gas 5.3 percent in the interim (DECC, 2013). Figure 2-22 shows UK industry upside potential and downside risks for renewables deployment.

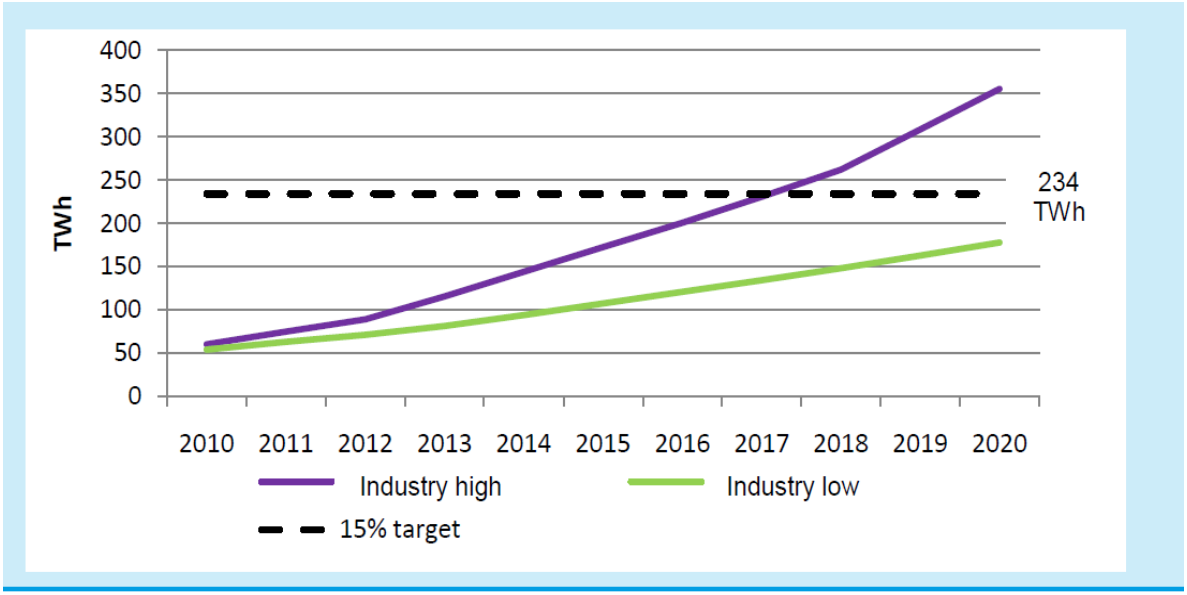


Figure 2-22: UK Industry Scenarios.

The UK GHGs mitigation policies and activities help support renewable energy development with various incentives. The industrialized countries designed mandates that triggered GHG mitigation to promote solar energy (McCrone et al., 2012) with grid-connected solar PV and solar thermal heating examples. They provided strong growth in solar energy markets driven by the implementation of sustained policy instruments in Europe, the United States and some of the developing countries. The PV and CSP for electric and direct heating applications increased solar power supplies (Young, 2011). According to the report, climate change can be limited to around 1 percent of global GDP each year and benefits for strong and early action far outweigh economic costs of not acting (Nicholas, 2007).

The European Union (EU) between 2001 and 2004, adopted a renewable energy policy framework for the promotion of electricity, heating, and cooling from renewable sources. The study found FIT policies as the most effective policy instrument used to promote solar, wind and biogas technologies among EU renewable energy (CEC, 2008) and overcome the barriers that turned European countries into world leaders of the renewables sector. According to CTI report, FIT played a major role in boosting solar energy in Germany and Italy in 2013 and currently the world leading solar energy market growth. It promotes the fastest expansion of renewable electric power at the lowest cost in spreading costs among all electric utility

customers (Mendonça and Jacobs, 2009). The sound benefits of FITs to RE-installations happened to be long-term planning certainty for investors/operators. German FIT payments are specific to project size in terms of technology and scale (Mendonca et al., 2009). The freestanding systems receive low FIT rate and the larger projects obtain lower FIT rate due to economies of scale (Sösemann, 2007).

The Germany and Spain rapid market growths for solar energy attributed to guaranteed FIT, attractive ROI, regulatory requirements with 100 percent mandate for grid access and power purchase (Jenner et al., 2013). The U.S federal and state incentives with regulatory mechanisms such as RPS received credits for rapid solar energy deployment. Studies claimed that FIT decrease could drive investors away from solar energy markets being the primary basis for investor's confidence (Kreycik et al., 2011 and Elliston et al., 2010). It attracted premium payment for generating electricity through RETs in developing countries with examples in China and India (Teodorescu et al., 2011; EPIA, 2011 and CERC, 2010), Republic of Korea, Singapore, South Africa, Tanzania (Cossen, 2013), Kenya (PV Magazine, 2013) and Philippines (Hans, 2013). In developing countries, policy incentives drive the PV market with increasing momentum.

2.4.1.2 Investment Tax Credit

Several governments around the world implemented different types of investment tax credits to support solar energy. For example, investment tax credits cost approximately GBP623 (US$907 million) over 10 years in the United States. The U.S federal government provided 30 percent investment tax credit for solar energy business expenditure on the electricity generated equipment for heating/cooling and hybrid solar lighting systems (Chirinko and Wilson, 2008). The investment tax credit through depreciation deductions accelerated the cost-recovery system. The investment tax credit through depreciation deductions accelerated the cost-recovery system. The American Recovery and Reinvestment Act in February 2009 provided 50% bonus depreciation that implemented 100% bonus depreciation between 2008 and 2010. After September 2010, solar energy technologies implemented and still in service.

The residential owners/households in the U.S claimed 30% qualified expenditures credit on solar energy equipment (e.g. labour costs for onsite preparation and assembly of original system installation). The 30 percent federal tax credits provided significant leverage to solar energy development and state governments supplement federal tax incentives with their own programs. In 2006, APS project installed 1MW CSP (i.e. Sugarno project). In 2007, Boulder City of Nevada installed 64 MW of CSP parabolic trough that largely benefited from the federal tax credit scheme (Gordon and Hines, 2002 and Canada, 2004). In 2016, the federal tax credit exceeded tax liability and excess amount carried forward to the succeeding taxable year. The developing countries with tax policy implementation in Bangladesh and India (Banerjee & Duflo, 2014 and ESMAP, 2011).

2.4.1.3 Subsidies

Direct subsidies and tax credits in most countries are the primary instruments used to support solar energy development in the form of investment grants/capacity payments soft loans (i.e. interest subsidies or production-based payments). The Spanish government in 2000 launched a program that provided grants between GBP218/m2 and GBP275/m2 (€240.40/m2 and €310.35/m2) for solar thermal technologies. Rebate under California Solar Initiative (CSI) presented a subsidy scheme/program for solar energy in California. In 2017, CSI program about GBP2.3 equivalent to ($3.3 billion) supported 3,000 MW PV development similar to EPBB rebates known as a performance-based incentive. The location and other factors are taken into account are Buy-Down level based on expected system performance. The smaller and 50 kW systems with better-projected system performance receive higher rebate benefit. The level of Buy-Down starts from GBP1.9/watt ($2.80/watt) for the private sector with federal tax credit without public sector and NPOs beneficiary. However, the rate declines with certain blocks of capacity and over 50 kW system eligible for five-year PBI similar to the declined EPBBs.

Private sector production incentives offered GBP0.27/kWh and GBP0.34/kWh for non-profit and public organizations preliminary results indicated ambitious target set under CSI reach (CPUC, 2011). In 2011, the incentive for residential sector progressed more impressively than

the non-residential sector with installed 506 MW and 403 MW pending. The previous experience and program indicated some troubles in achieving 29 targets without program adjustments (Harris and Moynahan, 2007). However, the increasing rate of new solar installation since 2008 has put back the program on track due to induced efforts to reduce PV costs.

In 2008, according to annual program projected for Go Solar in California, CSI declined faster than 7 percent. The levels to sustain market growth in the future due to low incentive forced installation costs low enough to supply attractive systems to customers (Hering, 2008). The tax rebates system in New Jersey cost GBP344 ($500 million) annually and only 10 kW of smaller systems qualify for the rebates whereas more than 10 kW larger systems compete for tradable solar renewable energy credit market enables the state government to reach the goal and avoid high costs (Winka, 2006).

2.4.1.4 Renewable Energy Portfolio Standard (RPS)

The RPS requires electricity suppliers (e.g. utilities, distributors) to have a certain percentage of supply from RE source at national, state/provincial levels and many developed countries set a penetration target for RE total electricity supply mix. This standard supplement the trading regime and utilities with limited renewable electricity content for overall supply portfolio. The high cost of RE development in Europe cannot meet the obligation of buying certificates from those with higher renewable electricity content through Tradable Green Certificate (TGC) schemes. However, 31 out of 50 states in U.S and Hawaii introduced 10-40 percent RPS by 2030 and several states created RPS with specific standards for solar energy.

New Jersey required 6.8 percent of electricity sold in the state from renewable and 0.16 percent from solar PV systems in 2008. Solar state electric facilities reported to generate 2,518 GWh by 2021 and 5,316 GWh by 2026 (Bird et al., 2011). This created a stand-alone market for solar RE credits (SRECs) and capped market price with the use of “alternative compliance payment” (ACP) for about GBP206/MWh ($300/MWh). Nevada’s RPS mandated 20 percent of the state electricity to come from a renewable resource and 5 percent from

solar power in 2015 (NREL, 2012 and 2008). The California RPS substantially contributed to the realization of large scale CSP plants of 500 MW project in the Imperial Valley.

2.4.1.5 Public Investment

The Federal Energy Policy Act under the public sector in the U.S established Clean Renewable Energy Bonds (CREBs) as a financing mechanism for renewable energy projects. The legislation between 1 January 2006 and 31 December 2007 issued and allocated GBP540 ($800 million) tax credit bonds. The Energy Improvement and Extension Act allocated ($800 million) new CREBs in 2008. The American through Recovery and Reinvestment Act allocated additional GBP1.09 equivalent to ($1.6) billion for new CREBs by increasing size of new CREB with GBP1.65 ($2.4 billion) allocation in 2009. The treasury department reported allocation of GBP1.5 ($2.2 billion) new CREBs for 805 projects in October 2009 across the country.

The CREBs for electricity issued in cooperatives, government entities, states, cities, counties, territories including the Indian tribal governments/any political subdivision and certain lenders. The Department of Agriculture established Rural Energy for America Program (REAP) to provide grants and loan guarantee for RE system investments, energy efficiency improvements and RE feasibility studies in the U.S (Willis et al., 2006). About GBP175, equivalent to ($255 million) funding was allocated under this program between 2009 and 2012 and the kind of investment used in financing RE by the public sector in developing countries. This is the main driver of solar energy development in China (Ma, 2004) and Philippines (WWF, 2008).

2.4.1.6 Net Metering

Net metering allows households and commercial establishments to sell excess electricity generated from solar systems to the grid. The countries that implemented this incentive are Australia, Canada and the United States with some European countries such as Denmark, Italy, and Spain. For example, the net metering programs in the USA are limited to RE facilities and up to 10 kW and 1 MW in California. In Prince Edward Island, up to 100 kW and 500 kW at Ontario in Canada. In addition, most other programs require only customer's total annual

consumption purchases without paying for any electricity generated or retail tariff amount received for the output. This program was implemented in Kenya (Meza, 2013) and Ghana (Bruckner, 2013) among developing countries in Africa.

2.4.1.7 Clean Development Mechanism (CDM)

The (UNEP, 2011) and (Curnow, 2006) found that CDM under Kyoto Protocol for climate change regime is the main vehicle for solar energy promotion in the developing countries of which industrialized countries purchase GHG reductions for projects in developing countries with cheaper price in reducing GHG emissions than industrialized countries. In July 2011, 6,416 projects were registered under CDM projects and about 109 projects under solar energy with an annual emission reduction about 3,570,000 tons of CO_2 and 89 projects in China, South Korea and India locations (Das, 2011). Solar energy projects accounted for very small fraction (< 1 percent) of total emission reductions for the total registered CDM projects (Burian and Arens, 2014).

2.4.1.8 Other Government Regulatory Provision

The governments of many countries introduced laws mandating transmission companies and electric utilities to provide transmission or purchase electricity generated from RETs including solar PV systems. The regulation mandated installation of solar thermal systems and the main driver for solar thermal development applications in Spain, Israel, China, Germany, etc. For example, Germany guaranteed all RE generators to have priority access to the grid. GOC (2005) reported that electric utilities are mandated to purchase 100 percent of the grid-connected PV system's output regardless of whether or not the systems are customer-sited.

2.4.2 National Energy Policy Framework

Nigeria Energy Policy is established to remove key barriers on RE and EE frameworks over other forms of energy including economic, regulatory and institutional issues. The drafted policy document in addressing diverse issues recognized the multi-dimensional nature of energy which includes RE supply and utilization; pricing and financing; legislation, regulation,

and standard. It aims to provide optimal utilization of the national energy resources for sustainable development that involves private sector active participation. Oyedepo's found that the Nigerian government has a major role to play in creating enabling environment in meeting energy challenges facing the country (Oyedepo, 2012b; IEA, 2011b).

Nigeria policy objectives and strategies fundamentally have demonstrated a crucial nature of energy for national goal development and implementation (Oyedepo, 2012a). Policy implementation for local RES is for encouraging and enhancing the country's electricity supply capacity; the policy strategies for promoting RES contribute towards electricity generation. The main goal for electricity objectives is to accomplish full deregulation of the electricity supply industry (ESI) to ensure Nigeria electricity supply industry meet the citizen's needs. The current and future electricity demands to modernize and expand coverage, support national economy and social development throughout the country with neighbouring countries relationship in 21st century. The priority to create efficient market structures within clear regulatory frameworks will encourage more competitive markets for electricity generation, to attract private investors and to ensure sound development system and efficient demand in an economically viable manner (Okolobah and Ismail, 2013).

The National energy development with a comprehensive integrated and well-informed RE and energy efficiency (EE) sector plans and programmes is to ensure effective development for diversified energy resources option use to achieve national energy security as well as energy efficient delivery system for optimal energy resource mix. To establish an appropriate financing mechanism to support private investment in the sub-sectors and ensure the development of nation's RE and EE resources with effective coordination and collaboration among all players of RE and EE activities in Nigeria (NERC, 2015 and NEP, 2003). The FMOP, FME, and ECN are established departments and agencies (MDA) with the responsibility of creating awareness to investors and consumers due to economic potential of RESs outside hydro source of energy. NERC, a government agency recognized RES potential and encouraged IPPs to carry out feasibility studies for RE generation while proposed FITs for electricity generation for RES developers based on PPAs data collection with off-taker negotiation (FMOP; NERC, 2014 and NERC, 2013).

2.4.2.1 Nigeria Electricity Sector Reform

Nigerian government holistic approach in 2000, for restructuring power sector reform and privatization of business units (Oyeneye, 2004). The constituted National Electric Power Policy (NEPP) established in 2001 includes the Electric Power Sector Reform Act (EPSRA) under fundamental power sector reforms framework. The reform acted aptly as a foundation to restructure the power sector which evolved NEPP to enable private companies to participate in the generation, transmission, and distribution of electricity (Okolobah and Ismail, 2013). The reform acted with two broad missions based on service delivery for completion of new NIPP projects and up-stream, mid and down-stream recovery of installed capacities.

The legal framework includes the Electricity Corporation of Nigeria Ordinance in 1950. Niger Dam Authority Act in 1962. The Cap 256 for National Electric Power Authority Act. The 1990 amended Laws of Federation of Nigeria (LFN). The LFN amended Cap 106 of the Electricity Act. The 2004 LFN C23, LFN P38 Cap for Public Enterprises (Privatisation and Commercialisation) Act. The LFN E12 Cap on Environmental Impact Assessment Act (EIA). The 1999 CAP Constitution of FRN; 2005 No. 6 Electric Power Sector Reform Act; 2007 No. 25 National Environmental Standards and Regulations Enforcement Agency (Establishment) Act. The 2006 SC Order No. 1 for Electric Power Sector Reform (Transfer of Assets, Employees, Liabilities, Rights, and Obligations); National Domestic Gas Supply and Pricing Regulations, National Domestic Gas Supply and Pricing Policy and 2010 Roadmap for Power Sector Reform (Ojo, 2017; Oni, 2013 and Okeke, 2015).

The overall broad policy formulation is FMOP, NERC, and others. The NERC carries out regulation and marketing of electric/power sector. The two agencies that drive the power sector reform and liberalization are BPE and NCP in Nigeria (Okoro and Chikuni, 2007). The NELMC, a special trade bulk purchase resales license to manage existing PPAs with new procurement of power transition. The EMSL carrying out consulting services provide sharing services such as logistics and meter testing. The NPTI provides world-class training to support utility workforce. The NBET bulk trader solves major problems of bankability of electricity projects. The TCN handles transmission of electricity across Nigeria. The CBN for revenue

shortfall follows pre-transition sage and sets up stabilization facility and conditional disbursements among other things with the current tariff rate migration from MYTO2 to MYTO 2.1 for more reflective cost (Newspaper, 2015 and Salami & Elebiju, 2004).

Nigeria experienced low per capita consumption with an average generation of 3,800 MW prior to 2005 EPSRA reforms. The reforms moved the power sector from the state of monopoly to a competitive electricity market. Nigeria has many successes from power sector through Pre-2010 reform. NERC licensed more than 20,000 MW power few years ago for grid but the licenses do not make real progress in executing the projects due to the inconsistent policy direction of the electricity supply industry. The past government policy decisions were based on political/administrative interest than efficient resource allocation that lacks strategy framework for sustainable development. The cost recovery is necessary for economic development but the country's strategic energy policy yet to be implemented (Okolobah and Ismail, 2013).

In May 2010, Goodluck Jonathan established the Presidential roadmap for power with earnest resumption of stalled NIPP program, the Presidential Task Force and Presidential Action Committee based on power inauguration. Nigeria Power Sector Reform launched a Road map with reconstitution of NERC Board in August 2010 (McKinley, 2014). The implementation started when policies moved into action from 2010-2012 with solid progress. In 2011, NERC effectively was re-established, the Bulk trader, NELMCO, NAPTIN, operational and privatization process. The operational management contractor for TCN also established while PHCN winds down in process. The World Bank supported PPAs with MOU for equity investment in power generation projects with General Electric, Siemens, Daewoo, Eletrobras and cost-reflective tariffs for renewables Feed-in tariff under MYTO II (NERC, 2016). In August 2012, the Manitoba Hydro International took over TSP with 3-5 years' management contract agreement (McKinley, 2014 and Ince et al., 2010). Table 2-4 represents the Key players reform functions and strategy ownership and control.

Table 2-4: Key Players Reform Functions and Strategy Ownership and Control

Key Players	Functions
Presidential Task Force	Drives the reforms by uniting different stakeholders, monitor plans and implement projects
Bureau of Public Enterprise (BPE)	Drives privatization of the government owned enterprise in the sector like Gencos and Discos
Nigerian Electricity Regulatory Commission (NERC)	Regulates the sector, issue licenses and set tariffs
Nigerian Electricity Liability Management Company (NELMCO)	Manages legacy liabilities and stranded assets
National Power Training Institute of Nigeria	Provides training required to support the power sector
Power Consumer Assistance Fund (POLAF)	Subsidizes electricity for consumers

Current Configuration

	Gas Production	Gas Transmission	Power Production	Power Transmission	Power Distribution
Ownership	Mixed	FGN	Largely FGN	FGN	FGN
Operational Control	Largely Private	FGN	Largely FGN	FGN	FGN

Required Configuration

	Gas Production	Gas Transmission	Power Production	Power Transmission	Power Distribution
Ownership	Mixed	Mixed	Largely Private	FGN	Fully Private
Operational Control	Largely Private	Largely Private	Fully Private	Fully Private	Fully Private

(Sources: NERC and McKinley, 2014).

Privatization commenced in December following successor companies on current reform when NEPA become dissolution to PHCN and 18 successor companies created such as six generation companies (Gencos), 11 distribution companies (Discos) and the national power transmission company (TCN). The FGN retained ownership of TCN under Manitoba Hydro

International management, wholly owned subsidiary of the electric Canadian company and natural gas utilities and handed the privatized generation and distribution assets to private owners. The reform brought liberalization and commercialization of the national utility company. In 2013, the second phase of the privatization process commenced to sale 10 government-owned independent power projects called NIPP (Newspaper, 2015). The process is a major transition from vertical integrated public-owned electricity network to large private-owned electricity network with different separation of electricity segments. The regulatory agencies are the Rural Electrification Agency, Fund, and Electric Power Consumer Assistance Fund.

The electric power sector reform bill with other key components mandated NERC the responsibility to regulate tariffs and quality service effectively; to oversees the industry with anti-competitive behaviour and licensed electricity companies for mergers and acquisitions; institutional and the enforcement requirement for regulatory regime; licensing generation Company's system operator, transmission services, distribution companies and trading companies. The legislative authority has special conditions for licenses while the provision is related to public policy interest to fuel supply on environmental laws, energy conservation, and management of scarce natural resources. The promotion of efficient energy and RE with the publication of reports and statistics and the legal basis is necessary for establishing, changing, enforcing and regulating technical rules with market rules and standards (Newspaper, 2015).

MDAs (an inter-ministerial committee of stakeholders) constituted and mandated RE and EE policies to attract investment in the electricity sector (Nebo, 2014) and developed some documents to pursue RE ventures. The government encouraging participation of private sector in power sector granted incentives with five years tax exemptions and customs duty for only importation of power plants/equipment and any other assistance to IPPs to fulfil all technical and commercial requirements towards building power plants (Naibbi and Tukur, 2017) and this is yet implemented to commence the development.

The Public-Private Partnership (PPP) needs to encourage a concession plan for distribution sector towards privatization to enables the private sector to create demand and allow IPPs to enter into Bi-lateral agreements with concessionaires. The involvement of private investor's sale or concession of NIPPs ensures fixing and completion of the projects. The government transfers or leases all NIPPs to the private investors for efficient management. The implementation involves construction and operation of plants to meet present-day realities of selling electricity to identify areas of need and allow quick generation of power to relieve present pressure on national grid as well as to remove the burden of worrying and stranded assets and government investments.

The FGN executed gas pricing regulation enshrined in Gas Master Plan for right pricing promptly to help aggregation of prices while putting in place incentives for private developers. To intensify Pre-paid metering efforts, provide prepaid meters to consumers to ensure judicious use of power and cut down on losses incurred for unsettled bills. Reducing the number of illegal connections and making consumers pay for electricity consumed is necessary. Strengthening distributed generation from the centrally controlled system for Nigeria grid system increases distribution efficiency and greatly reduces losses incurred from long distance distribution (Asaju and Akume, 2010).

2.4.2.2 International Donors and NGOs Participation

The federal government committed to mobilizing resources, the international cooperation towards RE development for sustainability in Nigeria, promotes financing of a grant from government agencies and independent foundations. The following objectives are to ensure international donors and NGOs active interest in developing RE in a well-coordinated manner, to ensure RE programs deployed for the desired impact that yield results by NGOs, to ensure Nigeria participates in RE programs rolled-out by NGOs with RE competence to drive refinancing. The FMOP strategies include engaging all NGOs operating in Nigerian RE sector with the intention of having them articulate annual RE program targets and continually ensure close cooperation during RE development projects. The government encourages NGOs to support RE sub-sector by producing competence building tools and capacity building

assessment and training. In addition, the NGOs, development partners, civil society and donors work with FMOP to fund RE projects demonstration and feasibility studies through the provision of grants and donations.

Power Africa supported the development of the energy sector through credit enhancement, grants, and technical assistance and investment promotion efforts. The measures include mobilizing affordable and long term financing to support capital and operational expenditure requirements for generation and distribution companies to accelerate electricity market development. In addition, Power Africa has helped to advance major infrastructure investments, promote U.S technological solutions and strengthen the Nigerian national systems through technical assistance and national organizations for improving electricity procurement and regulatory functions. They delivered power based on lending across a variety of recipients including agro-processors, healthcare facilities and households willing to retrofit facilities and companies willing to establish and maintain plants to generates clean energy (Obama, 2015).

Power Africa produced by U.S government agencies has provided support for trade missions engaging American companies interested in investment opportunities in Nigeria. The Power Africa Initiative has provided political risk insurance for project loans and risk mitigation efforts coordination with FGN. The agencies have awarded seven times GBP68, 729 ($100,000) grants to entrepreneurs for innovative and the off-grid energy projects in partnership with General Electric (U.S-African Development Foundation) and others. However, the partners for Power Africa include Heirs Holding, UBA Capital, General Electric, Africa Finance Corporation, Africa Development Bank, Standard Chartered Bank, Symbion Power, Africa Infrastructure Investment Managers, Nigeria Solar Capital Partners, America Capital Energy, and Infrastructure and World Bank in Nigeria (Africa, 2016).

The Power Africa goal is to increase electricity access by adding more than 30,000 MW of cleaner and more efficient electricity generation capacity to 60 million new home and business connections across sub-Saharan Africa. They work beyond grid sub-initiative to expand rural electrification access for small-scale off-grid technology including the New

Operating Model and mobilizing partnerships and investments in energy and the unique private sector. The expertise is drawn by power Africa with abilities of 12 U.S government agencies, the World Bank Group, the African Development Bank, the Government of Sweden, African governments and private sector partners. The “Toolbox” approach offers a range of resources and tools to advance key projects on electricity grid by leveraging U.S. expertise in energy technology and regulatory reform with the U.S government and private sector financial resources. Power Africa has helped to drive quick-impact interventions and policy reforms to push sustainable energy development (USAID, 2015) and Leverage Partnerships have increased access to power in Sub-Saharan Africa.

The U.S government on Power Africa initiative aims to increase the number of people with power access in sub-Saharan Africa. For example, the U.S ex-president worked with African governments and private sector partners to remove barriers that impede sustainable energy development in sub-Saharan Africa to unlock substantial wind, solar, hydropower, natural gas, biomass and geothermal resources in the continent (Obama, 2015). Power Africa has also leveraged more than GBP14 ($20 billion) commitments to the private sector on the off-grid new projects in sub-Saharan Africa. The U.S. government committed to providing more than GBP4.8 ($7 billion) financial support, loan guarantees and technical support. The U.S government committed to Power Africa have three dollars’ leverages in private sector investment commitments. In addition, the African Development Bank, the World Bank Group and the Swedish government who collectively committed additional GBP6 ($9 billion) in support of Power Africa (USAID, 2015).

2.4.2.3 Local-Indigenous and Foreign Banks Participation

Nigerian government alone cannot continue to provide major finance for developing RE sub-sector because of other computing needs to make private sector participation necessary and imperative in developing RE sector through indigenous participation to attract foreign investments. The efforts through lending to RE projects sensitize RE and incentivize investments to attract domestic banking sector participation. In late 2014, the Power Africa

in partnership with Standard Chartered Bank to make critical lending available for privatized Discos and Gencos.

The government and NGOs played a dominant role in sub-sector with the presence of the private sector in investments and technological input including value-added mainly from foreign NGOs in energy sector activities. Government spending in the sector to optimize and encourage the ability of indigenous private sector and ordinary Nigerian citizens to participate and compete in the process helps to secure healthy development of RE sub-sector with a high level of local content and value added to maintain RE sub-sector activities.

The objectives of indigenous participation include ensuring effective participation of indigenous private sector in RE industry value chain with regional policy indication, to ensure broad-based participation of Nigerians in RE sub-sector investment opportunities, to achieve a high level of local content activities, to ensure socio-economic and healthy politics and secured RE sub-sector development. The Vision 2020 is an economic role plan to make Nigeria electricity industry become one of the most 20 developed and largest economy in the world by 2020 (Asaju and Akume, 2010). Electricity industry allows private sector participation in the sector through favourable platform with respect to cost-effective tariff structure for end-users and systematic withdrawal of subsidy (Oyedepo, 2012b).

The short-medium term targets (3-5 years) include ensuring generation, transmission, and distribution systems with efficient, safe and affordable marketing throughout the country. To ensure the power sector attracts private investment in Nigeria and Overseas and develop a transparent and effective regulatory framework for the power sector. To develop and enhance indigenous capacity in the electric power sector technology and to participate effectively in international power sector activities and promote electric power development in meeting the country's international obligations and derive maximum benefit from international cooperation in these areas. To ensure government divests interest in the state-owned entities and entrenches key principles in restructuring while privatized power sector, and to promote competition to meet growing demand through full liberalization in the electricity market (FMOP, 2014).

2.4.2.4 Off-grid and Grid-Connected Electricity

The 1999 Constitution mandated state governments to be responsible for the development of off-grid electrification and joint responsibilities with the federal government on Electricity Power Stations (EPS). The state role involves regulation of off-grid non-centrally dispatched electricity operations and wholly limited within state boundaries. The privatized electricity industry competing over monopoly transmission and distribution grids requires effective regulatory agency independent of the government for all companies operating in the industry (NBS, 2012a). However, Ministry of Power and Steel provided new electricity law for an independent regulatory body with the clear appointment and dismissal rules including a source of independent funding, appropriate checks, and balances to ensure the regulation operates in a fair transparent way and continue vertically to integrate systems without any imposed separation of functions or cross-ownership restrictions (NBS, 2012b). There are many small-scale less than 50 kW solar PV mini-grid and rooftop PV projects distributed across Nigeria to be built with small loans issued by Bank of Industry and other lenders (Paisner, 2016). The introduction of FITs and establishment of NBET a credible and creditworthy for off-taker of renewable power supported by World Bank (Oni, 2013).

The rural electrification policy options for on-grids, off-grid, mini-grid, and non-thermal renewable primarily to access expansion in a cost-effective manner and ensure close coordination of rural electrification expansion with economic development objectives. The states, local community's businesses are encouraged to develop and contribute financially to rural electrification. The independent rural electrification fund by rural electrification agency is established for developing both grid-connection and off-grid rural electrification.

The long-term target (5 years) include providing a new regulatory environment and sufficiently flexible taking into account new technological development with international trends in the power sector. To ensure electricity supply more reliable, economically efficient and equitable to effectively support the socio-economic development of the country, to provide universal access to electricity not necessarily through the grid, to ensure leadership

role in the development of proposed West African Power Pool for Nigerians (IRENA, 2016 and IRENA, 2013).

2.4.2.5 Nigeria FIT Initiatives

Renewables Incentive Analysis based on FITs is an instrument for promoting the generation of electricity from RES. It allows power producers to sell generated RE electricity to an off-taker at a pre-determined tariff for a given period. The Nigerian government interested in RE resources introduced two incentives namely the financial and fiscal RE funds under the umbrella of FIT to promote the development of RE and EE development: To ensure a sustainable way of meeting energy demand and limiting high initial costs and preventing energy market across the country. The financial incentives on demand side are subsidies and grants and fiscal incentives on the supply side are tax relief, levy tariff and duties (ECN, 2012; Emodi and Ebele, 2016). The 30% subsidies and grants for RE initial cost and EE facility are for communities, enterprises, and individuals with the projects interest (Emodi, 2016). They provide a free sponsor training programme for capacity development of communities and individuals with interest in RE production, operation, and maintenance of woodstoves improvement, more efficient biomass stoves and O&M of solar PV system installations and import of energy efficient products for appliances and equipment.

The fiscal incentives include producers/providers of RE and EE goods and services, the manufacturers, corporate importers and suppliers, providers of technical services and supports. It provides corporate organizations with thirty percent low-profit tax over the prevailing 50% rate for RE and EE ventures; tax holiday for a new company into RE and EE with a minimum of ten years' operation and reduction of import duties for RE materials, components and equipment's imported. RE devices with the components, enjoy free import duties. It also includes, zero PV modules, module sub-assembly and spares; solar batteries, inverters, charge controllers; solar water pumps and solar refrigerators; sub-assembly spare parts, zero solar thermal water heaters for selective surfaces and transparent insulation; zero biomass energy processing equipment/plants. In addition, EE appliances and equipment with

twenty (20%) capital allowance investment per year for the first four years as well as (19%) in the fifth year whereas government retains one percent (NREEEP and ECN, 2015).

The government provides fifty (50%) free interest capital relief to manufacturers for initial RE investment and energy efficient equipment devices/facilities based on production activities. Repayment schedule relief of 10%, 20%, 30% and 40% in 1st, 2nd, 3rd and 4th repayment years starts from the second year of production. The initial purchase taxes such as VAT for an individual, corporate and community consumers into RE and EE technologies is to be ignored. Income taxes and levies for individuals and corporate bodies who acquire their own cost of RE and EE technologies are limited to 10% minimum on the amount spend for RE and EE technologies under income tax/community levies by the government (FMOP and NREEEP, 2015).

2.5 Summary

The theoretical information revealed that solar energy with PV system performance mostly depends on solar energy availability, the efficiency and system temperature for the power output. The review literature confirmed that solar energy could play a significant role in the country's expansion plans due to inadequate electricity supply from the weak transformer of the load capacity. Technically, solar abundance is useful for adequate generation and a good return on investment across the country despite high initial cost of the PV system and solar intermittency. Politically, government commitment to spending on solar technology development will facilitate the financial support from the banks, insurance and capital markets (private sector) and boost economic growth. Economically, increase investment for infrastructure development, improve quality of life and income growth for social and environmental benefits, and establishing programmes and schemes will ensure basic access needs such as education, energy services, goods, and services, enabling environment, transportation, communication, and other socio-economic activities in the country. In Nigeria However, the case study (Nigeria) has a limited number of published papers for the PV grid-connected system require further research.

CHAPTER 3: METHODOLOGY

3.1 Introduction

This chapter discusses the approaches and methods used to address the research questions. It used different methods of data collection such as the questionnaire, interview, and case studies. The RET Screen and PAYG models were used for classifying data. This study found the combination of interdisciplinary approaches, most suitable for answering research questions on technical, economic and policy perspectives (Multi-disciplinary) respectively. The mixture of qualitative and quantitative approaches offered more comprehensive measure for understanding the complex issue that a single approach could not provide which focused on related solar energy application with PV system in order to address demand and supply gap, cost and the environmental impact based on relevant policy to achieve the study objectives.

3.2 Types of Research Methods/Approaches

There are two approaches that can be used as methods for collecting data, which are quantitative, and qualitative research approaches. This study used both approaches. The quantitative research method is used for a target sample for participants through the questionnaire to generalize targeted population with demographic information on age, gender, and occupation. This study used a questionnaire to collect quantitative data which also used for more information to examine the statistical significance of practical results based on the size effect and confidence intervals percentage.

The qualitative research method provides background information about an application based on the origin of the investigation. This technique primarily describes the understanding of “others” need from different collective levels such as ethnic group (Small, 2009). In addition, it shows how people understand other’s need for research and difference in getting to the bottom of the differences (Gibbons, 2014). Therefore, favour studying of cases to gain in-depth understanding. The case studies which is descriptive added meaning to the entire study text carried out by reading and analyzing the case study findings.

This study employed both qualitative and quantitative methods due to the following reasons. The qualitative research improves data analyses, interpretation and focuses on the behavioural factors which answer the questions related to "why" and "how". The quantitative data support qualitative data with mathematical and statistical research techniques. The qualitative seeks answers to questions on how social experience creates meaning. In contrast, the quantitative provides measurements and analysis of causal relationships between variables without processes (Denzin and Lincoln, 2002; Denzin and Lincoln, 2011).

3.2.1 Quantitative Research Method

The quantitative research method was used in this study because it offers objective measurement based on analysis of numbers, research topic, questionnaire sample or survey. It classifies the features, counts them and constructs statistical models with an attempt to explain observations/results. It is used to determine the relationship between independent variable and dependent variable for the population in terms of regression. It also studies, gathers data and structures research instruments used for results on large sample size through the population representative (Brians, 2011a). It involves research questions that clearly define answers to objective required by a researcher (Brians, 2011b). It designs all aspects of study carefully before numbers and statistics data are collected, and often arranged in tables, charts, figures and other non-textual forms (McNabb, 2008). It generalizes concepts more widely to predict future results or investigate causal relationships. For example, researchers use questionnaire or computer software tools to collect numerical data.

3.2.2 Qualitative Research Method

The qualitative research method is widely applied in various research settings to define a process of exploring, interpreting and uncovering complex actions in a more subjective approach. In this study, it studies things in natural sceneries, makes logic out of meaning, and offers greater flexibility to address appropriately and effectively the research design to solve the research problem. This method engages things that generate factors into analyses and explanations (Murcott, 1997). It was used because it helps generate rich detailed data, leaving

participants' intact with perspectives while providing multiple contexts for an understanding of a phenomenon under study (Anderson et al., 2010).

This study employed case studies, interviews to provide the researcher with participants' perspective through direct interaction with them (Claire and Babbie, 2010). They allowed the researcher to describe the phenomena under study because they offer flexible ways to perform data collection with subsequent analysis and interpretation of information collected (Lincoln and Guba, 2000) in terms of quantity, amount, intensity/frequency, qualities of entities, processes, and meanings that are not experimentally measured (Ellis and Levy, 2012; McNabb, 2008 and Ellis, 2008). In this study, the researcher using the data sources to describe PV system quantity and quality of solar energy.

3.2.3 Sources and Data Collection Methods

During the investigation process, this provides added opportunity to evaluate outcome of collection from the questions selected based on appropriate strategy for narrative analysis (Creswell, 2008). Researchers can collect data from primary or/and secondary sources. Primary sources include surveys, observation, experiments, and interviews. The primary data was collected from the questionnaire, interview, and case studies. The RET Screen, regression and Innovative financing models were employed to process and classify data. However, this study used a secondary source such as books, internet publications from websites, published reports by the governments, the private, and documents from ministry considered.

The primary sources include an in-depth structured questionnaire, semi-structured interviews, and case studies. The quantitative and qualitative research methods were used for better understanding of solar systems deployed through a descriptive analysis of case studies conducted across the country. The questionnaire was distributed as a source of primary data from a large sample size of fifty-seven questionnaires. Interviews were conducted with focus groups. Moreover, case studies were selected based on the use of solar system deployment for the country's off-grid applications.

The secondary data source involves collecting information from journals, articles, official documents, business publications and internet assessment with the ideas used for the research question outline. The secondary sources included the reviewed literature based on the evidence documented from the investigation of primary source for off-grid installation as a justification in the case study. It helped the study to propose solar PV systems using software simulation for decentralized and centralized applications and further to reduce costs across the country. Figure 3-1 represents the data collection methods that also shown in selected and compared pros and cons table in Appendix 3a.

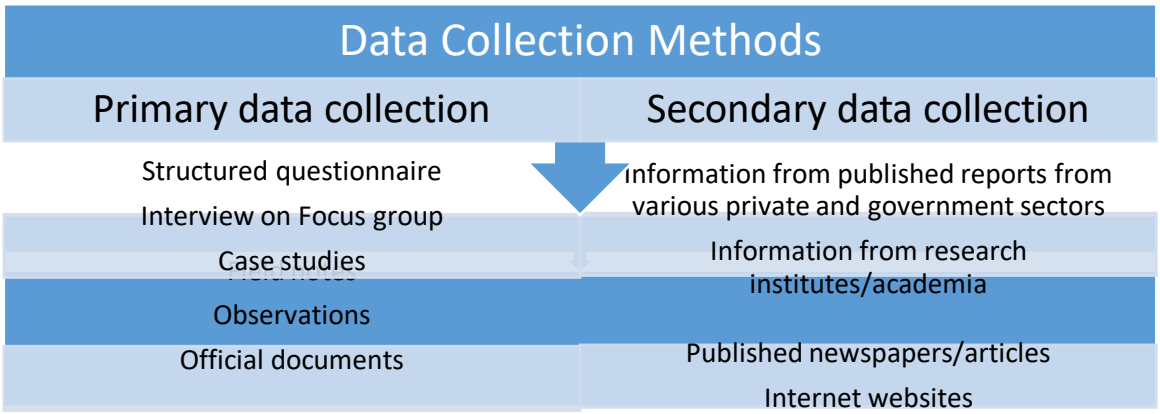


Figure 3-1: Instruments employed for Research Data Collection.

3.2.4 Questionnaire

The questionnaire is a source of data collection, which has been the most predominant design method for the distribution of the research questions. The sample size is relatively large number comprising of 57 questionnaires. It means the larger the number of questionnaire items the more statistically reliable the results. The questionnaire was used in the field that started in December 2015 until May 2016 in different selected locations visited in the case study. According to (Gall and Borg , 2007: p.228), designed questions are used to collect data of individual and social entity such as households, and institutions. The primary data collection provided socio-demographic information with respect to Nigeria installed PV system case studies with fifty-seven distributed questions during the field study.

The questionnaire was administered to workers in the energy/electricity sector and some financial organizations and the public/households. The questionnaire framework was with multiple-choice questions, sub-divided into three groups based on technical, economic and policy perspectives with response/answers to the conducted investigation. Section 1 is general questions on individual/consumer's perceptions about solar energy application for electricity generation in Nigeria. Section 2 addresses the perspectives based on the installed PV system that clearly explain the availability and important benefits. Section 3 compares the existing conventional plants and the off-grid installed solar PV systems in the country.

3.2.5 Interview on Focus Group

The interview involved oral questions directly asked by the interviewer to the interviewees, for oral responses mostly from energy organizations. The interviewer recorded a brief note based on interviewee's responses during the conduct of the interview. This helped the author to elicit substantial information about certain behavior based on opinions, values, and experiences from informants. A study mentioned that this is not directly observed (Borg and Gall, 2007). However, this engaged small focus groups within the selected organizations and some solar companies to explore knowledge related to costs and potential benefits of PV installation use for electricity generation in Nigeria.

It is a semi-structured interview and open-ended and this made some data possible to obtain with an explanation of interviewee's special interest. It was a face-to-face interview with a solar company's managers and the staff based on PV installed design locations in Nigeria. The focus group interview engaged two-four interviewees at different offices and sites for data collection. The interviewees were from private energy companies, which are involved in RE activities and in some government energy institutions/organizations such as ECN, SERC, TCN, NRECD, NERC, Discos and Gencos. Figure 3-2 represents a case study interview and observation evidences in the location with a solar company's manager. Figure 3-3 represents a community leader and ECN staff in one of the visited sites.

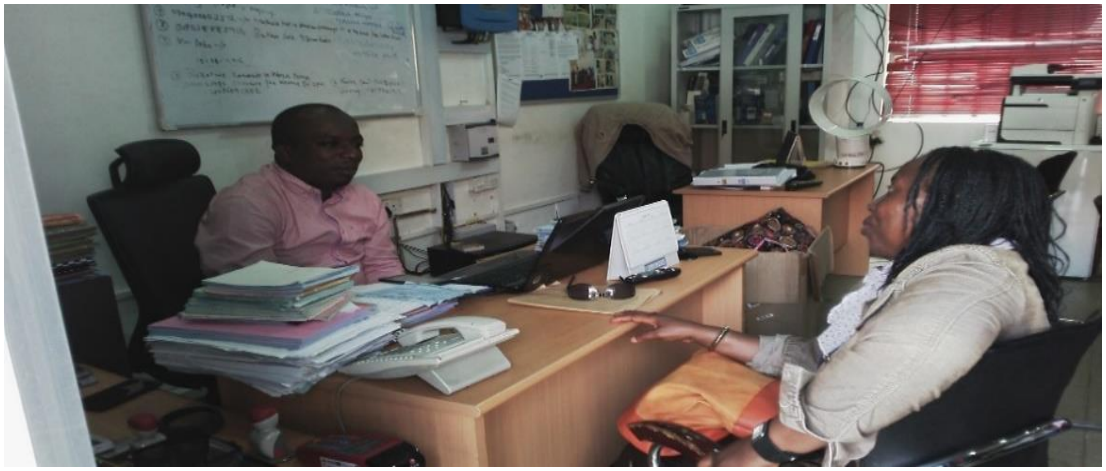


Figure 3-2: Interview chat with Blue Camel Energy Manager (Source: Trip, 2016).



Figure 3-3: Solar PV installation at Igu-Bwari community in Abuja (Source: Study, 2016).

The participant's anonymity truly conveyed a significant purpose of study without deception. In this study, they were used in an open-ended structured questionnaire and semi-structured in focus group based on one to one interviews. Figure 3-4 represents the semi-structured open-ended, structured, unstructured and semi-structured interviews with classification of main heading and sub-heading given in quantitative and qualitative research methods.

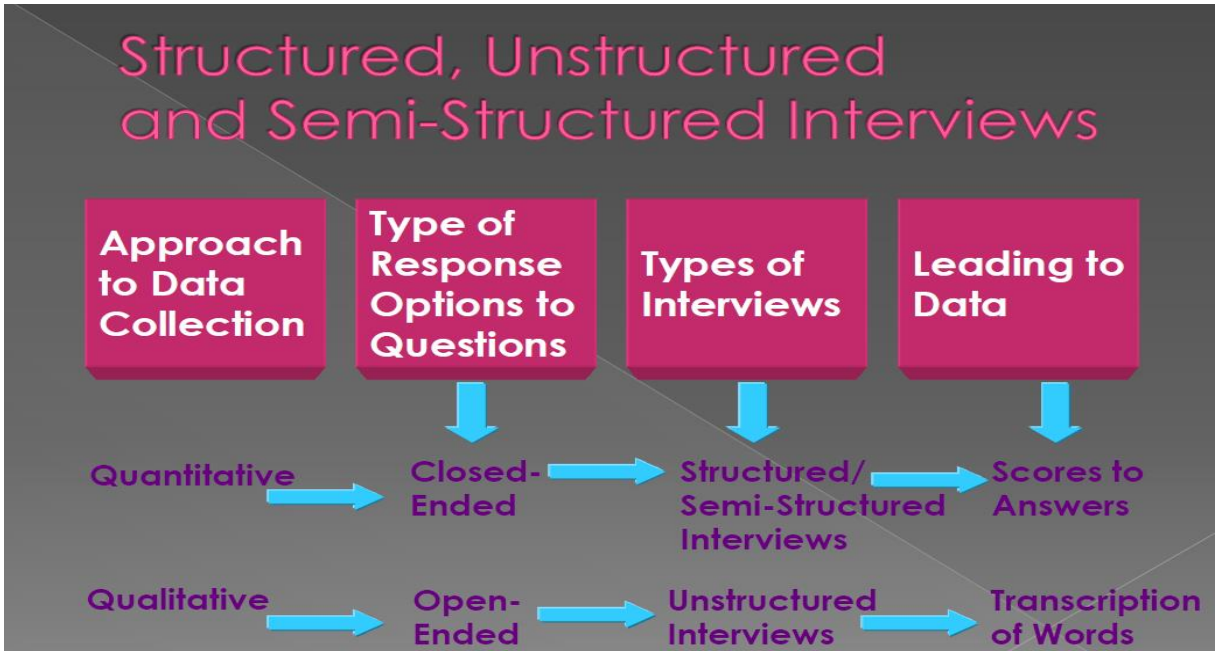


Figure 3-4: Structured, Unstructured and Semi-Structured Interviews (Source: Fischler, 2008).

3.2.6 Field Observation and Photography

During the fieldwork, some official letters were written to obtain access permission for visiting the organization's installation sites. This method of data collection was conducted to observe and understand the materials and other components used for the rooftop PV systems in the residential/communities and commercial building applications for electricity generation at different site locations. The observation focused on installed PV types, the number of panels, inverter and battery, and other specifications. A descriptive field note was used to describe the phenomena events and activities with evidence of photographs taken at the sites. It is an important role for visiting locations of the installed PV systems. The study is exciting because of the presence of community's leaders who acknowledged solar potential for power generation from the installed systems particularly in the rural-remote communities as indicated in Figure 3-3.

3.2.7 Audio-Visual Materials and Document Procedures

Climbing ladders as a documentary review material used to view the PV system installed during the fieldwork. The public data collected of little evidence based on government documents to private data obtained from case studies records that come with enough evidence with or without written text permission. The use of library facilities including some available documents was from public organizations such as Nigerian National Institute of Scientific and Raw Materials (NISRM); Nigerian National Petroleum Corporation (NNPC); National Bureau of Statistics (NBS) and Energy Commission of Nigeria (ECN) for data analysis. The data sourcing from these organizations helped the author to establish a relationship with the participants.

3.2.8 Case Study

The case study is employed to explore how to access solar PV electricity generation. The research conducted happens to be a real-life application that involved people with energy provision based on electricity generation. A study revealed that a case study is used to describe and explain the data collected in a reliable and accurate manner. It seeks to find how people and things interact in an environment without isolating the variables in the real world. It is in-depth empirical research conducted essentially for utilizing qualitative case study and participatory methods insight for energy projects (Gibbons, 2014). A study also described these methods to assist acquisition of first-hand data from field and the local people (Cook et al., 2005). The case study data include energy generation, consumption, the payback time and PV system efficiency based on the installed off-grid PV system to determine in this study. However, the off-grid systems with specifications were demonstrated mostly during pilot project installations revealed the relationship between electricity access and the potential benefits.

This study methodology, however, started with an institutional framework used to obtain data from established case studies. The data were obtained from established companies such as National Research Institutes/centres, Energy Commission of Nigeria (ECN), Sokoto Energy

Research Centre (SERC), Nsukka Research Energy Centre (NREC), and Power Holding Company of Nigeria (PHCN) including renewable solar companies. The majority of the companies are mentioned in the ethical approved form (EAF) from the University of Nottingham while visited during fieldwork for this study cases.

The data from some of the visited public institutions generally difficult to collect due to information sensitivity as well as not readily available. Some of the organizations visited during and after pilot projects have related responsibility towards solar PV system installation in Nigeria. However, different approaches were used to resolve long-standing inadequate power supply for electricity access in rural-remote and urban places as recommend in achieving the study objectives.

3.3 RET Screen Simulation Software Model

RET Screen is a simulation software used to compare between a typical base case (i.e. conventional technology) and a proposed case study (i.e. renewable energy technology). The RET Screen is used to determine energy efficiency, renewable energy, and cogeneration project feasibility analysis and ongoing energy performance analysis. It is also used to empower professionals and decision makers to rapidly identify, assess and optimize technical and financial viabilities of potential clean energy projects like PV technology. According to (Leng Gregory; IEA, 2017) report, intelligence software platform allows managers to measure easily and verify actual facilities performance and as well help to find additional energy savings and production opportunities. It also includes technical, economics and costs (internal rate of return (IRR) and net present value (NPV), the lifecycle costs and GHG emission reductions.

This software can be applied to any energy system from individual projects to a global application designed to capture and analyze all types of geographical data and assess the total irradiation in a specific region to maximize utilization of solar energy. In addition, planners and energy advisers on customized geographic information also use it for solar energy system development for being a decision support software. Connolly et al (2010) report that RET Screen relatively accounts for all thermal generation and renewable technologies. In addition,

Mardaljevic and Rylatt (2003) stated that computer program simulation is deployed to predict solar radiation to increase uptake of solar energy systems, particularly for urban areas. This study selected RET Screen tool to ascertain the amount of energy generation with a PV system and compared with field data. This software also provides detailed knowledge on effective planning of solar energy system.

3.4 Regression Model Analysis

Regression analysis allows the user to establish a relationship between factors of influence and energy use based on descriptive or mathematical analysis. The regression model is used to explain the dependent and independent variables. In this study, the dependent variables were used to predict the energy issue and the independent variables were used to address the factor influences. The monthly average temperature and relative humidity are among the factors influencing the PV system in this study. For example, solar radiation availability determined the PV system performance for the power generation. However, this model treats the PV system as an independent variable driver, which is assessed in the form of theoretical information. This analyzed the amount of generation, which depends on the condition of solar availability and technology use such as PV system. This descriptive data analysis for the study cases show sufficient generations in Nigeria study's locations. It also shows solar supply significantly can meet the energy demand of the population without electricity interruption on a daily basis.

3.5 Innovative Financing Model

Innovative financing model is used for solidarity, Private Power Purchases (PPPs) and facilitator mechanism to support fundraising in tapping from new sources that engage investors beyond financial dimension transactions (World Bank, 2009). It also engages partners and stakeholders in the development and delivery of financial solutions for problems on the ground. Study findings show that government finances RE investment in most countries to support (Akintoye and Beck, 2009). However, the government is minimizing the need for support through available market-based mechanisms within the private sector to increase and promote solar system projects (Young Ernest, 2014).

The study found innovative financing as a new source to help complement conventional financing mechanisms for most projects. However, innovative financing has been identified with more than five main models including Crowdfunding; Community funding through cooperative; Third-Party funding through Leasing, Yieldcos, Power Purchase Agreements (PPA); Microfinance funding; Solar loan funding; Pay As You Go (PAYG) funding and Institutional funding (e.g. insurance company and pension fund). These financing models have been tested and successfully adopted in some countries (Young, 2014) including Nigeria where some solar companies have adopted PAYG innovative source of financing. The case study using this method to reduce the initial upfront payment cost barrier for solar installation without consumer/customers paying from their own pockets. This method is used to examine unwarranted transaction based on the energy budget by consumers due to the energy provider's exploitation in the case study.

3.6 Summary

The data collected from organizations were both from rural and urban city locations in Abuja, Lagos, Enugu (Nsukka) and Awka, which represents the whole populations. The ethical consideration used for permission to the ministries such as government institutions and company owners to obtain data through interviews, case studies and questionnaires based on individual and organization participants. This chapter discussed the research data process used in addressing the main research questions through a questionnaire that generated descriptive statistics with engaged participants. The primary sources create a good understanding of the people's perception, opinion, and assertiveness about solar energy use with PV technology. The investigated case studies with PV system for electricity generation and electrical energy consumption. The study applied simulation software method to determine the amount of generation with the use of a PV system for off-grid installation and innovative financial model known as PAYG to assess the energy budget in Nigeria. The secondary sources being the theoretical information from books and digital publications for the understanding of solar system performance from global installations.

CHAPTER 4: MAJOR ENERGY SOURCES COMPARISON ANALYSIS

4.1 Introduction

This chapter presents Nigeria's major energy sources that compare and analyses the major energy sources due to the projected generation in meeting the current and future energy consumptions. The Nigerian economy has been the energy giant of Africa and the leading in oil production. According to a report by (Adaramola and Oyewola, 2011), Nigeria and Libya account for two-thirds of Africa's crude oil reserves and second to Algeria in the natural gas resource, estimated to last over a century. Other energy sources include wind, coal, biomass, animal wastes, etc.

Nigerian energy production and the utilization involve firewood that has the longest history. Domestically, the utilization is commonly used in cooking and lighting mostly in rural habitats. Nigeria currently produces 2 to 2.417 million barrels per day with proven oil reserves of about 36-37.2 billion barrels. Gas has 187 trillion (TCF) reserves and the gas production would last up to 120 years at a rate of 43.2 billion cubic meters per year (Petroleum, 2013). The main energy sources include biomass (81.25) percent, natural gas (8.2) percent, petroleum products (5.3) percent, crude oil (4.8) percent, hydropower (0.4) percent and others with <1 percent (Edozien and Fashola , 2016). The renewable sources are solar, wind, biomass and small hydro and large hydropower but the development of these natural resources primarily depends on the resources availability (Aliyu et al., 2015). Nigeria ranked the seventh largest OPEC crude oil producer between 2009 and 2013 globally. However, she still cannot sufficiently generate electricity to cover the rural and urban needs (Ohunakin et al., 2011). Table 4-1 represents the Nigeria's energy reserve capacity based on the total energy supply percentage.

Table 4-1: Nigeria's Energy Capacity Reserves

Nigeria Energy Resources	Estimated Potential Reserves	Percentage (%)
Crude Oil	36.2 billion barrels	4.8
Natural Gas	187.44 trillion second cubic feet (SCF)	8.2
Tar Sands	30 billion barrels of oil equivalent	<1
Coal and Lignite	2.7- 4 billion tonnes	
Large Hydro Power	11,250-11,500 MW	1
Small Hydropower	3,500 MW (<30MW)	
Solar Radiation Sunshine	3.5-7.0 kWh/m^2/day 4-8 hours/day	
Wind	2-6 m/s at 10 m height, low 1.4-30 m/s in southern areas except for coastal line and 4.0-5.1 m/s in the north. The plateau area particularly interesting	
Biomass		
Fuel wood	11 million Hectares of forest wood land	81.25
Animal Wastes	61 million tonnes/year and 245 million assorted animals in 2001	
Crop Residue Energy crops & agricultural residue	83 million tonnes/year 72 million hectares of agricultural land	

(Sources: SERC, 2015; ECN; DPR and NNPC, 2006, Okafor, 2009, CBN and UNDP, 2007).

4.2 Existing Energy Production

The Nigeria electricity generation is primarily from gas-fired and hydropower plants. However, the natural gas is the main fuel source of the grid electricity whose capacity is about 4,500 MW. This can meet only one-third of the current electricity demand in Nigeria. According to Nigeria National Committee of World Energy Council, the capacity is estimated to grow at a 10 percent rate (Aminu and Peterside, 2014). The country's electricity requirement by 2020 is expected to reach 30,000 MW and 78,000 MW by 2030 with the current GDP growth (Inugonam, 2016).

The allocation of resources from the federal government cannot adequately meet all requirements. Many areas are not covered by the national grid because it faces electricity generation challenge due to inadequate facilities network and delay in maintenance, lack of exploration to tap available resources including low staff morale in the country. Nigeria industries for over 100 years' experience erratic inadequate supply coverage by geographical spread (Zarma, 2006). However, the manufacturers generate 72 percent total power to run factories on the average (Iwuagwu, 2009) and the impact is mostly on the industrial sector, international companies, and other organizations that are on self-generated electricity 24 hours per day.

According to (Joe-Uzuegbu, 2012) report, the challenges of transmission are as follow: the maximum electricity wheeling capacity is below national need requirements and some are outdated. However, mesh transmission network arrangement, regular expand, update, modernize and maintain networks should be done. The regular vandalization of lines with a low level of surveillance including security of all electrical infrastructures should be carried out and electricity losses from transmission should be controlled (Okafor, 2009).

According to (NERC and TCN , 2016) reports, the electricity distribution challenges include the overloaded transformers and bad feeder pillars; weak and inadequate network coverage and sub-standard distribution lines; insufficient funds for maintenance activities; and inadequate logistic facilities. Despite that this system is highly subsidized, many electricity bills are never paid. The transmission and distribution losses are estimated to be 17-20 percent (Ohunakin

et al., 2011 and Inugonam, 2005). The Nigerian federal government solely fund transmission (TCN) while retaining ownership of transmission assets. It privatized the operation of TCN line in 2013. The TCN (i.e. PHCN successor) is privately managed by Manitoba Hydro International (Canada) and solely responsible for maintenance to achieve stable power transmission with limited system failure (NPSG, 2013). Figure 4-1 represents eleven (11) electricity distribution companies in Nigeria and four companies among them were studied by this research based on location.

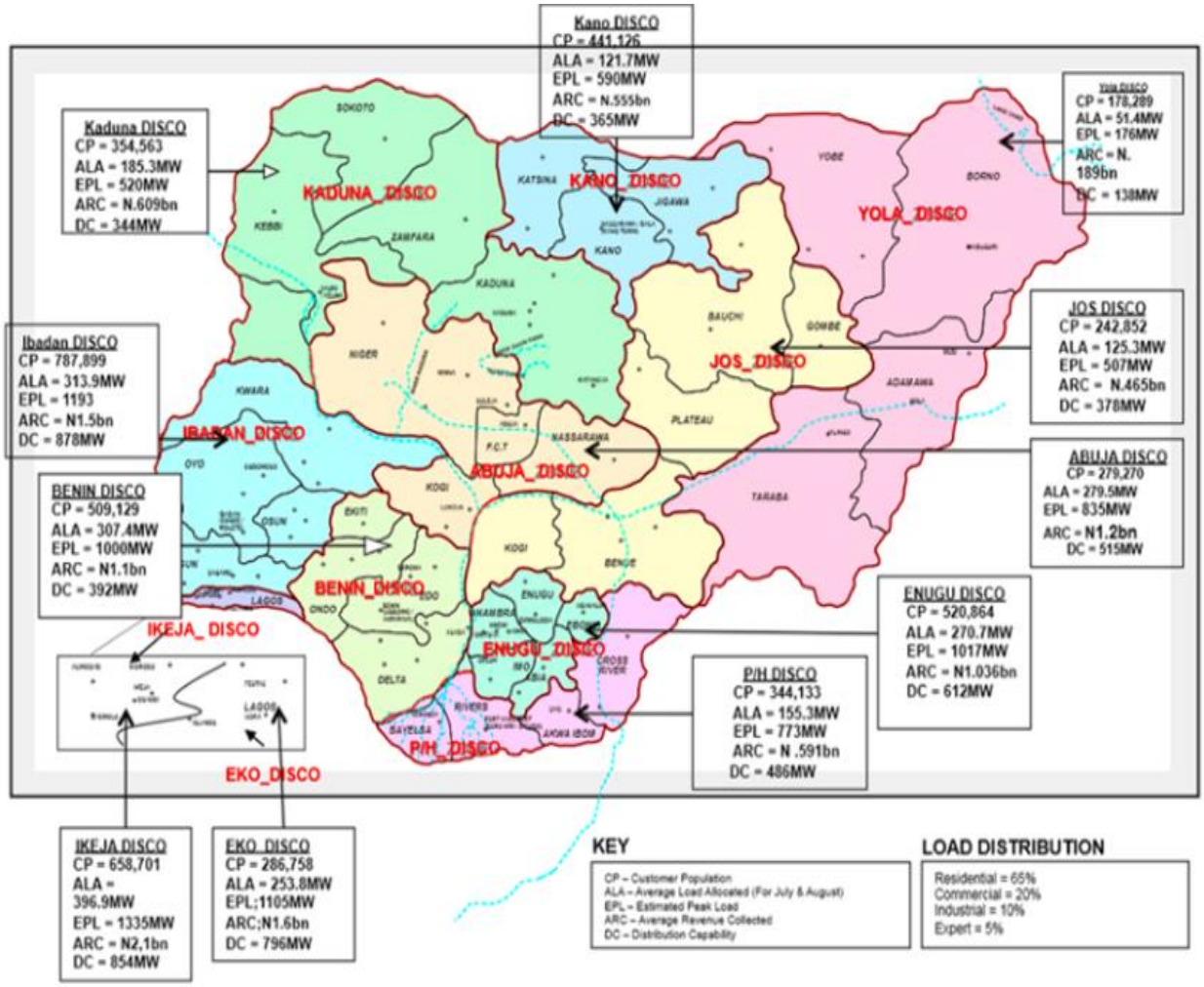


Figure 4-1: Nigeria Eleven Electricity Distribution Companies (Source: NPSG, 2013).

The federal government added new generation capacity to its electricity supply system to combat the power shortage in the country. In addition, NIPP is an integral part of 5,455 MW combined capacity from 10 NIPPs. Therefore, the federal government has three Nigeria bank

accounts for losses that Gencos may suffer in the course of power transmission. Table 4-2 represents the existing NIPP's generation capacities in the country.

Table 4-2: NIPP's generation capacities

S/N	NIPPs	Capacity (MW)	Completion Date
1	Alaoji Generation Company Nigeria Ltd	1,131	Jan 14
2	Benin Generation Company Ltd	508	Dec 13
3	Calabar Generation Company Ltd	634	Jan 14
4	Egbema Generation Company Ltd	381	Jan 14
5	Gbarain Generation Company Ltd	254	Jan 14
6	Geregu Generation Company Ltd	506	Jan 13
7	Gourde Generation Company Ltd	508	All Unit Commissioned
8	Olonunsogo Generation Company Ltd	754	All Unit Commissioned
9	Omoku Generation Company Ltd	265	Nil
10	Omotosho Generation Company	513	All Unit Commissioned

(Source: NDPHC, 2013).

In addition, the NDPHC that legally holds NIPP assets incorporated for construction and expansion of power infrastructure in order to boost electricity generation while the NERC focuses on stable power supply across the country. Figure 4-2 represents the increased generation of power plants in Nigeria.

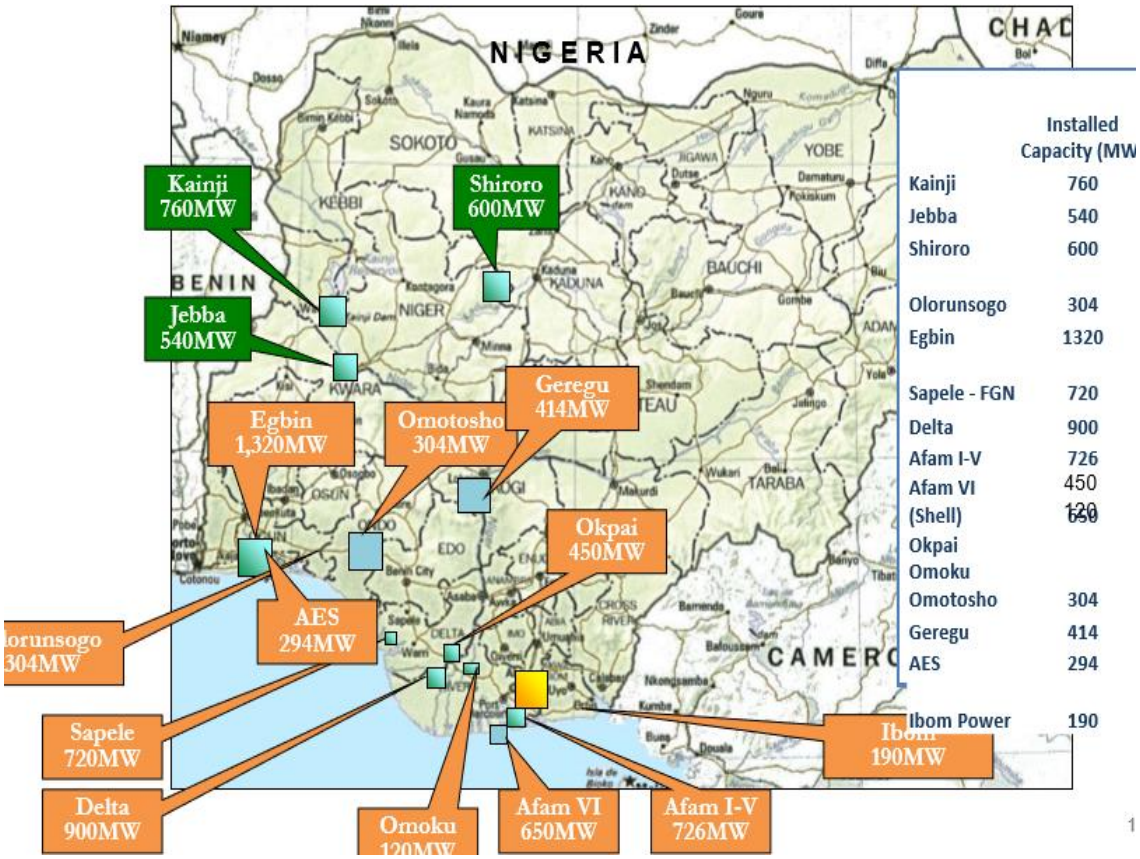


Figure 4-2: Completed increased Power Plant stations connected to grid (Source: FRN, 2016; World bank; IEA, UN and NBS, 2015).

However, the existence of independent power producers (IPPs) is prior to the privatization process where private sector owned and managed the power plants. The NERC recently has issued 70 licenses to IPPs to improve the power situation in the country. The existing IPPs are Shell-Afam VI with 642 MW capacity. Agip-Okpai with 480 MW and AES Barges with 270 MW. In August 1999, the NESCO, Shell, and AES-Lagos are IPPs that contributes 2-5 percent capacity to the national grid. The Nigeria AES implemented 270 MW capacity (Subsidiary of AES in the USA) in Lagos state with nine barge-mounted gas turbines and financed with £8 million ($12 million) by four foreign banks and three foreign institutions (U.S) (Filani et al., 2011). Figure 4-3 represents the installed transformer and electricity production by IPP in Lagos location of Nigeria.



Figure 4-3: Nigeria Electricity Transformer and Electricity Production by Independent Power Producer (IPP) (Source: Ehingbeti, 2008).

4.2.1 Energy Cost Implications

The Nigeria traditional electricity generation, transmission and distribution are capital-intensive. They require huge resources and funds (Onochie et al., 2015). Since 1960, the Nigerian electricity sector has invested over £43 billion (N2 trillion). Despite the energy reforms, the country has very little for investments. In 2000, the federal government financial support to NEPA amounted to £289 million (N14 billion) about 13 percent total capital expenditure (World Bank and Claessens et al., 2001). In 2003, the sum of £2.7 billion (N109 billion) aggregate demand (AD) was required in meeting 2006 projected power demand. The rising cost for annual investment will be about £15 billion (N748 billion) AD peak by 2028, roughly £7 billion (N3.5 trillion) in a year and over 25 year period with £189 billion (N9 trillion) total investment stream (Ibitoye and Adenikinju, 2007). In August 2005, the government, National Council of State (NCS) and National Assembly approved the sum of £1.8 billion (N70 billion).

In 2008, NIPP project got initial funding from "Excess Crude Oil Account" where National Executive Council (NEC) voted £3.7 billion (N149 billion) from the account called Power Emergency Fund (PEF) to be completed NIPP in 2012. In January 2009, NEC inaugurated NIPP Steering Council with the presence of Ex-President (Goodluck Jonathan), Ex-Vice President (Mohammed Sambo) and six state governors and four ministers (Odoyi, 2013 and Olotu,

2012). In February 2009, the council approved £1.5 billion (N61 billion) phase one budget for PEF to complete NIPP projects and approved £291 million (N1.2 billion) from special intervention fund for PHCN. In June 2010, the council approved £84 million (N3.4 billion) to augment phase 1 budget and £4 million (N1.750 billion) was used to buy NDPHC corporate headquarters in Abuja. These funds were used to build several gas turbine plants including distribution and transmission equipment lines (Ibanichuka and Olotu, 2014) with additional 1,687 MW to the national output in December 2012.

It is reported that Nigeria is losing £57 billion (N2.3 trillion) in Gross Domestic Product (GDP) per annum from optimal power generation for 13, 000 MW capacity. The realistic assumption for 40-45,000 MW power will cost close to £181 billion (N7.3 trillion) per annum and as such Nigeria may not get over the power problem (David-West, 2014).

4.2.2 Nigeria Energy Comparative Advantage

The comparative advantage is being described as a good service that produces a lower opportunity cost than other products within the country. Nigeria solar energy has a comparative advantage over other existing ones that are hardly available for electricity use due to the reliable nature throughout the year in the country. Solar PV system provides a comparative advantage over other technologies with free fuel cost for a long-term period. Table 4-3 represents comparative analysis of Nigeria Major Energy Sources in the country.

Table 4-3: Comparative Analysis of Nigeria Major Energy Sources

TECHNICAL				
FACTOR	PV	NATIONAL GRID	GENERATOR SET	FUEL-WOOD
Availability	It is available due to sunlight.	This partially available due to the high cost of infrastructure.	This scarcely available due to importation and exchange rate.	This scarcely available due to deforestation.
Reliability	Reliable due to a regular supply.	Unreliable due to a constant power outage.	Unreliable due to fuel scarcity and breakdown.	Unreliable due to the limited application and mainly for local cooking, drying, and heating.
Infrastructure	The modular form of technology has no moving parts.	Heavy equipment involving movement from one plant location to another in generation transmission and distribution.	Heavy equipment that involves transportation from one location to another.	Heavy wood that involves inconveniences of transportation from one location to another.

ECONOMIC				
FACTOR	PV	NATIONAL GRID	GENERATOR SET	FUEL-WOOD
Cost	High initial cost but affordable by individuals interest.	Capital intensive beyond individual and governmental affordability unless through partnership funding with local and international organizations.	It is capital intensive and the usage based on individual discretion and capability.	It is low cost but high undesirability due to the inconveniences and more limited to rural usage.
Job Creation	Supports unskilled, semi-skilled and skilled persons due to the opportunity of generating and installing the energy independently and easily.	It supports mainly skilled persons in terms of employment due to limited job opportunities.	Employment opportunities limited to only the manufacturers and dealers/marketers of the generator.	It supports local and mainly subsistence consumption.
Economic Growth	It has the potential for a large market and capable of supporting individual and national economic growth in a sustainable manner.	Provides sluggish economic growth due to the inadequate power supply to meet the growing energy demand in the country.	It has no visible support for economic growth.	Supports only subsistent family activities.
Entrepreneurial skill/innovation.	Supports entrepreneurial skills development.	Not really visible.	Partially the same as Photovoltaic through repairs.	N/A

POLICY				
FACTOR	PV	NATIONAL GRID	GENERATOR SET	FUEL-WOOD
Government Policy	It needs urgent support through subsidies, incentives, public-private partnerships, sound policy decisions, effective planning, regulation and legal framework for the implementation of solar energy in Nigeria.	Already has government support through subsidies but abolished and the results of the regulations and policies are not encouraging.	The importation of generators requires more restrictions through an increase in tariffs and import duties. This will encourage greater dependence on the PV and the National grid.	Government to provide alternative energy to the use of fuelwood for cooking particularly in rural villages.

ENVIRONMENTAL				
FACTOR	PV	NATIONAL GRID	GENERATOR SET	FUEL-WOOD
Environmental	Environmental friendly, which help, make the environment more conducive and emission-free.	The use of fossil fuel through electricity generation and consumption causes emission, which contributes, to environmental pollution and unfriendly environment.	It provides pollution, noise and inconveniences, health hazards, death, etc.	It provides smoke and health hazards mainly to women and children, particularly in rural areas.

SOCIAL				
FACTOR	PV	NATIONAL GRID	GENERATOR SET	FUEL-WOOD
Social	It improves the standard of living of the society and social development of individuals.	It reduces the quality of life due to constant power failure.	It constitutes hazards and brings agitation due to the noise of the gen set.	It shows a lack of progress in society.

POLITICAL				
FACTOR	PV	NATIONAL GRID	GENERATOR SET	FUEL-WOOD
Political	Political willingness, commitment, and effective planning are required to promote a green economy through implementation and application of PV system for power generation in residential and commercial, transportation, etc.	Political will, commitment gradually de-emphasize on the use of national grid due to its inconsistent cost of infrastructural, and unreliability in the generation, transmission and distribution lines.	Political will restricts the importation of generators due to the inconveniences in the environment.	Policy formulation due to the use of modern energy services and afforestation.

4.2.3 Comparative Cost and Capacity Projections Analysis

Table 4-3 below compared the energy sources for electricity generation of which the users pay different electricity prices. The monthly bill from the solar PV system is £37 (N15, 000) which is relatively lower when compared to national grid user at £49 (N20, 000) by consumers

because the government/power sector estimates the cost of bills and generator sets, the highest cost with sum of £99 (N40, 000). However, the energy generation from objective targets can efficiently achieve with PV system application that has the lowest cost as compared to others. In the above analysis from consumption's perspective based on case study data which counters the high cost of PV system when comparing with other sources. Table 4-4 shows average cost of electricity consumption per apartment in Nigeria.

Table 4-4: Comparison of Cost Analysis currently between PV, National Grid and Gen Set for Individual Users in Nigeria

Factors	PV	National Grid	Generator Set
Size of apartment	2-bedroom apartment	2-bedroom	2-bedroom
Period of charge	Monthly	Monthly	Monthly
Electricity bill per month	N15,000.00	N20,000.00	N40,000.00
Location	Abuja	Abuja	Abuja and Lagos
Facilities in use	Domestic appliances	Domestic appliances	Domestic appliances
No of users	5	5	5
Average cost per user	N3,000	N4,000	N8,000

Table 4-5: Projected Capacity Benefits for Energy Generation on each sources of Power

Resource	2015 (MW)	2020 (MW)	2030 (MW)
Hydro (LHP)	2,121	4,549	4,626.96
Hydro (SHP)	140	1,607.22	8,173.81
Gas	22,119	39,333.78	102,873.23

Solar	117	1,343	6,830.97
Biomass	55	631.41	3,211.14
Wind	50	57.40	291.92
Generator set (self-generated power	12,500	12,500	12,500
Total	37,102	60,021.98	138,508.03

(Source: NREEEP; FEC, FMOP & FRN, 2015 and ECN, 2009).

Table 4-5 showing the energy generation projected for each source with total energy generations of 60,021.98 MW by 2020 and 138,508.03 by 2030 that are far below the populations projected demand for electricity (Kuta, 2009b; ECN, 2009). The solar system is 100 percent powered by the sun, can reduce fossil fuel consumption and pollutions. It requires no scheduled maintenance as compared to conventional sources. The PV module long-life operating period can provide huge saving for the country. It is also cost-effective for lightings as compared to conventional sources from the utility grid and generator sets that commonly used in Nigeria.

Table 4-6: Energy Gap Projection Analysis

S/N	Projected Demand and Actual Supply	2015	2020	2030
1	Electricity Demand	64,200	107,600	297,900
2	Electricity Generation by government (grid connected actual generation	2,438	8,188.20	23,134.80

3	Gap between demand and generation	61,762	99,411.80	274,765.20

(Source: NREEEP; FEC, FMOP & FRN, 2015 and ECN, 2009).

As shown in Table 4-6, there are huge electricity gaps between projected consumption and demand around 61,762 MW in 2015, 99,411.80 MW by 2020 and 274,765.20 MW by 2030. Due to the effect of climate change, shortage of water and pipelines vandalism, the existing energy sources are unavailable. For example, the Nigeria existing capacity between 2015 and 2016 generated only 3472 MW (87%) from gas plant and 519 MW (13%) from hydropower plants. However, the projected electricity demands 107,600 MW by 2020 and 297,900 MW by 2030 show crucial need for electricity as presented in Table 4-6.

4.2.4 Study Results Analysis

The use of equipment and infrastructures in production, construction of pipeline storage and energy distribution are more expensive for the existing energies. This shows that solar energy has the opportunity over existing energies from the cost aspect. In addition, PV system generation has a huge future return on investment in terms of economic of scale as compared to the existing energies in Nigeria. Table 4-7 represents the projected solar energy generation percentage.

Table 4-7: Solar Energy Projected Percentage Generation

Total Generation	2015	2020	2030
All sources of generation (MW)	37,102	60,021.98	138,508.03
Solar generation (MW)	117	1343.17	6,830.97
Percentage (%) solar generation	0.32 %	2.24 %	4.93 %

Table 4-7 shows the projected solar energy generation percentages and the projected electricity contribution that accounts for 0.32% in 2015, 2.24% by 2020 and 4.93% by 2030. The solar source is required for generating more electricity to meet energy demand based on its potentials of availability, reliability, sustainability and environmental friendliness (safe and clean) in Nigeria. The existing energy sources presently have not and may not be able to cover the areas not connected to the grid by long-term projection. On the other hand, solar energy has the potential to generate adequate electricity for consumption.

4.3 Summary

Although Nigeria has huge non-renewable and renewable energy resources, it faces inadequate power supply from existing utility generation, transmission, and distribution. This means that energy production is lower than the demands limiting the country economic growth. Nigerian people lack electricity access in terms of modern energy services for lighting and other economic activities. The majority rely on fuel-wood for cooking and lighting, particularly in rural-remote areas. However, the lack of electricity access will affect economic growth and life quality of the citizens. Nigeria needs electricity generation to drive economic development and enable productive business activities to succeed. However, the PV system can offer an alternative option to address the electricity supply problem with sustainable energy service access in fostering economic development in Nigeria. In addition, since adequate electricity supply is a prerequisite for any nation's development, the solar PV system is imperative for widespread use in the whole country, especially in rural areas.

CHAPTER 5: QUESTIONNAIRE AND DISCUSSIONS

5.1 Introduction

This chapter presents the data collected through questionnaire method about solar energy development in Nigeria. The questionnaire was a useful methodology used for the information gathered from people's view on the implementation and application of solar energy in the country. It is a useful method because it helps to collect data from sites through email and physical visits. It facilitated the data collection about solar energy production, distribution, and application from the sampled/selected projects across the country.

The questionnaire was an acceptable interpretation tool used for the understanding of solar energy with PV application. Data from the questionnaires is among the most important materials in this study plotted in pie chart design. The questionnaire provided the participants with questions to identify the level of understanding of the PV system. During the fieldwork, fifty-seven questionnaires distributed to participants, only forty-five of them were completed and returned. In addition, thirty-two questionnaires fully filled and the three partially filled had a good number of answers to the returned questionnaires.

The research used a questionnaire to address the three categories based on the following: What could be the major barriers for solar energy application in Nigeria? What could be the policy barrier for solar application in Nigeria? Does the initial cost of PV installation affect solar application and implementation? What are the environmental, economic and social benefits of solar energy application in Nigeria? What are the technical and economic challenges for solar energy development in Nigeria? What major role can solar PV play in addressing the insufficient power supply problem in Nigeria? This focused on technical, policy and economic perspectives respectively.

Questionnaire as a quantitative research method used for gathering data. The returned questionnaire provided a good response from participants with the following results finding:

5.2 Statistical Questionnaire and Findings

Question 1: The Gender

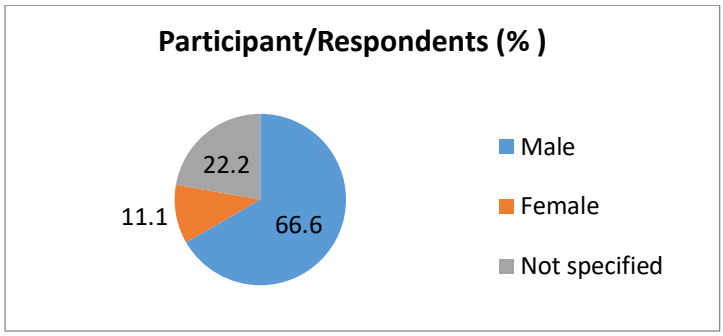


Figure 5-1: Sex of the Participants.

The results show that male responses are more than females. For example, it may be because women do not own houses and so not involved in issues related to energy.

Question 2: Age bracket

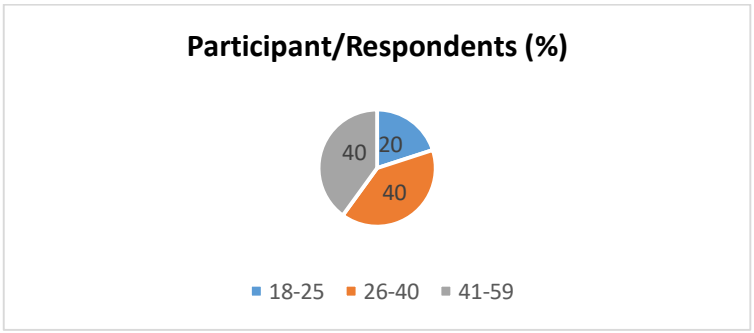


Figure 5-2: The participant's age bracket.

The results show participant's age brackets from (26-40) and (41-59) are 40 percent which is more than (18-25) age bracket. The 26-40 years' age bracket represents young people who own a home/apartment and are interested in an alternative source of power consideration. Majority of the people from age 41-59 years already had homes can afford solar PV system for their own energy needs. The majority of the people from age 18-25 years are unemployed. The PV system acceptance rate from the majority of the citizens is high due to the inadequate

power supply and they will independently become generators to power their homes in Nigeria.

Question 3: Occupation

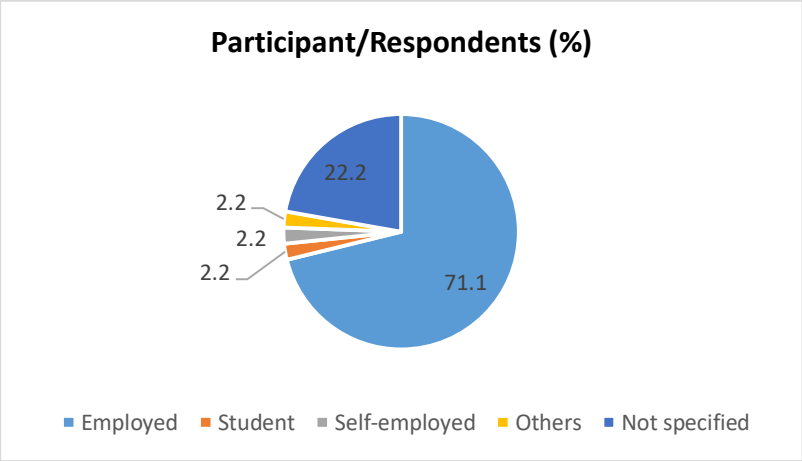


Figure 5-3: The participant's Occupation.

The results show the employed people have a high responding rate by being involved in energy-related company/organizations.

Question 4: Is PV system preferred in home to commercial area?

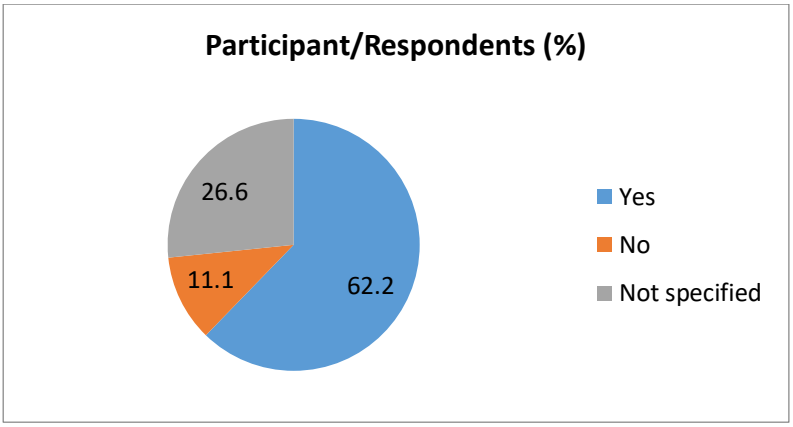


Figure 5-4: Installed homes with PV system.

The results show that a residential solar system is most preferred which can easily be subsidized. In addition, people are hungry for regular power service to improve their living standard against constant outages from the national grid.

Question 5: Is PV system preferred to existing/conventional sources?

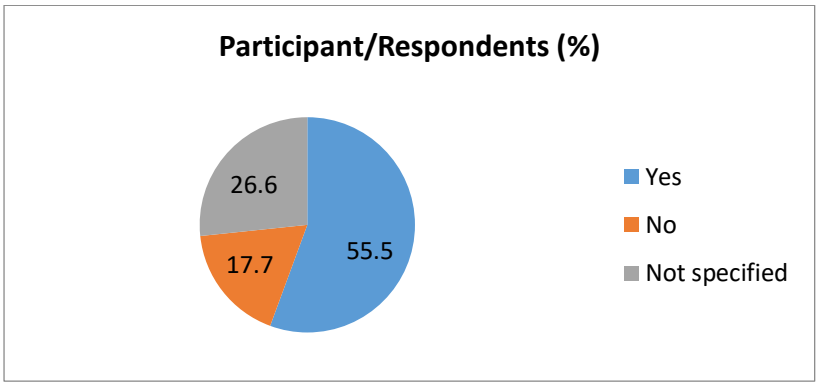


Figure 5-5: Installed PV system.

The results show solar PV is most preferred to the existing sources due to availability, reliability and the environmental friendliness which is used to compensate the on-going shortage of power supply and gas unavailability due to pipelines vandalism and theft. However, the current sabotage from generation, transmission and distribution lines contribute to energy poverty across the country.

Question 6: Does PV help to reduce electricity consumption from existing energy sources?

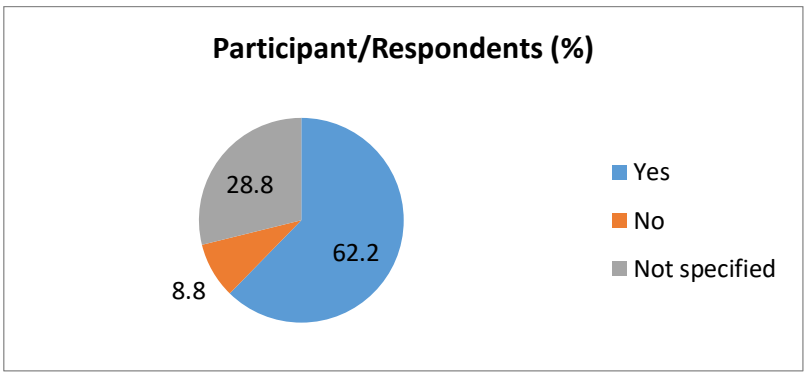


Figure 5-6: Electricity consumption between PV and Existing sources.

The results show that the PV system will help to curtail electricity blackouts. Its abundance and reliability help to complements existing supply from the utility grid, save energy to cover the time of shortage and change consumer's behaviour towards energy efficient use to reduce the electricity bill.

Question 7: Which of the following items have you powered using installed PV system?

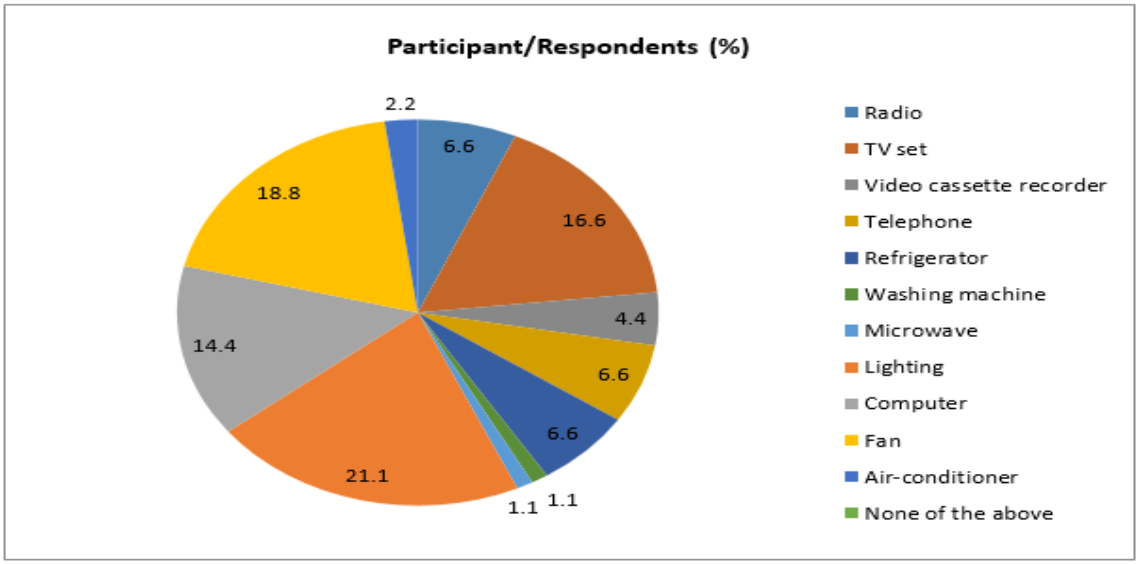


Figure 5-7: Appliances used with PV system.

The results show that appliances powered by PV system are home items than office items due to constant blackouts in residential households. However, office can afford a generating set for regular power during the office hours. The office complex can afford the system cost of capacity equipment. Moreover, the PV system awareness has not promoted reduction on the use of heavy equipment generator sets for household activities in the country.

Question 8: What time of the day does these appliances used?

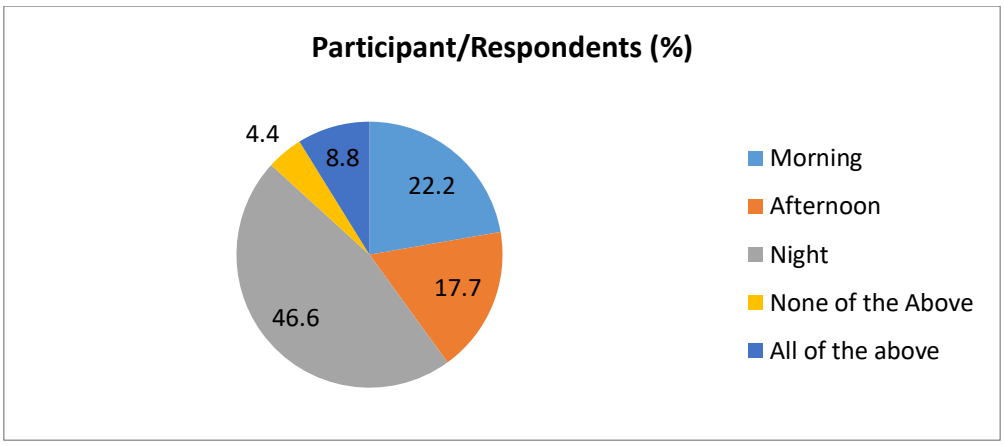


Figure 5-8: The time of appliance usage.

The results show that devices are mostly used at night for lighting, in playing games and doing homework by families.

Question 9: Which of the appliances often used during the day from installed PV system?

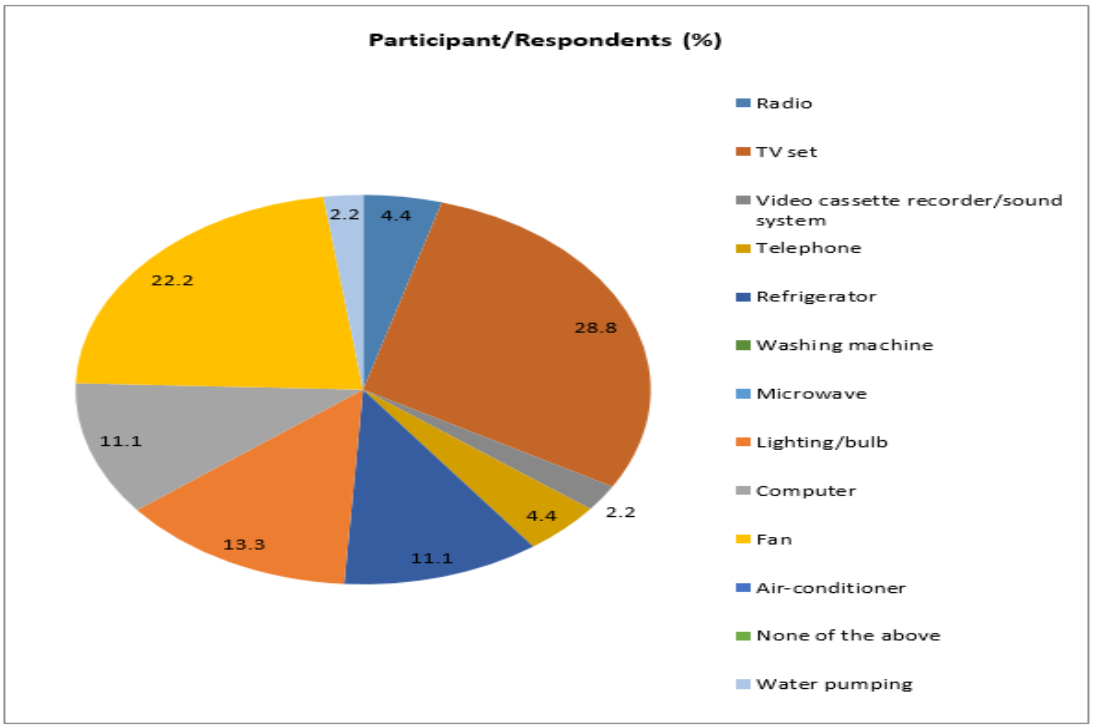


Figure 5-9: Appliances during daytime with PV system.

The results show refrigerator, fan, computer, TV set, A/C and lighting are often used in the day and night whereas A/C or fan and refrigerator are mostly used during the dry hot season due to hot weather condition.

Question 10: What is the capacity of PV system Installed?

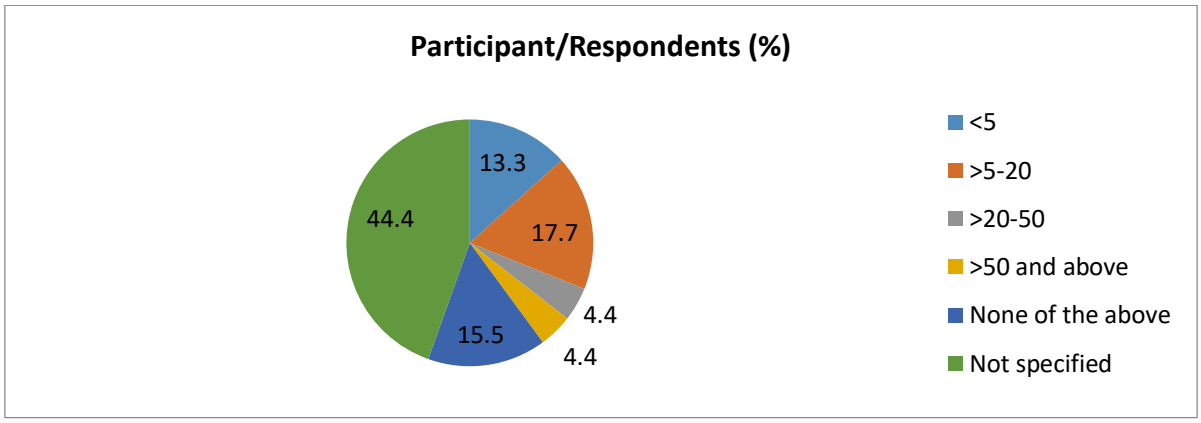


Figure 5-10: The PV capacity installed.

The results from Participant's responses show that a large portion of participants had little knowledge about solar PV capacity installed in their homes. This suggests a low public awareness in the country due to limited education and awareness creation initiatives.

Question 11: Are there suppliers of PV system and the components?

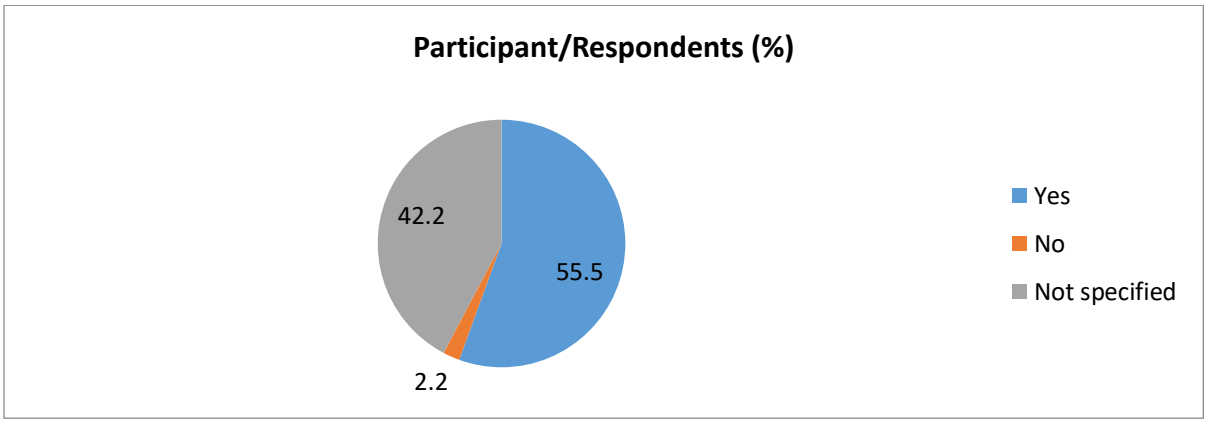


Figure 5-11: The PV system and its components suppliers.

The results show the respondents had an awareness of the availability of the PV supplies suggests that the solar PV system installer companies are already available in the country. The existing companies are a Blue camel, Pragmatic Nig. ltd, AY Global Int'l Consult Ltd, Panasonic, and Sharp, etc. They mainly marketers and distributors of the equipment and not suppliers across the country.

Question 12: Does solar PV system depend on only public funding for being expensive?

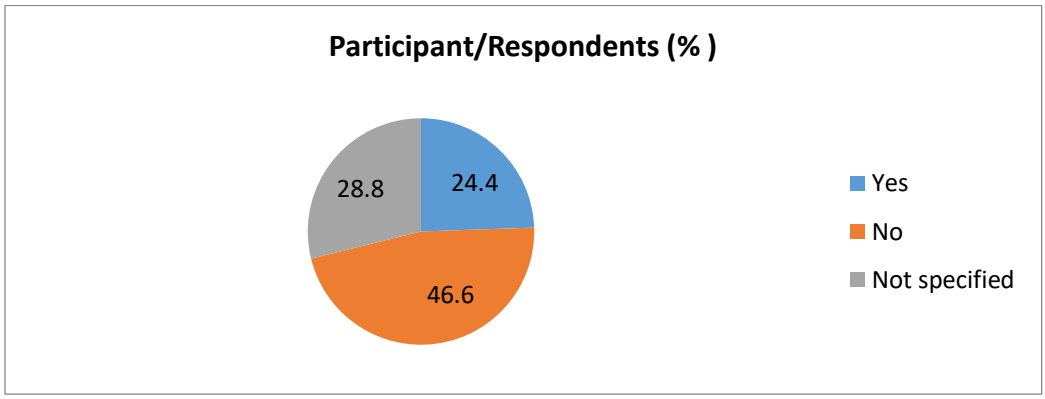


Figure 5-12: Public Funding for PV system.

The results confirmed solar energy with PV system to be expensive when compared with the current national electricity tariff, and this requires government funding with subsidies from the existing energy sources for PV development. The findings revealed that PV system deployment largely depends on financial capability and does not depend only on public funding. However, the development can be improved through public-private investments in Nigeria.

Question 13: Does solar PV depend both on public and private funding?

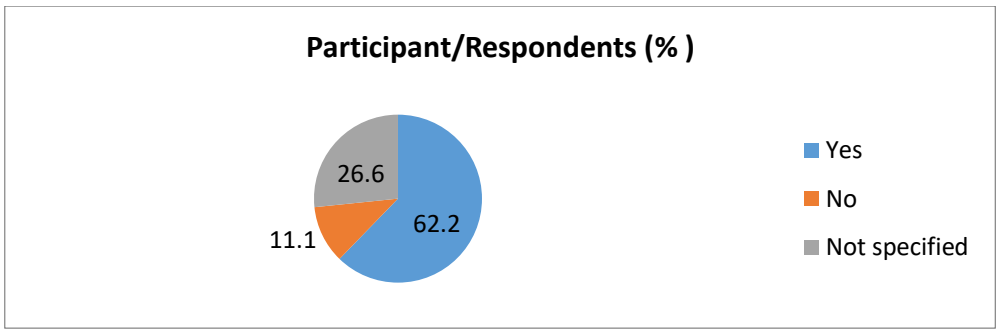


Figure 5-13: Combination of Public and Private Investment.

The results indicate most participants (62.2%) perceived that solar PV depends on both private and public funding. This implies that collaboration efforts are required for PV system implementation from the government with private sector participation to achieve Nigeria goal targets, the study objectives and the UN sustainable development goals.

Question 14: Is solar preferable to other renewable sources?

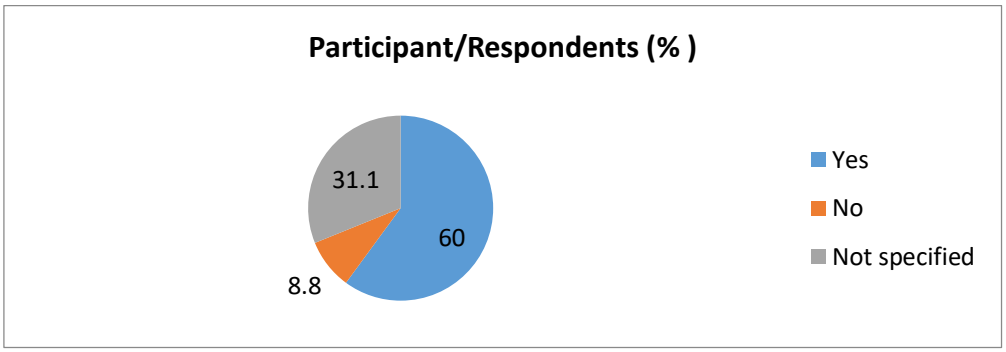


Figure 5-14: Preferred renewable sources.

The results show high participants' acceptance of the solar system. This may be due to the environmental benefit to other existing sources of renewable energy such as wind, hydropower, and biomass with the impact of climate change in Nigeria. For example, biomass, hydropower, and wind have limitations to current energy use.

Question 15: Which solar application is most preferred?

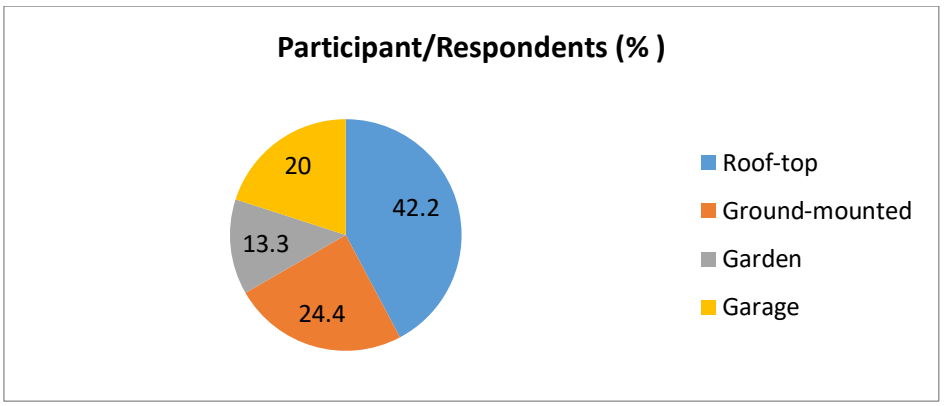


Figure 5-15: Most preferred solar application.

The results show that the rooftop-decentralized application is most preferred by the participant, which may be due to the nearness of building pattern. However, the assessment for building suitability is required due to the weight in carrying a PV system to avoid system failure.

Question 16: What type of PV system installation application is preferred?

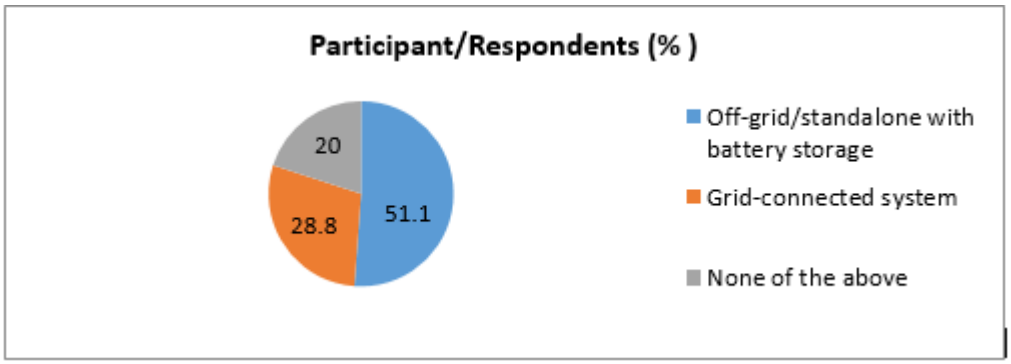


Figure 5-16: Most preferred PV installation.

The results show off-grid PV systems for electricity generation are most preferred by participants within urban areas. In June 2016, some companies licensed for grid-connection and operations had not yet started due to policy implementation delay. The decision on implementation and application of the solar system will to a large extent reduce generator

sets use by individuals and the company's owners for compensating insufficient and inconsistent power supply from the existing energy supply currently benefits those without access to grid electricity in the country.

Question 17: How can you rate overall performance (efficiency) of the installed PV system?

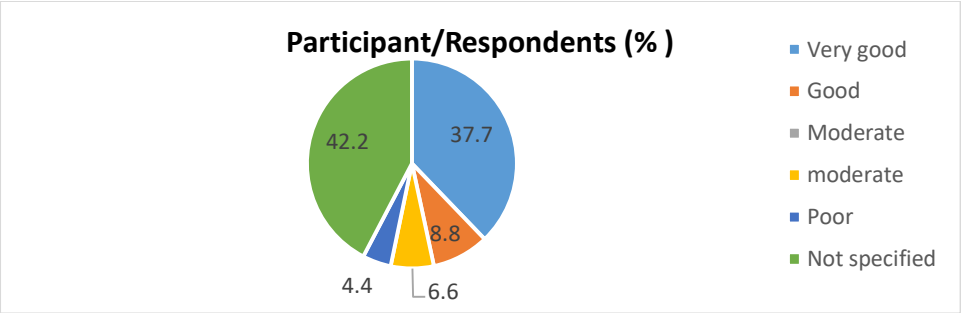


Figure 5-17: Rated efficiency of PV system.

The results show that PV performance rating from the participants indicated good system's performance, which depends on location, orientation, and tilt angle as well as a weather condition. This suggests that PV system installations require a knowledgeable installer for roof suitability check.

Question 18: Would you want the use of Renewable energy sources?

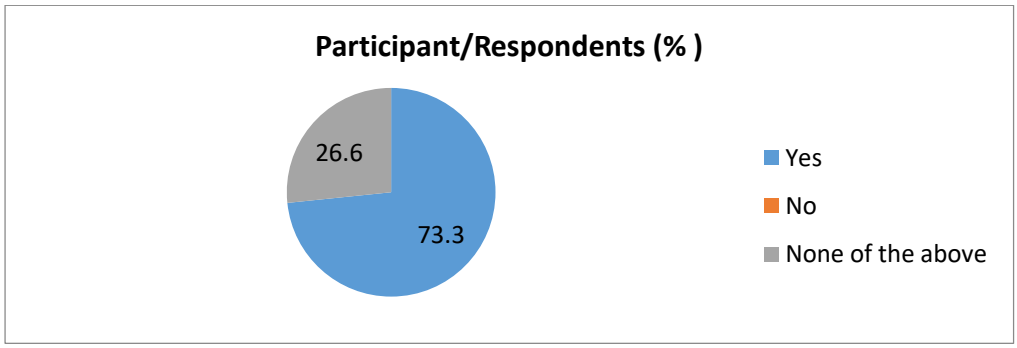


Figure 5-18: The use of renewable sources.

The results show that most participants accepted/preferred RE application due to renewable energy sources affordable. In addition, the people need the use of RE for electricity

considering the population growth, and it is a market for Nigerians in meeting the high energy demands from the growing population due to energy shortage currently in the country.

Question 19: Is your environment vulnerable to climate change based on other existing sources?

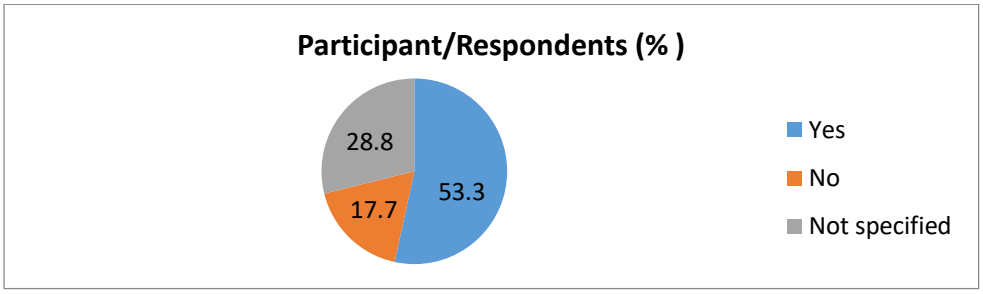


Figure 5-19: The environment vulnerable to climate change.

The results show that respondents' awareness of the vulnerability of the environment with the use of fossil fuels from existing energy sources due to climate change. This suggests that Nigeria presently experience environmental degradation and health disasters due to the exposure while flooding and falling of trees are causing desertification. These problems are contributing to the unfavourable environment.

Question 20: Can solar energy help to solve shortage in supply of power for a long-term in Nigeria?

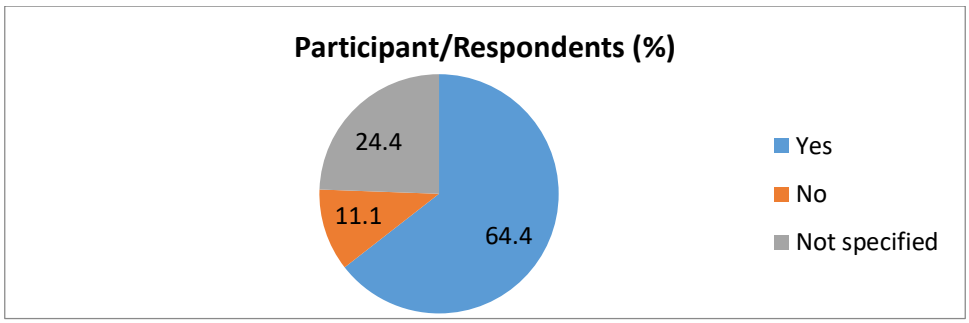


Figure 5-20: Solar a solution to power shortage.

The results show a large percentage of participants believe solar energy will help common Nigerians become independent generators, break the power of monopoly from the national grid generation, transmission, and distribution for a long or short term. This suggests that solar energy will make the population self-reliance whereby most communities can access electricity.

Question 21: Does power generator sets cause inconveniences and environmental threat?

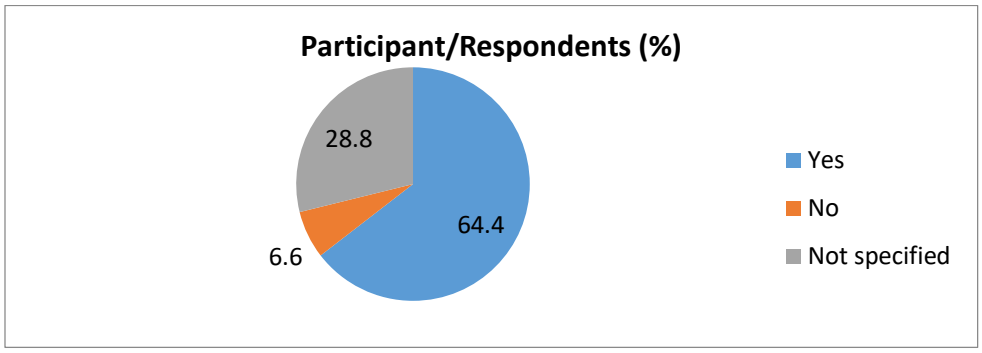


Figure 5-21: Generator sets threats and the inconveniences.

The results show that most (64.4%) participants' agreed that the generator is inconvenient. This may be due to negative impacts such as noise, air pollution, GHG emissions and local pollution to water. In addition, they might be aware that it affects crop harvest due to soil degradation and water pollution from oil leak and fume.

Question 22: Is PV panel system cheap to use?

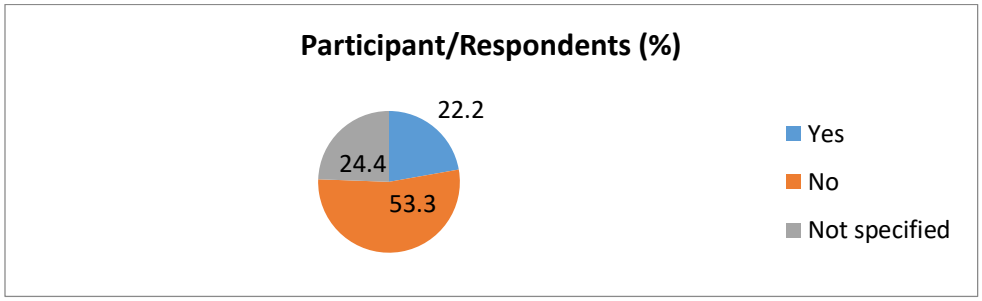


Figure 5-22: PV system panel economical.

The results show that the PV panel is not cheap by most (53.3%) participants because of a lack of awareness about PV technology improvement that attracts high deployment. For example, the global acceptance created awareness for the demand that drastically had reduced the high initial cost challenge. This suggests that PV system use can become cost-effective and competitive in addressing the sentiment as well as reduce the supply and demand gaps in Nigeria.

Question 23: Which of these applications are adopted by PV power output?

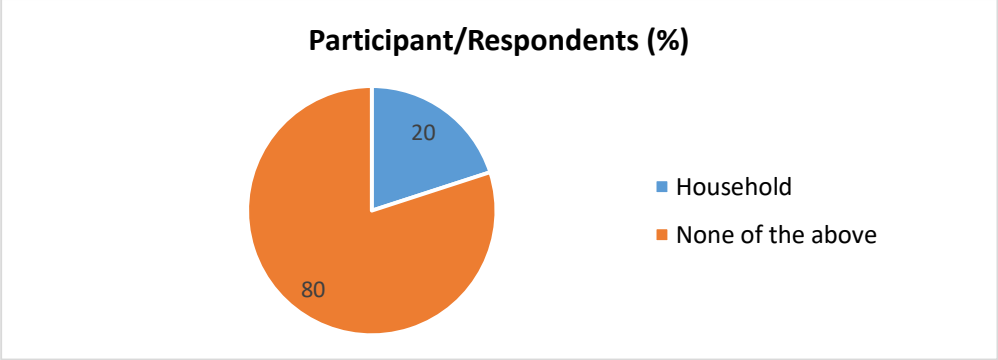


Figure 5-23: Adopted PV system application.

The results from the participant's response show that PV application has little publicity and cost of installation by individual and corporate for deployments due to lack of funding. In addition, some industries are not convinced that the PV system could generate enough capacity to power plants in place of generator sets in Nigeria.

Question 24: What are your reasons for not installing PV system yet?

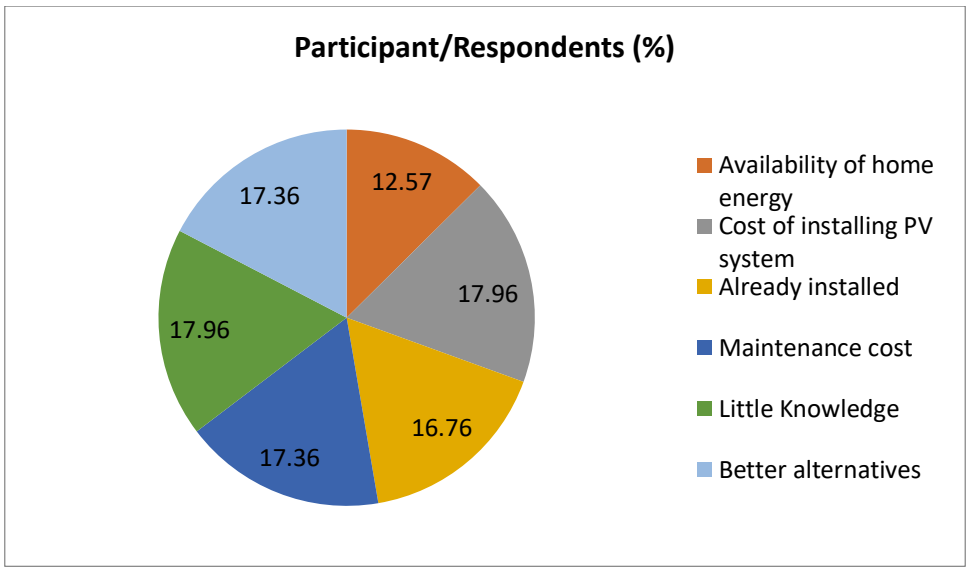


Figure 5-24: Reasons for not installing PV system.

The results show that cost of installing PV system, maintenance costs and lack of knowledge are stopping people from the installation. This suggests government support through programs or incentives in promoting PV installations to encourage private participation. In addition, effective planning and strong regulatory/legislative framework for large-scale development and training programs for an understanding of PV system benefit for rapid deployment across the country.

Question 25: Which of these factors can persuade installation of PV system?

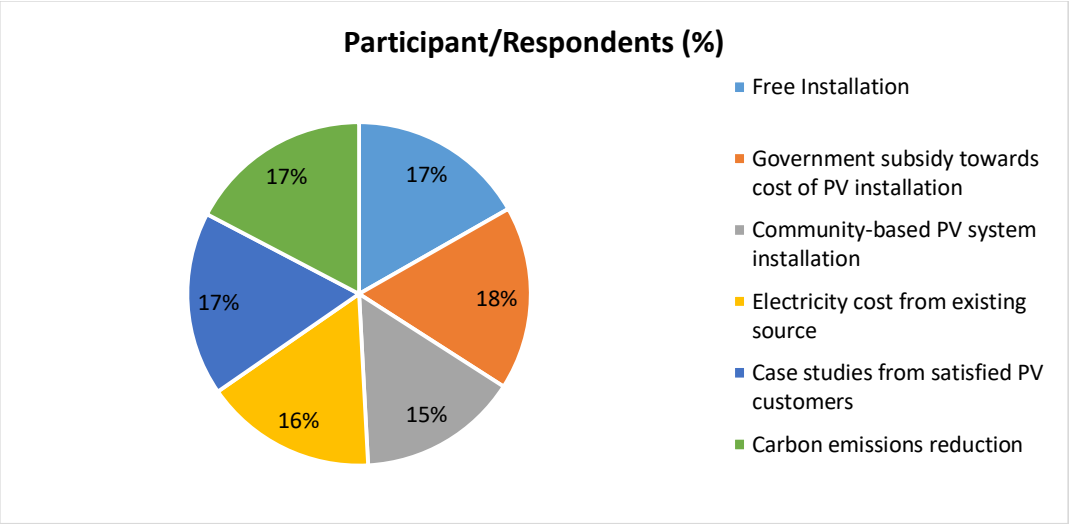


Figure 5-25: Persuading factors for PV system installation.

The results show that carbon emission reductions, government subsidy towards the cost of PV system installation and satisfied PV customers can encourage/persuade people for installing the PV system. This suggests the government supports through subsidy will be relevant to emission reductions that affect the whole economy. The performance of the PV system with proper installation operations will further encourage installation due to existing PV customers' satisfaction in Nigeria.

Question 26: What do you think will help influence GHG emissions reduction?

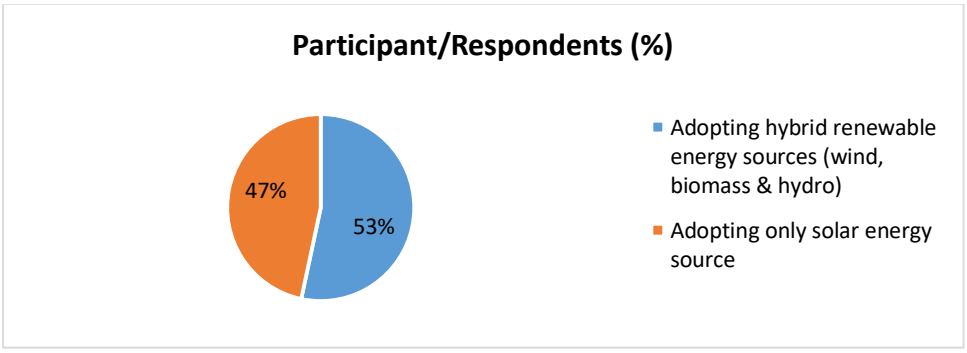


Figure 5-26: Factor of influence for emission reduction.

The results show that hybrid or solar energy source adoption can help greatly for GHG emission reductions in Nigeria.

Question 27: Does government support the PV system use in Nigeria?

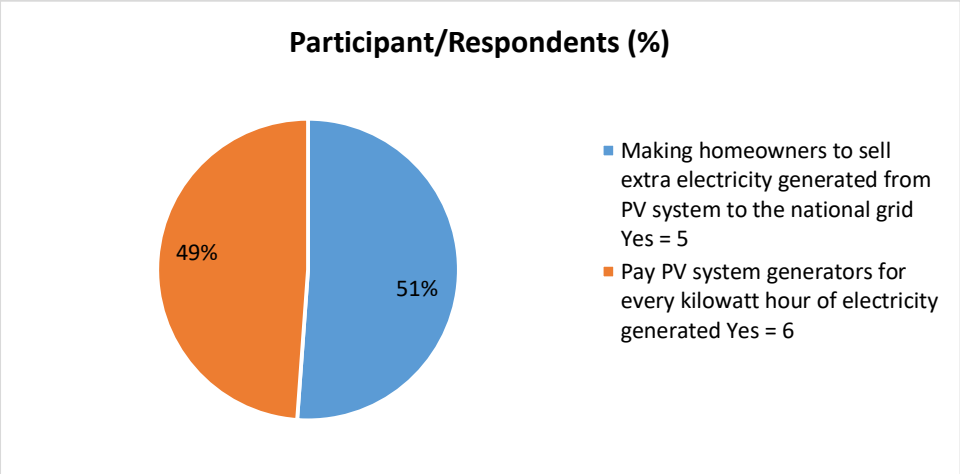


Figure 5-27: Government support to PV system use.

The results show that solar application with government support will be of more influence in paying the generators for every kilowatt-hour of electricity generated with a PV system. This suggests that financial supports capability can be through government or private sector investment in funding, research, and development for motivation.

Question 28: Which of the renewable energy source do you considered installing now?

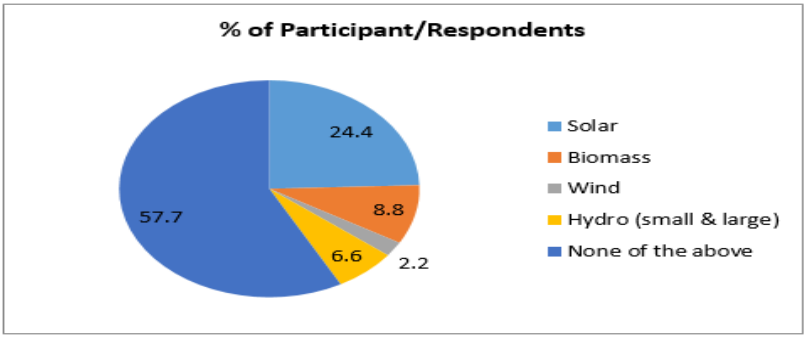


Figure 5-28: Renewable energy considered installing.

The results show that solar PV deployment due to the urgent need for electricity to meet the country's demand is highly preferred.

Question 29: Are the citizens happy to see renewable energy including solar implemented and applied?

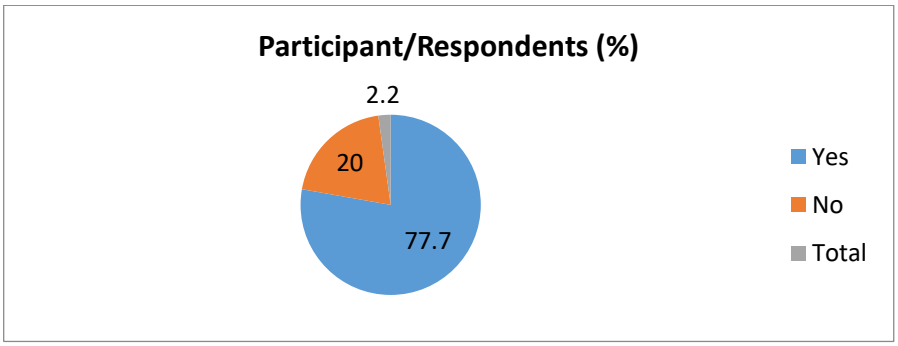


Figure 5-29: The implemented renewables including solar energy.

The results show that most (77.7%) citizens are happy with solar energy implementation and application because solar energy will repair the damaged environment. This suggests that independent use of solar electricity generation can easily meet energy demand, improve people's standard of living and promote energy efficiency, in turn, eradicate energy and abject poverty in the society.

Question 30: Does your home have alternative energy source?

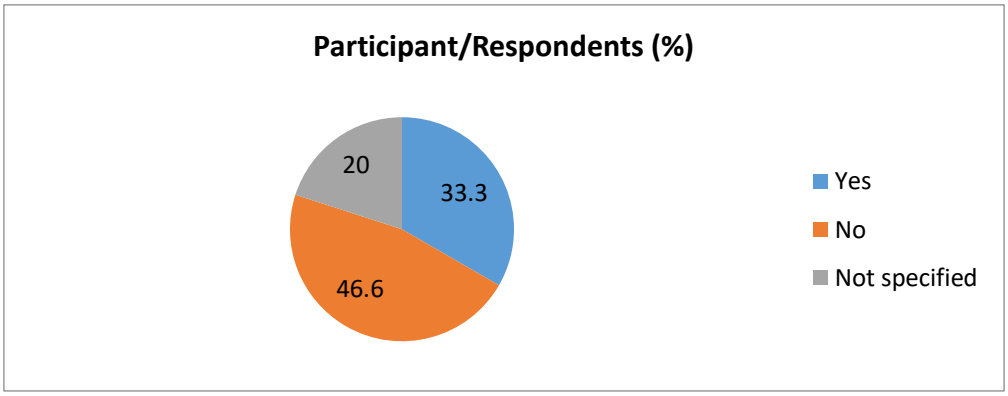


Figure 5-30: Alternative energy source for home.

The results show most participants (46.6%) had no alternative energy source, while (33.3%) participants had an alternative source suggests awareness creation is required for a home/residential deployment with alternative energy sources benefit in Nigeria.

Question 31: Can the citizens benefit or profit more from the use of solar energy?

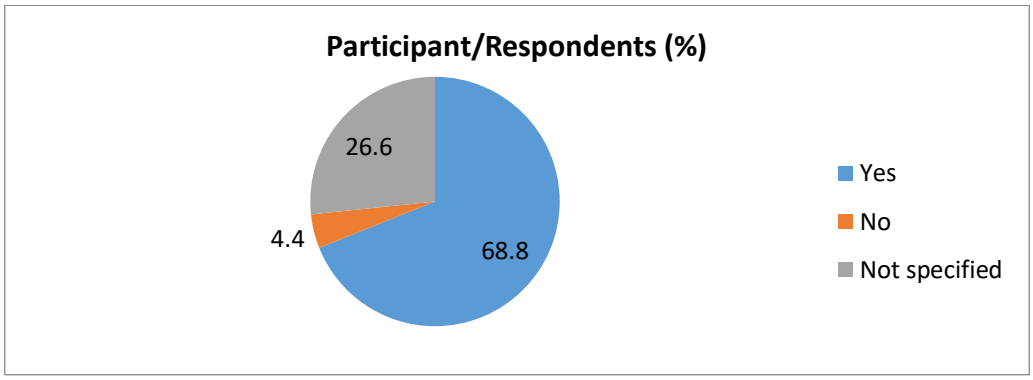


Figure 5-31: The benefit for solar energy use.

The results show that solar energy is beneficial and profitable because it enables small-scale businesses to increase local employment opportunity, enhance productivity through established solar firms with entrepreneurial skills for the benefits of food preservation, improved livelihood and health and comfort life to Nigerians with the electricity consumption.

Question 32: Does cost reduction encourage PV system adoption in homes more than the commercial places?

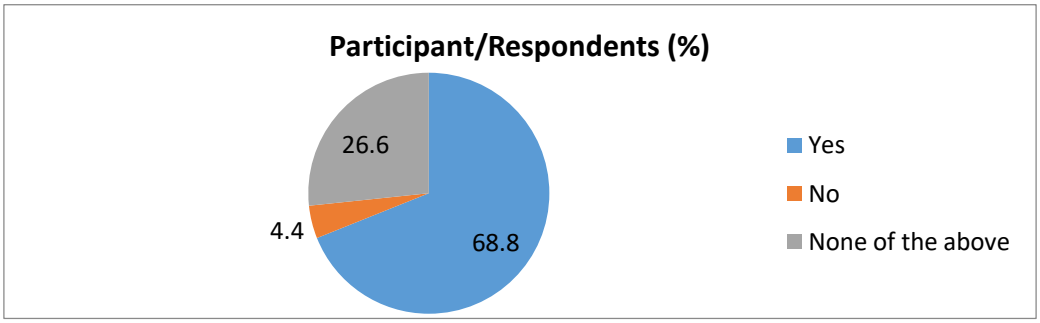


Figure 5-32: The PV system adoption cost reduction.

The results show that further cost reduction could encourage home adoption of PV system than the commercial places because most individual household cannot afford the initial cost of the PV system initial cost. In addition, the largest energy consumer with over 50 percent of the country's population is residential households suggests government financial support with private investment for massive deployment and huge emission reductions in the country.

5.3 Result Discussions

The questionnaire responses by individual participants are anonymous in confidentiality. The attached personal information sheet to the questionnaire distributed for the study has no adverse effect on the participants. The questionnaire is designed to identify how participants perceive the study. The results show favorable positive responses with participants' opinions and based on public acceptance has a social influence on PV system installation.

The percentage represents a number of participants that answer the questions. The general questions from public opinion on cost reduction for electricity generation can be through policy implementation. The perspectives focus on energy-related organizations technically to understand the system operation from the tested pilot projects demonstration in Nigeria. Table 5-1 represents the percentage rate of the distributed questionnaires.

Table 5-1: Questionnaire Distribution and Returned Percentage Rate

Questionnaire	Number
Distributed	57
Returned	45
Total Percentage	79%

Fifty-seven questionnaires distribution to participants represents the country's populations based on reasonable percentage number of people's view about solar energy application in Nigeria. However, the use of quantitative and qualitative research methods provided the best research outcome of 79% total responses presented in the above table.

5.4 Summary

The questionnaire is a piece of self-structured information as well as a collection method that compares study findings quickly and cost-efficiently. The interview as qualitative data enables participants to express views in their own words with the interviewer. The results show influence on the populace re-directing their attention to solar PV system application due to the favourable response by public acceptance in Nigerian communities. Acceptance to solar PV system use for electricity generation by the populations will reduce huge cost of estimated electricity bills for those connected to the grid and make them independent generators in powering their buildings and access to those not connected to the grid. The government incentives considering the economic factors will promote and facilitate investment opportunities of the solar resource with PV system use in Nigeria. However, the people accepting of solar PV system confirmed positive responses with the sampled size and the comparative analysis for major energy sources due to effective performance of the PV system. This encourages future energy users to install more in the country.

CHAPTER 6: CASE STUDY

6.1 Introduction

This chapter describes 11 case studies with weather conditions and a design model that ascertained the electricity generated. The research investigated the 11 solar off-grid case studies in four different state locations including Abuja, Awka, Lagos, and Nsukka in Nigeria. The PV system is used for electricity generation due to solar energy potential and this is because the country has a solar energy resource that is reliable and abundant. The payback period is computed manually to ascertain financial feasibility for the investment decision. Figure 6-1 represents the weather map for the selected PV installation sites with indication of red arrow in Nigeria.



Figure 6-1: Nigeria weather map with red arrow indication of the case study's locations.

6.2 Abuja Area Case Studies

6.2.1 Abuja Weather Condition

Abuja has an average temperature, precipitation with a clear sky and zero clouds covering including the yearly sunshine hours. This location with good weather in June, July, August, and September but often exhibits high temperature. The rainy season falls mostly in May, June, July, August, September, and October and the period of the dry season starts from November, December January, and February. The warmest month is March and August is the coldest month, September is the wettest and January is the driest month. In Abuja metropolis, there are six case studies situated at Guzape; Igu-Bwari; Central district; Karu, Garki, and Wuse location sites with PV installations. Figure 6-2 represents the statistical monthly average temperature, precipitation and yearly sunshine hours.

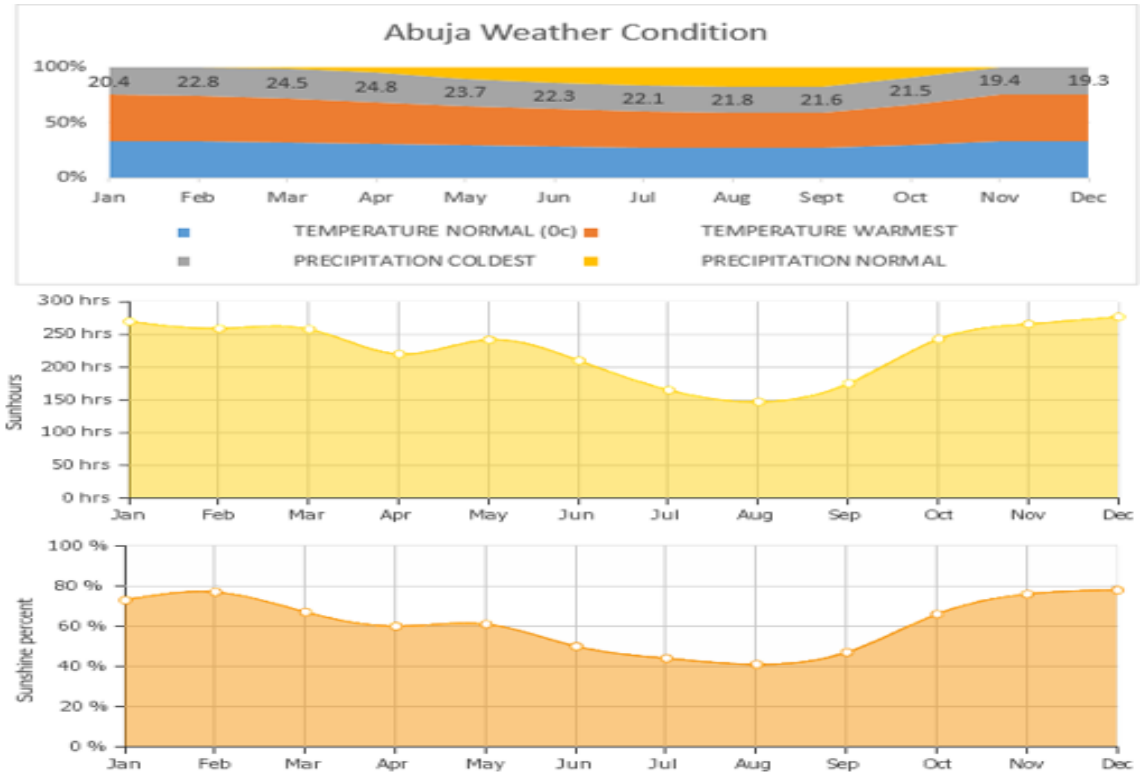


Figure 6-2: The average monthly temperature, precipitation total hours and percentage of sunshine over the year (Source: Copyright© 2016-www.weatherandclimate.com).

6.2.2 Case Study 1: Guzape 33 kW PV Capacity

6.2.2.1 PV Installation

A 33 kW installed an off-grid PV system at Guzape area in Abuja. The building with the PV system is a terrace duplex house with 55 rooms on three floors housing families. Figure 6-3 represents eleven apartment building Installation at Guzape area in Abuja.



Figure 6-3: Eleven Apartment building Installation (Source: Study, 2016).

The Blue Camel Energy designed this off-grid/stand-alone rooftop building application system with PV polycrystalline panel that converts available solar energy into electricity. The inverter converted the DC energy into electrical energy for home appliances/load. The batteries being the energy storage facility used for supply of electricity when needed.

Table 6-1 represents polycrystalline silicon PV system with 240 watts.

Table 6-1: 240W Suntech Polycrystalline PV Panel Specifications

Configuration	Superior frame specifically designed on drainage holes and rigid construction that prevents frame from deforming which is screw less frame design for long term durability.
Application	Off-grid
PV System Capacity Size (kWp)	33
Manufacturer	Suntech
Rated PV Watt (W)	240
PV Type Used	Poly-crystalline
Number of Panels (units)	140
Annual Generation (kWh)	72,576
Mounted Method	Fixed
Number of Batteries	12
Battery Capacity (Ah)	400
Inverter Capacity (kW)	60
Charge controllers	2 of 40 A and 48 A
Angle degree	15^0c
Hours of sunshine	8-9
Peak sunshine	6
PV life span	25

ELECTRICAL CHARACTERISTICS	
STC	PLUTO 240-Wde
Optimum Operating Voltage (Vmp)	29.6 V
Optimum Operating Current (Imp)	8.11 A
Open Circuit Voltage (Voc)	36.9 V
Short Circuit Current (Isc)	8.46 A
Maximum Power at STC (Pmax)	240 W
Module Efficiency	14.5 %
Operating Module Temperature	-40^0c to + 85^0c
Maximum System Voltage	600 VDC (UL)/1000 VDC (IEC)
Maximum Series Fuse Rating	20 A
Power Tolerance	0/+5%

Nominal Operating cell Temperature (NOCT)	PLUTO 240-Wde
Maximum Power at NOCT (Pmax)	176 W
Optimum Operating Voltage (Vmp)	26.9 V
Optimum Operating Current (Imp)	6.54 A
Open Circuit Voltage (Voc)	33.9 V
Short Circuit Current (Isc)	6.84 A

MECHANICAL CHARACTERISTICS	
Solar Cell	Polycrystalline 156 x 156 mm (6 inches)
No. of Cells	60 (6 x 10)
Dimensions	1665 x 991 x 50 mm (65.6 x 39.0 x 2.0 inches)
Weight	19.8 kgs (43.7 lbs)
Front Glass	3.2 mm (0.13 inches) tempered glass
Frame	Black anodized aluminium alloy
Junction Box	IP67 rated
Output Cables	4.0 mm^2 (0.006 $inches^2$) symmetrical lengths (-) 1000 mm (39.4 inches and (+) 1000 mm (39.4 inches)
Connectors	H4 connectors (MC4 compatile)

TEMPERATURE CHARACTERISTICS	
Nominal Operating Cell Temperature (NOCT)	45 ± 2^0c
Temperature Coefficient of Pmax	-0.400%/^{0}c
Temperature Coefficient of Voc	-0.314%/^{0}c
Temperature Coefficient of Isc	-0.051%/^{0}c

(Source: Blue Camel Energy).

Note: Excellent performance under weak light conditions at an irradiation intensity of 200 W/m^2 can achieve 96 percent or higher of STC efficiency of 1000 W/m^2 STC: Irradiance 1000 W/m^2, Module temperature: 25^0c, AM: 1.5 Best in class AAA solar simulator (IEC 60904-9) used, Power measurement uncertainty within +/-3%. NOCT: Irradiance 800 W/m^2, ambient temperature: 20^0c, AM: 1.5, Wind speed: 1 m/s best in class AAA solar simulator (IEC 60904-9) (Suntech, 2012).

The installed 33 kW PV system in this case technically generates 72,576 kWh/year.

6.2.2.2 Breakdown Cost Investment

The investment breakdown costs include the module, inverter, battery, operation and maintenance costs (O&M) with a projection of ten years including other installation costs, etc. Table 6-2 indicates the total cost for solar PV installation with all components and labour expenses at the location. Table 6-2 represents cost breakdown of the business model for the apartments due to load consumption from the generation supply to the building. However, the maintenance and battery replacement is the projection over 10 years' time.

Table 6-2: Business Model Cost Breakdown

N/S	Cost	Amount Invested (N)
A	Initial investment	N14,828,000
B	Maintenance & battery replacement over 10 years	N10,000,000
C	Yearly maintenance cost	N1,000,000
D	Labour cost	N972.00
E	Monthly labour cost excluding interest rate (funding not borrowed)	N29,160 (i.e. 972 x 365)

F	Yearly cost excluding interest rate (funding not borrowed)	1,000,000 + 29,160 (C + E) = 1,029,160
G	Income based on yearly consumption with electricity rate	N7,347,890 (66,799 x 110)

(Source: Blue Camel Energy and Research, 2016).

Table 6-3: Appliances for Study data Generation and Consumption

Appliance	Quantity	App. Watt	No. of Hours Used	Total Watt Con/day	Gen Watt/day	Variance b/w Gen and Con	% Utilized
Bulb	55	11	12	7250			
Fan	10	100	12	12000			
TV	10	188	6	11280			
Fridge	10	160	18	28800			
Freezer	10	200	18	36000			
Elec/Cooker	10	1000	1	10000			
Computer	10	100	8	8000			
A/C	6	1119	8	53712			
Blender	10	300	1	3000			
Microwave	10	750	1	7500			
Iron	10	90	1	900			
W/Pumping	1	600	1	600			
W/Machine	5	1300	1	6500			
Total				185552	201600	16048	92%

The electricity from the installed panels with an average 6 hours' peak sunshine generated 201.6 kWh/day or 72,576 kWh/year. The generation and consumption shown in Table 6-4. It is advisable to increase the number of appliances to maximize the generated power. Figure 6-4 represents the total power (watt) with the installed kilowatt (kW) capacity. Table 6-5 represents the RET Screen simulation results for off-grid system.

Table 6-4: Generation over Consumption

Case Study 1	Total Watt Consumed/day (W)	Total Watt Generated/day (W)	% of Generation over Consumption	% of Maximum watt consumable/day	Excess Utilized (%)
Guzape Estate	185,552	201,600	192	100	92

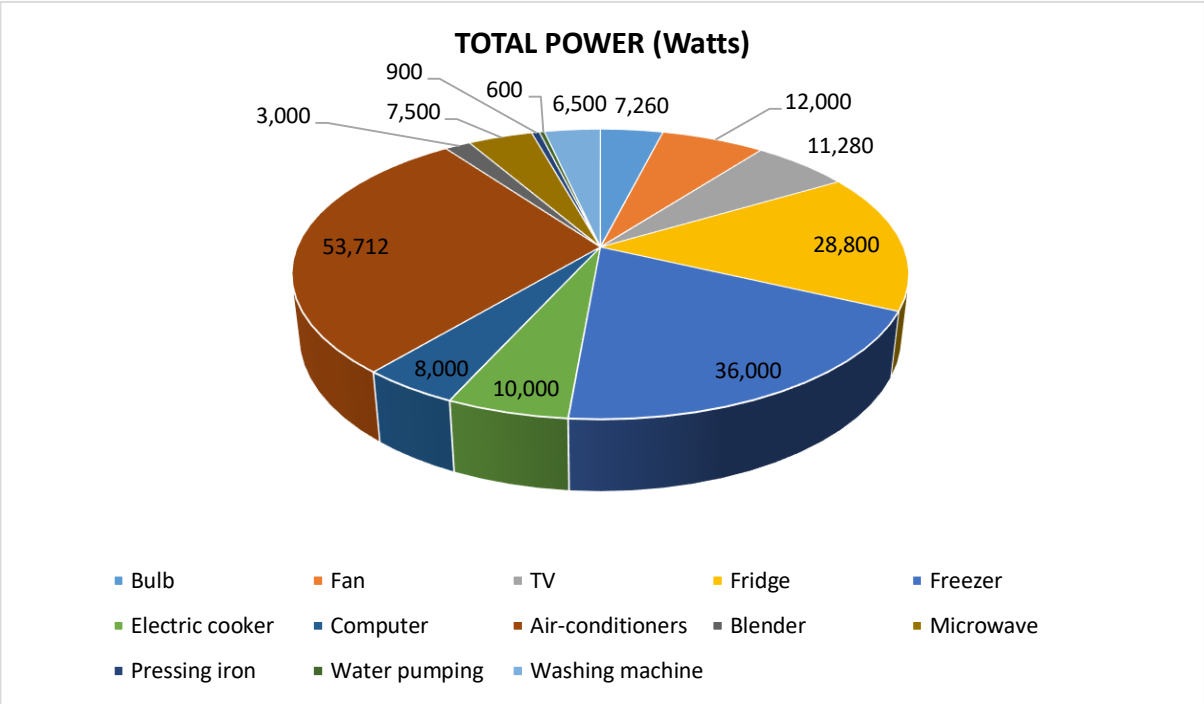


Figure 6-4: The total power in watts.

Table 6-5: Case Study 1 Off-grid Base Case Simulation

Grid type	Off-grid
Technology	Grid Electricity
Fuel Rate (NGN)	110.00
Capacity (NGN/kWh)	33
Annual O&M Cost (NGN)	3,630
Electricity Rate-Base Case (NGN/kWh)	110.090
Total Electricity Cost (NGN)	4,420,130

Table 6-6 represents the current national electricity fuel rate that is equal to GBP0.06 (N24.30), and the solar company's electricity rate GBP0.3 (N110) that is used for proposed central grid-connection in Nigeria. They both generated the same capacity with a little fraction on yearly cash-flow. For example, the cumulative cash flow for 25 years realized the sum of GBP37, 011 (N14, 909,463) with N110 rate or GBP36, 701 (N14, 845,996) with N24.30 rate return. The difference between them is equal to GBP311 (N63, 467) cash-flow benefit to the generator. However, the national electricity rate classified to be a public good is highly subsidized in Nigeria. The cash-flow from a business perspective may not account much because the energy generated is most needed. However, the cumulative cash flows for PV life cycle in appendix 6.

Table 6-6: Proposed Grid-Connected with the current National and Solar Company's Rate

Analysis Type			Method 2	
Solar Tracking mode			Fixed	
Angle/slope			15^0	
Month	Horizontal Daily Solar Radiation ($kWh/m^2/day$)	Tilted Daily Solar Radiation ($kWh/m^2/day$)	Electricity Export Rate (NGN/MWh)	Electricity Exported to Grid (MWh)
January	5.88	6.56	24.30	5.832
February	6.09	6.49	24.30	5.192
March	6.27	6.36	24.30	5.639
April	6.06	5.84	24.30	5.070
May	5.58	5.19	24.30	4.674
June	5.06	4.65	24.30	4.086
July	4.44	4.14	24.30	3.804
August	4.19	4.02	24.30	3.710
September	4.73	4.69	24.30	4.155
October	5.31	5.53	24.30	5.006
November	5.98	6.60	24.30	5.702
December	5.86	6.64	24.30	5.905
Annual	5.45	5.55	24.30	58.774
Horizontal		MWh/m^2	1.99	
Tilted		MWh/m^2	2.03	

Analysis Type			Method 2	
Solar Tracking mode			Fixed	
Angle/slope			15^0	
Month	Horizontal Daily Solar Radiation ($kWh/m^2/day$)	Tilted Daily Solar Radiation ($kWh/m^2/day$)	Electricity Export Rate (NGN/MWh)	Electricity Exported to Grid (MWh)
January	5.88	6.56	110	5.832
February	6.09	6.49	110	5.192
March	6.27	6.36	110	5.639
April	6.06	5.84	110	5.070
May	5.58	5.19	110	4.674
June	5.06	4.65	110	4.086
July	4.44	4.14	110	3.804
August	4.19	4.02	110	3.710
September	4.73	4.69	110	4.155
October	5.31	5.53	110	5.006
November	5.98	6.60	110	5.702
December	5.86	6.64	110	5.905
Annual	5.45	5.55	110	58.774
Horizontal		MWh/m^2	1.99	
Tilted		MWh/m^2	2.03	

6.2.2.3 Rationale Evaluation

Case study 1 represents the amount of generation that could meet consumption and investment based on financial viability. The system generated adequate electricity 72,576kWh per year with 33 kW capacity. This case with very good return resulted in short payback due to the capacity installed and high invested capital. The electricity generated was more useful to waste based on the quantity generated and consumed. The standard electricity rate of (N110) compared to the national rate (N24.30) attracted huge yearly returns/savings. In addition, this case study projected battery and maintenance cost breakdown over 10 years even though not up to 10 years of installation. Table 6-7 presents the computation of generation, consumption and payback period.

Table 6-7: Computation of Generation, Consumption and Payback

INVESTMENT POTENTIAL COMPUTATION						
LOCATION	CASE STUDY CAPACITY (kW)	YEARLY POWER CONSUMPTION (kWh)	ELECTRICITY RATE (N/kWh)	AMOUNT YEARLY/SAVING (N)	CAPITAL INVESTMENT (N)	PAYBACK PERIOD (YEAR)
Guzape District Estate Abuja	33	66,799	110	6,606,490	14,828,000	2.2

GENERATION OUTPUT CONSUMPTION AND PAYBACK PERIOD				
CASE STUDY	PV CAPACITY (kW)	POWER GENERATION YEARLY (kWh)	POWER CONSUMPTION YEARLY (kWh)	PAYBACK PERIOD (YEAR)
1	33	72,576	66,799	2.2

AVERAGE RETURN ON INVESTMENT PER YEAR USING PAYBACK PERIOD			
CASE STUDY	AMOUNT INVESTED (N)	PAYBACK PERIOD (YEARS)	AVERAGE AMOUNT REALIZED PER YEAR (N/YR)
1	14,828,000	2.2	6,606,490

6.2.3 Case Study 2: Igu-Bwari Community

The Igu-Bwari is a remote community area of Abuja that the government installed 5 kW PV panels for solar electrification. This project financed by the federal government with high investment capital for the small capacity installed as shown in Table 6-14 is off-grid pilot project demonstrated to promote solar electricity generation with the installation of a PV system in Nigeria. The energy commission of Nigeria (ECN) established by the federal government in 2011 supervised the project with other government agencies such as the National Centre for Energy Research and Development (NCERD), and Sokoto Energy Research Centre (SERC). There is no grid-connection presently to warrant electricity generated sold to the grid from the off-grid installation. The literature finding also revealed that no grid-

connected renewable energy project operating except for hydropower in Nigeria (McKinsey analysis and NERC, 2015). This study with this information proposed grid-connection for more adequate generation from off-grid cases simulations for a grid-tied system to meet peak demand. Figure 6-5 shows the map location of Igu-Bwari area in Abuja which indicated in brown colour cone.



Figure 6-5: Map of Igu-Bwari area location in Abuja with brown colour indication.

The Igu-Bwari installed 5 kW PV panels situated in a remote community area of Abuja as indicated in Figure 6-6 presents the PV specifications used with 235-watt model and other components for the electricity generation.



Figure 6-6: 5kW Mini Grid PV capacity installation in Igu-Bwari Community.

Table 6-8: Solar World 230W Monocrystalline PV and the Technical Specifications

Configuration	
Application	Off-grid
PV System Capacity Size (kWp)	5
Manufacturer	Solar World
Rated PV Watt (W)	235
PV Type Used	Mono-crystalline
Number of Panels (units)	24
Annual Generation (kWh)	16,243
Mounted Method	Fixed
Number of Batteries	24
Battery Capacity (Ah)	200
Inverter Capacity (kW)	5
Hours of sunshine	8
Peak sunshine hours	5
PV life span	25
Commencement Date	2011

ELECTRICAL CHARACTERISTICS	
SW 230	
Performance Under standard Test Conditions (STC): 1000W/m^2, 25^{0}c, AM 1.5	
Maximum Power (Pmax)	230 Wp
Open circuit voltage (Voc)	37.4 V
Maximum power point voltage (Vmpp)	30.0 V
Short circuit current (Isc)	8.16 A
Maximum power point current (Impp)	7.68 A
Performance at 800 W/m^2, NOCT, AM 1.5	
Maximum Power (Pmax)	166.9 Wp
Open circuit voltage (Voc)	33.9 V
Maximum power point voltage (Vmpp)	27.2 V
Short circuit current (Isc)	6.58 A
Maximum power point current (Impp)	6.14 A
Thermal Characteristics	
NOCT	46^{0}c
TC (Isc)	0.004%/k
TC (Voc)	-0.30%/k
TC (Pmpp)	-0.45%/k
Operating temperature	-40^{0}c to 85^{0}c
Component Materials	
Cell per module	60
Cell type	Monocrystalline
Cell dimensions	6.14 in x 6.14 (156 mm x 156 mm)
Front	Tempered glass (EN 12150)
Frame	Clear anodized aluminum
Weight	46.7 lbs (21.2 kg)
System Integration Parameters	
Maximum system voltage SC11	1000 V
Max. system voltage USA NEC	600 V
Maximum reverse current	16 A
Number of bypass diodes	3
UL Maximum Test Load	45 psf (2.1 kN/m^2)
IEC Maximum Snow Test Load	113 psf (5.4kN/m^2)
Additional Data	
Power tolerance	-0 Wp/+5 Wp
J-Box	IP65
Connector	MC4
Module efficiency	13.72%
Fire rating (UL 790)	Class C

(Source: Fieldwork and ECN, 2016).

Note: Minor reduction in efficiency under partial load conditions at 25^{0}c from 200W/m^2, 95% (+/-3%) of STC efficiency (1000 W/m^2). Appropriate factors of safety applied according to the test standard and local building code requirements when designing a PV system.

6.2.3.1 PV Installations

This project demonstrated the PV system potential for solar electrification in the rural-remote area of Nigerian states. This project executed by the government to provide electricity access to locations without national grid access due to wire extension cost for the connection. The

outcome shows best-case-scenario in the location unlike a few other locations with non-functionality. The community presently enjoys cost-effective electricity with a conducive environment as presented in Figure 6-7.



Figure 6-7: Some ECN and SERC solar electrification installations (Source: ECN 2005).

6.2.3.2 Breakdown Cost Investment

Table 6-9 indicates financial breakdown for cost analysis of solar PV system in the location and other components used for the investment. Table 6-10 presents the consumption (appliances) and generation.

Table 6-9: Business Model Cost Breakdown

PV Installed capacity (kW)	Item Description	Quantity	Unit Cost (NGN): N:K	Amount (NGN): N:K	Total Investment (NGN): N:K
5	PV Module	32	100,000	3,200,000	
	Deep-cycle batteries	17	95,000	1,615,000	
	Charge controller	4	60,000	240,000	
	Inverter	2	170,000	340,000	
	Supporting structure	-	400,000	400,000	
	Cost of Accessories	-	200,000	200,000	
	Contingency/transport	-	240,000	240,000	
	Labour	-	-	200,000	
Total					N6,435,000.00

Table 6-10: Appliances for Study data Generation and Consumption

Appliance type	Quantity	Appliance wattage	No. of hours used	Total watt consumed per day (Wh)	Generation watt per day (Wh)	Variance between generation & consumption	% Utilized
Lighting bulb	80	3	24	5,760			
Security bulb	80	5	24	9,600			
Total				15360	45120	29760	34%

The electricity from installed PV panels' generated 16,243 kWh/year can meet full load capacity with more appliances. Table 6-11 shows the total generation and consumption. It is advisable to increase the number of appliances to maximize generated power. Figure 6-8 presents the total amount of energy consumed in the pie chart. Table 6-12 represents the RET Screen simulation results in this study.

Table 6-11: Generation over Consumption

Case Study 2	Total Watt Consumed/day (W)	Total Watt Generated/day (W)	% of Generation over Consumption	% of Maximum watt consumable/day	Excess Utilized (%)
Igu-Bwari	15,360	45,120	134	100	34

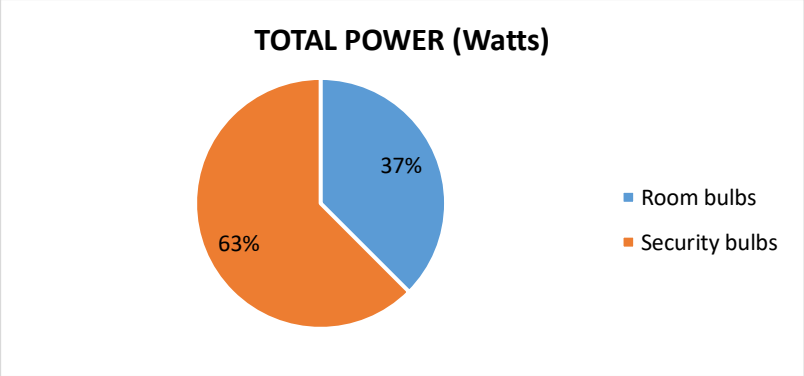


Figure 6-8: The total power in watts.

Table 6-12: Case Study 2: Off-grid Base Case Simulation

Grid type	Off-grid
Technology	Grid Electricity
Fuel Rate (NGN)	110.00
Capacity (NGN/kWh)	5
Annual O&M Cost (NGN)	550

Electricity Rate-Base Case (NGN/kWh)	110.014
Total Electricity Cost (NGN)	4,417,060

Table 6-13: Proposed Grid-connected with current National and Solar Company's Rate

Analysis Type		Method 2		
Solar Tracking mode		Fixed		
Angle/slope		15^0		
Month	Horizontal Daily Solar Radiation ($kWh/m^2/day$)	Tilted Daily Solar Radiation ($kWh/m^2/day$)	Electricity Export Rate (NGN/MWh)	Electricity Exported to Grid (MWh)
January	5.88	6.56	24.30	0.902
February	6.09	6.49	24.30	0.803
March	6.27	6.36	24.30	0.872
April	6.06	5.84	24.30	0.784
May	5.58	5.19	24.30	0.723
June	5.06	4.65	24.30	0.632
July	4.44	4.14	24.30	0.588
August	4.19	4.02	24.30	0.574
September	4.73	4.69	24.30	0.642
October	5.31	5.53	24.30	0.774
November	5.98	6.60	24.30	0.882
December	5.86	6.64	24.30	0.913
Annual	5.45	5.55	24.30	9.087
Horizontal		MWh/m^2	1.99	
Tilted		MWh/m^2	2.03	

Analysis Type		Method 2		
Solar Tracking mode		Fixed		
Angle/slope		15^0		
Month	Horizontal Daily Solar Radiation ($kWh/m^2/day$)	Tilted Daily Solar Radiation ($kWh/m^2/day$)	Electricity Export Rate (NGN/MWh)	Electricity Exported to Grid (MWh)
January	5.88	6.56	110.0	0.902
February	6.09	6.49	110.0	0.803
March	6.27	6.36	110.0	0.872
April	6.06	5.84	110.0	0.784
May	5.58	5.19	110.0	0.723
June	5.06	4.65	110.0	0.632
July	4.44	4.14	110.0	0.588
August	4.19	4.02	110.0	0.574
September	4.73	4.69	110.0	0.642
October	5.31	5.53	110.0	0.774
November	5.98	6.60	110.0	0.822
December	5.86	6.64	110.0	0.913
Annual	5.45	5.55	110.0	9.087
Horizontal		MWh/m^2	1.99	
Tilted		MWh/m^2	2.03	

Table 6-13 presents the current national electricity fuel rate GBP0.06 (N24.30) and solar company's electricity rate GBP0.3 (N110) due to the proposed central grid-connection in Nigeria. They generated the same amount in capacity with a little fraction on yearly cash flow (N/kWh or MWh). For example, the cumulative cash flow for 25 years' realized GBP15, 951

(N6, 459,989) using N110 rate and GBP15, 903 (N6, 440,520) using N24.30 rate. The difference between them is equal to GBP48 (N19, 469).

6.2.3.3 Rationale Evaluation

Case study 2 shows a long payback period from less consumption to generation with high investment capital based on the capacity installed. The standard electricity rate (N110) attracted good yearly return/savings. The government pilot project helps to reduce short-term costs for long-term benefits particularly rural-remote areas with scare income and without national grid connections. The literature finding confirmed that government incentives with long-term payback through the financing of pilot project reduced short-term costs while making solar PV project relatively cost-effective for long-term benefits, to support PV investment and boost solar energy deployment in Nigeria (Oyedepo, 2012). In addition, solar energy potential for electricity generation depends on the amount of investment and capacity installed in Nigeria. Table 6-14 presents sufficient generation, which provided the people with modern solar electrification access services in the community.

Table 6-14: Generation Consumption, and Payback Computation

INVESTMENT POTENTIAL COMPUTATION						
LOCATION	CASE STUDY CAPACITY (kW)	YEARLY POWER CONSUMPTION (kWh)	ELECTRICITY RATE (N/kWh)	AMOUNT YEARLY/SAVING (N)	CAPITAL INVESTMENT (N)	PAYBACK PERIOD (YEAR)
ECN IGU-BWARI ABUJA	5	5,530	110	286,550	6,435,000	15.4
GENERATION OUTPUT CONSUMPTION AND PAYBACK PERIOD						
CASE STUDY	PV CAPACITY (kW)	POWER GENERATION YEARLY (kWh)	POWER CONSUMPTION YEARLY (kWh)	PAYBACK PERIOD (YEAR)		
2	5	16,243	5,530	15.4		
AVERAGE RETURN ON INVESTMENT PER YEAR USING PAYBACK PERIOD						

CASE STUDY	AMOUNT INVESTED (N)	PAYBACK PERIOD (YEARS)	AVERAGE AMOUNT REALIZED PER YEAR (N/YR)
2	6,435,000	15.4	286,550

6.2.4 Case Study 3: Central Area District of Abuja Location

Case study 3 site is in central area district that has many government offices. Figure 6-9 presents the location with a red dotted circle.

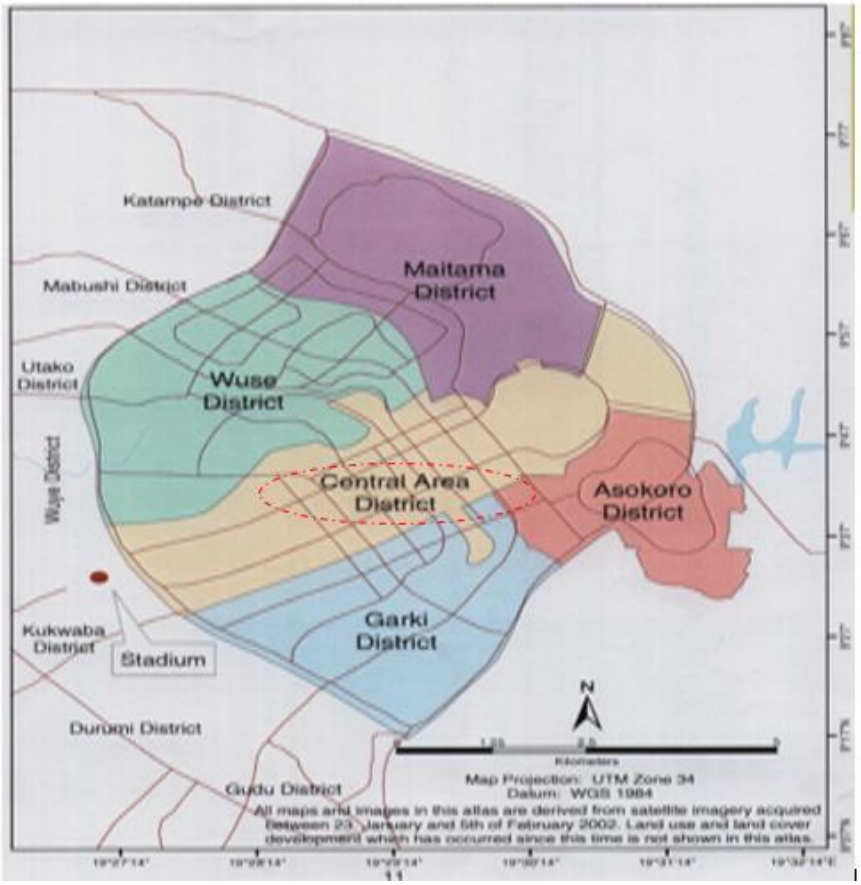


Figure 6-9: Location with a Red spotted Circled Line.

6.2.4.1 Abuja Central District 3.2 kW PV Installation

Figure 6-10 presents air-conditioner powered by solar PV system in the location. Table 6-15 presents the PV system specifications and other components used for electricity generation in the location.



Figure 6-10: Powered Air-conditioner installation (Window unit).

Table 6-15: Sun power SPR-210-WHT Monocrystalline PV System and the Technical Specifications

Configuration	A sturdy anodized frame that allows panel to operate reliably in multiple mounting.
Application	Off-grid
PV System Capacity Size (kWp)	3.2
Manufacturer	Sunpower
Model	SPR-210-WHT
Rated PV Watt (W)	210
PV Type Used	Mono-crystalline
Number of Panels (units)	16
Area covered (m^2)	21
Annual Generation (kWh)	9,677
Mounted Method	Fixed
Number of Batteries	8
Battery Capacity (Ah)	200
Battery days of Autonomy	3
Inverter Capacity (kW)	4.2
Inverter Efficiency (%)	98
Charge controllers	2 of 40 A and 48 V
Angle degree	15^0c
Hours sunshine	8-9 (Average =8)
PV life span	25
Commencement Date	June 2015

ELECTRICAL CHARACTERICS	
STC is defined as: Irradiance of 1000w/m^2, Spectrum AM: 1.5g and Cell Temperature of 25^0c	
Peak Power (Pmax)	210 W
Rated Voltage (Vmp)	40.0V
Rated Current (Imp)	5.25A
Open circuit Voltage (Voc)	47.7V
Short Circuit Current (Isc)	5.75A
Series Fuse Rating	15A
Maximum System Voltage	600V (UL)
	1000C (IEC)
Module Efficiency	16.9%
Peak Power per Unit Area	15.7W/sq.ft.; 169W/m^2
PTC Rating	193.7W
Peak Power Tolerance	+/-5%
Power Guarantee	25
TEMPERATURE COEFFICIENTS	
Power	-0.38%/^{0}c
Voltage (Voc)	-136.8mV/^{0}c
Current (Isc)	3.5mA/^{0}c
MECHNICAL SPECIFICATIONS	
Length	61.39 in x 31.42 in (1559 mm x 798 mm)
Thickness including Junction box	1.81 in (46 mm)
Weight	33 lbs (15 kg)

This project is designed for domestic household use specifically for the air-conditioner to reduce the load on weak grid infrastructure services and to offset electricity costs associated with the cooling demand. However, the practical limitations of conventional electricity make PV off-grid cooling system technically feasible and economically viable.

6.2.4.2 Breakdown Cost Investment

Table 6-16 indicates a financial breakdown of the solar PV system including other components and labour expenses for the investment. Table 6-17 presents generation and consumption.

Table 6-16: Business Model Cost breakdown

PV INSTALLED CAPACITY (kW)	ITEM DESCRIPTION	QUANTITY	UNIT COST	AMOUNT	TOTAL
3.2	PV Panel	16	30,000 (DP)	480,000	
	Inverter	1	370,000	370,000	
	Battery	8	56,000	448,000	
	Installation			50,000	
Total					N1,348,000.00

Table 6-17: Appliances for Study data Generation and Consumption

Appliance	Quantity	App. Watt	No. of Hours Used	Total Watt Con/day	Gen Watt/year	Variance b/w Gen and Con	% Utilized
Air-conditioner	2	1119	8	17904	26880	8976	67%

The PV panels generated 26.9 kWh/day electricity or 9,677 kWh/year. The installed PV capacity can meet all the full load capacity with the excess generation of 8,976 kWh (67%). Table 6-18 shows the percentage of power consumption out of total generation. Figure 6-11 shows a plotted chart used to demonstrate the total amount of power from the installed system. Table 6-19 represents the RET Screen simulation results in this study.

Table 6-18: Generation over Consumption

Case Study 3	Total Watt Consumed/day (W)	Total Watt Generated/day (W)	% Generation over Consumption	% of Maximum Watt Consumable/day	Excess Utilized (%)
Abuja central	17,904	26,880	167	100	67

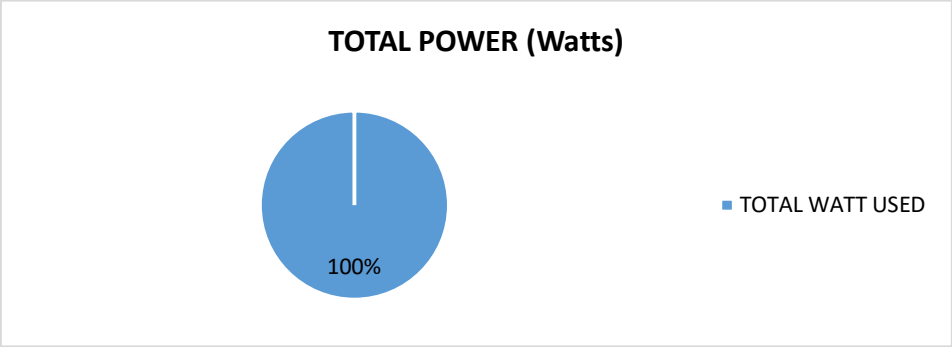


Figure 6-11: The total power in watts for Air-conditioner.

Table 6-19: Case Study 3 Off-grid Base Case Simulation

Grid type	Off-grid
Technology	Grid Electricity
Fuel Rate (NGN)	110.00
Capacity (NGN/kWh)	3.2
Annual O&M Cost (NGN)	352
Electricity Rate-Base Case (NGN/kWh)	110.009
Total Electricity Cost (NGN)	4,416,852

Table 6-20: Proposed Grid-connected with current National and Solar Company's Rate

			Method 2	
Solar Tracking mode			Fixed	
Angle/slope			15^0	
Month	Horizontal Daily Solar Radiation ($kWh/m^2/day$)	Tilted Daily Solar Radiation ($kWh/m^2/day$)	Electricity Export Rate (NGN/MWh)	Electricity Exported to Grid (MWh)
January	5.88	6.56	24.30	0.577
February	6.09	6.49	24.30	0.514
March	6.27	6.36	24.30	0.558
April	6.06	5.84	24.30	0.502
May	5.58	5.19	24.30	0.463
June	5.06	4.65	24.30	0.404
July	4.44	4.14	24.30	0.376
August	4.19	4.02	24.30	0.367
September	4.73	4.69	24.30	0.411
October	5.31	5.53	24.30	0.495
November	5.98	6.60	24.30	0.564
December	5.86	6.64	24.30	0.584
Annual	5.45	5.55	24.30	5.816
Horizontal		MWh/m^2	1.99	
Tilted		MWh/m^2	2.03	

Analysis Type			Method 2	
Solar Tracking mode			Fixed	
Angle/slope			15^0	
Month	Horizontal Daily Solar Radiation ($kWh/m^2/day$)	Tilted Daily Solar Radiation ($kWh/m^2/day$)	Electricity Export Rate (NGN/MWh)	Electricity Exported to Grid (MWh)
January	5.88	6.56	110.0	0.577
February	6.09	6.49	110.0	0.514
March	6.27	6.36	110.0	0.558
April	6.06	5.84	110.0	0.502
May	5.58	5.19	110.0	0.463
June	5.06	4.65	110.0	0.404
July	4.44	4.14	110.0	0.376
August	4.19	4.02	110.0	0.367
September	4.73	4.69	110.0	0.411
October	5.31	5.53	110.0	0.495
November	5.98	6.60	110.0	0.564
December	5.86	6.64	110.0	0.584
Annual	5.45	5.55	110.0	5.816
Horizontal		MWh/m^2	1.99	
Tilted		MWh/m^2	2.03	

Table 6-20 presents the current national electricity fuel rate of GBP0.06 (N24.30) for the proposed central grid-connection and solar company's electricity rate GBP0.3 (N110) (USD $0.30). They both generated the same amount of electricity and a slight difference for the yearly cash-flow. The cash flow for 25 years' with N110 rate GBP3, 368 (N1, 363,993) and GBP3, 337 (N1, 351,533) with N24.30 rate. The difference between them is equal to GBP31 (N12, 460).

6.2.4.3 Rationale Evaluation

Case study 3 shows short-term payback period because of the huge return on investment. The amount invested is reasonable based on consumption and generation. This off-grid investment system potential for individual home installation project and the electricity rate of N110 do not involve electricity sale to the national grid. As outlined in Chapter 2 summary, the literature finding revealed a limited publication for the grid-connection system in Nigeria. Table 6-21 presents a sufficient amount of solar electricity generated to less consumption that powered air-conditioner reduced emissions around the surrounding location.

Table 6-21: Generation Consumption, and payback Computation

INVESTMENT POTENTIAL COMPUTATION						
LOCATION	CASE STUDY CAPACITY (kW)	YEARLY POWER CONSUMPTION (kWh)	ELECTRICITY RATE (N/kWh)	AMOUNT YEARLY/SAVING (N)	CAPITAL INVESTMENT (N)	PAYBACK PERIOD (YEAR)
CENTRAL DISTRICT ABUJA	3.2 kW	6,445	110	641,550	1,348,000	2
GENERATION OUTPUT CONSUMPTION AND PAYBACK PERIOD						
CASE STUDY	PV CAPACITY (kW)	POWER GENERATION YEARLY (kWh)	POWER CONSUMPTION YEARLY (kWh)	PAYBACK PERIOD (YEAR)		
3	3.2	9,677	6,445	2		
AVERAGE RETURN ON INVESTMENT PER YEAR USING PAYBACK PERIOD						

CASE STUDY	AMOUNT INVESTED (N)	PAYBACK PERIOD (YEAR)	AVERAGE AMOUNT REALIZED PER YEAR (N/YR)
3	1,348,000	2	641,550

6.2.5 Case Study 4: Karu Residential Home

This residential location is in the largest cities of FCT-Abuja with blue arrow indication. Figure 6-12 represents Karu Location area with Blue arrow in Abuja. Figure 6-13 represents the residential (Home) solar PV installation.



Figure 6-12: Karu Location area with Blue arrow in Abuja.

6.2.5.1 Karu 2.16 Kilowatt PV Capacity Installation

This is the PV system on the rooftop at Karu city surrounded by the green environment. Table 6-22 presents the PV model technical specifications and other components used for electricity generation.



Figure 6-13: Residential (Home) solar PV installation.

Table 6-22: Solar World 230W Monocrystalline PV System and the Technical Specifications

Configuration	
Application	Off-grid
PV System Capacity Size (kWp)	2.16
Manufacturer	Solar World
Rated PV Watt (W)	230
PV Type Used	Mono-crystalline
Number of Panels (units)	17
Annual Generation (kWh)	14,076
Mounted Method	Fixed
Number of Batteries	9
Battery Capacity (Ah)	200
Days of Autonomy	3
Inverter Capacity (kW)	2.16
Charge controllers	2 of 40 A and 48 V
Depth of Discharge (%)	80
Angle degree	$15^{o}c$
Average radiation intensity	$600w/m^{2}$
Hours sunshine	10
Daily hour use	9
PV life span	25

SW 230	
Performance Under standard Test Conditions (STC): 1000W/m^2, 25^{0}c, AM 1.5	
Maximum Power (Pmax)	230 Wp
Open circuit voltage (Voc)	37.4 V
Maximum power point voltage (Vmpp)	30.0 V
Short circuit current (Isc)	8.16 A
Maximum power point current (Impp)	7.68 A
Performance at 800 W/m^2, NOCT, AM 1.5	
Maximum Power (Pmax)	166.9 Wp
Open circuit voltage (Voc)	33.9 V
Maximum power point voltage (Vmpp)	27.2 V
Short circuit current (Isc)	6.58 A
Maximum power point current (Impp)	6.14 A
THERMAL CHARACTERISTICS	
NOCT	46^{0}c
TC (Isc)	0.004%/k
TC (Voc)	-0.30%/k
TC (Pmpp)	-0.45%/k
Operating temperature	-40^{0}c to 85^{0}c

Component Materials	
Cell per module	60
Cell type	Monocrystalline
Cell dimensions	6.14 in x 6.14 (156 mm x 156 mm)
Front	Tempered glass (EN 12150)
Frame	Clear anodized aluminum
Weight	46.7 lbs (21.2 kg)
System Integration Parameters	
Maximum system voltage SC11	1000 V
Max. system voltage USA NEC	600 V
Maximum reverse current	16 A
Number of bypass diodes	3
UL Maximum Test Load	45 psf (2.1 kN/m^2)
IEC Maximum Snow Test Load	113 psf (5.4kN/m^2)
Additional Data	
Power tolerance	-0 Wp/+5 Wp
J-Box	IP65
Connector	MC4
Module efficiency	13.72%
Fire rating (UL 790)	Class C

Note: Minor reduction in efficiency under partial load conditions at 25^0c from 200W/m^2, 95% (+/-3%) of the STC efficiency (1000 W/m^2) achieved.

6.2.5.2 Breakdown Cost of Investment

Table 6-23 indicates the financial breakdown including other components and labour expenses incurred from the investment. Table 6-24 shows consumption and generation.

Table 6-23: Business Model Cost Breakdown

PV Installed capacity (kW)	Item Description	Quantity	Unit Cost (NGN): N:K	Amount (NGN): N:K	Total Investment (NGN): N:K
2.16	Module	17	100,000	1,700,000	
	Deep-cycle batteries	9	95,000	855,000	
	Charge controller	2	60,000	120,000	
	Inverter	1	170,000	170,000	
	Supporting structure	-	200,000	200,000	
	Cost of Accessories	-	100,000	100,000	
	Contingency/transport	-	-	120,000	
	Labour	-	-	100,000	
Total					N3,365,000.00

Table 6-24: Appliances for Study data Generation and Consumption

Appliance	Quantity	App. Watt	No. of Hours Used	Total Watt Con/day	Gen in Watt/day	Variance b/w Gen and Con	% Utilized
Lighting bulb	10	11	9	990			
Security bulb	4	30	9	1080			
Fan	5	100	9	4500			
TV	1	100	9	900			
Fridge	1	100	24	2400			
Freezer	1	100	24	2400			
Air-conditioner	1	1119	6	6714			
Cooker	1	1000	1	1000			
Phone charging	2	2	2	8			
Total				20442	39100	18658	52%

Table 6-25: Generation over Consumption

Case Study 4	Total Watt Consumed/day (W)	Total Watt Generated/day (W)	% of Generation over Consumption	% of Maximum watt consumable/day	Excess Utilized (%)
Karu House	20,442	39,100	152	100	52

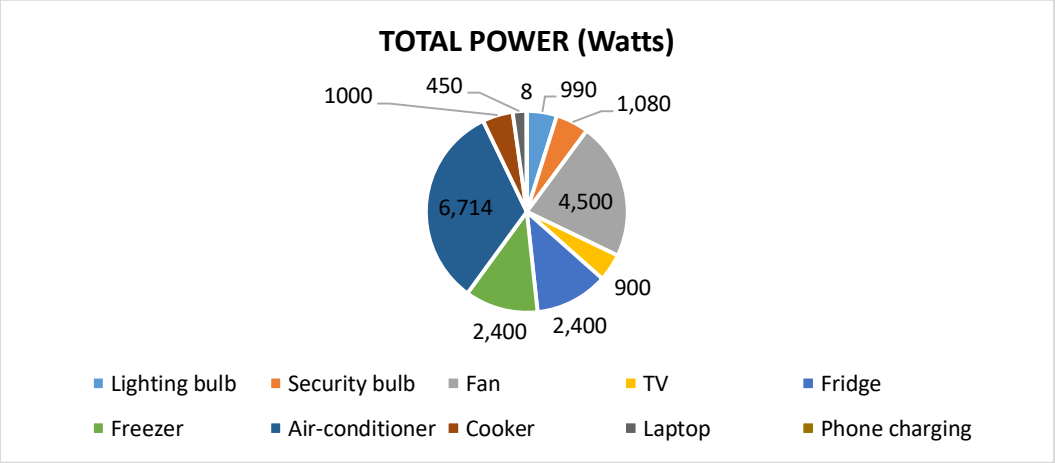


Figure 6-14: The total power in watts.

Table 6-26: Case Study 4 Off-grid Base Case Simulation

Grid type	Off-grid
Technology	Grid Electricity
Fuel Rate (NGN)	110.00
Capacity (NGN/kWh)	2.16
Annual O&M Cost (NGN)	238
Electricity Rate-Base Case (NGN/kWh)	110.006
Total Electricity Cost (NGN)	4,416,738

Table 6-27: Proposed Grid-connected with current National and Solar Company's Rate

Analysis Type		Method 2		
Solar Tracking mode		Fixed		
Angle/slope		15^0		
Month	Horizontal Daily Solar Radiation ($kWh/m^2/day$)	Tilted Daily Solar Radiation ($kWh/m^2/day$)	Electricity Export Rate (NGN/MWh)	Electricity Exported to Grid (MWh)
January	5.88	6.56	24.30	0.390
February	6.09	6.49	24.30	0.347
March	6.27	6.36	24.30	0.377
April	6.06	5.84	24.30	0.339
May	5.58	5.19	24.30	0.312
June	5.06	4.65	24.30	0.273
July	4.44	4.14	24.30	0.254
August	4.19	4.02	24.30	0.248
September	4.73	4.69	24.30	0.278
October	5.31	5.53	24.30	0.334
November	5.98	6.60	24.30	0.381
December	5.86	6.64	24.30	0.394
Annual	5.45	5.55	24.30	3.926
Horizontal		MWh/m^2	1.99	
Tilted		MWh/m^2	2.03	

Analysis Type		Method 2		
Solar Tracking mode		Fixed		
Angle/slope		15^0		
Month	Horizontal Daily Solar Radiation ($kWh/m^2/day$)	Tilted Daily Solar Radiation ($kWh/m^2/day$)	Electricity Export Rate (NGN/MWh)	Electricity Exported to Grid (MWh)
January	5.88	6.56	110.0	0.390
February	6.09	6.49	110.0	0.347
March	6.27	6.36	110.0	0.377
April	6.06	5.84	110.0	0.339
May	5.58	5.19	110.0	0.312
June	5.06	4.65	110.0	0.273
July	4.44	4.14	110.0	0.254
August	4.19	4.02	110.0	0.248
September	4.73	4.69	110.0	0.278
October	5.31	5.53	110.0	0.334
November	5.98	6.60	110.0	0.381
December	5.86	6.64	110.0	0.394
Annual	5.45	5.55	110.0	3.926
Horizontal		MWh/m^2	1.99	
Tilted		MWh/m^2	2.03	

The current national electricity fuel rate that is equal to GBP0.06 (N24.30) for central grid-connected. The solar company's electricity rate is equal to GBP0.3 (N110). The cash flow is equal to GBP8, 335 (N3, 375,795) using N110 rate and GBP8, 315 (N3, 367,385) with N24.30 rate for 25 years'. The difference between them is GBP21 (N8, 410).

6.2.5.3 Rationale Evaluation

Case study 4 show medium-term payback period due to good return on investment depending on the amount invested. Table 6-28 presents sufficient amount of generation and less consumption that provided the household need with modern access services, clean and safe energy in the location.

Table 6-28: Generation Consumption, and Payback Computation

INVESTMENT POTENTIAL COMPUTATION						
LOCATION	CASE STUDY CAPACITY (kW)	YEARLY POWER CONSUMPTION (kWh)	ELECTRICITY RATE (N/kWh)	AMOUNT YEARLY/SAVING (N)	CAPITAL INVESTMENT (N)	PAYBACK PERIOD (YEAR)
KARU RESIDENTIAL HOME	2.16		110	641,240	3,365,000	4.8

GENERATION OUTPUT CONSUMPTION AND PAYBACK PERIOD				
CASE STUDY	PV CAPACITY (kW)	POWER GENERATION YEARLY (kWh)	POWER CONSUMPTION YEARLY (kWh)	PAYBACK PERIOD (YEAR)
4	2.16	14,076	7,359	4.8

AVERAGE RETURN ON INVESTMENT PER YEAR USING PAYBACK PERIOD			
CASE STUDY	AMOUNT INVESTED (N)	PAYBACK PERIOD (YEARS)	AVERAGE AMOUNT REALIZED PER YEAR (N/YR)
4	3,365,000	4.8	641,240

6.2.6 Case Study 5: Garki 1 location

This is a very popular area with many business activities being the first discovered part of FCT-Abuja. Figure 6-15 presents a residential solar PV location with the blue arrow indication. Figure 6-16 presents the installed PV system for the home application.



Figure 6-15: Garki with the Blue arrow indication in Abuja.

6.2.6.1 Garki 2 Kilowatt PV Capacity Installation



Figure 6-16: Solar PV residential home installation in Abuja location.

Table 6-29 presents the PV model technical specifications with other components used for electricity generation in the location.

Table 6-29: Solar World 230W Monocrystalline PV System and the Technical Specifications

Configuration	
Application	Off-grid
PV System Capacity Size (kWp)	2.0
Manufacturer	Solar World
Rated PV Watt (W)	230
PV Type Used	Mono-crystalline
Number of Panels (units)	15
Annual Generation (kWh)	12,420 or 9,936 (Average)
Mounted Method	Fixed
Number of Batteries	8
Battery Capacity (Ah)	200
Days of Autonomy	3
Inverter Capacity (kW)	2
Charge controllers	2 of 40 A and 48 V
Depth of Discharge (%)	80
Angle degree	15^0c
Average radiation intensity	600w/m^2
Hours sunshine	10
Daily hour use	9
PV life span	25

SW 230	
Performance Under standard Test Conditions (STC): 1000W/m^2, 25^0c, AM 1.5	
Maximum Power (Pmax)	230 Wp
Open circuit voltage (Voc)	37.4 V
Maximum power point voltage (Vmpp)	30.0 V
Short circuit current (Isc)	8.16 A
Maximum power point current (Impp)	7.68 A
Performance at 800 W/m^2, NOCT, AM 1.5	
Maximum Power (Pmax)	166.9 Wp
Open circuit voltage (Voc)	33.9 V
Maximum power point voltage (Vmpp)	27.2 V
Short circuit current (Isc)	6.58 A
Maximum power point current (Impp)	6.14 A
THERMAL CHARACTERISTICS	
NOCT	46^0c
TC (Isc)	0.004%/k
TC (Voc)	-0.30%/k
TC (Pmpp)	-0.45%/k
Operating temperature	-40^0c to 85^0c
Component Materials	
Cell per module	60
Cell type	Monocrystalline
Cell dimensions	6.14 in x 6.14 (156 mm x 156 mm)
Front	Tempered glass (EN 12150)
Frame	Clear anodized aluminum
Weight	46.7 lbs (21.2 kg)
System Integration Parameters	
Maximum system voltage SC11	1000 V
Max. system voltage USA NEC	600 V

Maximum reverse current	16 A
Number of bypass diodes	3
UL Maximum Test Load	45 psf (2.1 kN/m^2)
IEC Maximum Snow Test Load	113 psf (5.4kN/m^2)
Additional Data	
Power tolerance	-0 Wp/+5 Wp
J-Box	IP65
Connector	MC4
Module efficiency	13.72%
Fire rating (UL 790)	Class C

Note: Minor reduction in efficiency under partial load conditions at 25^{0}c from 200W/m^2, 95% (+/-3%) of the STC efficiency (1000 W/m^2) achieved.

6.2.6.2 Breakdown Cost of Investment

Table 6-30 indicates the financial breakdown for solar PV installation cost with other components including labour expenses used for the investment. Table 6-31 shows consumption and generation.

Table 6-30: Business Model Cost Breakdown

PV Installed capacity (kW)	Item Description	Quantity	Unit Cost (NGN): N:K	Amount (NGN): N:K	Total Investment (NGN): N:K
2.0	Module	15	100,000	1,500,000	
	Deep-cycle batteries	8	95,000	760,000	
	Charge controller	2	60,000	120,000	
	Inverter	1	170,000	170,000	
	Supporting structure	-	200,000	200,000	
	Cost of Accessories	-	100,000	100,000	
	Contingency/transport	-	-	120,000	
	Labour	-	-	100,000	
Total					N3,070,000.00

Table 6-31: Appliances for Study data Generation and Consumption

Appliance	Quantity	App. Watt	No. of Hours Used	Total Watt Con/day	Gen in Watt/day	Variance b/w Generation and Consumption	% Utilized
Lighting bulb	10	11	9	990			
Security bulb	4	30	9	1080			
Fan	5	100	9	4500			
TV	1	100	9	900			
Fridge	1	100	24	2400			
Freezer	1	100	24	2400			
Air-conditioner	1	1119	6	6714			
Cooker	1	1000	1	1000			
Laptop	1	50	9	450			
Phone charging	2	2	2	8			
Total				20442	34500	14058	59%

The installed PV panels generated 34.5-kilowatt-hour per day or 12,420 kWh/year. This installed solar PV capacity can meet all the full load capacity with more appliances utilized from excess generation 14,058 in watt per day. Table 6-32 presents generation over-consumption. This case consumes less than power generated and advised to increase the number of appliances to maximize the power generated. Figure 6-17 demonstrates the total amount consumed in a plotted pie chart. Table 6-33 represents the RET Screen simulation results in this study.

Table 6-32: Generation over Consumption

Case Study 5	Total Watt Consumed/day (W)	Total Watt Generated/day (W)	% of Generation over Consumption	% of Maximum watt consumable/day	Excess Utilized (%)
Garki House	20,442	34,500	159	100	59

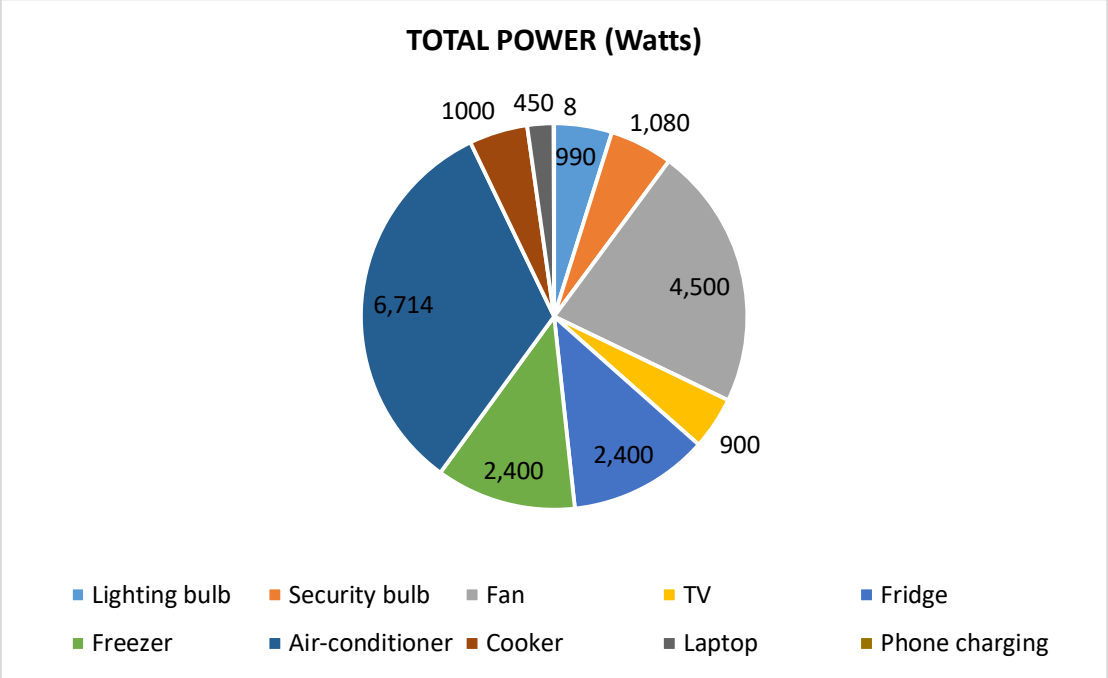


Figure 6-17: The total power in watts.

Table 6-33: Case Study 5 Off-grid Base Case Simulation

Grid type	Off-grid
Technology	Grid Electricity
Fuel Rate (NGN)	110.00
Capacity (NGN/kWh)	2
Annual O&M Cost (NGN)	220
Electricity Rate-Base Case (NGN/kWh)	110.005
Total Electricity Cost (NGN)	4,416,720

Table 6-34 shows the current national electricity fuel rate is equal to GBP0.06 (N24.30) for central grid-connected. The solar company's electricity rate is equal to GBP0.3 (N110). They both generated the same amount of capacity value and cash flow for 25 years' with N110 rate is GBP7, 605 (N3, 079,996) and N24.30 rate is GBP7, 586 (N3, 072,208). The difference between them is equal to GBP19 (N7, 788).

Table 6-34: Proposed Grid-connected with the current National and Solar Company's Rate

Analysis Type			Method 2	
Solar Tracking mode			Fixed	
Angle/slope			15^0	
Month	Horizontal Daily Solar Radiation ($kWh/m^2/day$)	Tilted Daily Solar Radiation ($kWh/m^2/day$)	Electricity Export Rate (NGN/MWh)	Electricity Exported to Grid (MWh)
January	5.88	6.56	24.30	0.361
February	6.09	6.49	24.30	0.321
March	6.27	6.36	24.30	0.349
April	6.06	5.84	24.30	0.314
May	5.58	5.19	24.30	0.289
June	5.06	4.65	24.30	0.253
July	4.44	4.14	24.30	0.235
August	4.19	4.02	24.30	0.229
September	4.73	4.69	24.30	0.257
October	5.31	5.53	24.30	0.310
November	5.98	6.60	24.30	0.353
December	5.86	6.64	24.30	0.365
Annual	5.45	5.55	24.30	3.635
Horizontal		MWh/m^2	1.99	
Tilted		MWh/m^2	2.03	

Analysis Type			Method 2	
Solar Tracking mode			Fixed	
Angle/slope			15^0	
Month	Horizontal Daily Solar Radiation ($kWh/m^2/day$)	Tilted Daily Solar Radiation ($kWh/m^2/day$)	Electricity Export Rate (NGN/MWh)	Electricity Exported to Grid (MWh)
January	5.88	6.56	110.0	0.361
February	6.09	6.49	110.0	0.321
March	6.27	6.36	110.0	0.349
April	6.06	5.84	110.0	0.314
May	5.58	5.19	110.0	0.289
June	5.06	4.65	110.0	0.253
July	4.44	4.14	110.0	0.235
August	4.19	4.02	110.0	0.229
September	4.73	4.69	110.0	0.257
October	5.31	5.53	110.0	0.310
November	5.98	6.60	110.0	0.353
December	5.86	6.64	110.0	0.365
Annual	5.45	5.55	110.0	3.635
Horizontal		MWh/m^2	1.99	
Tilted		MWh/m^2	2.03	

6.2.6.3 Rationale Evaluation

Case study 5 shows medium-term payback period due to a good return on investment depending on the high amount invested. Table 6-35 presents a sufficient amount generated with less consumption. This solar electrification provided the household with modern access service in the location.

Table 6-35: Generation Consumption, and Payback Computation

INVESTMENT POTENTIAL COMPUTATION						
LOCATION	CASE STUDY CAPACITY (kW)	YEARLY POWER CONSUMPTION (kWh)	ELECTRICITY RATE (N/kWh)	AMOUNT YEARLY/SAVING (N)	CAPITAL INVESTMENT (N)	PAYBACK PERIOD (YEAR)
GARKI RESIDENTIAL HOME	2	7,359	110	655,990	3,070,000	4.3

GENERATION OUTPUT CONSUMPTION AND PAYBACK PERIOD				
CASE STUDY	PV CAPACITY (kW)	POWER GENERATION YEARLY (kWh)	POWER CONSUMPTION YEARLY (kWh)	PAYBACK PERIOD (YEAR)
5	2	12,420	7,359	4.3

AVERAGE RETURN ON INVESTMENT PER YEAR USING PAYBACK PERIOD			
CASE STUDY	AMOUNT INVESTED (N)	PAYBACK PERIOD (YEARS)	AVERAGE AMOUNT REALIZED PER YEAR (N/YR)
5	3,070,000	4.3	655,990

6.2.7 Case Study 6: Ademola Adetokunbo Location

This location is in wuse district the busiest business area of FCT-Abuja with a red dotted circle. Figure 6-18 presents the project location. Figure 6-19 presents the PV system installation.



Figure 6-18: The Abuja Location circled with a red dotted.

6.2.7.1 Ademola Adetokunbo 1 Kilowatt PV Capacity Installation

The installation of 1 kW off-grid PV is to provide clean and affordable electricity to homes and small businesses. Figure 6-20 presents the suitcase size solar system type.



Figure 6-19: Abuja location Rooftop building installation.



Figure 6-20: Lumos GP-080P-36 Polycrystalline PV design.

This company provides affordable service that allows customers to utilize the “pay-as-you-go” (PAYG), model. The system comes with a home solar panel, indoor storage and connection unit, allows customers access with a significant amount of power for a day and night demands. They offer a simple solar power service in an affordable way to homes and small businesses. Due to the small instalment payment by the customer, the technology has become cheaper than kerosene. Table 6-36 presents the PV model technical specifications.

Table 6-36: Lumos GP-080P-36 Polycrystalline PV Panel and the Technical Specifications

Configuration	Anodize aluminium improved with strong lightweight aluminium frame design with reinforced sealing and load hold to prevent freezing and warping that stand against high wind.
Application	Stand-alone
PV System Capacity Size (kWp)	1
Manufacturer	Lumos
Model	GP-080P-36
PV Type Used	Poly-crystalline
Number of Panels (units)	1
Annual Generation (kWh)	173 or 58 (Peak)
Mounted Method	Fixed
Number of Batteries	1
Battery Capacity (Ah)	200
Days of Autonomy	3
Inverter Capacity (kW)	1
Charge controllers	-
Depth of Discharge (%)	80
Angle degree	-
Hours sunshine	6
Peak hour of sunshine	1-3 pm (2 hours)
PV life span	25

Lumos Model	GP-080P-36
Peak Power (Pmax)	80 W
Maximum Power Voltage (Vmp)	17.7 V
Maximum Power Current (Imp)	4.52 A
Open circuit Voltage (Voc)	21.7 V
Short circuit current (Isc)	4.9 A
Module Efficiency	16.14 %
Operating Module Temperature	-40^{0}c to + 85^{0}c
Maximum System Voltage	800 V
Series Fuse Rating	10
Power Tolerance	±3%
MECHANICAL CHARACTERISTICS	
Solar Cell	36 cells in series
No. of Cells	36 (4 x 9)
Dimensions	890 x 670 x 30mm (35.04 x 26.38 x 1.18 inch)
Weight	7.1 kg (15.62 lbs)
Front Glass	EVA, TPT
Junction Box	IP65 rated with UL and TUV
Cables (Output optional)	LAPP (4mm)
Length	900mm (-1 and 900mm (+)
Connector	MC Plug Type IV
TEMPERATURE COEFFICIENTS	
Current Temperature Coefficient of Isc	A (Isc) 0.08%/^{0}c
Voltage Temperature Coefficient of Voc	8 (Voc) -0.32%/^{0}c
Power Temperature Coefficient of Pmax	Y (Pmax)-0.38%/^{0}c

6.2.7.2 Cost Investment Breakdown

Table 6-37 indicates a financial breakdown of solar PV installation total cost including labour expenses used for the investment.

Table 6-38 shows the consumption and generation.

Table 6-37: Business Model Cost Breakdown

SOLAR PV PANEL INSTALLED	ITEM INSTALLED	QUAUNTY	TOTAL PROJECT COST
1	80 W Large Panel	1	
	Solar Cable	1	
	Solar Control & Storage	1	
	Sockets DC 12 V Max	8	
	USB Mobile Phone Adapter	1	
	Powerful LED Bulbs	2	
	Easy Self-Installation Mounting Kit	1	N238,000.00

Table 6-38: Appliances for Study data Generation and Consumption

Appliance	Quantity	App. Watt	No. of Hours Used	Total Watt Con/day	Gen Watt/day	Variance b/w Generation and Consumption	% Utilized
Bulb	4	6	24	576			
Fan	2	15	24	720			
TV (Optional)	-	-	-	-			
Total				1296	1800	504	72%
Total Generation per Year				648 kWh			

The 1 kW installed capacity generated 1.8 kWh/day or 648 kWh/year. This installed PV capacity can meet all the full load capacity in the residential home with the excess generation 504 kWh over-consumption. Table 6-39 presents the generation over-consumption. Figure 6-21 presents the total power used plotted in Pie chart.

Table 6-39: Generation over Consumption

Case Study 6	Total Watt Consumed/day (W)	Total Watt Generated/day (W)	% of Generation over Consumption	% of Maximum watt consumable/day	Excess Utilized (%)
Ademola Adetokunbo	1,296	1,800	172	100	72

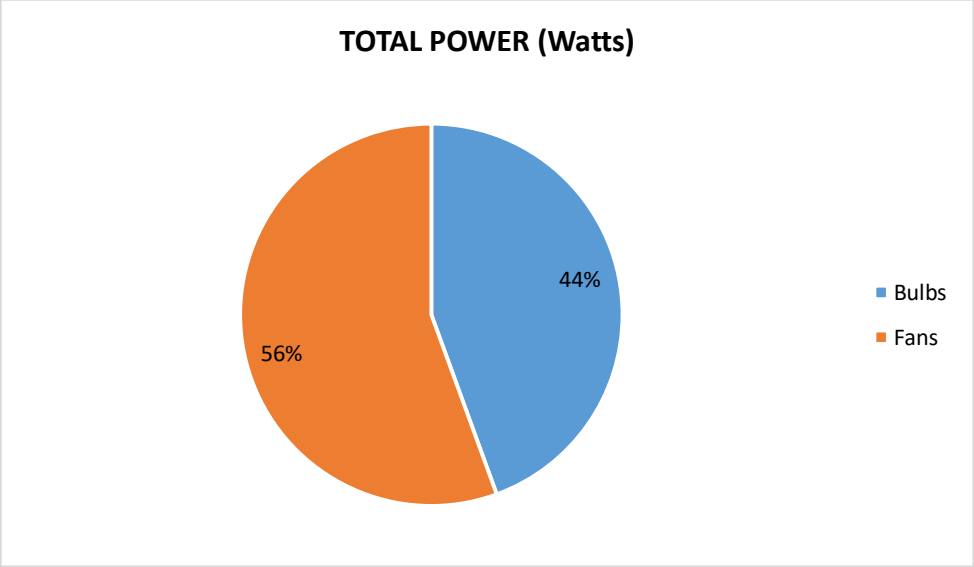


Figure 6-21: The total power in watts.

This case study consumes less than power generated. It is advisable to increase the number of appliances to maximize the power generated. Table 6-40 represents the RET Screen simulation results in this study.

Table 6-40: Case Study 6 Off-Grid Base Case Simulation

Grid type	Off-grid
Technology	Grid Electricity
Fuel Rate (NGN)	110.00
Capacity (NGN/kWh)	1
Annual O&M Cost (NGN)	110
Electricity Rate-Base Case (NGN/kWh)	110.003
Total Electricity Cost (NGN)	4,416,610

Table 6-41: Proposed Grid-Connected with the current National and Solar Company's Rate

Analysis Type			Method 2	
Solar Tracking mode			Fixed	
Angle/slope			15^0	
Month	Horizontal Daily Solar Radiation ($kWh/m^2/day$)	Tilted Daily Solar Radiation ($kWh/m^2/day$)	Electricity Export Rate (NGN/MWh)	Electricity Exported to Grid (MWh)
January	5.88	6.56	24.30	0.179
February	6.09	6.49	24.30	0.159
March	6.27	6.36	24.30	0.173
April	6.06	5.84	24.30	0.155
May	5.58	5.19	24.30	0.143
June	5.06	4.65	24.30	0.125
July	4.44	4.14	24.30	0.116
August	4.19	4.02	24.30	0.114
September	4.73	4.69	24.30	0.127
October	5.31	5.53	24.30	0.153
November	5.98	6.60	24.30	0.175
December	5.86	6.64	24.30	0.181
Annual	5.45	5.55	24.30	1.799
Horizontal		MWh/m^2	1.99	
Tilted		MWh/m^2	2.03	

Analysis Type			Method 2		
Solar Tracking mode			Fixed		
Angle/slope			15^0		
Month	Horizontal Daily Solar Radiation ($kWh/m^2/day$)	Tilted Daily Solar Radiation ($kWh/m^2/day$)		Electricity Export Rate (NGN/MWh)	Electricity Exported to Grid (MWh)
January	5.88	6.56		110	0.179
February	6.09	6.49		110	0.159
March	6.27	6.36		110	0.173
April	6.06	5.84		110	0.155
May	5.58	5.19		110	0.143
June	5.06	4.65		110	0.125
July	4.44	4.14		110	0.116
August	4.19	4.02		110	0.114
September	4.73	4.69		110	0.127
October	5.31	5.53		110	0.153
November	5.98	6.60		110	0.175
December	5.86	6.64		110	0.181
Annual	5.45	5.55		110	1.799
Horizontal		MWh/m^2		1.99	
Tilted		MWh/m^2		2.03	

Table 6-41 shows the current national electricity fuel rate, which is equal to GBP0.06 (N24.30) for central grid-connected. The solar company's electricity rate is equal to GBP0.3 (N110) with the same amount of capacity value. Cash flow for 25 years' using N110 rate is equal to GBP600 (N242, 998), and it is GBP590 (N239, 104) using N24.30 national rate. The difference between them equal to GBP10 (N3, 894).

6.2.7.3 Case Study 6 Rationale Evaluation

Case study 6 shows medium to long-term payback period and a good return on investment depending on the small amount invested. Table 6-42 presents a sufficient amount generated with less consumption. The solar electrification provides homes, community, and businesses with modern access services.

Table 6-42: Generation Consumption, and Payback Computation

INVESTMENT POTENTIAL COMPUTATION						
LOCATION	CASE STUDY CAPACITY (kW)	YEARLY POWER CONSUMPTION (kWh)	ELECTRICITY RATE (N/kWh)	AMOUNT YEARLY/SAVING (N)	CAPITAL INVESTMENT (N)	PAYBACK PERIOD (YEAR)
LUMOS ADEMOLA ADETOKUNBO ABUJA	1	467	110	39,470	238,000	5.4

GENERATION OUTPUT CONSUMPTION AND PAYBACK PERIOD				
CASE STUDY	PV CAPACITY (kW)	POWER GENERATION YEARLY (kWh)	POWER CONSUMPTION YEARLY (kWh)	PAYBACK PERIOD (YEAR)
6	1	648	467	5.4

AVERAGE RETURN ON INVESTMENT PER YEAR USING PAYBACK PERIOD			
CASE STUDY	AMOUNT INVESTED (N)	PAYBACK PERIOD (YEARS)	AVERAGE AMOUNT REALIZED PER YEAR (N/YR)
6	238,000	5.4	39,470

6.3 Awka Area Case Study 7

6.3.1 Awka Weather Condition

Awka is the capital city of Anambra state created 27th August 1991 with over 300,000 populations. The Awka geographical coordinates are Latitude 6˚20' N and Longitude 7˚00'E and the elevation 105 meters (344 feet). The people with over 60 percent leave in urban areas making the state one of the most urbanized places in Nigeria. The temperature ranges between 25.4˚C and 30.6˚C and a tropical forest type of vegetation (Elochukwu, 2015). Awka temperature is generally comfortable at 27-30 Celsius degrees between June and December and rises to 32-34 degrees between January and April. The temperature varies between driest

and wettest months by 3.8 °C with 299 mm difference in precipitation (Jackson, 1986). The warmest month of the year is March with an average temperature (29.0 °C) and August is the lowest average temperature (25.2 °C) for the whole year (Gismeteo, 2016). The precipitation mostly falls in September with 306 mm average and December the driest month with 7 mm (Ike, 2012; Anyadike, 1993 and Brooks, 1916). Figure 6-22 presents Awka location with the red dot-circle line. Figure 6-23 represents Awka normal and monthly average temperature and precipitation.

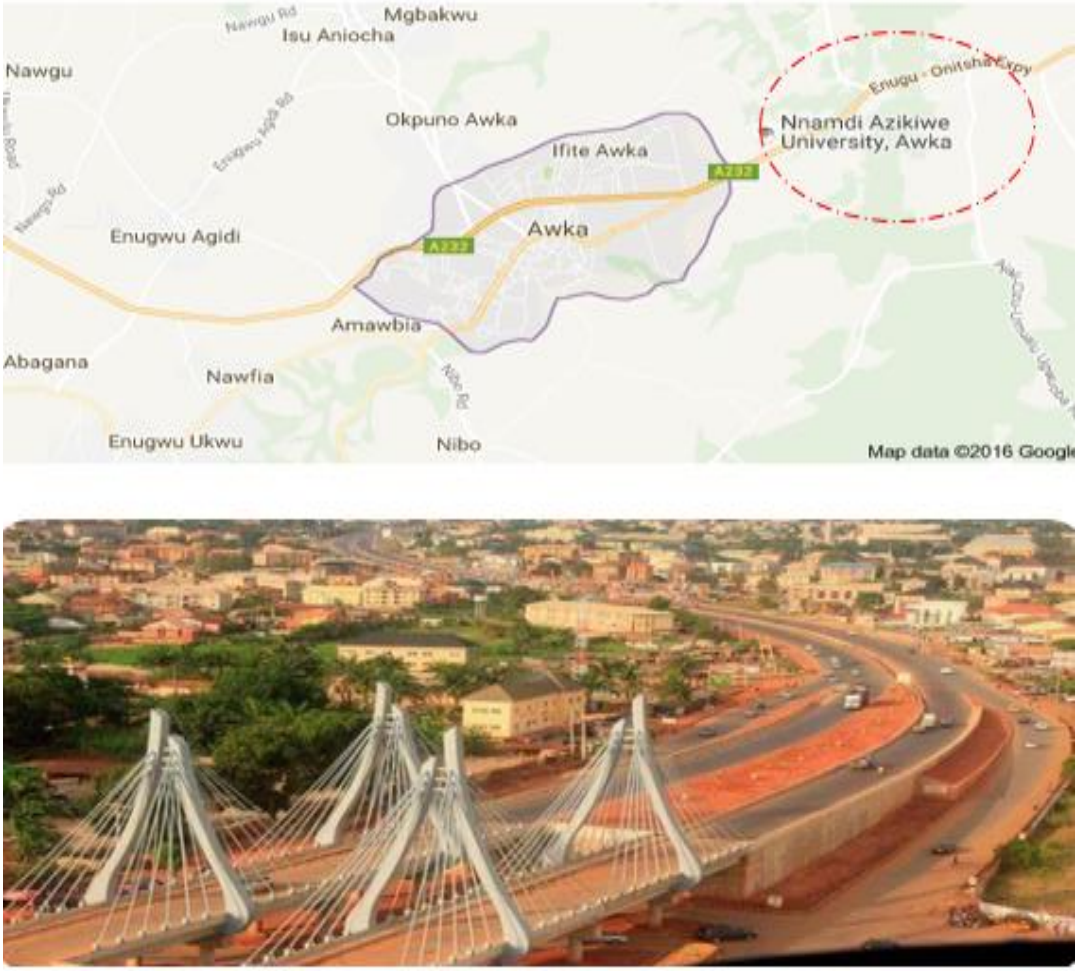


Figure 6-22: Awka location with red dot-circle line (Source: Chinyelu, 2015).

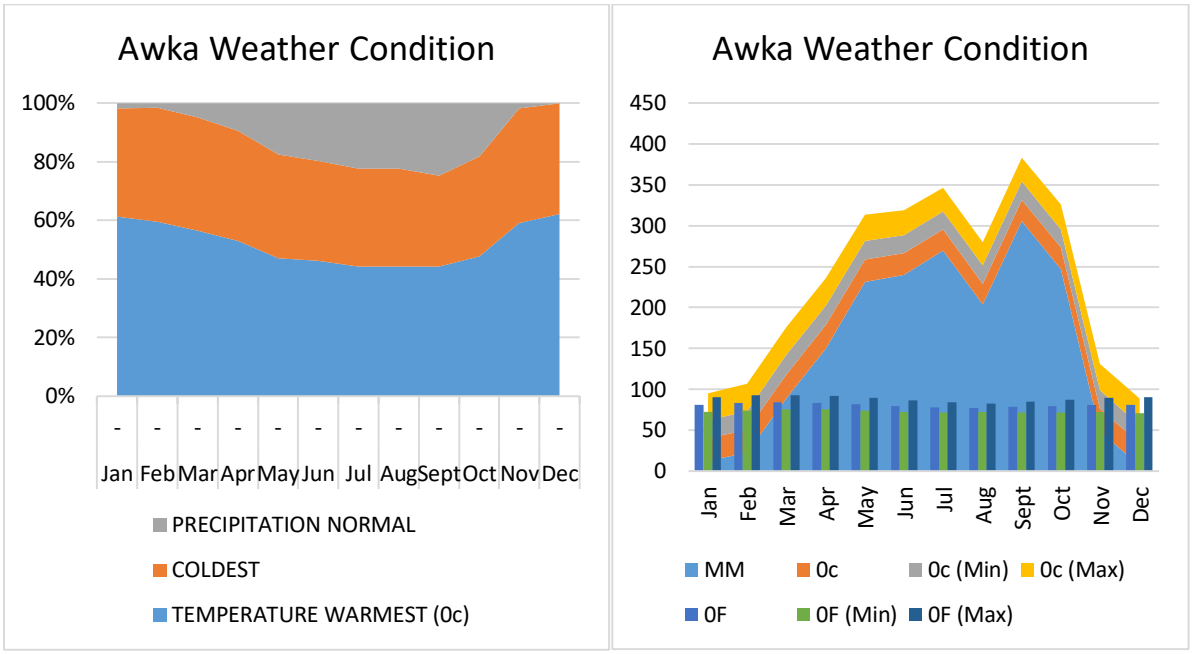


Figure 6-23: Awka Normal and Monthly Average Temperature and Precipitation.

6.3.2 Nnamdi Azikiwe University 1 Kilowatt PV Capacity

6.3.2.1 PV Installation

The PV systems installed at Dora Akunyili and Stella Okoli female hostels for security lighting in Awka at Nnamdi Azikiwe University. Table 6-43 presents the PV system technical specifications with other components used for the electricity generation.

Table 6-43: Suntech STP 250S-20 Monocrystalline PV System and the Technical Specification

Location	Awka (south-east Nigeria)
Application	Off-grid or Stand-alone
PV Capacity Installed	1 kW
Manufacturer	Suntech
Each rated PV Watt	250W
PV type used	Mono-crystalline panel
Number of panels	4
Generation	150 V used to power battery bank
Mounted Method	Fixed angle horizontal
Tracking Method	MPPT
Oritentation or Tilt angle used	6.2^0 south
Battery used	6 V Trojan lead-acid of 435 Amp-hr
Hour of Sunshine	8
Average Sunshine	4
Hours of power demand throughout the night	12
Connection	Series
PV life-span	20-25 years

ELECTRICAL CHARACTERISTICS	
STC	
Optimum Operating Voltage (Vmp)	30.7 V
Optimum Operating Current (Imp)	8.15 A
Open Circuit Voltage (Voc)	37.4 V
Short Circuit Current (Isc)	8.63 A
Maximum Power at STC (Pmax)	250 W
Module Efficiency	15.4 %
Operating module temperature	-40^0c to $+85^0$c
Maximum system voltage	1000 V DC (IEC)
Maximum series fuse rating	20 A
Power Tolerance	0/+5%
NOCT	
Maximum Power at NOCT (Pmax)	183 W
Optimum Operating Voltage (Vmp)	27.9 V
Optimum Operating Current (Imp)	6.55 A
Open Circuit Voltage (Voc)	34.4 V
Short Circuit Current (Isc)	6.96 A

TEMPERATURE CHARACTERISTICS	
Nominal Operating Cell Temperature (NOCT)	45±2°c
Temperature Coefficient of Pmax	-0.45 %/°c
Temperature Coefficient of Voc	-0.34 %/°c
Temperature Coefficient of Isc	0.050 %/°c
MECHNICAL CHARACTERISTICS	
Solar Cell	Monocrystalline silicon 156 x 156 mm (6inches)
No. of cells	60 (6 x 10)
Dimensions	1640 x 992 x 50 mm (64.6 x 39.1 x 2.0 inches)
Weight	19.1 kgs (42.1 lbs)
Front Glass	3.2 mm (0.13 inches) tempered glass
Frame	Anodized aluminium alloy
Junction Box	1P67 rated (3 bypass diodes)
Output Cables	TUV (2pfg1169:2007), UL 4703, UL44, 4.0 mm^2 (0.006 $inches^2$) symmetrical lengths (-) 1000mm (39.4 inches) and (+) 1000 mm (39.4 inches)
Connectors	MC4 connectors

6.3.2.2 Dora Akunyili and Stella Okoli hotels for Solar Electrification

This stand-alone installed PV system for security lights between two hostels (Dora Akunyili and Stella Okoli) due to grid supply shortage and outages. This provided the campus with electricity access for lighting with 4 monocrystalline panels, MPPT charge controller, deep-cycle lead-acid Trojan batteries, fuses, switches, conduct wires, and 6 LED Lamp heads (Ike Chinelo et al., 2013). The electrification using solar regular light supply put away the night darkness around the surroundings. It also helps to reduce environmental impact. Figure 6-24 presents the solar PV electrification demonstration.

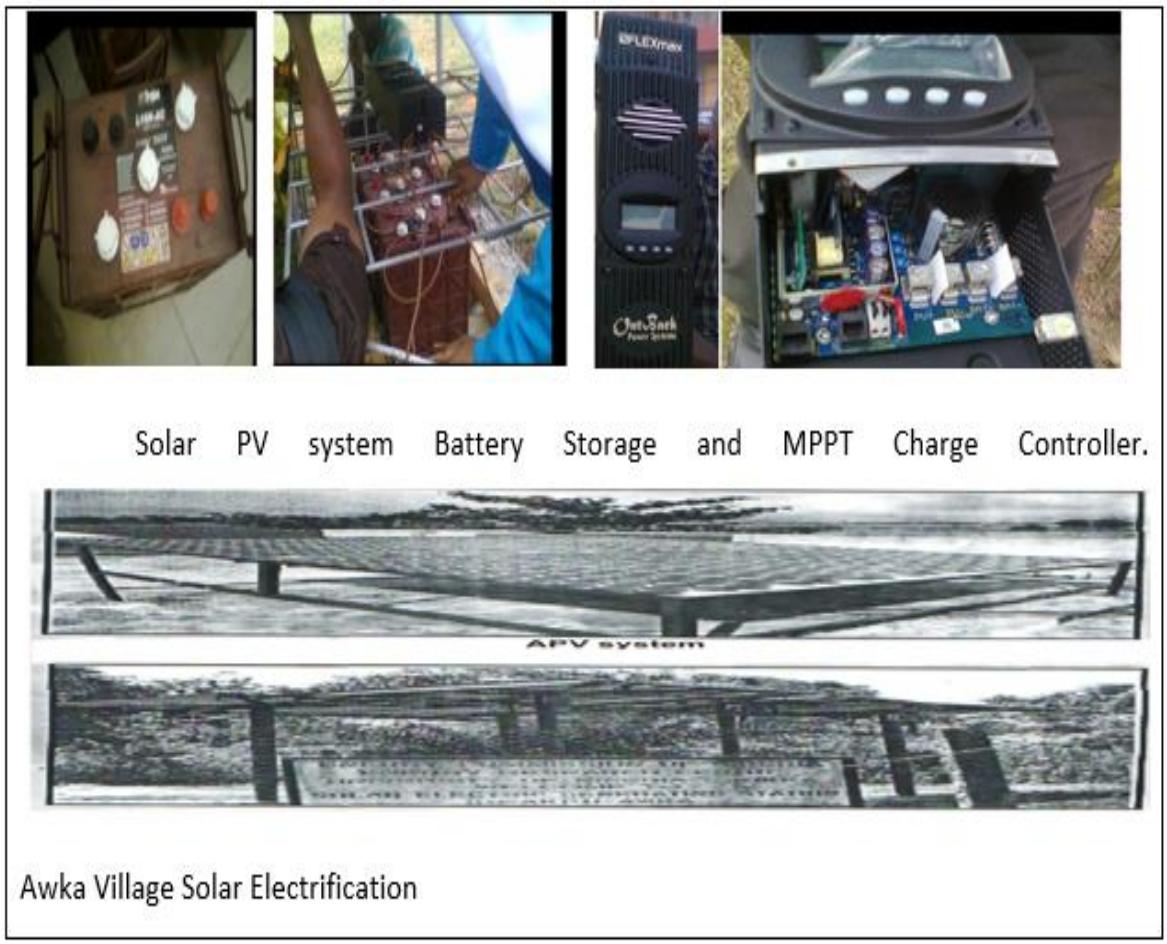


Figure 6-24: Awka Solar PV Electrifications (Source: University, 2001).

6.3.2.3 Cost Investment Breakdown

Table 6-44 indicates the financial breakdown for solar PV installation total cost including all components and labour expenses used for the investment. Table 6-45 presents the load consumption appliances used for the lighting in the location.

Table 6-44: Business Model Cost Breakdown

PV Capacity Installed	Total Investment (NGN) N:K
1 kW	N500,000

Table 6-45: Appliances for Study data Generation and Consumption

Appliance	QTY	Watt	Hour	Consumed Watt/Day	Generation Watt Per Day	Excess electricity	Utilized power (%)
LED lamp head for security light	6	6	12	432	8,000	7,568	5.4%

The 1 kW installed capacity with eight hours' sunshine with 250 W of 4 PV panels generated 8-kilowatt hour.

Table 6-46: Generation over Consumption

Case Study 7	Total Watt Consumed/day W)	Total Watt Generated/day (W)	% of Generation over Consumption	% of Maximum watt consumable/day	Excess Utilized (%)
Dora & Stella Hostels	432	8000	105	100	5

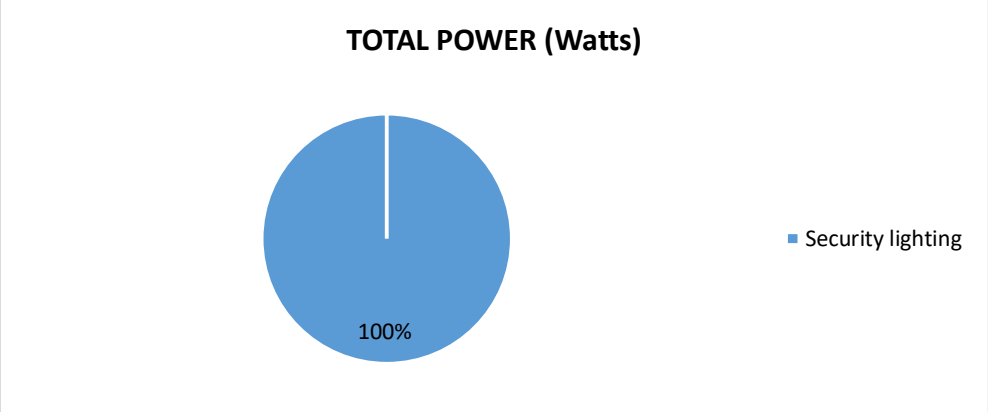


Figure 6-25: The total power in watts for LED security lighting.

Table 6-46 shows consumption and generation. This case consumes less than power generated and is advisable to increase the number of appliances use to maximize the power generated. Figure 6-25 presents the total power used for LED security lighting. Table 6-47 presents the electricity generated from the RET Screen simulation result.

Table 6-47: Case Study 7 Off-grid Base Case Simulation

Grid type	Off-grid
Technology	Grid Electricity
Fuel Rate (NGN)	110.00
Capacity (NGN/kWh)	1
Annual O&M Cost (NGN)	110
Electricity Rate-Base Case (NGN/kWh)	110.003
Total Electricity Cost (NGN)	4,416,610

Table 6-48: Proposed Grid-connected with the current National and Solar Company's Rate

Analysis Type		Method 2		
Solar Tracking mode		MPPT		
Angle/slope		6.2^0		
Month	Horizontal Daily Solar Radiation (kWh/m²/day)	Tilted Daily Solar Radiation (kWh/m²/day)	Electricity Export Rate (NGN/MWh)	Electricity Exported to Grid (MWh)
January	5.68	5.94	24.30	0.164
February	5.74	5.90	24.30	0.147
March	5.57	5.61	24.30	0.155
April	5.25	5.19	24.30	0.140
May	4.94	4.82	24.30	0.135
June	4.54	4.41	24.30	0.120
July	4.14	4.04	24.30	0.115
August	3.91	3.86	24.30	0.110
September	4.19	4.19	24.30	0.115
October	4.57	4.64	24.30	0.131
November	5.11	5.30	24.30	0.144
December	5.46	5.73	24.30	0.159
Annual	4.92	4.96	24.30	1.634
Horizontal		MWh/m²	1.80	
Tilted		MWh/m²	1.81	

Analysis Type		Method 2		
Solar Tracking mode		MPPT		
Angle/slope		6.2^0		
Month	Horizontal Daily Solar Radiation (kWh/m²/day)	Tilted Daily Solar Radiation (kWh/m²/day)	Electricity Export Rate (NGN/MWh)	Electricity Exported to Grid (MWh)
January	5.68	5.94	110.0	0.164
February	5.74	5.90	110.0	0.147
March	5.57	5.61	110.0	0.155
April	5.25	5.19	110.0	0.140
May	4.94	4.82	110.0	0.135
June	4.54	4.41	110.0	0.120
July	4.14	4.04	110.0	0.115
August	3.91	3.86	110.0	0.110
September	4.19	4.19	110.0	0.115
October	4.57	4.64	110.0	0.131
November	5.11	5.30	110.0	0.144
December	5.46	5.73	110.0	0.159
Annual	4.92	4.96	110.0	1.634
Horizontal		MWh/m²	1.80	
Tilted		MWh/m²	1.81	

Table 6-48 shows the current national electricity fuel rate is equal to GBP0.06 (N24.30) for central grid-connected. The solar company's electricity rate is GBP0.3 (N110). They both generated the same amount in capacity. The cash flow for 25 years' with N110 rate is equal

to GBP1, 246 (N504, 493), and it is GBP1, 237 (N500, 993) with N24.30 rate. The difference between them is equal to GBP7 (N3, 500).

6.3.2.4 Rationale Evaluation

Case study 7 invested small capital for small installed capacity and consumed much less over the generation. The yearly huge electricity generation amounted to waste due to less consumption and this resulted in a small amount of return on investment with a longer payback. The payback from consumption can take more than the PV life cycle whereas the payback from quantity generated may take shorter period assuming no waste. This shows that the amount invested with less return can take a longer period to payback. This state government solar PV installed project specifically used for charging the battery for street lightings in the two hostels during outages in the school premises. The essence of PV installation mostly for electricity supply at night in the location. Table 6-49 presents a sufficient amount of generation and less consumption for two hostels with modern access services in the location.

Table 6-49: Generation Consumption, and Payback Computation

INVESTMENT POTENTIAL COMPUTATION						
LOCATION	CASE STUDY CAPACITY (kW)	YEARLY POWER CONSUMPTION (kWh)	ELECTRICITY RATE (N/kWh)	AMOUNT YEARLY/SAVING (N)	CAPITAL INVESTMENT (N)	PAYBACK PERIOD (YEAR)
DORA STELLA HOSTELS AWKA	1	156	110	17,160	500,000	29
GENERATION OUTPUT CONSUMPTION AND PAYBACK PERIOD						
CASE STUDY	PV CAPACITY (kW)	POWER GENERATION YEARLY (kWh)	POWER CONSUMPTION YEARLY (kWh)	PAYBACK PERIOD (YEAR)		
7	1	2,880	156	29		
AVERAGE RETURN ON INVESTMENT PER YEAR USING PAYBACK PERIOD						

CASE STUDY	AMOUNT INVESTED (N)	PAYBACK PERIOD (YEARS)	AVERAGE AMOUNT REALIZED PER YEAR (N/YR)
7	500,000	29	17,160

6.4 Nsukka Area Case Study 8

Nsukka is a town in southeast local government area situated in Enugu state of Nigeria with 1,377,001 populations based on the cultural zone (NIMET, 2008). National Centre for Energy Research and Development (NCERD) is located at University of Nigeria (UNN), Nsukka in Enugu state. It is one of the government solar pilot installation projects in 2007. The Enugu geographic coordinates are latitude 6027'30.12 N (6.458366), longitude 7^0 32'47 E (7.546389) and Elevation of 151.91 metres (498.38 feet). The Nsukka coordinates are latitude 6.856667, longitude 7.395833 and elevation 442.94 metres (1,388 feet), it has a tropical climate with two seasons like any other state in Nigeria and much rainfall (Geiger, 2015). Figure 6-26 represents the location at the University of Nigeria in Nsukka with red circle line.

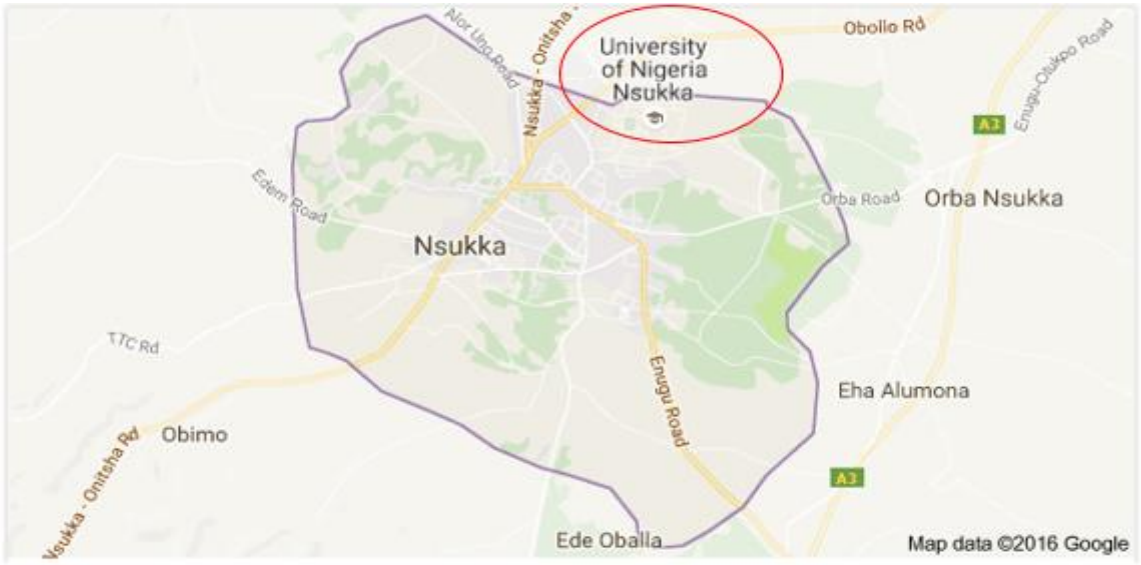


Figure 6-26: Nsukka location in the University of Nigeria with red circle line.

6.4.1 Weather Data

Nsukka average temperature is between 23^{0}c and 24.9^{0}c with about 1579 mm annual rainfall. The most dried month is January with 10 mm rain and the average precipitation peak reaches 299 mm in September. The average yearly temperature and warmest month are 27.0 °C in March and the coldest month is in August at 22.9 °C. The monthly average precipitation is about 17 inches (439 mm) with 23 days of rain and drizzle throughout the month. The monthly average weather condition is presented in Figure 6-27 (NIMET, 2008). Figure 6-28 represents the rooftop location installation at NCERD in Nsukka.

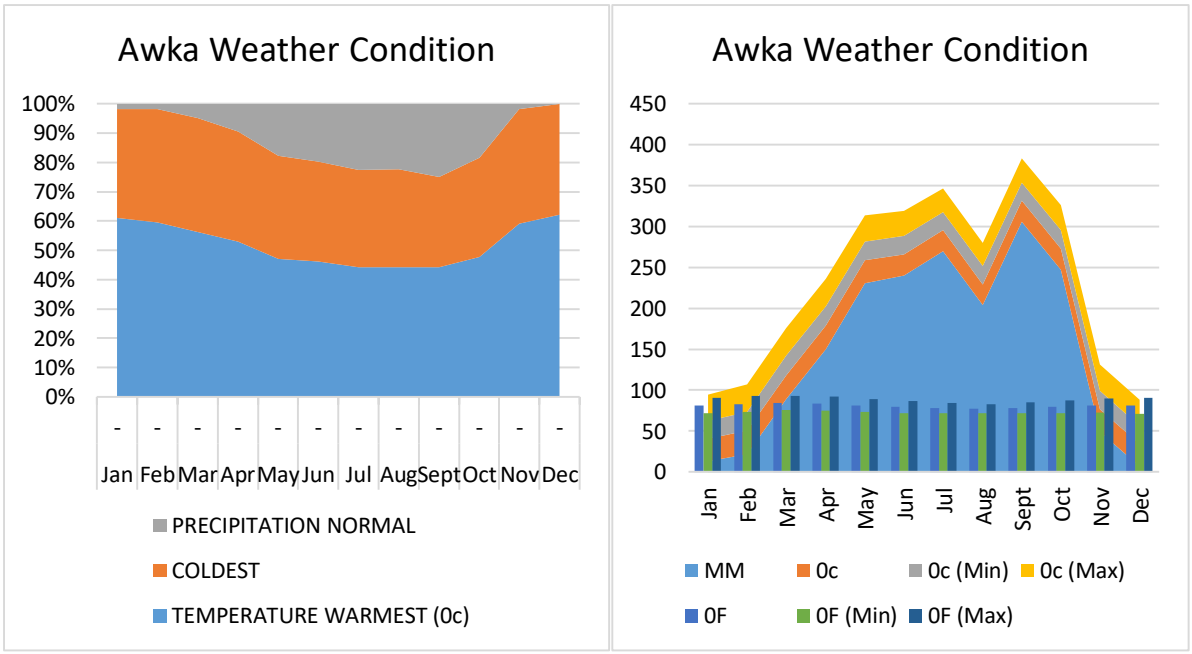


Figure 6-27: Nsukka Average Monthly Temperature and Precipitation.

6.4.2 NCERD 3.2 Kilowatt PV Capacity

6.4.2.1 PV Installation



Figure 6-28: Nsukka NCERD location Rooftop installation (Source: Akor, 2016).

NCERD is a government organization office at UNN site and was established by the National Assembly Act in 1980 with three other research centres but started full operation in 1982. The Centre expanded its infrastructural and research facilities significantly to promote research and development activities with 3.2 kW PV capacity installation in fulfillment of UN summit mandate. It contains 20 module cells for 160 watts PV system. The installed solar power system powered the entire administrative block of NCERD at UNN in Nsukka. Figure 6-29 presents the NCERD commission demonstration with technical specifications and other components used for the electricity generation. Table 6-50 represents the model type of PV system technical specifications used.



Figure 6-29: Solar Battery Installation Commission (Source: Akor, 2016).

Table 6-50: Lorentz LA 160W-24S Mono-crystalline Solar PV System and the Technical Specifications

Configuration	
Application	Off-grid
PV System Capacity Size (kWp)	3.2
Manufacturer	Lorentz
Model	LC160-12M/LA160-24S
Rated Watt (W)	160
PV Type Used	Mono-crystalline
Number of Panels (units)	20
Area Covered (m^2)	26.4
Annual Generation (kWh)	9,216 or 8,064 (Average)
Mounted Method	Fixed
Number of Batteries	12
Battery Capacity (Ah)	600 and 48 V
Battery Efficiency	90
Days of Autonomy	3
Inverter Capacity (kW)	3
Inverter Efficiency (%)	95
Charge controllers efficiency (%)	95
Depth of Discharge (%)	80
Angle degree	15^0c
Hours of sunshine	6-8
Daily hour use	8
PV life span	25

ELECTRICAL SPECIFICATIONS	
Peak POWER (Pmax)	160 W
Power tolerance	+10%/-5%
Max Power current (Imp)	5.0 A
Max Power Voltage	32.3 V
Short Circuit current (Isc)	5.5 A
Open Circuit Current (Voc)	39.9 V
Efficiency of Cells	19.7%
Temperature Co-efficient for Pmax	-0.38%/^{0}c
Temperature Co-efficient for Voc	-60.8mV/^{0}c
Temperature Co-efficient for Isc	3.5 mA/^{0}c
Max System Voltage	750 V
CELLS DATA	
Number of cells per module	20-60
Cell Technology	Monocrystalline
Cell Shape	Rectangular
PHYSICAL SPECIFICATIONS	
Dimension	669 x 1556 x 35 mm
Weight	16.0 kg
Connectors	MC3
Electrical Performance	I-V Curves

6.4.2.2 Cost Investment Breakdown

Table 6-51 indicates the financial breakdown of solar PV installation total cost with other components including labour expenses used for the investment in the location. Table 6-52 shows consumption load appliances from generation supply to the administrative building.

Table 6-51: Business Model Cost Breakdown

PV Installed capacity (kW)	Item Description	Quantity	Unit Cost (NGN): N:K	Amount (NGN): N:K	Total Investment
3.2	PV Panel	20	35,000	700,000	
	Inverter	1	120,000	120,000	
	Battery	12	45,000	540,000	
	Charge Controller	1	15,000	15,000	
	Accessories	-	35,000	35,000	
	Battery & panel hanger	-	16,000	16,000	
	Installation Cost	N/A	-	-	
Total					N1,426,000.00

Table 6-52: Appliances for Study data Generation and Consumption

Appliance	Quantity	App. Watt	No. of Hours Used	Total Watt Consumed per day	Generation in Watt per Day	Variance Between Generation & Consumption (Excess)	% Utilized
Bulb	20	14	8	2240			
Desktop	4	100	8	3200			
Laptop	18	80	8	11520			
Printer	5	70	3	1050			
Photo-copier	1	140	8	1120			
Fourier Infrared	1	150	8	1200			
Total				20330	25600	5270	79%

The PV panels generated 25.6-kilowatt-hour/day or 9,216 kWh/year. The installed capacity can meet all the full load capacity in the office with other equipment use from the output power generated.

Table 6-53: Generation over Consumption

Case Study 8	Total Watt Consumed/day (W)	Total Watt Generated/day (W)	% of Generation over Consumption	% of Maximum watt consumable/day	Excess Utilized (%)
NCERD	20,330	25,600	179	100	79

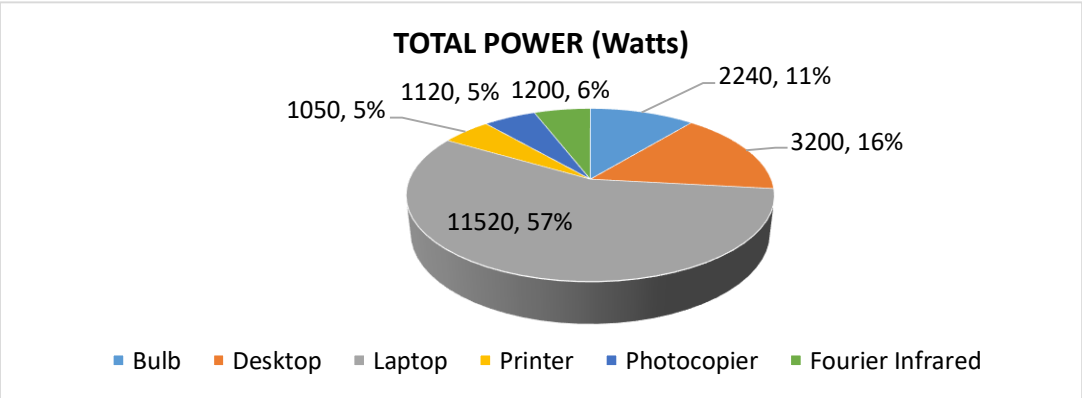


Figure 6-30: The Total Power in watts.

Table 6-53 presents consumption and generation. This case consumes less than power generated and is advisable to increase the number of appliances to maximize the power generated. Figure 6-30 demonstrates the total amount of power consumed. Table 6-54 presents electricity generation from the simulation.

Table 6-54: Case Study 8 Off-grid Base Case Simulation

Grid type	Off-grid
Technology	Grid Electricity
Fuel Rate (NGN)	110.00
Capacity (NGN/kWh)	3.2
Annual O&M Cost (NGN)	352
Electricity Rate-Base Case (NGN/kWh)	110.009
Total Electricity Cost (NGN)	4,416,852

Table 6-55: Proposed Grid-connected with the current National and Solar Company's Rate

Analysis Type		Method 2		
Solar Tracking mode		Fixed		
Angle/slope		15°		
Month	Horizontal Daily Solar Radiation (kWh/m²/day)	Tilted Daily Solar Radiation (kWh/m²/day)	Electricity Export Rate (NGN/MWh)	Electricity Exported to Grid (MWh)
January	5.68	6.22	24.30	0.526
February	5.74	6.03	24.30	0.461
March	5.57	5.59	24.30	0.476
April	5.25	5.04	24.30	0.417
May	4.94	4.58	24.30	0.393
June	4.54	4.16	24.30	0.347
July	4.14	3.84	24.30	0.335
August	3.91	3.73	24.30	0.326
September	4.19	4.13	24.30	0.348
October	4.57	4.69	24.30	0.405
November	5.11	5.49	24.30	0.455
December	5.46	6.04	24.30	0.513
Annual	4.92	4.95	24.30	5.003
Horizontal		MWh/m²	1.80	
Tilted		MWh/m²	1.81	

Analysis Type		Method 2		
Solar Tracking mode		Fixed		
Angle/slope		15°		
Month	Horizontal Daily Solar Radiation (kWh/m²/day)	Tilted Daily Solar Radiation (kWh/m²/day)	Electricity Export Rate (NGN/MWh)	Electricity Exported to Grid (MWh)
January	5.68	6.22	110.0	0.526
February	5.74	6.03	110.0	0.461
March	5.57	5.59	110.0	0.476
April	5.25	5.04	110.0	0.417
May	4.94	4.58	110.0	0.393
June	4.54	4.16	110.0	0.347
July	4.14	3.84	110.0	0.335
August	3.91	3.73	110.0	0.326
September	4.19	4.13	110.0	0.348
October	4.57	4.69	110.0	0.405
November	5.11	5.49	110.0	0.455
December	5.46	6.04	110.0	0.513
Annual	4.92	4.95	110.0	5.003
Horizontal		MWh/m²	1.80	
Tilted		MWh/m²	1.81	

Table 6-55 shows the current national electricity fuel rate is equal to GBP0.06 (N24.30) for

central grid-connected. The solar company's electricity rate is equal to GBP0.3 (N110). Both generated the same amount in capacity value. The 25 years' cash flow for N110 rate is equal to GBP3, 555 (N1, 439,757), and it is GBP3, 528 (N1, 428,926) with N24.30 rate. The difference between them is equal to GBP27 (N10, 831).

6.4.2.3 Rationale Evaluation

Case study 8 is reasonable with the amount invested based on a good return on investment, which attracted a short payback period. It shows that a good return on investment with a reasonable investment capital might result in a short payback period. The solar electricity generation provided the energy centre block with modern access service, regular and reliable uninterrupted light during office hours. Table 6-56 presents a sufficient amount of generation with less consumption.

Table 6-56: Generation Consumption, and Payback Computation

INVESTMENT POTENTIAL COMPUTATION						
LOCATION	CASE STUDY CAPACITY (kW)	YEARLY POWER CONSUMPTION (kWh)	ELECTRICITY RATE (N/kWh)	AMOUNT YEARLY/SAVING (N)	CAPITAL INVESTMENT (N)	PAYBACK PERIOD (YEAR)
NERCD NSUKKA	3.2	7,319	110	733,790	1,426,000	1.9

GENERATION OUTPUT CONSUMPTION AND PAYBACK PERIOD				
CASE STUDY	PV CAPACITY (kW)	POWER GENERATION YEARLY (kWh)	POWER CONSUMPTION YEARLY (kWh)	PAYBACK PERIOD (YEAR)
8	3.2	9,216	7,319	1.9

AVERAGE RETURN ON INVESTMENT PER YEAR USING PAYBACK PERIOD			
CASE STUDY	AMOUNT INVESTED (N)	PAYBACK PERIOD (YEARS)	AVERAGE AMOUNT REALIZED PER YEAR (N/YR)
8	1,426,000	1.9	733,790

6.5 Lagos Area Case Studies

Lagos state is a sprawl inland in south-western coast of Nigeria from Gulf of Guinea across Lagoon. This is formally Nigeria's Capital before re-location to FCT as one of the biggest cities of the federation and one of the largest urban areas in the world. This area has four case studies including Surulere location. Figure 6-31 presents the Lagos state Mainland area.



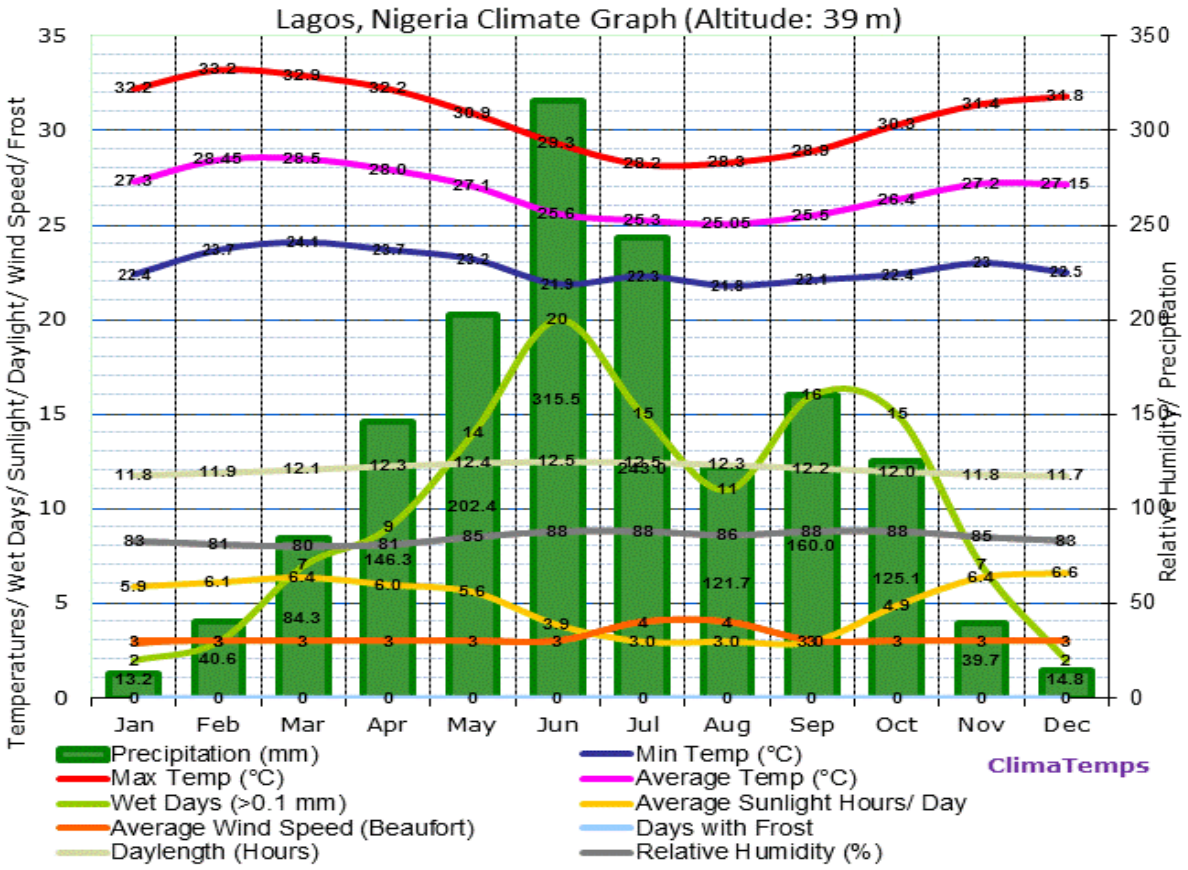
Figure 6-31: Surulere Location in Lagos state (Source: Udeze, 2016).

6.5.1 Lagos Weather Condition

This environment is characterized as coastal wetlands with sandy barrier islands, beaches, low-lying tidal flats, and estuaries. It is hot and wet tropical climate similar to the rest in southern Nigeria (e.g. Port/Harcourt, Benin, and Asaba). The dry/savannah climate comes in

low sun months with the pronounced dry season and high sun months in the rainy season (Geiger, 2015). The Lagos state geographical coordinates are latitude 6.5244^0 N and longitude 3.3792^0 E. The metropolis at latitude 6.6080^0 N, the longitude at 3.6218^0 E and Elevation at 39-41 metres (128-135 feet). The average temperature in January is 27 °C (79°F) and July at 25°C (77°F) (Engelbrecht and Engelbrecht, 2016). The weather condition with an average annual rainfall is 1532 mm (Peril, 1991; Abiodun, 1997 and Aina, 1994).

The hottest months are February and March with a mean temperature at 29°C (84°F). The warmest month in May, the coldest in July and August, the wettest in June and the driest month in January that are within the state average. The highest average temperature is in March is around 28.6^0c and the lowest average temperature in August around 25.2^0c (Gagneroc, 2016). Figure 6-32 presents the yearly Lagos state statistical weather conditions.



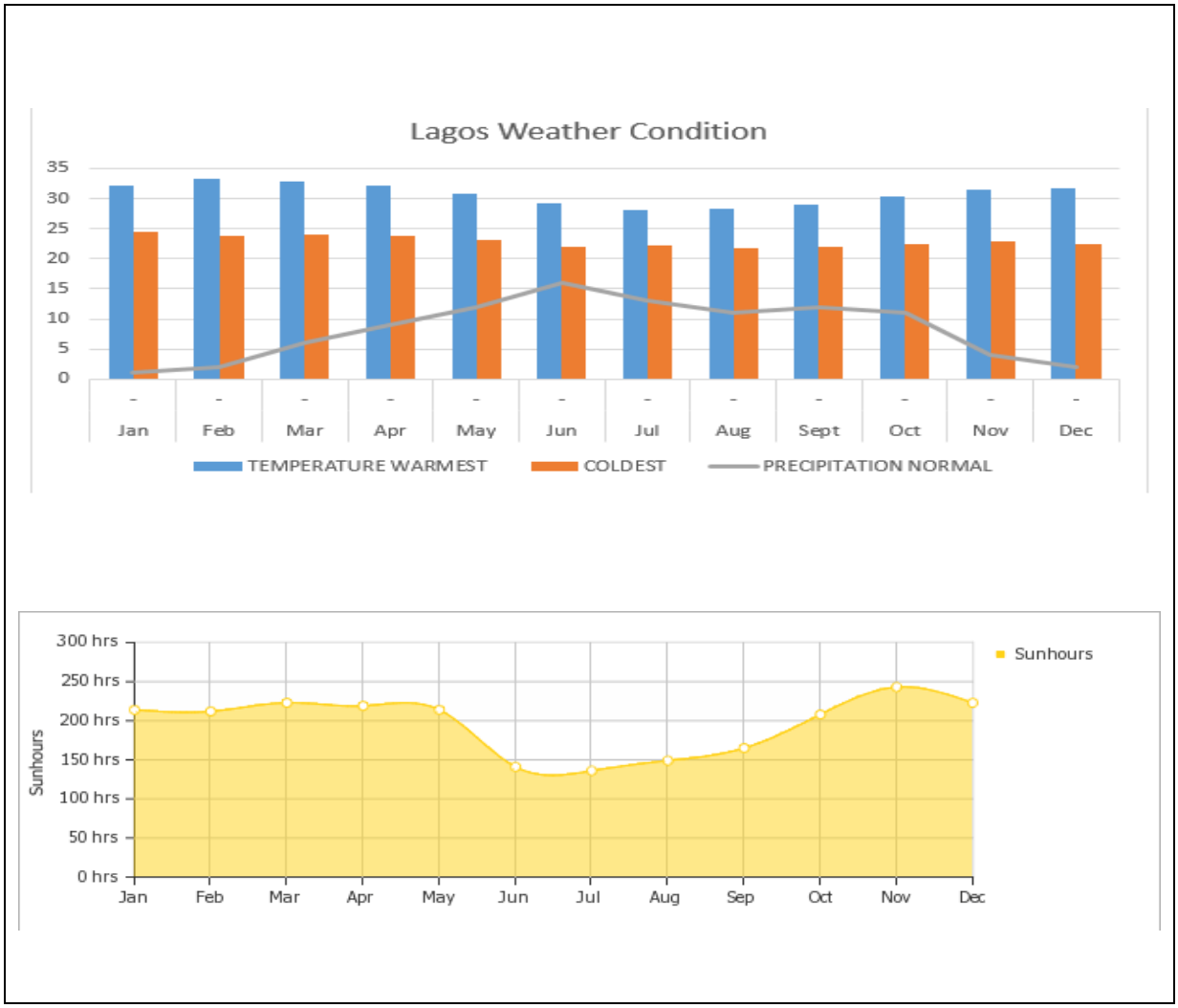


Figure 6-32: Monthly Average precipitation, temperature and Sun hours over the year (Source: Gagneroc, 2016).

6.5.2 Case Study 9: Surulere 4 Kilowatt PV Capacity

Surulere known for a traditional hand-made textile business by the indigenes of the state is one of the local government areas in Lagos state. This residential location due to unstable power supply needed solar PV installation. The company installed four KWp off-grid PV system with 16 PV panels that generated around 7,884 kWh on the residential household rooftop. The other components used include 7.5 KVA (6 kW) inverter, 10 x 200 Ah Gel batteries. The charge controller regulates power generated to prevent over/under charging of the batteries. Figure 6-33 represents the household rooftop application in Lagos state.

Table 6-57 presents the PV model technical specifications and other components used for the electricity generation.

6.5.2.1 PV Installation



Figure 6-33: Household rooftop Application in Lagos.

Table 6-57: Yingli Solar 250 W Polycrystalline PV System and the Technical Specifications

Location	Lagos
Application	Off-grid or Stand-alone
PV System Capacity Size	4 KWp
Manufacturer	Yingli Solar
Each Rated PV Watt	250 W
PV Type Used	Poly-crystalline
Number of Panels	16
Generation Expectation	7,884 kWh annually
Mounted Method	Fixed
Latitude	6° 35′ N,
Longitude	3° 20′ E
Elevation	39 metres (129 feet).
Gel Batteries	10 x 200 Ah
Inverter	7.5 kVA = 6 kW (i.e. 7.5 x 0.8 power factor due to fluctuations)
PV life span	25
ELECTRICAL CHARACTERISTICS	
Maximum Power Voltage (Vmpp)	30.40 Volts
Maximum Power current (Impp)	8.24 Amps
Open Circuit Voltage (Voc)	38.40 Volts
Short Circuit Current (Isc)	8.79 Amps
Maximum System Voltage	600.00 Volts
Module Watts STC	250 Watts
Module Watts PTC	226.20 Watts
Module Efficiency	15.30 %
Series Fuse rating	15 Amps
MECHANICAL DATA & COMPONENTS	
Module Technology	Poly
Cells per Module	60
Module Frame Material	White
Module Connector	Amphenol
Module Output Cables	PV Wire

This case with existing energy problem of the low generation led to power outages from weak transformer use due to overload in the urban areas that connected to the national grid. The household with this experience installed a solar system to replace use of a generator set for a solar stable power supply that reduced dependence on grid supply to the building. However, most households pay N110 rate on each unit of electricity generated from the installed PV capacity and the panels on each day generate adequately to run the home appliances in the Lagos locations.

6.5.2.2 Cost Investment Breakdown

Table 6-58 indicates the financial breakdown of the total cost of solar PV installation with all components including labour expenses for the investment in the location. Table 6-59 shows the appliances load consumption from generation supply to the building.

Table 6-58: Business Model Cost Breakdown

S/N	ITEM DESCRIPTION	QTY	UNIT COST (N:K)	AMOUNT (N:K)
1	Module 250 W, 24 V	16	110,000	1,760,000
2	Deep-Cycle Batteries 200Ah, 12 v	9	96,000	864,000
3	Charge Controller	2	65,000	130,000
4	Inverter 4.5 KVA	1	180,000	180,000
5	Supporting Structure	-	210,000	210,000
6	Accessories Cost	-	100,000	100,000
7	Transport	-	130,000	130,000
8	Labour	-	110,000	110,000
Total				3,484,000

Table 6-59: Appliances for Study data Generation and Consumption

Appliance	Quantity	App. Watt	No. of Hours Used	Total Watt Consumed/day	Generation in Watt/day	Variance Between Generation and Consumption	% Utilized
Bulb	6	24	12	1728			
Fan	3	100	12	3600			
TV	2	150	12	3600			
Total				8928	22000	13072	41%

The installed PV panels generated 22-kilowatt-hour per day and annually 7,920 kWh. The solar PV installed capacity can meet the full load capacity in the house building.

Table 6-60: Generation over Consumption

Case Study 9	Total Watt Consumed/day (W)	Total Watt Generated/day (W)	% of Generation over Consumption	% of Maximum watt consumable/day	Excess Utilized (%)
Surulere	8,928	22,000	141	100	41

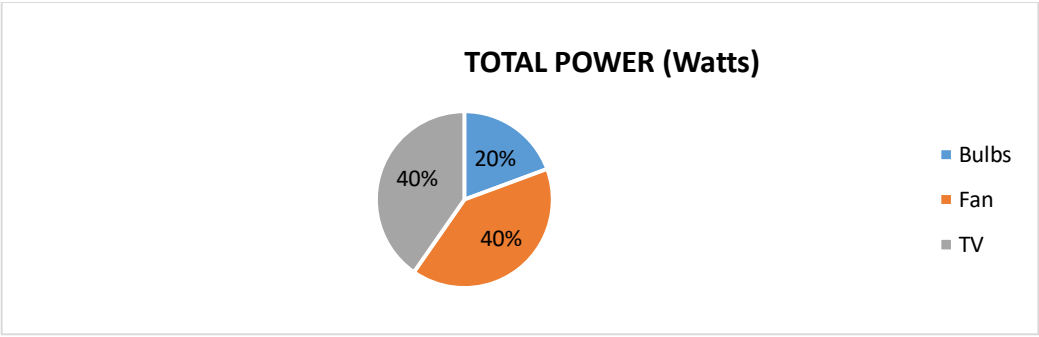


Figure 6-34: The total power in watts.

Table 6-60 shows the consumption and generation. This case consumes less than power generated and is advisable to increase the number of appliances to maximize the generated power output. Figure 6-34 demonstrates the total amount of power consumed with installed capacity plotted in the pie chart. Table 6-61 presents the electricity generated.

Table 6-61: Case Study 9 Off-grid Base Case Simulation

Grid type	Off-grid
Technology	Grid Electricity
Fuel Rate (NGN)	110.00
Capacity (NGN/kWh)	4
Annual O&M Cost (NGN)	440
Electricity Rate-Base Case (NGN/kWh)	110.011
Total Electricity Cost (NGN)	4,416,940

Table 6-62: Proposed Grid-connected with the current National and Solar Company's Rate

Analysis Type		Method 2		
Solar Tracking mode		MPPT		
Angle/slope		15^0 c		
Month	Horizontal Daily Solar Radiation (kWh/m²/day)	Tilted Daily Solar Radiation (kWh/m²/day)	Electricity Export Rate (NGN/MWh)	Electricity Exported to Grid (MWh)
January	5.28	5.75	24.30	0.636
February	5.49	5.76	24.30	0.574
March	5.46	5.48	24.30	0.607
April	5.21	5.00	24.30	0.538
May	4.76	4.42	24.30	0.494
June	4.04	3.73	24.30	0.407
July	3.95	3.68	24.30	0.417
August	3.98	3.80	24.30	0.432
September	4.09	4.03	24.30	0.442
October	4.55	4.67	24.30	0.524
November	4.95	5.31	24.30	0.572
December	5.17	5.69	24.30	0.630
Annual	4.74	4.77	24.30	6.275
Horizontal		MWh/m²	1.73	
Tilted		MWh/m²	1.74	

Analysis Type		Method 2		
Solar Tracking mode		MPPT		
Angle/slope		15^0 c		
Month	Horizontal Daily Solar Radiation (kWh/m²/day)	Tilted Daily Solar Radiation (kWh/m²/day)	Electricity Export Rate (NGN/MWh)	Electricity Exported to Grid (MWh)
January	5.28	5.75	110.0	0.636
February	5.49	5.76	110.0	0.574
March	5.46	5.48	110.0	0.607
April	5.21	5.00	110.0	0.538
May	4.76	4.42	110.0	0.494
June	4.04	3.73	110.0	0.407
July	3.95	3.68	110.0	0.417
August	3.98	3.80	110.0	0.432
September	4.09	4.03	110.0	0.442
October	4.55	4.67	110.0	0.524
November	4.95	5.31	110.0	0.572
December	5.17	5.69	110.0	0.630
Annual	4.74	4.77	110.0	6.275
Horizontal		MWh/m²	1.73	
Tilted		MWh/m²	1.74	

Table 6-62 shows the current national electricity fuel rate is equal to GBP0.06 (N24.30) for central grid-connected. The solar company's electricity rate is equal to GBP0.3 (N110) and both rates generated the same amount in capacity value. The 25 years' cash flow at N110 rate is equal to GBP8, 645 (N3, 501,257) and at N24.30 rate is GBP8, 612 (N3, 487,813). The difference between them is equal to GBP33 (N13, 445).

6.5.2.3 Rationale Evaluation

Case study 9 shows long payback due to the return on investment from the high amount invested. This household's location has modern access services from the PV generation supply. Table 6-63 presents the consumption and generation.

Table 6-63: Generation Consumption, and Payback Computation

INVESTMENT POTENTIAL COMPUTATION						
LOCATION	CASE STUDY CAPACITY (kW)	YEARLY POWER CONSUMPTION (kWh)	ELECTRICITY RATE (N/kWh)	AMOUNT YEARLY/SAVING (N)	CAPITAL INVESTMENT (N)	PAYBACK PERIOD (YEAR)
SURULERE RESIDENTIAL LAGOS	4	3,214	110	179,340	3,484,000	13.9

GENERATION OUTPUT CONSUMPTION AND PAYBACK PERIOD				
CASE STUDY	PV CAPACITY (kW)	POWER GENERATION YEARLY (kWh)	POWER CONSUMPTION YEARLY (kWh)	PAYBACK PERIOD (YEAR)
9	4	9,216	3,214	13.9

AVERAGE RETURN ON INVESTMENT PER YEAR USING PAYBACK PERIOD			
CASE STUDY	AMOUNT INVESTED (N)	PAYBACK PERIOD (YEARS)	AVERAGE AMOUNT REALIZED PER YEAR (N/YR)
9	3,484,000	13.9	179,340

6.5.3 Case Study 10: Iju Senior Secondary Location

This case is located in local government areas in Lagos state with local businesses and highly populated with low-income earners. Figure 6-35 presents the Iju location with red arrow indication.



Figure 6-35: Map of Iju location in Lagos state with red arrow.

6.5.3.1 Iju 13 Kilowatt PV Capacity Installation

This is 13 KWp solar PV system installed at Iju Senior Secondary School to ensure the school has enabling environment for learning and state development. This off-grid PV ground-mounted application includes 100 panels Suntech of 130 watts, pure sine wave inverters, maximum power point tracking charge controllers and 42 deep-cycle batteries bank (Greenicles, 2016). The design allows flexibility based on the angular orientation to help not to lose some percentage of production output (Okanlawon, 2016). Figure 6-36 presents the off-grid ground-mounted PV application in the location. Table 6-64 presents PV model technical specifications and other components used for electricity generation.



Figure 6-36: The off-grid ground-mounted application at Iju-Agege.

Table 6-64: Suntech STP 130 W Polycrystalline PV System and the Technical Specifications

Location	Iju- Lagos
Application	Ground-Mounted
PV System Capacity Size	13 kWp
Manufacturer	Suntech
Model	STP130-12/Tb
Each Rated PV Watt	130 W
PV Type Used	Poly-crystalline
Number of Panels	100
Generation Expectation Annually	35,040 kWh
Mounted Method	MPPT
Number of Deep-cycle Batteries	42
Inverter	N/A
PV life span	25
Commencement Date	2014

ELECTRICAL CHARACTERISTICS	
Cell	Multicrystalline silicon solar cells 156 mm x 156 mm
No of cells and connections	36 (4 x 9)
Open-circuit voltage (Voc)	22 V
Optimum Operating Voltage (Vmp)	17 V
Short Circuit Current (Isc)	8.09 A
Optimum Operating Current (Imp)	7.47 A
Maximum Power at STC (Pmax)	130 Wp
Operating Temperature	-40^{0}c to + 85^{0}c
Maximum System Voltage	1000 V DC
Module Efficiency	13%
MECHANICAL CHARACTERISTICS	
Dimensions	1482 x 676 x 35 mm
Weight	12 kg
TEMPERATURE COEFFICIENTS	
NOCT	45^{0}C ± 2^{0}C
Short circuit current temperature coefficient	(0.055 ± 0.01) %/K
Open circuit voltage temperature coefficient	-(75 ± 10) %/K
Peak power temperature coefficient	-(0.47 ± 0.05) %/k
Power Tolerance	± 5 %
Output	
Cable	LAPP (4.0 mm^{2})
Lengths	750 mm (-) and 750 mm (+)
Connection	MC Plug Type IV

This ground-mounted installation solar power system is contributing to zero-carbon by the available solar radiation in the school location. The solar electricity generation is helping to run the school appliances by powering fan/A/C to reduce heat gain inside the classroom. It provides natural air ventilation into the classroom and making the office block environmentally friendly. The application helps to provide more electricity generation than from the national grid associated with a weak transformer and unstable power supply in the country states.

6.5.3.2 Cost Investment Breakdown

Table 6-65 indicates the financial breakdown for solar PV installation total cost including labour expenses use in the investment. Table 6-66 presents the load consumption appliances used from generation supply to the office and classroom blocks.

Table 6-65: Business Model Cost Breakdown

S/N	ITEM DESCRIPTION	QTY	UNIT COST (N:K)	AMOUNT (N:K)
1	Module 120 W	100	100,000	10,000,000
2	Deep-Cycle Batteries	42	85,000	3,570,000
3	Charge Controller	2	60,000	120,000
4	Inverter 36 KVA	2	350,000	700,000
5	Supporting Structure	-	400,000	400,000
6	Accessories Cost	-	100,000	100,000
7	Transport	-	150,000	150,000
8	Labour	-	100,000	100,000
Total				15,140,000

Table 6-66: Appliances for Study data Generation and Consumption

Appliance	Quantity	App. Watt	No. of Hours Used	Total Watt Consumed per Day	Generation in Watt per Day	Variance Between Generation & Consumption	% Utilized
Classroom bulb	10	15	8	1200			
Library bulb	10	15	8	1200			
Laboratory bulb	10	15	8	1200			
Computer room bulb	10	15	8	1200			
Computer	5	125	8	5000			
Administrative Office bulb	10	15	8	1200			
Security bulb	10	20	12	2400			
Fridge	5	100	8	4000			
Fan	15	70	8	8400			
TV	3	80	8	1920			
Total				27720	97333	69613	28%

The installed PV panels generated 97.3-kilowatt-hour per day or 35,040 kWh/year. The installed solar PV capacity can meet all the full load capacity within the school blocks.

Table 6-67: Generation over Consumption

Case Study 10	Total Watt Consumed/day (W)	Total Watt Generated/day (W)	% of Generation over Consumption	% for Maximum Watt Consumable/day	Excess Utilized (%)
Iju Senior Secondary	27,720	97,333	128	100	28

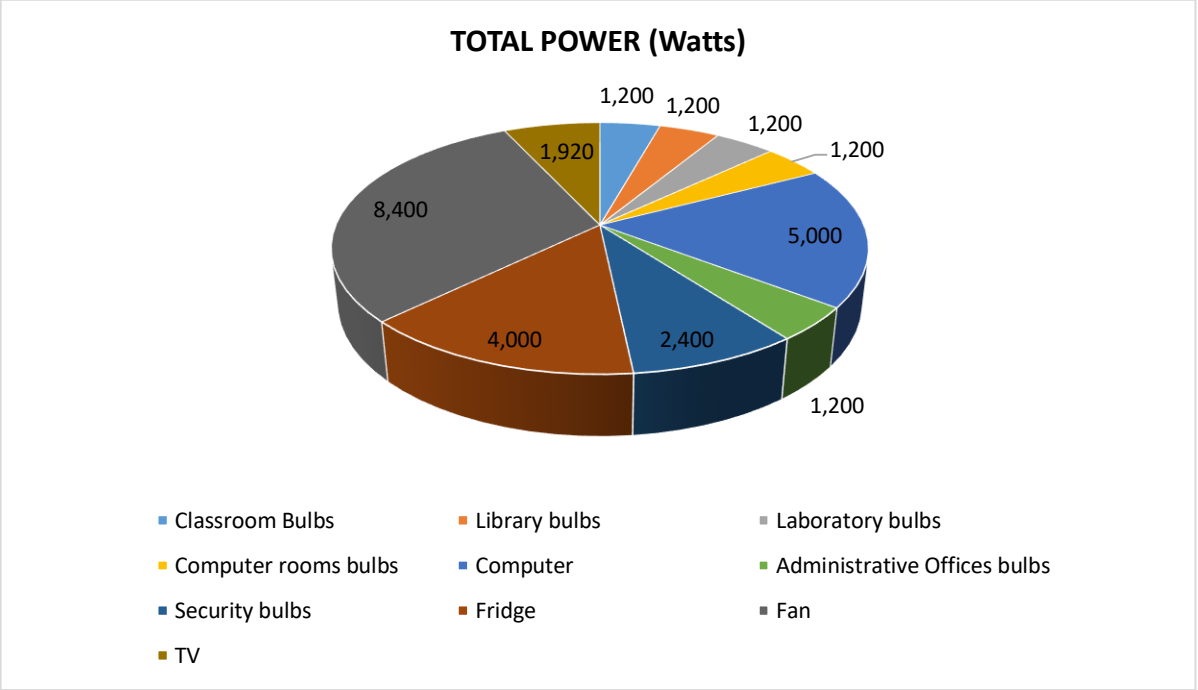


Figure 6-37: The total power in watts.

Table 6-67 shows consumption and generation. It is advisable in this case study, to increase the number of appliances to maximize the power generated. Figure 6-37 demonstrates the total amount of power consumed plotted in the pie chart. Table 6-68 presents the electricity generated.

Table 6-68: Case Study 10 Off-grid Base Case Simulation

Grid type	Off-grid
Technology	Grid Electricity
Fuel Rate (NGN)	110.00
Capacity (NGN/kWh)	13
Annual O&M Cost (NGN)	1430
Electricity Rate-Base Case (NGN/kWh)	110.036
Total Electricity Cost (NGN)	4,417,930

Table 6-69: Proposed Grid-connected with the current National and Solar Company's Rate

Analysis Type		Method 2		
Solar Tracking mode		MPPT		
Angle/slope		15^0 c		
Month	Horizontal Daily Solar Radiation (kWh/m²/day)	Tilted Daily Solar Radiation (kWh/m²/day)	Electricity Export Rate (NGN/MWh)	Electricity Exported to Grid (MWh)
January	5.28	5.75	24.30	2.068
February	5.49	5.76	24.30	1.867
March	5.46	5.48	24.30	1.973
April	5.21	5.00	24.30	1.750
May	4.76	4.42	24.30	1.604
June	4.04	3.73	24.30	1.324
July	3.95	3.68	24.30	1.355
August	3.98	3.80	24.30	1.403
September	4.09	4.03	24.30	1.438
October	4.55	4.67	24.30	1.704
November	4.95	5.31	24.30	1.859
December	5.17	5.69	24.30	2.049
Annual	4.74	4.77	24.30	20.394
Horizontal		MWh/m²	1.73	
Tilted		MWh/m²	1.74	

Analysis Type		Method 2		
Solar Tracking mode		MPPT		
Angle/slope		15^0 c		
Month	Horizontal Daily Solar Radiation (kWh/m²/day)	Tilted Daily Solar Radiation (kWh/m²/day)	Electricity Export Rate (NGN/MWh)	Electricity Exported to Grid (MWh)
January	5.28	5.75	110.0	2.068
February	5.49	5.76	110.0	1.867
March	5.46	5.48	110.0	1.973
April	5.21	5.00	110.0	1.750
May	4.76	4.42	110.0	1.604
June	4.04	3.73	110.0	1.324
July	3.95	3.68	110.0	1.355
August	3.98	3.80	110.0	1.403
September	4.09	4.03	110.0	1.438
October	4.55	4.67	110.0	1.704
November	4.95	5.31	110.0	1.859
December	5.17	5.69	110.0	2.049
Annual	4.74	4.77	110.0	20.394
Horizontal		MWh/m²	1.73	
Tilted		MWh/m²	1.74	

Table 6-69 shows the current national electricity fuel rate is equal to GBP0.06 (N24.30) for the central grid-connected. The solar company's electricity rate is equal to GBP0.3 (N110) that also generated the same amount of capacity value. The cash flow for 25 years using N110 rate

is equal to GBP37, 526 (N15, 198,084) and at N24.30 rate, it is equal to GBP37, 413 (N15, 152,389). The difference between them is GBP113 (N45, 695).

6.5.3.3 Rationale Evaluation

Case study 10 shows long payback due to the return on investment from the high amount invested. This provided a sufficient amount of generation with less consumption within twenty-four years (24) payback. The school people are enjoying modern access services from solar electricity supply. The classroom teachers with the schoolchildren have reliable and constant electricity to teach and learn. This presently contributes to the school financial savings rather than spending more money on fuel-powered generators due to the problem of unstable grid supply. Table 6-70 represents the amount of generation, consumption and the payback.

Table 6-70: Generation Consumption, and Payback Computation

INVESTMENT POTENTIAL COMPUTATION						
LOCATION	CASE STUDY CAPACITY (kW)	YEARLY POWER CONSUMPTION (kWh)	ELECTRICITY RATE (N/kWh)	AMOUNT YEARLY/SAVING (N)	CAPITAL INVESTMENT (N)	PAYBACK PERIOD (YEAR)
IJU SECONDARY SCHOOL LAGOS	13	9,979	110	340,690	15,140,000	24

GENERATION OUTPUT CONSUMPTION AND PAYBACK PERIOD				
CASE STUDY	PV CAPACITY (kW)	POWER GENERATION YEARLY (kWh)	POWER CONSUMPTION YEARLY (kWh)	PAYBACK PERIOD (YEAR)
10	13	35,040	9,979	24

AVERAGE RETURN ON INVESTMENT PER YEAR USING PAYBACK PERIOD			
CASE STUDY	AMOUNT INVESTED (N)	PAYBACK PERIOD (YEARS)	AVERAGE AMOUNT REALIZED PER YEAR (N/YR)
10	15,140,000	24	340,690

6.5.4 Case Study 11: Lekki Metromart Commercial location

This is a rich beautified city of Lagos state where majority dwellers are high-class income earners. Figure 6-38 presents the location map with blue arrow indication. Figure 6-39 presents solar PV system capacity installation in the location.

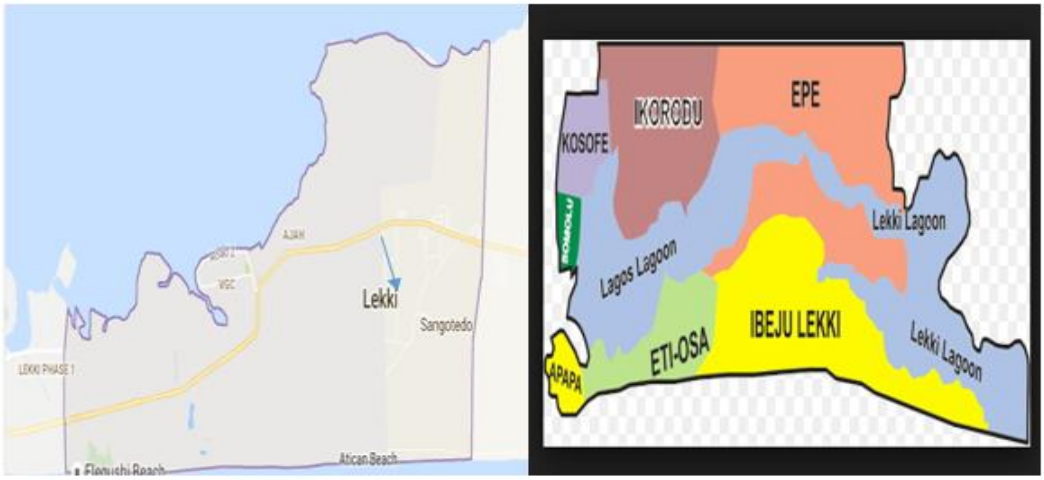


Figure 6-38: Lekki Location in Lagos State of Nigeria with blue arrow indication (Source: Google, 2016).

6.5.4.1 Lekki 16.3 Kilowatt PV Capacity Installation

The solar PV system with rooftop installation is for multi-purpose megastore in Lekki location with 64 Canadian solar panels of 255 rated watts, 2 x 10 KVA inverters, 30 x 200 Ah Gel batteries and 2 x 180 V charge controllers generated annually 71,552 kWh. Table 6-71 presents the PV system technical specifications that include other components for the electricity capacity generation.



Figure 6-39: Lekki Off-grid commercial Application.

Table 6-71: Canadian Solar 255 W Polycrystalline PV System and the Technical Specifications

Location	Lekki- Lagos
Application	Off-grid roof-top
PV System Capacity Size	16.3 kWp
Manufacturer	Canadian solar
Model	CS6P-255P BLK
Each Rated PV Watt	255 W
PV Type Used	Poly-crystalline
Number of Panels	64
Generation Expectation Annually	71,552 kWh
Mounted Method	Fixed
Number of Gel Batteries	30 x 200 Ah
Inverter	2 x 10 KVA = 16 kW
Charge controller	2 x 180 V
PV Life-span	25

ELECTRICAL CHARACTERISTICS	
Configuration	Robust frame up to 5400Pa, anti-reflective with self-cleaning surface and outstanding performance at low irradiance.
Watts (STC)	255 W
Watts (PTC)	185 W
Max Power Voltage (Vmpp)	30.2 V
Max Power Current (Impp)	8.43 A
Open Circuit Voltage (Voc)	37.4 V
Short Circuit Current (Isc)	9.00 A
Max System Voltage DC	600 V
Solar Module Cells	60
Module Efficiency	15.54%

MECHNICAL CHARACTERISTICS	
PV Type	Polycrystalline
Dimensions	64.5'' x 38.7'' x 1.57''
Weight	41.9 lbs
Frame	Black
Connector	MC4 or MC4 Comparable
NOCT	High energy yield at low NOCT
Power Tolerance	0-+5W
Power Output Warranty Period of for Years	80%
Power Output Warranty Period for 10 Years	90%
Workmanship Warranty Period	10 Years

This case study is designed for multi-purpose megastore due to a problem with generator sets use, costs of generating the electricity in terms of diesel/fuel buying and the maintenance. The generating sets are a common case scenario used by Nigerians residential and commercial to compensate inadequate power supply from the national grid. However, the installed solar power system is a solution to meet the electricity demand and reduce the escalating costs of purchasing diesel to power the megastore. The PV system generates 71,552 kWh/year electricity and the monthly power generating has reduced the fuel costs by 80 percent with the uninterrupted power supply to the premises. Moreover, the solar installation is able to meet the electricity demand in the mall.

6.5.4.2 Cost Investment Breakdown

Table 6-72 shows the financial breakdown for solar PV installation total cost with other components including labour expenses used for the investment in the location. Table 6-73 presents the amount of cost of electricity generated from the simulation.

Table 6-72: Business Model Cost Breakdown

S/N	ITEM DESCRIPTION	QTY	UNIT COST (N:K)	AMOUNT (N:K)
1	Module 120 W	64	100,000	6,400,000
2	Deep-Cycle Batteries	30	85,000	2,550,000
3	Charge Controller	2	60,000	120,000
4	Inverter 10 KVA	2	350,000	700,000
5	Supporting Structure	-	400,000	400,000
6	Accessories Cost	-	100,000	100,000
7	Transport	-	150,000	150,000
8	Labour	-	100,000	100,000
Total				10,520,000

Table 6-73: Case Study 11 OFF-grid Base Case Simulation

Grid type	Off-grid
Technology	Grid Electricity
Fuel Rate (NGN)	110.00
Capacity (NGN/kWh)	16.3
Annual O&M Cost (NGN)	1,793
Electricity Rate-Base Case (NGN/kWh)	110.045
Total Electricity Cost (NGN)	4,418,293

Table 6-74: Proposed Grid-connected with the current National and Solar Company's Rate

Analysis Type		Method 2		
Solar Tracking mode		MPPT		
Angle/slope		15^0 c		
Month	Horizontal Daily Solar Radiation (kWh/m²/day)	Tilted Daily Solar Radiation (kWh/m²/day)	Electricity Export Rate (NGN/MWh)	Electricity Exported to Grid (MWh)
January	5.28	5.75	24.30	2.593
February	5.49	5.76	24.30	2.341
March	5.46	5.48	24.30	2.474
April	5.21	5.00	24.30	2.194
May	4.76	4.42	24.30	2.011
June	4.04	3.73	24.30	1.660
July	3.95	3.68	24.30	1.700
August	3.98	3.80	24.30	1.759
September	4.09	4.03	24.30	1.803
October	4.55	4.67	24.30	2.137
November	4.95	5.31	24.30	2.331
December	5.17	5.69	24.30	2.569
Annual	4.74	4.77	24.30	25.571
Horizontal		MWh/m²	1.73	
Tilted		MWh/m²	1.74	

Analysis Type		Method 2		
Solar Tracking mode		MPPT		
Angle/slope		15^0 c		
Month	Horizontal Daily Solar Radiation (kWh/m²/day)	Tilted Daily Solar Radiation (kWh/m²/day)	Electricity Export Rate (NGN/MWh)	Electricity Exported to Grid (MWh)
January	5.28	5.75	110.0	2.593
February	5.49	5.76	110.0	2.341
March	5.46	5.48	110.0	2.474
April	5.21	5.00	110.0	2.194
May	4.76	4.42	110.0	2.011
June	4.04	3.73	110.0	1.660
July	3.95	3.68	110.0	1.700
August	3.98	3.80	110.0	1.759
September	4.09	4.03	110.0	1.803
October	4.55	4.67	110.0	2.137
November	4.95	5.31	110.0	2.331
December	5.17	5.69	110.0	2.569
Annual	4.74	4.77	110.0	25.571
Horizontal		MWh/m²	1.73	
Tilted		MWh/m²	1.74	

Table 6-74 shows the current national electricity fuel rate is equal to GBP0.06 (N24.30) for proposed central grid-connection. The solar company's electricity rate is equal to GBP0.3 (N110). They both generated the same amount of capacity value. The cash flow for 25 years using N110 rate is equal to GBP26, 149 (N10, 590,321) and at N24.30, it is equal to GBP26, 014 (N10, 535,535). The difference between them equal to GBP135 (N54, 786).

6.5.4.3 Rationale Evaluation

Case study 11 is for the shopping mall energy analysis, the electricity consumption is larger than the generated electricity of the PV system, so all the generated electricity of the PV system is assumed to be consumed in this case. This power system is helping to meet the energy need of shop owners in the mall with modern access service in the location. Table 6-75 presents the generation computation.

Table 6-75: Generation Computation

INVESTMENT POTENTIAL COMPUTATION						
LOCATION	CASE STUDY CAPACITY (kW)	YEARLY POWER GENERATION (kWh)	ELECTRICITY RATE (N/kWh)	AMOUNT YEARLY/SAVING (N)	CAPITAL INVESTMENT (N)	PAYBACK PERIOD (YEAR)
LEKKI MEGASTORE LAGOS	16.3	71,552	110	7,870,720	10,520,000	1.4

GENERATION OUTPUT CONSUMPTION AND PAYBACK PERIOD				
CASE STUDY	PV CAPACITY (kW)	POWER GENERATION YEARLY (kWh)	POWER CONSUMPTION YEARLY (kWh)	PAYBACK PERIOD (YEAR)
11	16.3	71,552	71,552	1.4

AVERAGE RETURN ON INVESTMENT PER YEAR USING PAYBACK PERIOD			
CASE STUDY	AMOUNT INVESTED (N)	PAYBACK PERIOD (YEARS)	AVERAGE AMOUNT REALIZED PER YEAR (N/YR)
11	10,520,000	1.4	7,870,720

6.6 Case Study's Results

The cases investigated were used to understand the existing off-grid solar PV system performance in various locations of the country. The purpose of the case study for people's opinion about the implementation and application of solar energy due to the identified gaps in Nigeria. This cases are about electricity supply to various household using a PV system for power consumption with analysis of the payback period.

The findings revealed that the Bank of Industry (BOI) is the only financial institution with the responsibility for accessing RE development loan across the country under Central Bank of Nigeria (CBN) mandate. The off-grid deployment has started to grow even without the implementation of solar energy and subsidy. The average installation per year has increased significantly because energy consumption is needed for Nigerian economic activity and growth across the country. This study found that the role of finance is very significant to minimize the financial gap for rural and urban electrification in the country. The results show that PV system installation is a boost to the local economy with establishment of solar industries in the country.

The cases are used to identify the amount of electricity generated in meeting consumption due to an increase in energy demand and this could be the best option for cost and emission reductions. Table 6-76 and Table 6-77 present the results for large installed PV system and small domestic application capacities. Table 6-78 presents the breakdown Analysis based on Payback Period for the generation and consumption

Table 6-76: Analysis between 33kW and 3.2kW Capacity for Domestic Installed PV system

Factors	Estate Apartment	Individual Apartment
PV capacity	33 kW	3.2 kW
Number of panels	140	16
Total cost	N14,828,000	N1,348,000

Installation cost per apartment	N1,348,000 (i.e. (N14,828,000/11)	N674,000 (N1,348,000/2)
Power output	72,576 kWh	9,677 kWh
Yearly consumption from each apartment	66,799 kWh	6,445 kWh
Number of apartments serviceable	11	2

Table 6-77: Analysis Breakdown of Estate and Individual off-grid PV System Apartment

N/S	Parameter	Estate Apartment	Individual Apartment
A	Initial Investment Capital	N14,828,000	N1,348,000
B	Yearly power output consumption	66,799 kWh	6,445 kWh
C	Number of apartment serviceable	11	2
D	Yearly electricity consumption per apartment	6,072.6 kWh (66,799/11)	3,222.5 kWh (6,445/2)
E	Electricity rate (unit cost)	N110/kWh	N110/kWh
F	Yearly consumption rate	6,072.6363 x 110 = (N667,990/12) = 55,665.8333	3,222.5 x 110 = (N354,475/12) = 29,539.5833
G	Monthly bill per apartment	N55,666	N29,540
H	The electricity consumption	N557/kWh (N55,666/110)	N269/kWh (N29,540/110)
I	Annum total amount	N7,347,912 (55,666 x 11 x 12)	N708,960 (29,540 x 2 x 12)

J	Payback period based on interest rate (%)	2.2 years	2 years

Table 6-76 and Table 6-77 show estate apartment with high investment capital from the installed capacity, which realized a huge income/savings yearly. An individual apartment with small investment capital from the small installed capacity realized returns as well. The PV system good performance by self-financing resulted in short payback in the location. The estate capacity with polycrystalline PV Panel generated more and consume more than the individual with a small monocrystalline PV panel installed capacity. The different in generation output may be due to the system size, the number of module cells and efficiency. For example, the estate apartments with 33 kW installed capacity used 240W of 140 panels for 6 hours' average (240 x 140 x 6) to generate 201,600 kWh/day. The power generated per year equal to 72,576 kWh (201,600 x 30 x 12 = 72,576,000/1000). The individual 3.2 kW installed capacity used 210W of 16 panels for 8 hours generated 26,880 kWh/day. The power generated per year equal to 9,677 kWh (26,880 x 30 x 12 = 9676800/1000) based on solar availability in each of the locations.

Table 6-78: Apartment Analysis breakdown based on Payback Period

Parameter	Estate Apartment	Individual Apartment
Total cost	N14,828,000	N1,348,000
Yearly Payment	N1,980,000.00	N360,000.00
Monthly bill per apartment	N55,666	N29,540
Payback period	2.2 Years	2 Years
Life span of PV system	25 years	25 years

Table 6-78 represents the estate apartment and individual apartment with different monthly bills. The estate apartment in the above analysis resulted in short payback (2.2) years and individual apartment relatively payback in (2) years based on the amount invested. This pay better for the company and the consumer which shows that the two projects are less risky and realistic with short payback periods because a short payback can be less risky to a long payback based on generation and consumption.

Table 6-79: Short/Medium and Long-term Investment

Investor	PV Capacity (kW)	Amount Invested (N)	Generated (kWh)	Consumed (kWh)	No of Apartment	Payback Period (Year (S)
Estate	33	14,828,000	72,576	66,799	11	2.2
Individual	3.2	1,348,000	9,677	6,445	2	2

This study agrees with the previous research that government incentives are required to reduce short-term costs for long-term benefits to support PV investment and boost solar energy deployment as well as makes solar PV project relatively cost-effective in Nigeria (DOE, 2010: IEA-PVPS, 2007). For example, government financial support for PV pilot project demonstration expanded the deployment of the system in Nigeria because the populations are in need of electricity and the price of solar systems installation may decrease at long-term. In addition, most Nigerians are low-income earners such as the rural poor that lack capital for investment.

Table 6-79 shows the generation and consumption due to payback period in utilizing solar energy potential with PV systems in Nigeria. The two projects apart from having different PV installed capacities are a viable investment because they both benefited potentially and financially with the short paybacks. This proved the result analysis outlined in chapter 5 under

question 31 that ‘‘citizens will benefit more from the use of solar energy both for individuals and businesses in Nigeria.’’

Table 6-80: Useful Electricity and Electricity Wasted

CASES	GENERATION(kWh)	CONSUMPTION (kWh)	USEFUL ELECTRICITY (%)	ELECTRICITY WASTED (%)
1	72,576	66,799	92	8
2	16,243	5,530	34	66
3	9,677	6,445	67	33
4	14,076	7,359	52	48
5	12,420	7,359	59	41
6	648	467	72	28
7	2,880	156	54	46
8	9,216	7,319	79	21
9	7,884	3,214	41	59
10	35,040	9,979	28	72
11	71,552	71,552	100	0

The above analysis in Table 6-80 show that not all generated were consumed which resulted to waste in this study. For example, case study 2, 7, 9 and 10 with a longer payback period could be as a result of high investment capital. The huge waste apart from the returns/savings realized based on the following percentages (66%, 46%, 59%, and 72%). The short payback from self-financing shows less waste while case study 2, 7, 9 and 10 with long paybacks show a huge waste of electricity which are mainly the government pilot projects.

For this cases, generation over-consumption means excess generations that was wasted due to no grid-connected system yet in the country. Case study 2, 9 and 10 show a longer payback period due to too much electricity wasted when compared with others. Case study 7 with a much longer payback period (29) which is over the assumed life-cycle of the project with less consumption from the capacity generated. In this study, the PV generators could afford the

cash purchase of the system for the well-designed solar system that generated adequately and realized enough savings/returns whereas case study 1, 3, 8 realized in a few years.

The cases are for non-profit solar customers such as individual's residence, school and government office block that solar company's designed for their benefits means Apart from the government pilot projects for public benefit in the installed locations, the savings can be shared between the consumers and the company. For example, case study 1 and 6 are solar company installation based on PAYG for non-profit customers allowing them to share in the savings.

The case studies from self-financing through savings were not a loan by borrowing for solar projects. However, cash is a key driver for finance choice, which attracted short, medium and long-term payback depending on the amount of capital invested for the installations in Nigeria. The cost of PV systems for case study 1, 2, 4, 5, 9, 10 and 11 happened to be higher than case study 3, 6, 7 and 8, which involved individuals, company's financing options and the government with pilot projects. Case study 1, 3, 4, 5, 6 and 8 with short-medium term payback whereas case study 2, 7, 9 and 10 with long-term investment payback, and they both realized good returns from the amount invested. The government equity generated both short and long-term and this applicable to case study 2, 7, 8, 9 and 10 depending on the purpose of use from the amount of capital invested.

Table 6-81: Comparison between UK and Nigeria Payback based on Generation

UK (GBP)				
Capacity (kW)	Yearly Power Generation (kWh)	Invested Capital/ Investment Cost (£)	Total Annual Earning (£)	Payback (Year)
1.08	918	£2,250	132	17
2.16	1,836	£3,500	264	13
2.88	2,448	£5,000	352	14
3.96	3,366	£7,000	483	15

Nigeria (NGN)				
1	2,880	N500,000 (£1,235)	N316,800 (£982)	1.57
2.16	14,076	N3,365,000 (£8,309)	N1,548,360 (£3,823)	2.35
3.2	9,216	N1,426,000 (£3,521)	N1,013,760 (£2,503)	1.49
4	7,884	N3,484,000 (£8,602)	N867,240 (£2,141)	4.59

Table 6-81 analysed the generation between UK and Nigeria based on yearly power generation. The UK FIT tariffs is 14.4p/kWh based on total annual earnings (return on investments) for the grid-connection while Nigeria solar rate which is assumed if it is grid-connected to be N110 (£0.27).

The UK Feed-in tariff (FIT) rate for solar PV between 2010 and 2012 was 43.3p/kWh. Presently, FIT rate with average electricity price is 14.4p/kWh as indicated in Table 6-81. The UK government implemented renewable development with FIT rate for grants and borrowing. In comparing Nigeria solar rate equivalent to (£0.27) is higher than UK rate because the PV systems are not locally manufactured for the cases based on the quality, type, cell per module and module efficiency and the size for adoption. Nigeria total annual earnings is three times more than UK yearly power generation due to solar availability throughout the year. In Nigeria context:

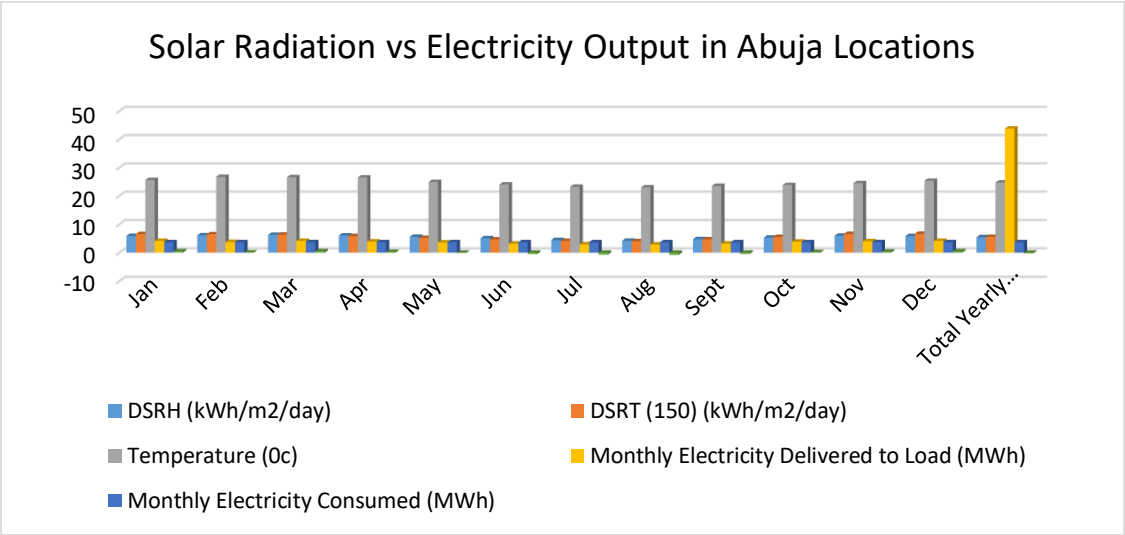
1) The abundant solar resource resulted to adequate generation with installed PV capacity with good earnings.
2) The installed off-grid PV system for maximum benefit due to inadequate power supply and outages.
3) The cost factors have not been taken into consideration for generation since no grid-connection in Nigeria. In UK, government has put all the cost factors into consideration due to implemented FITs for grid-connection and a return on investment based on 5% or 8% for projects.

4) The generation payback period shows short-medium-term investment for capacity installed in Nigeria. In UK context, the small capacity installed due to repayment of grants and cost of borrowing in generation shows a long-term payback. In 2016, the literature finding revealed that UK FIT rate cut to 4.39p/kWh would take a much longer time to recoup by solar consumer/generator. In Nigeria, more electricity use from solar PV could be better than buying from the grid due to constant outages.

In Nigeria, individuals or businesses preferred self-financing due to high interest rate (20%-22%) per annum by banks with a very short payback time of 1- 3 years and without government subsidies make investment in solar energy less developed (Eromni, 2014). In addition, absence of appropriate policy to expand solar market and lack of motivation measure (Akpu, 2012). The PV system deployment from the findings largely depend on financial capability but PV development can improve through public-private investment in Nigeria. In real situation of the case study, those that could afford PV system cost apart from government sponsored solar pilot demonstrations are self-financing for the off-grid installation by individual and company for residential, offices and business applications. The data collected from the case study is not based on borrowing for PV system adoption. However, implementation of incentives could result to borrowing is yet to be effective or implemented in Nigeria.

Figure 6-40 presents the Abuja case studies with use of monocrystalline and polycrystalline silicon PV systems. The average daily solar radiation horizontal (DSRH) at 5.45kWh/m^2/day for monthly generation simulation results shows that: During rainy season, there are more solar availability in March, February, April, January, May and June, and declines in July, August and September based on proposed export to grid and rises towards average in October, November and December yearly. The electricity exported to grid from simulation indicated negative from May to September which shows reduction in number of hours of sunshine due to rainfall. Based on solar radiation, the output generation in plotted charts show the relationship between DSRH and daily solar radiation tilted (DSRT). It shows that DSRH can generate less output during raining season than DSRT because of more radiation received from tilt direction. It is advisable to use monocrystalline for better generation performance

during this period of season with energy storage (battery) during day generation for night use respectively.



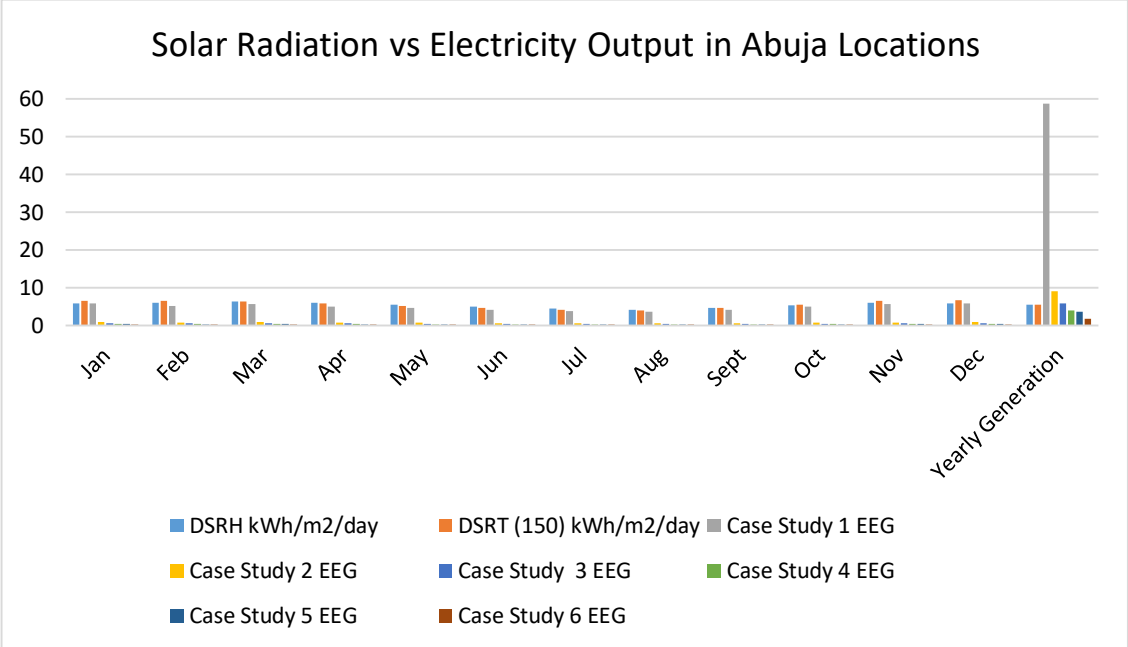
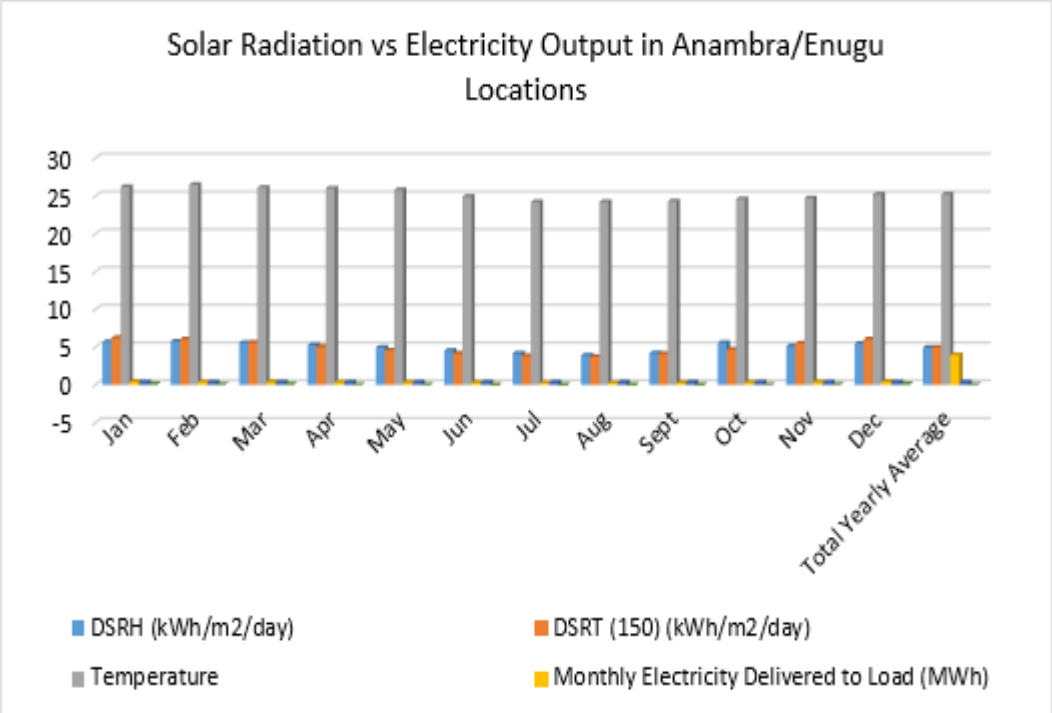


Figure 6-40: Abuja solar radiation and the electricity outputs.

Figure 6-41 presents the Awka and Nsukka case studies with monocrystalline and polycrystalline silicon PV system with the same DSRH value at latitude and longitude. The solar radiations for yearly total average are 4.92 kWh/m^2/day. It is available more in January, February, March and April, but moves towards average in May, June and July and declined in

August at peak rainfall every day. During start of dry season, it moves towards average in September and becomes more available in October, November and December. During rainy season, the output generation from May to September is reduced due to less number of sunshine hours. It is advisable to use monocrystalline for high efficiency performance for the PV off-grid application that generates with energy storage during the day for night use.

However, the DSRH represents Daily Solar Radiation Horizontal; DSRT represents Daily Solar Radiation Tilted; EG represents Electricity Generation; MG represents Monthly Generation; EC represents Electricity Consumption; EEG represents Electricity Export to Grid and ER represents Electricity Rate.



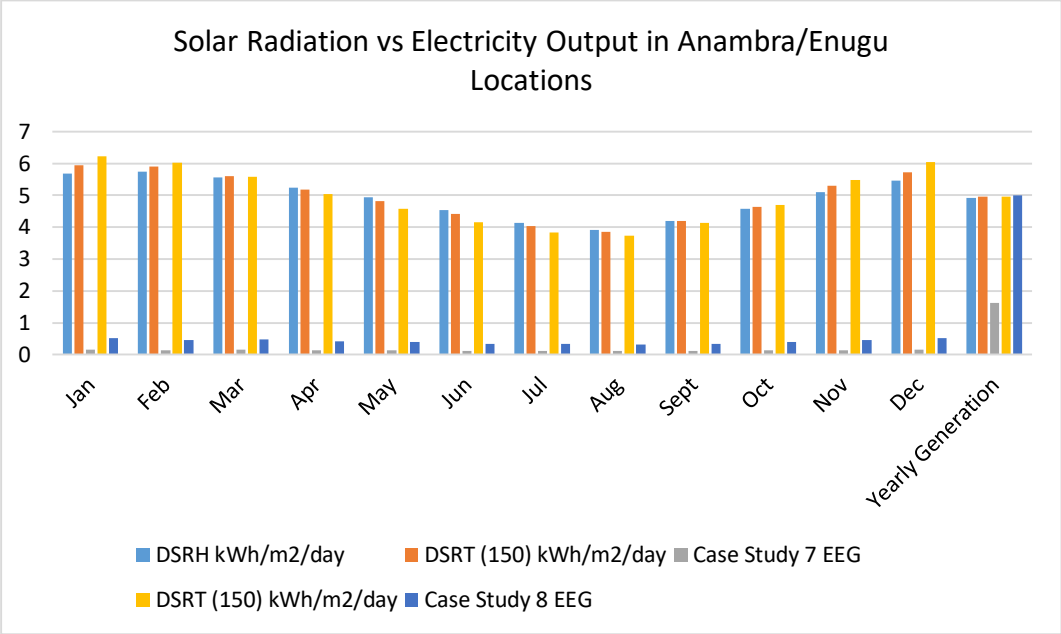


Figure 6-41: Enugu solar radiation and the electricity outputs.

Figure 6-42 presents the Lagos case studies with monocrystalline and polycrystalline silicon PV system for solar radiation on yearly total average of 4.74 kWh/m^2/day. More solar radiation is available in January, February, March, April and May and within average in June, and declined in July and August during normal peak of raining season, and moves towards average in September, October and November and becomes more available during dry season in December. It is advisable during raining season, to use monocrystalline for high performance off-grid application using energy storage (battery) during day generation for usage at night without generation.

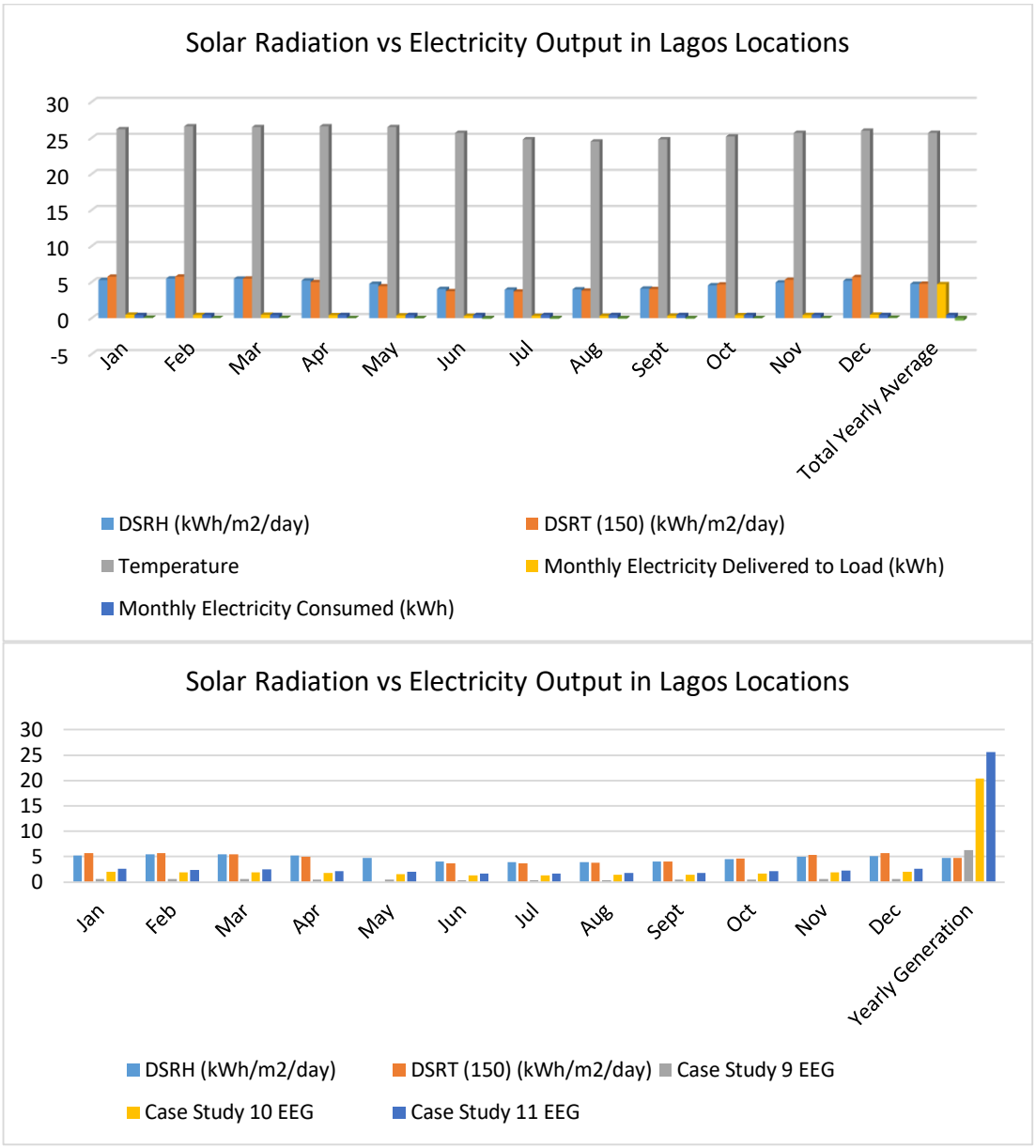


Figure 6-42: Lagos solar radiation and the electricity outputs.

The off-grid PV electricity delivered to load are for all the case studies. The energy saved for proposed case simulation analysis show negative due to increased consumption on monthly percentage use of electricity that expected export by grid-connection. The electricity delivered to load from the case studies between small and large-scale for installed PV capacity (1 to 33 kW) shows that more use of appliances is associated with more consumption. In addition, increase in energy demand from the growing population will continue due to increase standard of living and economic growth. Table 6-82 presents the field data versus the proposed case simulation.

Table 6-82: Generation Capacity for Field Base and Proposed Case Simulation

Case Study	Annual Generation Field Data			Annual Generation Simulation	
				Base Case	Propose Case
	Capacity (kW)	kWh	MWh	kWh/MWh	kWh/MWh
1	33	72,576	72.58	43,820 (43.82)	58,774 (58.774)
2	5	16,243	16.24	6,820 (6.82)	9,081 (9.081)
3	3.2	9,677	9.67	4,360 (4.36)	5,816 (5.816)
4	2.16	14,076	14.08	2,940 (2.94)	3,926 (3.926)
5	2	12,420	12.42	2,730 (2.73)	3,635 (3.635)
6	1	648	1.00	1,800 (1.82)	1,799 (1.799)
7	1	2,880	2.88	1,630 (1.63)	1,634 (1.634)
8	3.2	9,216	9.22	3,950 (3.95)	5,003 (5.003)
9	4	7,884	7.88	4,710 (4.71)	6,275 (6.275)
10	13	35,040	35.04	20,390 (20.39)	20,394 (20.394)
11	16.3	71,552	71.55	25,570 (25.57)	25,571 (25.571)

The RET Screen solar radiation database however, was used to ascertain the monthly and yearly generation obtained with the current national and solar company's rates based on accuracy for proposed grid-connected in the above case studies computation. In addition, the yearly investment cost per kWh differs in cost per kWh for the PV system installed in each case location. In the above analysis, the results show that high rate of electricity based on solar standard electricity rate (N110) could further reduce emissions to national rate (N24.30) which is less. So also, case studies with more generation equally consumed more than less generated and consumed.

6.7 Comparisons

The results of electricity output display some differences between the field data and simulation. For example, case study 9 from field data generated 7,884 kWh/year electricity output but the electricity delivered for proposed export to grid from simulation show 10,985 kWh about 31% higher. The variance in output can be due to non-availability of the monitoring system and cost of national grid electricity with higher estimated bills could affect this case due to non-monitoring equipment.

The difference between electricity delivered to load and export to grid show off-grid PV installed capacity only generated for energy needed. The RET Screen simulation database presents ideal condition used to obtain energy generation with a number of peak sun hours, degree angle and solar radiation resource whereas, PV system functioning is based on angle position obtained from month to year in the location. Nigeria case studies for a solar off-grid PV system in Abuja, Awka, Lagos and Nsukka locations, the electricity generation and consumption depend on number of household/office use and the payback period.

In real operating conditions, energy losses occur mostly in grid-connected components with large-scale capacity installation for electricity generation (Kumar and Sudhakar, 2015) and the losses can be evaluated using monitoring system to capture the losses caused by cell temperature higher than 25^0C. In addition, miscellaneous losses can be caused by wiring, string diodes, low irradiance, partial shadowing and mismatching, maximum power tracking errors, dust limitation including Harmattan and losses from energy conduction in PV Modules ((Mirian et al, 2016 and Marion et al, 2005). Table 6-83 represents the installation location for cases serviced such as residential, administrative office block, business places, and institution.

Table 6-83: Case Studies Generation and Consumption Location (Abuja, Awka, Lagos and Nsukka)

Case Study	Capacity (kW)	No. of Panel	Total Cost of Investment	Generation (kWh)	Consumption (kWh)
1	33	140	N14,828,000.00	72,576	66,799
2	5	24	N6,435,000.00	16,243	5,532
3	3.2	16	N1,348,000.00	9,677	6,445
4	2.16	17	N3,365,000.00	14,076	7,359
5	2	15	N3,070,000.00	12,420	7,359
6	1	16	N238,000.00	648	467
7	1	4	N500,000.00	2,880	156

8	3.2	20	N1,426,000.00	9,216	7,319
9	4	16	N3,484,000.00	7,884	3,214
10	13	100	N15,140,000.00	35,040	9,979
11	16.3	64	N10,520,000.00	71,552	71,552

The installed PV capacity in the absence of existing grid connection in this study include large-scale capacity greater than or equal to 3 kW and small-scale PV capacity installed less than 3 kW for generation and consumption. Based on the business model, the total cost of investment analysis depends on individual, company and government agencies. However, the monthly electricity output generation varies over the year due to local weather conditions associated with little cloud cover, dust, Harmattan including other factors. For example, Abuja study's locations has the highest generation in January, February, March, April, May and June due to regular solar radiation; low in July, August and September and average in October, November and December due to high temperature. Awka in Anambra and Nsukka in Enugu state's locations have the highest generation in January, February, March and April, low in August and average in May, June, July and September, and high in October, November and December. The highest generation in Lagos locations is January, February, March, April, average in May, June, September, October and November but high in December.

The electricity load consumption with solar system and battery for residential, institution and commercial areas application. The load distribution from off-peak to peak time shows solar PV system energy efficient. In residential sector, peak time consumption mostly in the morning and evening after business activities and energy storage in the absence of electricity light from national grid. According to law of demand and supply, peak time demand always attracts higher price and introducing price incentive during this time, could be more expensive with grid-connection in this study.

The quantity of generation in this study is to meet consumption whereas the payback period is to determine whether the investment can be profitable for business consideration. Figure 6-43 represents the line chart trends over time.

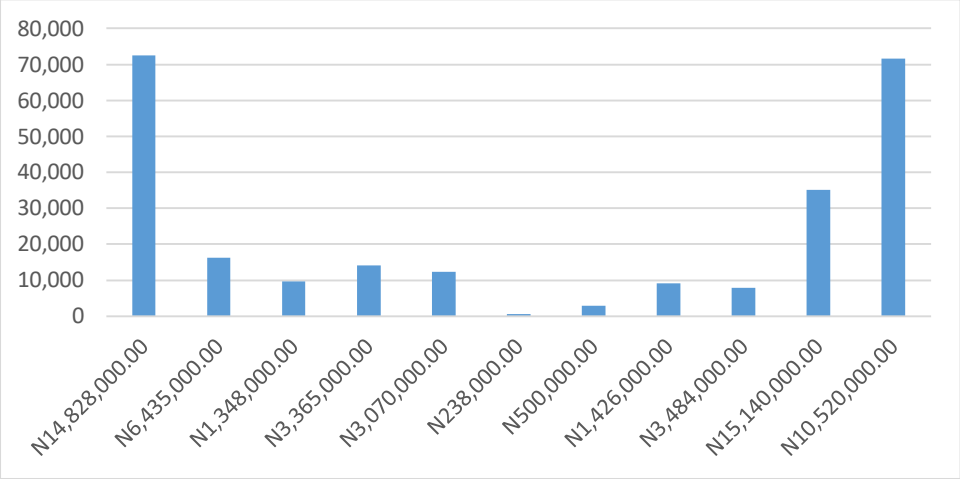


Figure 6-43: Line chart of Investment.

Figure 6-44 indicates the correlation between generation and consumption due to adequate generation with blue line and consumption with brown line for using PV system based on the capital invested. For example, case study 1 with 33 kW capacity and case study 11 with 16.3 kW capacity generated more output by installing high capacity PV system due to cost of investment consideration.

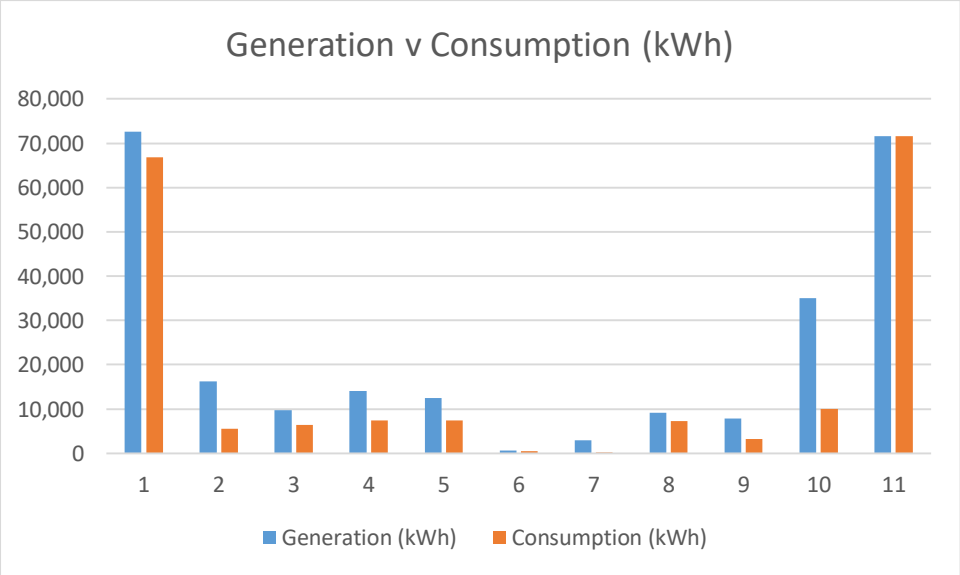


Figure 6-44: Indicating Line chart Generation and Consumption.

Figure 6-45 presents a relationship between generation and consumption based on realized income. The results show positive returns. Figure 6-46 shows the total electricity generated

and consumed that could change over time. Figure 6-47 presents a relationship between generation, consumption and payback with scattered chart depending on the amount invested, capacity installed and return to be realized. The results of generation over consumption based on payback period happens to be reasonable using quality PV system. The personal off-grid installations provided good return on investment for short-term apart from long-term periods in this study. The application also contributed to additional electricity production across the country.

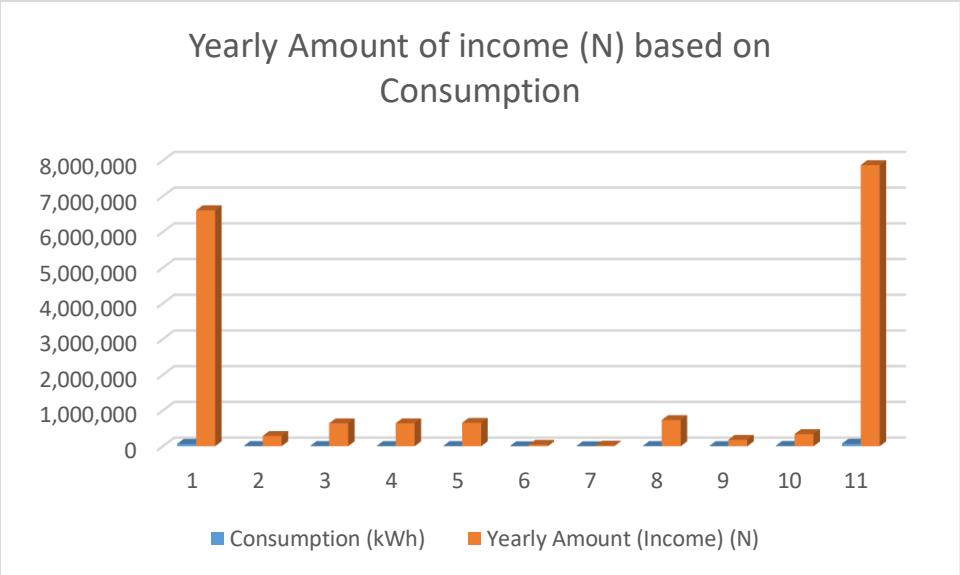


Figure 6-45: Sum of case studies Income based on Consumption.

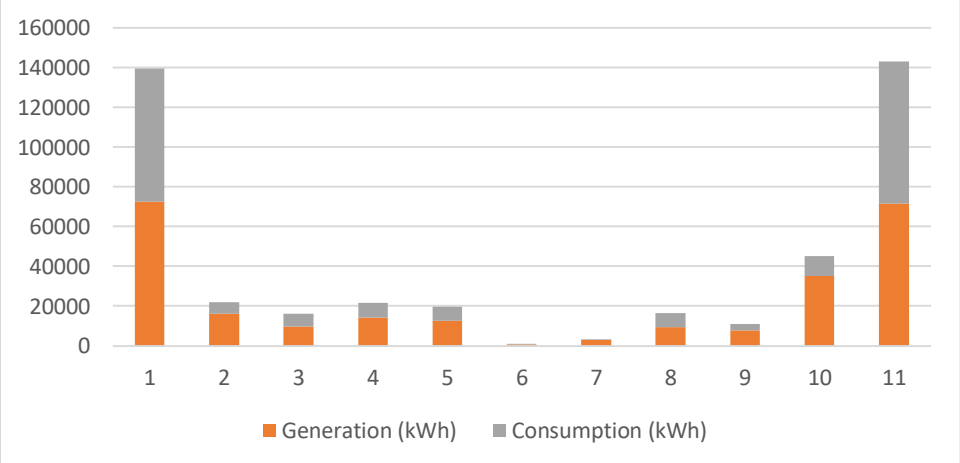


Figure 6-46: Generation and Consumption.

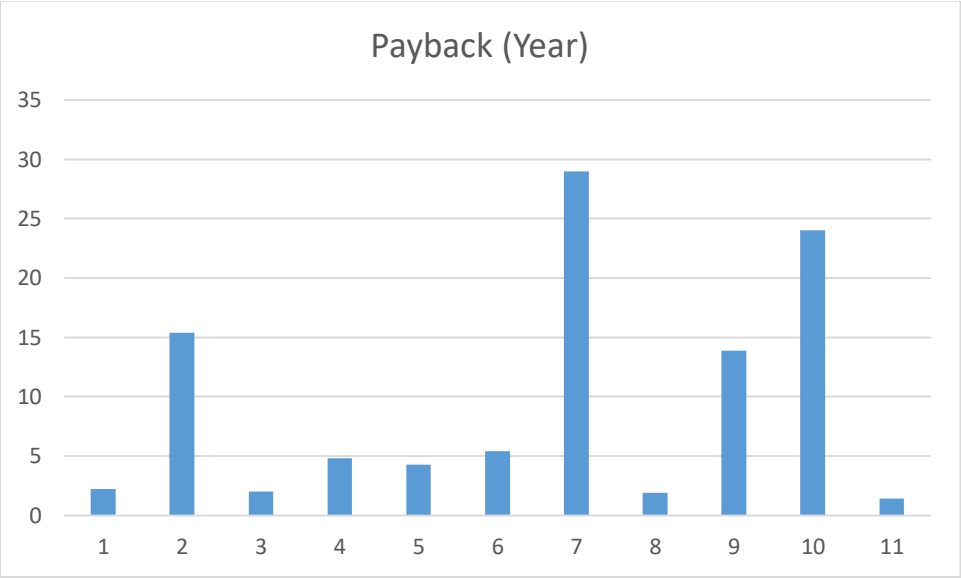


Figure 6-47: Payback Period.

6.8 Possible Links

The 11 cases located at four main regions represent the main weather conditions in Nigeria. Case study 1, 3, 4, 5, 6, 9 and 11 are rooftop installation type while case study 2, 7, 8 and 10 are roof-ground-mounted type of applications. Case study 1, 6, 9, 10 and 11 use polycrystalline PV type while case study 2, 3, 4, 5, 7 and 8 adopted monocrystalline PV type. Abuja with solar radiation potential ranges from 4.19 to 6.27kWh/m^2/day throughout the year. Awka, Lagos and Nsukka in Southern, Western and Eastern part of Nigeria have moderate weather conditions. During rainy season, the four locations experience low solar radiation. This study found that Abuja is best option for PV system installation due to high availability of solar radiation (6.27kWh/ m^2/day) throughout the year. Table 6-84 represents the monthly average solar radiation on horizontal surface. Figure 6-48 represents the insolation value. Table 6-85 presents the possible links between the case studies.

Table 6-84: Monthly Average Solar Radiation on Horizontal Surface (kWh/m^2/day)

(Dependent Variable)

State location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Abuja: Lat. (9^{0}N) Long (7^{0}E)	5.88	6.09	6.27	6.06	5.58	5.06	4.44	4.19	4.73	5.31	5.98	5.86
Awka: Lat. (6^{0}N) Long (7^{0}E)	5.68	5.74	5.57	5.25	4.94	4.54	4.14	3.91	4.19	4.57	5.11	5.46
Nsukka: Lat. (6^{0}N) Long (7^{0}E)	5.68	5.74	5.57	5.25	4.94	4.54	4.14	3.91	4.19	4.57	5.11	5.46
Lagos: Lat. (6.5^{0}N) Long (3^{0}E)	5.28	5.49	5.46	5.21	4.76	4.04	3.95	3.98	4.09	4.55	4.95	5.17

Location	Abuja	Awka	Nsukka	Lagos
Annual Average	5.45	4.92	4.92	4.74

The weather data are analysed by using statistical tool of bar/column chart.

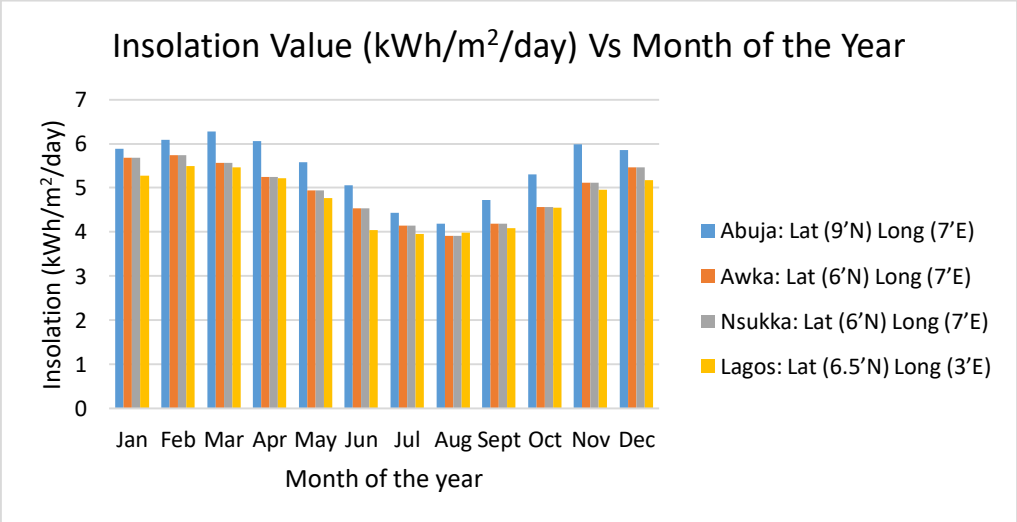


Figure 6-48: Isolation value.

The major output parameters for the case studies comprises of generation, consumption and payback period (ROI). The other input and output parameters are the basic factors such as

sizing of PV system; finance and costs; solar energy availability; geographical location and PV system types. Table 6-85 shows the possible links between them.

Table 6-85: Possible Links between Case Studies

Location	Rate of Solar Availability	Cost in terms of electricity	Income	Rural/Urban	Zone	Rationale
Abuja	High	Moderate	High	Electricity Access due to energy demand for consumption	Northern	PV system adequate generation
Awka	Moderate		High		Southern	
Nsukka			Average		Eastern	
Lagos		High	High & Average		Western	

The generation, consumption and payback time are used to determine the return on investment, electricity access for both rural and urban community's household and businesses. The solar radiation is essentially available in every location for economic evaluation of solar system design particularly on-grid connection in Nigeria.

6.9 Factors Affecting PV Electricity Output

The case study has huge solar radiation available for electricity conversion. A proper installation including good orientation and a gap between the rooftop and PV system could largely help sustain maximum output. In addition, generation with a PV system depends on amount of installed capacity and available solar radiation from horizontal or tilt position.

The literature finding revealed that PV module tilt angle position is considered for maximum solar radiation depending on the geographical location of the system plant (Labed and Lorenzo, 2004). The studied cases with 15^0 degree tilt angle during dry and rainy seasons (the seasonal operation) increased solar PV system output. The simulation results for tilt solar

panels generated more than the horizontal fixed by the amount of solar radiation emitted from sun.

The performance ratio (PR) is an important value used to evaluate the quality of PV installation that makes installation performance independent of orientation including inclination of the panel, losses from the inverter, temperature, DC & AC cables, shading, weak radiation, dust, Harmattan etc. These losses based on PR value depend on the site, the technology and the systems sizing. RET Screen tool used in this study to investigate the feasibility of solar off-grid PV system at each given location under standard test conditions (STC) with intention of proposed grid-connection generation based on simulation. In addition, the database due to off-grid PV system performance help reduced losses that PV panels would have incurred.

The PR values assessed the quality of PV installation based on output generation from selected sites in the case study. The PR in Abuja location is about 89 percent and the highest value in January, February, March, April, May, June, October, November and December and 6 percent lowest in August. The PR in Enugu location is about 63 percent and the highest value in January, February, March, April, October, November, December and 7 percent lowest in August. The PR in Lagos location is about 47 percent and the highest value in January, February, March, April and December and 7 percent lowest in July. The high efficiency PV monocrystalline and polycrystalline silicon technologies installed provided good performance in the four different locations due to solar radiation availability in Nigeria. However, PR value attributes to assessment of improper/unfitting operation of the system, losses from inverter, DC and AC cables, temperature, dust etc.

In Abuja locations, the average PR (14%) is in July and September. In Enugu and Anambra locations, the average PR (22%) is in June, July and August. In Lagos location, the average PR (31%) in August, September, October and November. During the months of rainfall, the results show weak radiation and losses can easily affect PV performance at this period of the year in different locations. Literature revealed that many performance parameters for energy production used to define the overall system performance (Abbasoglu and Emodi , 2015).

The capacity factor (CF) is the ratio between installed capacity and actual energy generated over time, typically for one year. However, the solar PV systems capacity factor varies from 10 to 25 per cent depending on the location and function of tracking. The CF for solar PV system from study report falls within the 10-25% range and mostly below 50% for renewable energy sources. The study found that solar capacity factor is low when the sun becomes half above the horizon and the variation due to losses from local climatic conditions (Energy, 2016a and Energy, 2014). The peak power for all electrical components in delivery can be sized when plant runs at high capacity because higher capacity factor suggests less fluctuation, cost-effective and efficient (Kamal, 2016 and Shiva, 2015). In addition, the higher capacity factor can lower cost of electricity generation by installation. In this study, solar availability from simulation of installed off-grid PV system capacity generated about 18% capacity factor in each location falls within solar PV system range of 10-25%.

6.10 Factors Affecting PV Installation in Nigeria

This study with sensitivity and risk analysed to be the factors affecting the failure of solar installation in Nigeria. The sensitivity is defined as a technique that takes into account uncertainty and does not require estimates of probabilities (Kreith, 2007) to tests economic performance for alternative values and uncertainty. This shows decision makers how economic viability changes for RE or EE projects due to fuel prices, discount rates, time horizons and other critical factors.

The sensitivity analysis of the total cost of the PV system when taking conventional system externalities into consideration equal to grid supply capacity due to national rate with a subsidy. This study examines the extent of which installed PV system can affect certain event of occurrences. The following factors can pose as threats to PV system installation: low technical expertise, sub-standard materials or low-quality PV system, accidental damage to PV Street light or billboards and natural disaster such as heavy wind/rain in the study locations.

In Nigeria, the technical knowledge is low in understanding PV system installation performance. The low availability of technical expertise can be difficult for repairs in case of

any fault or breakdown and in turn affect PV efficient performance in terms of power output from generation location. It is important to take seriously the education of local professionals such as building architects, engineers and developers/investors, suppliers into consideration for proper installation to avoid future failures for installation design of renewable sources.

The PV panel installation with use of low-quality materials, charge controller, inverter, battery, cables, fuse or circuit breakers can result in installation failure affecting the system performance during generation. Implementing of policy/regulation is required for guiding production and importation of solar PV system components in order to address consequent issues. In addition, Standard Organisation of Nigeria (SON) is also required to certify companies supplying these materials with strict monitoring mechanism or clear sanctions for non-compliance.

6.11 Payback Justification

Nigeria investment capital is based mostly on personal funding or financial support from relatives, families and friends apart from the pilot projects sponsored by the government across the country. In fact, financing by borrowing money with interest always requires repayment to reduce debt payment every year with interest. Presently, self-financing preferred for not borrowing due to high-interest rate. This cases with 'self-financing' for those who can afford PV system installation as well as government PV pilot projects investment is to attract investors.

The business outlay considering payback period on cash flow is to increase net cash inflow over cash outflow. It also describes the level of sales in order to achieve desired profits and number of units' seller that sells to cover costs (Schmidt, 2016). Literature found that cash flow forecast could use investment appraisal/evaluation methods such as simple payback or discounted payback (DPB), Levelized cost of electricity (LCOE), Life cycle cost (LCC), internal rate of return (IRR), Benefit cost ratio (BCR). They help decide whether to go with investment or not (Goswami and Kreith, 2007). It is used to obtain largest savings for a fixed budget and target savings for the lowest budget with a limited application that aims in minimizing total costs or maximizing net benefits/savings from renewable energy or energy efficiency

expenditure (Schmidt, 2016). This study shows that more sale of PV panels at a shorter time may cover costs on time. Table 6-86 represents case studies summary consumption paybacks with interest rate (5%).

Table 6-86: Payback Period for Consumption with Interest rate (5%)

Cases	Consumption (kWh)	Rate (N)	Yearly Amount of Income (N)	Payback (Year)
1	66,799	110	7,347,890 (14,828,000/6,606,490)	2.2
2	5,530		608,300 (6,435,000/286,550)	15.4
3	6,445		708,950 (1,348,000/641,550)	2
4	7,359		809,490 (3,365,000/641,240)	4.8
5	7,359		809,490 (3,070,000/655,990)	4.3
6	467		51,370 (238,000/39,470)	5.4
7	156		17,160 (500,000/17,160)	29
8	7,319		805,090 (1,426,000/733,790)	1.9
9	3,214		353,540 (3,484,000/179,340)	13.9
10	9,979		1,097,690 (15,140,000/340,690)	24
11	71,552		(10,520,000)	1.4

This study with some case studies examples to justify a PV system adequate generation over consumption with solar energy potential in Nigeria. This study also recognized solar energy with PV system for electricity generation to solve the problem of inadequate power supply in

the country. This study focused on consumption to justify the payback period which is time expected for an investment on a project to recoup the initial cost that takes years to return the initial investment. This study with simple payback suitable in comparing different solar PV system and the components are not of the same price per kWh generation. The off-grid case studies payback calculated for consumption due to waste of excess generation because of no grid-connected systems yet in the country. The self-financing from savings are those who could afford the installation of off-grid PV system apart from pilot project installation mostly in rural-remote locations.

In this study, each case study realized good return within short, medium and long-term payback period with different solar PV types based on cost breakdown of the business model. The total capital invested realized yearly return on investment. In calculating payback period, several factors considered include:

1. Capacity installed with the amount invested may increase or reduce the payback period
2. Generation output or consumption with yearly return may have an influence on the payback period
3. Good return on investment based on the amount invested may take short payback
4. Self-financing may attract a shorter payback period
5. High electricity rate with small initial capital may take a shorter time to payback than lower electricity rate depending on the capacity installed and for what purpose.

For example, a solar company such as Blue camel energy had used personal funding for off-grid residential and small businesses installations in the country. This study with short/medium and long-term payback is realistic and the government long-term payback more realistic due to no tax or risk. However, this may not be a worthwhile investment to short payback based on self-financing from individual and business perspective respectively. Finding from the study shows that small businesses often want to see investment with short payback period because it often lack cash flow of capital streams to maintain business operations while waiting for an investment to pay for itself (Hanks, 2016).

6.12 Summary

This chapter established that PV installation capacity depends on solar availability and amount of investment for a good return on investment. The PV systems provided adequate generation based on simulation results of 11 investigated case studies due to efficient good performance and battery storage for electrical energy. The good performance in the generation is able to meet uninterrupted consumption. The 11 cases carried out provided good returns within short, medium and long-term investments which confirmed to be a reasonable, affordable and profitable investment based on output generation, investment cost and savings. The system with tracking method generated high output than fixed angle installation system.

This study with demonstration of adequate generation value from PV system application might help solve inadequate electricity supply associated with outages for grid-connected urban areas and a solution to rural-remote areas without grid-connection. It may also encourage further installation in residential, commercial and institution in meeting the population energy demands. Government with sufficient incentives towards proposed grid-connection will reduce cost, mitigate more emissions, and make solar PV system competitive for the Nigerian power sector. However, government implementing solar energy application will promote solar power system development for the benefit of Nigerian citizens and the economic sectors. This is because solar energy technology is environmentally friendly and sustainable to mitigate climate change, add value to building by installation and jobs for the youths with a large percentage of unemployment. In general, boost economic growth and firm's competitiveness across the country.

CHAPTER 7: FRAMEWORKS FOR IMPLEMENTATION

7.1 Introduction

Nigerian economy is wholly dependent on the petroleum industry for energy and revenue in driving growth but the energy industry has been associated with major issues. However, Nigeria's energy policy was established to remove key barriers with RE and EE frameworks over other forms of energy which includes economic, regulatory and institutional issues. The policy document was drafted to address diverse issues that show the multi-dimensional nature of energy. It includes RE supply and utilization; pricing and financing; legislation, regulation, and standard. The policy was to provide optimal utilization of the national energy resources for sustainable development with private sector active participation. Moreover, the implementation of policy objectives and strategies fundamentally was to demonstrate the crucial nature of energy for the national development goal (Oyedepo, 2012a). However, the Nigerian government has a major role to play in case of a conducive environment to meet the energy challenge facing the country (Oyedepo, 2012b) and (IEA, 2011b).

The government established FMOP, FME and ECN ministries, departments and agencies (MDA) with the responsibility for creating awareness to investors and consumers about the economic potential for RESs outside hydro source of energy. NERC, a government agency recognizes RES potential for RE generation carried out feasibility studies and proposed FITs for RES developers based on PPAs data collection with off-taker negotiation (FMOP, 2014); NERC, 2014 and NERC, 2013). This includes national energy development with the option of diversified energy resources to achieve national energy security and energy efficient delivery system towards optimal energy resource mix. The policy strategies are to promote RES contribution towards electricity generation and to encourage and enhance the country's electricity supply capacity.

7.2 Renewable Energy policy Objectives

This recognized RE as a reliable, affordable, equitable and sustainable energy supply in various sectors of the economy. For Vision 2020, the role of electricity industry includes implementation of short-medium term targets (3-5 years) and long-term target (5 years). It also includes off-grid electrification and grid-connected electricity with rural electrification. A comprehensive, integrated and well informed RE and EE sector with plans and programmes to ensure effective development. The successful use of the nation's abundant energy resources to provide abundant electricity access to almost half of the Nigerian population that currently without electricity access with more sustainable provisions for domestic use and cooking. To establish an appropriate financing mechanism to support private investment in sub-sectors. To ensure the development of the nation's RE and EE resources through effective coordination and collaboration among all players of RE and EE activities in Nigeria (NEP, 2003).

For ensuring the provision of electricity to all remote and off-grid areas. To increase energy mix grid-supplied electricity in line with regional/ECOWAS policy target. It also aims at stimulating industrialization in rural and remote areas to retard rural-urban migration particularly industries in the remote. The off-grid areas for productive use mainly to provide a reliable and stable power supply to consumers. To ensure removal of bottlenecks for development of off-grid electricity, broaden energy options for generating electricity and to maximize Nigerians access to investment opportunities in the electricity industry created by power sector reforms (NEC, 2005).

The Ministry of Power developed a draft of renewable energy policy (REP) in 2005 due to renewable policy initiatives to drive RES development in the country. In 2001, the National Electric Power Policy (NEPP) set a target of 10 percent renewable energy mix for all new connection by 2020. In June 2012, NERC published FITs for most RE (www.nercng.org), to provide investors cost recovery and guaranteed return on investment. The federal government established NBET, a credible and creditworthy for off-taker of power and renewables and World Bank Partial Risk Guarantee supported the off-taker. The REA established REF focusing on the promotion of renewable in rural areas. The NERC developed

regulation to promote and guide power generation including renewable power generation within existing distribution networks (McKinley, 2014).

7.2.1 Solar Photovoltaic (PV) Policies

This includes electricity generation to drive solar development for the effective harnessing of the solar resource that integrates with other energy resources. The policies to promote efficient use of solar energy through PV conversion technologies for power generation and productive use. To intensify efforts to increase the percentage of solar energy in the present energy mix. The nation aims to promote the development of energy storage technologies to complement solar power development with energy efficiency programmes (NEC, 2005).

7.2.1.1 Solar Photovoltaic Objectives

This is to provide percentage increase of solar energy contribution to total energy mix to ensure 3 percent minimum electricity contribution by 2020 and 6 percent by 2030; to conserve non-renewable resources for electricity generation while diversifying targeted energy resource of the nation. Furthermore, to contribute to remote and off-grid power development to ensure minimum damage to Nigeria ecosystem (NEC, 2005).

7.2.1.2 Solar Photovoltaic Strategies

Solar PV strategies are for developing extension programmes, which includes facilitating the use of SHSs while promoting R&D for solar energy technology. For translating solar energy into potential power at the local level, that requires various resources and training workforce skill for maintenance of solar system conversion. In developing skilled workforce and providing basic engineering infrastructure for local production of components and spare parts of solar energy conversion systems in line with regional ECOWAS target (Emodi, 2015) and appropriate pricing structure and FITs will encourage development of CSP or other similar project.

7.2.2 Financing Policy

Financing of renewable energy is a crucial element for realizing federal government's policy thrust on renewable electricity. However, investments substantially require research and exploitation activities but financing for long-term involves foreign and domestic resources. Nevertheless, foreign investment capital provides a greater proportion of funds needed. The risk in financing renewable electricity projects requires government providing guarantees and financial frameworks for stimulating renewable electricity market expansion. According to the Mckinley report, the federal government is to continuously improve conditions to enhance funding of renewable electricity through equity, debt financing, grants, and microfinance (McKinley, 2014).

7.2.2.1 Financing Objectives

The objectives include ensuring adequate funding available for RE sub-sector and continuity in funding sub-sector projects to ensure adopted RE supply option is most cost-effective to increase foreign exchange earnings through exporting RE from the country. To encourage local development of RE in minimizing cost is in line with regional/ECOWAS policy as well as target to encourage local government and community investment in RE projects. Furthermore, the key objectives are to ensure effective participation of indigenous private sector in RE industry value chain in the regional policy.

7.2.2.2 Financing Strategies

The key strategies include establishing a financing mechanism to support indigenous investments in RE and putting in place other incentives appropriate for RE sub-sector. In promoting indigenous private sector participation as well as competitiveness in the sub-sector. In creating appropriate motivation with NGOs through MOU for RE sub-sector and increasing the local content value added in the activities of energy sector industries. The strategies also include dedicating a certain percentage of the nation's revenues from conventional energy sub-sector to support renewable electricity sub-sector. Involving

training, research development, and demonstration, technical standards, and technology acquisition.

Dedicating a significant percentage of the nation's revenues from privatization of Nigeria's PHCN infrastructure as well as grants to local communities for investment in RE projects. Implement a framework for use of sovereign guarantees to support appropriate renewable electricity projects. Provide fiscal incentives, subsidies to alleviate up-front costs, tax and duty exemptions useful for prospective investors in the RE sub-sector (Kuta, 2009a). It also involves reasonable ROIs from cost-effective renewable electricity pricing. To establish guaranteed and dependable repayment schemes for investments in RE projects and RE firms are to be encouraged to source development funds from the Nigerian capital market.

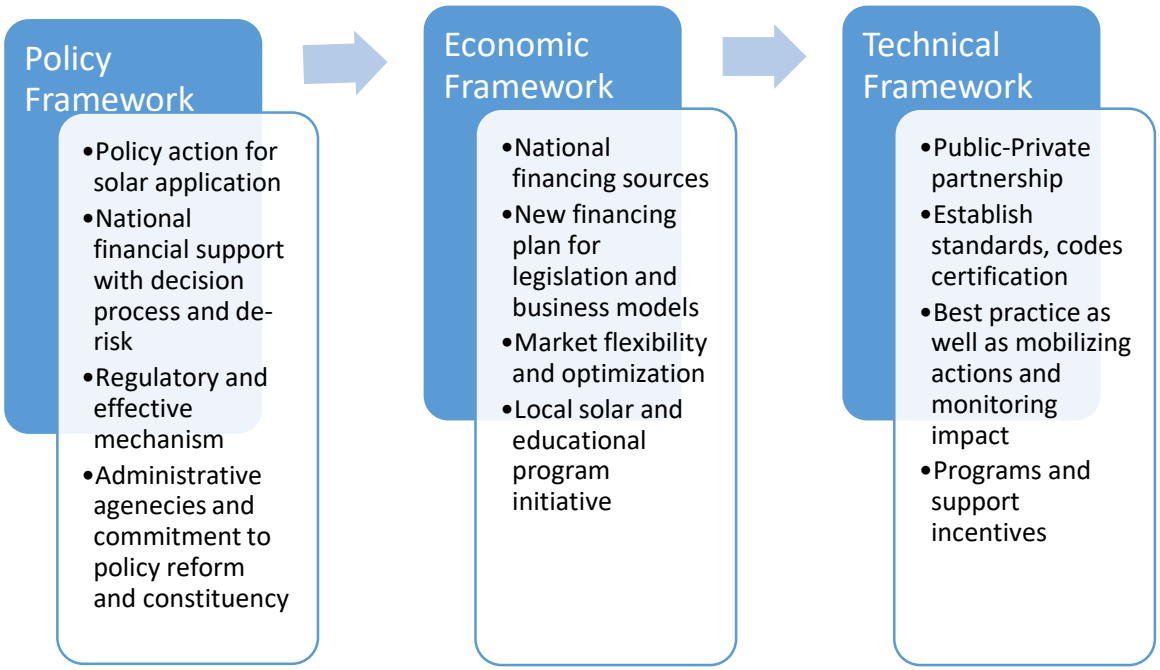
The overall macro-economic and financial framework to improve to ensure availability and affordability of long-term funding for investors in renewable electricity. Maintaining RE in the country's institutional legal as well as regulatory frameworks for grants to local governments and communities in order to support RE planning and implementation projects. Furthermore, the involvement of international donors and NGOs, local and foreign banks participation, indigenous people participation. It also involves feed-in tariffs based on regulation and incentives.

This study found that Nigeria with incoherent laws are affecting economic, regulatory and institutional issues because it overlaps duplicates and conflicting. It also a key barrier to RE and EE framework as well as the development of PV for electricity generation. However, the policy formulation dissemination is yet to be implemented since fifteen years ago. The following key actions for an effective framework in Nigeria.

7.3 Proposed Framework

The policy framework is significantly necessary for solar implementation. The implementation might facilitate stakeholders' participation and impact positively because financing has been an impediment to PV development. PV renewable systems globally experienced exponential growth since the 1990s. Finance can be difficult but a prerequisite for PV system power

development in Nigeria. Energy policy requires a framework for a strategic shift to sustainable development due to off-grid PV electricity generation. The findings suggest that policies have a significant impact on legislative and community participation. The participants in the legislative process as outlined in this study usually are unable and unwilling to develop precise guideline due to complexity, lack of time and interest issues. The following are proposed frameworks.



The policy implementation could be the most important action to enforce law into impact in Nigeria. This is because policy formulation dissemination and implementation can influence positively or negatively. This implies that policies can facilitate or hinder the participation of PV development. However, this study encourages RE policies implementation to enhance the country's electricity supply for additional energy with PV systems. The findings suggest that government intervention for the development of PV should be strong, effective and consistent to balance policy support for the PV market expansion. This might help solve the problem of legislation set of process.

According to Bardach report, the public policy-making process involved setting agenda to policy evaluation and implementing policy. This has to do with political, financial and administrative issues that require motivation, proper, and appropriate lobbying, technical,

professional and administrative support (Bardach, 1977). UK report indicated that policies are ideas, goals and plans of action adopted by some agencies (Essays, 2015) which is a logical structure established to organize policy documentation into groups. It also easier for people to find and understand the contents of various policy documents.

Nigeria lack of continuity in administration, financing and government bureaucracy (mismanagement) affecting the development of PV system for electricity generation. Despite that, the policies designed is to drive and promote the efficient use of renewable solar energy with PV system conversion in Nigeria. However, lack of funding requires government funding and support with subsidies and incentives. Based on current electricity tariffs, PV deployment is highly relevant in reducing GHG emission that affects the whole economy and improved funding could help offset the cost of PV installation in the country. This is because most Nigerians are low- income earners and cannot afford PV system development unless with financial support from government and private sector participation.

The findings suggest that a strong government policy framework based on public-private investments may improve PV system development. In addition, effective planning and strong regulatory/legislative framework may promote large-scale PV development and deployment across the country. This study focused on affordable solar energy with PV system derivable benefits due to electricity generation challenges. The residential solar systems can easily be subsidized with a large group of purchase, making the system affordable since Nigerian populations are hungry to improve their living standard against constant outages from the national grid. Moreover, government guaranteed financial support provision would stimulate renewable electricity market expansion in Nigeria.

The proposed framework is effective action that requires government promotion of grid-connection to attract more incentives for PV system development based on the adequate generation of electricity, in turn, mitigate emissions. This is because investigated case studies established that Nigeria has abundant and reliable solar energy resource that can be utilized to cover the energy shortage, change consumer's behaviour, reduce electricity bills, curtail electricity blackouts and as well provide significant benefits to those without access to grid

electricity. The solar PV system use for electricity generation can meet Nigeria electricity demand with over 180 million populations and as well reduce the tendency of depending on diesel-fuel generators in the future.

The proposed framework is to ensure affordability for long-term funding to support RE planning and implementation process. The following structured elements are guidelines and responsibilities for promoting policy implementation and facilitating the implementation process:

7.3.1 Policy Action on Solar Application

The tendency for effective policy framework is due to proposed grid integration and investment on new grid infrastructure technologies that requires Nigerian government to act upon and regulators for long-term planning initiative to increase PV system flexibility and grid management based on strong direct normal irradiation in Nigeria. Concurrently, development of CSP dispatchable will allow a large amount of PV grid-connection that requires government plan for high use of PV system generation and the co-finance smart grid demonstration systems for faster large-scale PV deployment across the country. This is because the government adopting a policy for building a PV system might sensitize the populations in taking up installation for efficient and adequate PV electricity to mitigate the estimated excessive bill. In addition, government benefiting from emission reductions is to comply with the Kyoto protocol target decision**.** Figure 7-1 represents the proposed application benefits for solar PV deployment in the country.

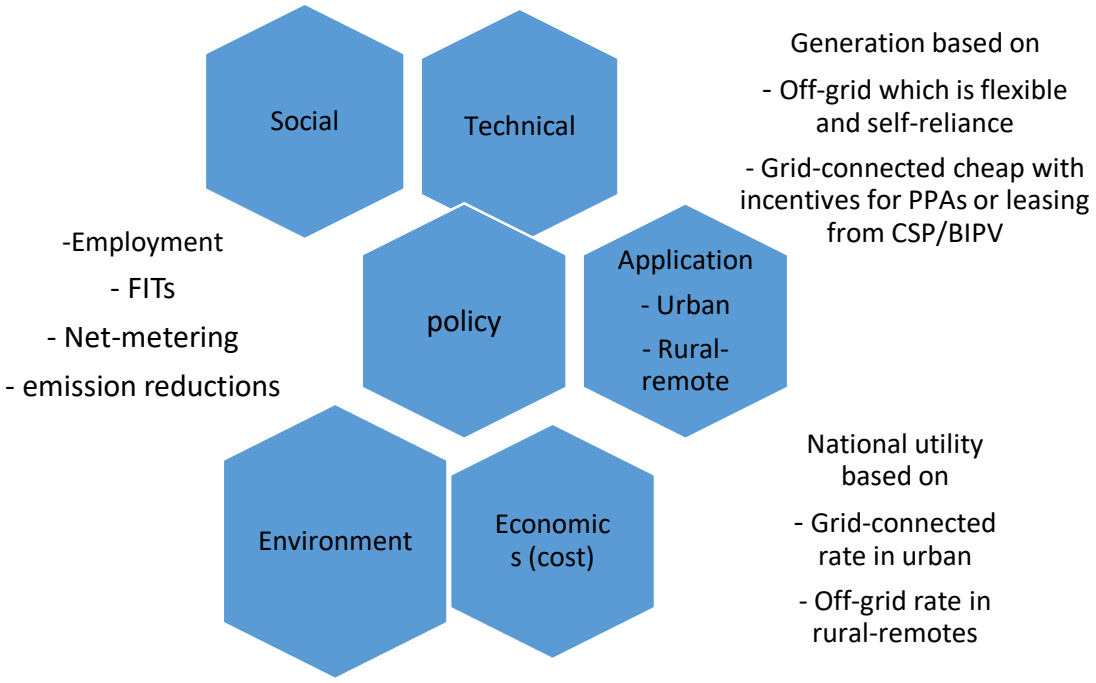


Figure 7-1: Application Benefits for Solar PV deployment.

7.3.1.1 National Financial Support with International Mechanism

The national support through government investment could enhance the rate of return and shorten payback period to attract investors. It can encourage generators to target clean energy development by all stakeholders in the country. For example, since 1993, the World Bank (WB) and the Global Environmental Facility (GEF) have supported projects to improve commercial markets by financing RETs in developing countries (World Bank and GEF, 2007). In Nigeria, the government continues on the improvement of conditions would be to enhance funding of renewable electricity through equity, debt financing, grants, and micro-finance in order to encourage foreign investors.

From 1999-2007, WB and GEF have provided £27 million ($40 million) grants and loans to fund market surveys, key capital investments, product development, standards and certification in China. This effort played an important role by supporting the PV system's sales to approximately 400, 000 to rural households and institutions. Base on this, China for the eight-year period become the top producer of solar equipment and components in today's world

(World Bank and GEF, 2007). In addition, Multilateral Development Bank has been a source of financing for joint development efforts. Bilateral Development Bank also an important source of development finance and German state-owned Kreditanstalt fuer Wiederaufbau Bank (KfW) invested £234 million ($340 million) and (€230 million) for renewable energy projects in developing economies in 2008.

7.3.1.2 Decision Process and De-risk

In considering sustainability, institutional investors and building managers required 'De-risk' in their investment decision process and strategies for increasing green investment transparency. This will encourage investment in solar electricity assets by investor and making conventional power assets to become more expensive due to the risk of climate change. In addition, it also will attract new investors either to provide or invest new funds for solar energy projects. De-risking solar PV investment can fundamentally ensure stable, significant and observable government policies for clear long-term planning in the country.

7.3.1.3 Establish Effective Regulatory Mechanism

This ensures appropriate policy incentives thereby making the environment conducive and to remove barriers. It contributes to long-term transparent support due to effective and predictable regulatory targets. It includes an economic, institutional and attitudinal framework for building PV investment confidence in the country. This regulatory mechanism could be financial incentive schemes such as PPAs to enable PV system to compete in Nigeria energy markets. In addition, ensure priority access to grids for a long-term generation.

It is a clear, effective and predictable long-term financing incentive like FITs or investment subsidies to ensure that government guaranteed a loan for matured PV technology with direct support payment to renewable generators. It can be more efficient than tax credits and subsidies such as grants/aids to support output. This is because incentives for long-term energy policy objectives might foster innovation and development of most cost-efficient technologies in Nigeria. This framework with efficient market structure may encourage PV electricity generation becoming more competitive to attract private investors but

government support with enough incentives can deploy PV system rapidly for electricity generation.

7.3.1.4 Effective Management based on Political will

Government intervention in form of urgent action shows effective management for private participation, which can ensure coherence and coordination between different authority's procedures for the off-grid and grid PV systems implementation. Nigerian government with a strong political will can expand RE market through solar aid projects and encourage the market coverage across the country and other neighbouring regions/countries. This is because urgent action by intervention can unlock the solar potential for electricity generation in Nigeria.

This framework involves appropriate people driving the implementation process forward and getting the policy accepted and desirable due to the negative aspect of corruption in society. This can attract active support gain from groups who consider proposed policy implementation desirable and commitment to action in achieving the national policy objectives. It also encourages set of people with effort and commitment to make policy achievable through workshop participation by public and private players (stakeholders) with relevant discussion from each sector in resolving drafted policies issues for the benefit of renewable resources available in the economy for implementation.

7.3.1.5 Effective Administration and Policy Reform Commitment

This study proposes the involvement of community organization and groups' participation in the policy implementation process apart from government executives. This requires serious attention, time and efforts to investment/funding for solar PV system development by government administrative agencies. However, the government concentrating on states with more resources may facilitate RE implementation. This is because the state's capacity relies more on available resources and always a factor affecting success or failure of policy implementation. Additionally, the legislature undertakes policy formulation in order to remedy past problems, in turn, prevent future potential problems based on rules or rights.

The problem of bureaucracy and corruption result in lack of commitment to funding ability, legal and institutional framework as outlined in chapter 5 towards Renewable Energy Master Plan (REMP) by Nigerian governments. Administrative hurdle also hampered policies effectiveness for PV development may be a delay to IPPs operation despite that they are licensed and registered for intending PV development in Nigeria. For example, the power sector suffers policy tumble due to administrative changes because new policies come with the new administration.

7.3.2 Economic Framework

7.3.2.1 National Financing Source Development

The national financing is a source of funding programme for PV development electrification in urban and rural areas. This could be by levying or tariffs on grid electricity through taxing other energy sources. This can provide market mechanisms such as clean energy development mechanism (CDM) in terms of certified emission reductions and this can drastically reduce Nigeria industrial sector emissions. Due to lack of skilled personnel and local capacity, appropriate measures for effective coordination and planning of government ministries, implementing agencies, installers and maintenance operators including staff is needed.

The endemic poverty in the country requires government funding and financial support from subsidies and incentives to improve funding in order to offset the cost of PV installation. For example, residential solar systems with a large group of purchase could make the system affordable to meet peoples' demands to ensure good living standard against constant national grid outages. The findings suggest that robust government policy framework will encourage public-private investments to increase and improve PV system development. Additionally, effective planning and strong regulatory/legislative framework can promote large-scale PV system development across the country.

Nigerian government increasing R&D funding from matured PV systems design will ensure long-term sustainability for the country's industrialization improvement. It will also improve

the product requirements for building PV integration due to the significant potential of solar energy and large-scale PV systems deployment can minimize environmental impacts and accelerate cost reductions at different locations. The government priority on PV research and development (R&D) for short, medium and long-term will improve the technical performance, cost of solar panels and its system components for the existing and new solar technologies.

7.3.2.2 New Financing Plan for Legislation and Business Models

This supports new investment by re-directing capital from conventional power plants to solar PV systems for sustainable growth of solar energy application in Nigeria. This will help legislation to create a checklist for green investment and financing activities whereby the regulators use the checklist to encourage banks financing green projects in form of easing capital requirements or having a label for sustainable financial products. For instance, Nigeria insurance companies will consider ensuring buildings using solar PV system with less premium. The stock market to attract institutions and private/individual investors on solar investment through fund-raising for PV development while taking customers with sustainability preferences into account.

This can encourage the government to provide guaranteed financial support to stimulate renewable electricity market expansion because of the risk in financing renewable electricity projects. This requires considerable PV up-front investments due to high capital cost as a major barrier with a large population of low-middle class earners for off-grid residential and small commercial. Due to investment barriers, uncomplicated financing approach and innovation would be required for PV market development in Nigeria. The finding suggests that most incentives for PV grid-connection with high efficiency may not benefit isolated homes/clusters. However, this study suggests a business model that requires energy service companies into PV system development for efficient delivery service to end-user. In addition, the government can promote financial incentive such as a loan for off and grid-connected PV developers/installers because this will help the end-user with periodic payment without necessary the owner or responsible for the system maintenance.

Nigeria requires implementing of a new model for financing and operating PV system due to a number of low-income earners with limited access to funding. For example, direct sales, credit and hire or leasing in rural-remote communities may encourage widespread use of PV to overcome the barrier of high capital costs across the country. This also may enable end-user to become PV system owner or directly sell generated electricity for cash and obtain credit sales through micro-credit initiatives from PV supplier/dealer or third party and become PV system owner or by using the system as loan collateral. This is because PV supplier or financial intermediary through hire/ lease can purchase or lease PV system to end-user whereby ownership may or may not be transferred to end-user at the end of the lease period. This type of model can attract a fee for service depending on the arrangements. It may be part of FITs or net metering that allows end-user to earn from export and import meter based on supply and demand.

7.3.2.3 Market Flexibility and Optimization

This requires a high degree of system flexibility, which is the amount, dispatched quickly during generation whereas interconnection and storage available can respond to fluctuations in supply and demand to increase the market and measures transmission optimization. The market measure will expand the system market due to overall variability through intermittency and other factors and the system being easy, flexible, safe and reliable can balance demand, supply, and direct electricity supply into the grid. The transmission optimization measure will improve the interconnection and adoption of advanced transmission, management of technologies. This will enable smart grids and metering to enhance energy storage.

7.3.2.4 Local Solar Program and Educational Initiative

Government implementing the solar national program will provide quick response to the energy needs of the citizens by making PV system prevalent for generation over existing infrastructure due to quick installation. This will enhance renewable integration independently from the main grid with a new inverter, transmission, and interconnection. The smart-grid applications will enable people already using solar PV electricity to continue

importing and exporting. In addition, mandate commercial banks in financing small and large renewable energy capacity projects across Nigeria. This will encourage future training workshops on specialized operation, technical and financial aspects of large-scale solar projects in addition to technology risk and feasibility to innovative financial instruments in the country.

Solar programs can promote competitive advantage at local-regional levels and strategic choice towards solar energy application in the country. The educational initiative for awareness creation of large-scale solar projects, which ensure success in installation or construction. This program encourages all stakeholders' involvement with consultation on land rights for the permission process, research, innovation and market programs for deployment in Nigeria. The government implementing local learning by doing operation while financing through financial institutions can promote the rapid deployment of the PV system to reduce the cost of PV system development. This may flow from insurance companies, stock exchange market, community and local source of finance through communities or cooperative society across the country.

Government introducing economic evaluation methods for financial viability can be most profitable for long-term RE investment such as life-cycle cost (LCC), Levelized cost of electricity (LCOE), Net present value (NPV), Benefit/cost ratio or savings-to-investment ratio (SIR), internal rate of return (IRR), discounted or simple payback (DPB) and overall rate-of-return (ORR) including EE program for operational evaluation. These depend on the level of energy conservation and the maximum benefit from conservation, technical experts and building owner. These multiple techniques for evaluating economic performance are combined with risk analyses to improve decisions in energy efficiency and renewable energy investment.

These methods will support the goal of achieving economic efficiency that differs from engineering technical efficiency. However, economic performance in a variety of ways depends on decision maker performance with respect to NPV, LCCs, cost of energy, the rate of return, years of payback or ratio under the condition of uncertainty. These risk assessment

techniques reflect on the risk exposure of project and decision maker attitude to risk. There could be used to decide whether to invest in a given RE system or EE, to determine whether the system size design is economically efficient; find systems and components expected to have cost- effective; estimate how long before a projected breakeven in order to decide energy-related investments that can provide the highest rate of return to the investor.

7.3.3 Technical Element

7.3.3.1 Public-private partnership

This key approach for achieving long-term research and development and demonstration (R&D&D) can lead to design success and this might enable Nigerian government not to impose local content requirements on developers of the solar project rather encourage foreign and private investors to be competitive in reducing the price of solar energy systems for consumers. This is crucial, as it will increase public RD&D funding to accelerate the process of PV deployment in short-term due to public-private sector involvement in Nigeria.

7.3.3.2 Establish Standards and Codes/Certificates

This requires better handling of PV products safety and quality assurance in terms of confidence by the Nigerian government. This development guideline guaranteed quality along with value chain and reuse/ recycle of PV components, in turn, permit the increase of variety deployment of PV technologies. The priority should focus more on internal standard and codes for PV system industry based on multifunctional products and the power supplier of interconnection issues. For example, building integrated PV (BIPV) can support the utility grid during greater demand period due to high-energy efficiency. This is because solar BIPV can reduce energy cost for building owners mostly with energy system integration.

7.3.3.3 Best Practice, Mobilizing and Monitoring Impact

Nigeria with abundant solar energy requires best practice to support PV technology development for environmental protection as well as avoid deployment barriers for local expertise. Nigerian economy with solar energy significant value a mechanism for climate

protection and rapid PV deployment for rural electrification and economic development. This help avoids administrative hurdles, reduce unit costs and improve industry competitiveness based on successful technology from information transfer.

This help builds favourable constituencies to organize implementation and thus with commitment and resources make change happen. It also helps build consensus between the government and civil society because, the task includes identifying, activating and pursuing action to create, develop and carry out steps essential for interpreting aim and objectives into results including trained constituency and funds among organizational structures. For example, decision-makers monitoring impact systems can monitor implementation progress alerts as well as intentional and unintentional impacts of implementation efforts due to the obstacles in Nigeria.

The monitoring will help establish policy analysis and implementation unit in assisting the present administration to improve policy decision-making with a strong focus in pursuing and achieving implementation results. This framework will help monitor action plan committees in compliance with plans from problems observed to reduce unnecessary regulation in the country. This will enable policy-makers to consider cost-effective policy in driving the impact of policies to realize the objectives, which depends on government role for PV system solar power generation development. This is because effective Policy implementation can achieve a cost reduction of technology development for business activities.

7.4 Implementation with Possible Outcomes

The findings in this study show 1) lack of government financial support to solar energy. 2) Lack of public awareness. 3) A low national grid performance thus, proposes the following: Financial provision to support the real-life application of solar energy system. Local-based policy for price rate and loan facilities in making solar system electricity generation attractive and tax reduction on equipment related to solar energy technologies. Increase public awareness through programs because a large proportion of the public has little knowledge about solar PV capacity. Collaboration between government and private organizations due to potential benefits, environmental friendliness, legal requirements, and financial assistance.

For example, government provision of subsidy for solar PV system development can attract maximum benefit to end-users and suppliers, in addition, make utility grid performance competitive access to independent power producers (IPPs) in the country.

Moreover, solar PV system development is government policy option due to the huge technical potential. This will significantly contribute to emission (GHG) reductions for the benefit of the country because government direct and indirect policies can reduce the cost of a PV system, which is relevant to climate change, energy conservation and energy efficiency for improvement of market distribution in Nigeria. This justifies the higher cost of solar PV systems due to the greater value of electricity supply to consumers based on the competitive advantage over conventional technology in Nigeria. The government, therefore, need to strengthen regulatory policy for solar energy system development in terms of transparency in transactions.

7.5 Summary

Solar PV system development requires government intervention and private sector participation for financial supports and incentives in order to save cost. This innovative research approach on demonstration and development shows that the PV system is feasible and useful for electricity generation. The design framework is a good practice for administration and management campaign in Nigeria. On one hand, Government effort without RE policies implementation into law, on one hand, may not achieve 5 percent, 7 percent and 13 percent growths by 2020, 2030 and 2050 targets within the regulatory guidelines. Solar potential benefits without government support, on the other hand, may not be realized for investment opportunities. In this study, these frameworks might help policymakers to understand and improve the implementation process and re-design policies for effective action in favour of the society. It can also help facilitate the implementation of policy documents with sufficient incentives to attract households and businesses into solar system installation across the country. The proposed strategies may address the country's urgent electricity need to stimulate economic impact and entrepreneurial skills for the development of PV systems in Nigeria.

CHAPTER 8: CONCLUSIONS AND RECOMMENDATIONS

8.1 Conclusions

This study provides an overview of PV use for electrical energy generation in Nigeria, and proposes the use of solar Photovoltaic (PV) systems to meet electricity consumption to reduce the tendency of depending on diesel-fuel generators in the future and addresses the significance of the study. The term 'Off-grid installation' in this study, refers to solar PV system that only generated electricity/power when utility power grid is always not available for residential and commercial uses and this mostly installed is for charging of the battery for night use during outages.

First, the study shows how the research questions were answered, secondly, discusses the significance of the study and the knowledge claims and thirdly, proposes a recommendation for policy, practice, and research based on data collected. The study focused on technical, economic and policy perspectives respectively to address the challenges. The study targets on how much electricity can be generated, the economic benefit from affordable solar energy potential and policy implementation by government intervention for financial support and incentives due to cost constraints. This study analyses the benefits of PV systems with solar energy potential due to economic, technical, social, environmental and political impacts over the existing conventional energy technologies based on comparative advantages and cost analysis.

The theoretical analysis from data collection through questionnaire was used to understand the population perceptions about solar energy use with PV technologies. The case studies adopted were used to identify electricity generation, consumption, and payback period from individuals and governments for installed PV systems due to financial decisions viability in the country. The RET Screen software for accuracy was used for simulations to determine the amount of electricity output with costs and emission reductions from different PV panel types (mono and polycrystalline silicon) based on off-grid applications. The energy budget was assessed using innovative financing (PAYG) model to ascertain energy consumption per user against cost decision.

Answering the research Questions

The aim of this study is to find out the relationship between solar energy potential currently available with PV systems performance for electricity generation in an affordable and environmentally clean way. The quantity of electricity that needs to be generated in promoting PV installation which minimizes the gap between demand and energy supply in Nigeria. Five main questions are addressed through this inquiry:

Research question 1: What could be the major barriers to solar energy application in Nigeria?

The barrier to solar energy application includes initial cost that slows PV system installations and this requires financial supports and incentives through government and private participation. The study data reveal that government incentives might reduce short-term costs for long-term benefits in order to support PV investment, boost solar energy deployment and make solar PV project relatively cost-effective. The data also show that the majority of the populations are low-income earners who cannot afford a PV system that hinders them from installation participation and this could contribute to socio-economic development of the community and the economy.

Another barrier includes lack of funding and commitment by the government and the results show that this might be a delay to the renewable energy project implementation because it is yet to be passed into law due to the problem of bureaucracy and corruption. The data also reveal that commitment to policy implementation through action might enforce private participation and this could play a significant role in facilitating PV system deployment for community development in Nigeria. It could also motivate states/neighbouring countries participation and contributions to PV development.

Research question 2: What could be the policy barrier for solar application in Nigeria?

The barrier includes private sector participation, community, and legislature in decision-making. The private participation generally perceived is all about resource mobilization for PV electricity generation investment. The drafted policies from national authorities obliged

private sector participation has not been implemented, will require private sector participation to adhere to the decision in the implementation of the national policies, and directives. The study data show that policies can be used to enhance private participation because it makes them aware they are responsible to participate in the development activities.

The barrier to the private sector and community participation includes lack of involvement in government policies decisions. The lack of financial support may be because they are not consulted about the policies during formulation and lack of motivation due to lack of funding suggested a passive response to PV development by the participants. This is because an individual/developer had little influence on the decision. The results reveal that private funding with community funding could supplement governments funding that is insufficient. The study data reveal that the government had no sufficient funds to support except with private sector support for PV system development.

Another barrier includes strategies from national energy policy for solar PV, which were not effective for private sector participation. This is because among the people, the policy awareness is limited due to lack of understanding about the information contained in the policy document and this could be influenced negatively on the motivation for participation from the study participants. However, this study aims to encourage government implementing the policies through commitment and contributions in terms of financial support and incentives.

Research question 3: To what extent does the initial cost of PV installation affect solar application and implementation?

The PV system off-grid applications in four locations of the case study are generally applied in school, office, home, and community. The installation is for individual purposes rather than on policies and strategies in the document. However, the data show that individual participation was limited due to a lack of funding ability because participation levels for the PV system development are generally low. This is because not everybody can afford the

system cost and data show that the government and private participation should be responsible.

The results show lack of knowledge about PV systems is stopping people from an installation that requires support through programs/incentives, training and workshops to promote awareness for the benefit of rapid use in the country. This is needed because many homes and residential households lack electricity and they are more than 50% of the country's energy consumers in addition to rural areas without access to the grid. The results show that home adoption of PV systems is most preferred because many individual households cannot afford the initial cost of the system. In addition, the application of PV systems could be a renewable market in Nigeria.

Research question 4: What are the environmental, economic and social benefits of solar energy application in Nigeria?

The results show that the benefits perceived by the private sector and community participation may facilitate PV deployment. This is because education, programs, and training benefits could result in emission reductions, generation performance, and job creation in order to encourage the private sector and community involvement in PV development. The data reveal that participating in PV development by the rural-remote community areas could be for electricity access distribution. The data also show that investment increase may further boost PV installation for economic, social, environmental and technical benefits thereby improve quality of life, reduce poverty rate from jobs opportunities and income generation and overall economic growth.

Research question 5: What are the environmental and economic challenges for solar energy development in Nigeria?

The use of fossil fuels leads to a shortage of electricity supply and outages including rapid deforestation, air, and water pollutions as well as climate change due to GHG emissions. The results show that the PV system might help to curtail the electricity outages with solar abundance and reliability in turn help supplement the existing supply from the utility grid.

The study also reveal that solar energy is an innovative solution towards sustainable development and economic approach towards minimizing the impact of electricity generation on the environment.

Research question 6: What major role can solar PV play in addressing the insufficient power supply problem in Nigeria?

The data reveals that the solar PV system might contribute to socio-economic development based on the adequate electricity generation and supplement energy supply to meet the energy demand of the citizens. This study provides in-depth awareness/understandings of the perceptions/opinions, real-life proofs/practices and the barriers to PV system development for electricity supply. It also provides research-based data of value to regulators, policymakers, energy service providers/developers/installers, customers/end-users, professionals, investors, administrators, group activists, and researchers.

The findings suggest that more people preferred the solar system used to the generating set and fossil fuels that have negative impacts on the people's health and the environment (land degradation, air, and water). This shows that solar energy is important in repairing Nigeria's damaged environment. The independent electricity generation in terms of self-reliance with the system can easily meet energy demand to improve people's standards of living whereas the electricity access will help enhance energy efficiency in the power sector. The conclusion of this study also reflects on the contribution based on background, theoretical, and empirical significance.

Background Significance

This study provides an understanding that Nigeria abundant and reliable solar energy resource can be utilized to supplement the existing energy supply to cover the shortage and electricity access. This may achieve a reduction in the use of heavy diesel generator for household activities. The data from this study contribute to knowledge about public awareness in public and private sectors critically for rapid promotion of PV developments. From the results, electricity to meet the country's demand is urgently needed. This study also

generated a piece of new knowledge about the use of insurance and capital markets to facilitate solar technology development. In addition, the results show that government commitment and support with incentives for private participation can pay PV generators for generating electricity to meet the energy needs of the country.

Theoretical Significance

The study establishes that the off-grid decentralized application can be dominant for the provision of electricity supply and capacity-building programs in the country. The results show that decentralization can bring electricity access to rural villages and supports for lower income earners. However, a comprehensive framework could be used to increase private and community participation. The framework can be used by researchers which can be useful for explanation of initiatives and strategies and also be useful in advancing knowledge for local finance sourcing initiatives. Moreover, the theoretical framework could be useful to institutional and legislative structures in understanding and interpreting policies through collaboration.

The results show that training and workshop programs might provide critical skills in managing PV installations. They also show that good performance of solar PV systems due to proper installation can as well provide a good and reasonable return on investment from generation and consumption. This study also establishes that the Nigerian government focusing more on sustainable future will help pursue economic diversification to reduce impacts of climate change. This is because solar energy implementation and application for electricity generation can significantly resuscitate the damaged environment, eradicate poverty and improve livelihood, in addition increase local businesses, employment, and productivity in Nigeria.

Empirical Significance

This research provides knowledge that contributes to the understanding of solar PV performance and the roles: The evidence from existing PV system case study's projects shows

solar PV systems had a good performance that satisfied solar electricity customers due to well-designed installation with the following examples:

Case study 1 invested GBP36, 612 (N14, 828, 000), generated 72,576 kWh, consumed 66,799 kWh, realized GBP16, 312 (N6, 606, 490) annual return and payback in 2.2 years. Case study 2 invested GBP15, 889 (N6, 435, 000), generated 16,243 kWh, consumed 5,530 kWh, realized GBP708 (N286, 550) annual return and payback within 16 years. Case study 3 invested GBP3, 328 (N1, 348, 000), generated 9,677 kWh, consumed 6,445 kWh, realized GBP1, 584 (N641, 550) annual return and payback in 2 years. Case study 4 invested GBP8, 309 (N3, 365, 000), generated 14,076 kWh, consumed 7,359 kWh, realized GBP1, 583 (N641, 240) annual return and payback within 5 years.

Case study 5 invested GBP7, 580 (N3, 070, 000), generated 12,420 kWh, consumed 7,359 kWh, realized GBP1, 619 (N655, 990) return annually and payback within 5 years. Case study 6 invested GBP588 (N238, 000), generated 648 kWh, consumed 467 kWh, realized GBP97.5 (N39, 470) return annually and payback 6 years. Case study 7 invested GBP1, 235 (N500, 000), generated 2,880 kWh, consumed 156, realized GBP42 (N17, 160) annual return and payback in 29 years. Case study 8 invested GBP3, 521 (N1, 426, 000), generated 9,216 kWh, consumed 7,319 kWh, realized GBP1, 812 (N733, 790) annual return and payback within 2 years.

Case study 9 invested GBP8, 602 (N3, 484, 000), generated 7,884 kWh, consumed 3,214 kWh, realized GBP443 (N179, 340) return annually and payback within 14 years. Case study 10 invested GBP37, 383 (N15, 140, 000), generated 35,040 kWh, consumed 9,979, realized GBP841 (N340, 690) annual return and payback within 24 years. Case study 11 invested GBP25, 975 (N10, 520, 000) and generated and consumed 71,552 kWh, realized GBP19, 434 (N7, 870,720) return annually and payback within 2 years.

This study utilized multiple approaches for data collected from four different locations in both urban and rural communities whereas the previous studies adopted a single context respectively. The use of multiple methods in this study shows detail understanding of PV installation cases from different location designs. The quantitative approaches such as case studies and questionnaire are the main data collection tools. The questionnaire did not

provide in-depth data for the understanding of the phenomenon. However, the data may help regulators assess the exact cost for the amount of electricity to be generated and consequently checkmate users' exploitation by suppliers.

The results reveal that simulation used to determine the amount of generation from off-grid PV installation might facilitate the technology development for the reductions of emissions and pollutions. In the context of financial resources that are not available, financing model (PAYG) was used to ease the burden of cost from the energy users, which shows that costs might be associated with energy budget for Nigerian consumers. This study contributes to knowledge for the individual understanding of PV performance and the exact costs for installation, generation, and consumption.

8.2 Recommendations

Policy Recommendations

The study shows that national policies to guide people lack transparency and ineffective. The lower income source shows that the government should be responsible to fund the system including public awareness through training. Government policy process should be sensitive to energy needs and focused on local priorities for economic growth and development. The following are policy recommendations:

1. The regulators and policy decision makers should consider the integration of other renewables with reasonable tariffs. To implement CDM for selling carbon credit in acquiring RE technologies that could massively be used to reduce the cost of emissions for health benefit due to climate change and making solar PV market competitive in Nigeria.

2. The government should introduce public funding to encourage foreign solar company's cooperation with local developers and real estate investment trust (REIT) for capital utilization in Nigeria.

3. The government should focus on new scheme solutions for promoting sustainable energy use. For example, policy and decision makers should consider incorporating trust fund

scheme for the local community who are beneficiaries of such policies. This is because establishing programs and schemes can facilitate basic access needs such as education, energy services, goods and services, conducive environment, transportation, communication, and other socio-economic activities for economic growth and development in Nigeria.

4. The government should collaborate with well-informed professionals, legislative, regulatory and proactive organizations and other related groups on renewable issues for new electricity market. The regulations should provide an avenue for local funding from financial institutions such as cooperative society, insurance companies, local communities and councils due to the market complexity. This can ensure that PV systems compete favourably for massive deployment within the state's country and neighbouring countries because joint efforts with closer neighbouring countries could help raise fund for utilizing RETs effectively and maximize electricity output generation potential for revenue and wealth creation.

Recommendation for Practice

1. The governments and the private sector should develop a dispatchable CSP system for PV cost reduction. They should have a joint partnership with NGOs, the communities and Gencos/TCN/Discos to ensure maximum growth and best practice in monitoring, auditing, reporting management of PV grid-connection for effective delivery for the interest of government actors and players such as the regulators and policy makers, developers, and consultants in Nigeria.

2. The government should implement FITs incentives for generators and also leasing for rooftop space due to the cost of land space by independent generators for PV design. The government should educate building architects, engineers, and developers for proper PV installation in order to avoid future failure. In addition, the government should collaborate with professionals and educate design installer for solar projects to prevent weak performance due to the effect of local factors.

3. Solar home/distributed solar systems designs on household buildings should be recommended because it is profitable and can eliminate the possibility of individual system

theft and maintenance. For example, mini-grids for estates, communities and business organization should be designed because adopting this opportunity could help reduce CO_2 emissions faster in residential places, which emits more of GHGS. This could help cut the cost of electricity in homes, mechanical farming, irrigation, parks, beaches, etc.

Recommendation for Research

This research shows that solar PV system is a viable strategy for electricity generation and financial support from the government, private and community participation to rapidly facilitate the development. In addition, cash is significant for renewable energy policies to be successful and development of PV systems in Nigeria. This study was limited to four locations in Nigeria due to time constraints and resources that requires further investigation. Furthermore, research on renewable hybrid system development is required for sufficient generation to mitigate climate change (GHG emissions) nationwide.

REFERENCES

ABDUSSALAM, A. F. 2014. Climate influences on infectious diseases in Nigeria, West Africa. University of Birmingham.

ABIODUN, J. O. 1997. The challenges of growth and development in metropolitan Lagos. *The urban challenge in Africa: growth and management of its large cities***,** 192-222.

ACEMOGLU, D., GOLOSOV, M. & TSYVINSKI, A. 2011. Power fluctuations and political economy. *Journal of Economic Theory,* 146**,** 1009-1041.

ADARAMOLA, M. & OYEWOLA, O. 2011. Wind speed distribution and characteristics in Nigeria. *ARPN Journal of Engineering and Applied Sciences,* 6**,** 82-86.

ADEAKIN, I. 2016. The military and human rights violations in post-1999 Nigeria: Assessing the problems and prospects of effective internal enforcement in an era of insecurity. *African Security Review,* 25**,** 129-145.

ADEJUYIGBE, S. B., BOLAJI, B. O., OLANIPEKUN, M. U. & ADU, M. R. 2012. Development of a solar photovoltaic power system to generate electricity for office appliances. *Engineering Journal,* 17.

ADEWOLE, B., POPOOLA, O. & ASERE, A. 2015. Thermal Performance of a Reflector Based Solar Box Cooker Implemented in Ile-Ife, Nigeria. *International Journal of Energy Engineering,* 5**,** 95-101.

ADEYEMO, H. 2013. Challenges facing solar energy projects in Nigeria; A case study of Lagos state.

ADEJUMO, A.V and ADEJUMO, O.O. 2018. Sustainable Development: Implications for Energy Policy in Nigeria. Towards a Sustainable Bio economy: Principles, Challenges and Perspectives, pages 395-433.

AFRICA, P. 2016. Power Africa Annual Report: A U.S Government-Led *Partnership.* [Online]. Availablehttps://www.usaid.gov/sites/default/files/documents/1860/Power_Africa_AR2016-optimized.pdf [Accessed 26 February 2017].

AFRICA, S. 2012. *Secure Africa* [Online]. Available: http://www.secureafrica2012.org/index.php/about-abuja [Accessed [Accessed 5 May] 2015].

AGBONGIARHUOYI, A. 2015a. *Promoting renewable energy use in Nigeria* [Online]. Available: http://www.vanguardngr.com/2015/08/promoting-renewable-energy-use-in-nigeria/ [Accessed 6 December 2015].

AGBONGIARHUOYI, A. 2015b. Promoting renewable energy use in Nigeria. *Vanguard*, 8 August 2015.

AGUNBIADE, T. 2016. Arnergy is bringing Pay-As-You-Go Solar Power to Rural Communities across Nigeria. [Online]. *Arnergy Solar Company.* Available: http://technical.com/2016/06/07/arnergy-nigeria-is-bringing-pay-as-you-go-solar-power-services-to-rural-communities/ [Accessed 12 September 2016].

AINA, J. K., OGUNDELE, A. G. & OLANIPEKUN, S. S. 2013. Students' proficiency in English language relationship with academic performance in science and technical education. *American Journal of Educational Research,* 1**,** 355-358.

AINA, L. O. 1994. "The Challenges of Training the New Information Worker for Africa". Librarian Career Development, 2, 13-17.

AJIBOLA, G. M. A. A., S. 2015. Housing Rehabilitation Strategy as Enabling Approach for Development of Rural Housing Poverty in Nigeria. *World Journal of Social Sciences and Humanities,* 1**,** 11-17.

AKHIL, A. A., HUFF, G., CURRIER, A. B., KAUN, B. C., RASTLER, D. M., CHEN, S. B., COTTER, A. L., BRADSHAW, D. T. & GAUNTLETT, W. D. 2013. *DOE/EPRI 2013 electricity storage handbook in collaboration with NRECA*, Sandia National Laboratories Albuquerque, NM.

AKINBORO, F., ADEJUMOBI, L. & MAKINDE, V. 2012. Solar energy installation in Nigeria: observations, prospect, problems and solution. *Transnational Journal of Science and Technology,* 2**,** 73-84.

AKINTOYE, A. & BECK, M. 2009. Policy, management and finance of public-private partnerships, John Wiley & Sons.

AKINYELE, D., RAYUDU, R. & NAIR, N. 2015. Global progress in photovoltaic technologies and the scenario of development of solar panel plant and module performance estimation–Application in Nigeria. *Renewable and Sustainable Energy Reviews,* 48**,** 112-139.

AKINYELE, D. O. 2016. Techno-economic and life-cycle impact analysis of solar photovoltaic Micro-grid systems for off-grid communities. Doctor of Philosophy Victoria University of Wellington.

AKINYEMI, O., OGUNDIPE, A. A. & ALEGE, P. 2015. Energy supply and climate change in Nigeria. *Energy Supply and Climate Change in Nigeria,* 4.

ALIYU, A. S., DADA, J. O. & ADAM, I. K. 2015. Current status and future prospects of renewable energy in Nigeria. *Renewable and sustainable energy reviews,* 48**,** 336-346.

ALSADI, S. & ALSAYID, B. 2012. Maximum power point tracking simulation for photovoltaic systems using perturb and observe algorithm. *International Journal of Engineering and Innovative Technology (IJEIT),* 2**,** 80-85.

ALVESSON, M. & SANDBERG, J. 2011. Generating research questions through problematization. *Academy of management review,* 36**,** 247-271.

ALVESSON, M. & SANDBERG, J. 2013. Constructing research questions: Doing interesting research, Sage.

AMADI, S. & CHIGBU, T. 2014. The Need for Accurate and Timely Weather and Climate Services in a Developing Economy: Nigeria in Perspective. *Journal of Current Research in Science,* 2**,** 680.

AMBITUUNI, A., ET AL. 2014. Analysis of safety and environmental regulations for downstream petroleum industry operations in Nigeria: Problems and prospects. [Online]. Available:https://www.researchgate.net/publication/259525822_Analysis_of_Safety_and_Environmental_Regulations_for_Downstream_Petroleum_Industry_Operations_in_Nigeria_Problems_and_Prospects [Accessed 13 July 2017].

AMINU, I. & PETERSIDE, Z. B. 2014. The Impact of Privatization of Power Sector in Nigeria: A Political Economy Approach. *Mediterranean Journal of Social Sciences,* 5**,** 111.

ANDERSON, J., ADEY, P. & BEVAN, P. 2010. Positioning place: polylogic approaches to research methodology. *Qualitative Research,* 10**,** 589-604.

ANDERSON, K. & MAY, F. A. 2010. Does the method of instruction matter? An experimental examination of information literacy instruction in the online, blended, and face-to-face classrooms. *The Journal of Academic Librarianship,* 36**,** 495-500.

ANYADIKE, R. 1993. Seasonal and annual rainfall variations over Nigeria. *International journal of climatology,* 13**,** 567-580.

ARENT, D. J., WISE, A. & GELMAN, R. 2011. The status and prospects of renewable energy for combating global warming. *Energy Economics,* 33**,** 584-593.

ARTHUR, S. S., T AND DUNLOP, D.E. 2009. The results of Performance Measurements of field-aged crystalline silicon Photovoltaic Modules. *Progress in Photovoltaics Research and Applications,* 17**,** 227-240.

ARTICLE, F. 2016. *Photovoltaic Efficiency:The Temperature Effect* [Online]. Available: http://www.cub_pveff_lesson02_fundamentalsarticle_v6_tedl_dwc.pdf [Accessed 10 July 2017].

ASAJU, K. & ADAGBA, S. O. 2013. Women Participation in National Development in Nigeria: The Imperative of Education. *Journal of Public Administration and Governance,* 3**,** 57-69.

ASAJU, K. & AKUME, A. Vision 20: 2020: Realities and Challenges. Faculty of Administration Conference Proceedings, ABU Zaria, 2010. 162-173.

BABATOPE, S., OLALEKAN, B., USUNOBUN, M. & ROTIMI, M. 2013. Development of a Solar Photovoltaic Power System to Generate Electricity for Office Appliances.

BABBIE, E. J. 2010. The Practice of Social research. 12th ed. Belmont: CA: Wadsworth Cengage.

BALL, G. V., M AND VLAICU, M. 2012. Electrifying Solutions: Can Power Sector Aid boost Economic Growth and Development. *Energy for Sustainable Development,* 16**,** 26-34.

BANERJEE, A. V. & DUFLO, E. 2014. Do firms want to borrow more? Testing credit constraints using a directed lending program. *Review of Economic Studies,* 81**,** 572-607.

World BANK, 2001. Nigeria's electric power sector reform: what should form the key objective? *Energy Policy,* Vol. 33**,** 1213-1221.

World BANK, 2009. World Development Report: Reshaping economic geography. [Online]. Available:http://documents.worldbank.org/curated/en/730971468139804495/pdf/437380REVISED01BLIC1097808213760720.pdf [Accessed 8 June 2015].

BARKEMEYER, R., HOLT, D., PREUSS, L. & TSANG, S. 2014. What happened to the 'development'in sustainable development? Business guidelines two decades after Brundtland. *sustainable development,* 22**,** 15-32.

BAZILIAN, M., NAKHOODA, S. & VAN DE GRAAF, T. 2014. Energy governance and poverty. *Energy Research & Social Science,* 1**,** 217-225.

BAZILIAN, M., ONYEJI, I., LIEBREICH, M., MACGILL, I., CHASE, J., SHAH, J., GIELEN, D., ARENT, D., LANDFEAR, D. & ZHENGRONG, S. 2013. Re-considering the economics of photovoltaic power. *Renewable Energy,* 53**,** 329-338.

BENEDICTTA, D. 2016. Field study Data: Implementation and Application of Solar Energy based on Nigeria National electricity Rate. June 2016, Nigeria.

BERNANKE, B. S. A. R., K. 2001. *Annual NBER Macroeconomics* [Online]. MIT Press..

BHANDARI, R. & STADLER, I. 2009. Grid parity analysis of solar photovoltaic systems in Germany using experience curves. *Solar Energy,* 83**,** 1634-1644.

BHANDARI, S. B. 1986. Discounted payback: A criterion for capital investment decisions. *Journal of Small Business Management,* 24**,** 16.

BIRD, L., CHAPMAN, C., LOGAN, J., SUMNER, J. & SHORT, W. 2011. Evaluating renewable portfolio standards and carbon cap scenarios in the US electric sector. *Energy Policy,* 39**,** 2573-2585.

BLOOMBERG. 2012. *BNEF Survey Multi Crystalline Silicon Module China Spot Price Analysis (SSPSMCSC).* [Online]. Available: http://www.bbc.co.uk/news/business-29643612 [Accessed 18 April 2017].

BLOOMBERG 2016. Investment Outlook: Investment Opportunities-Sustainable Investing.

BOGDAN, R. C. & BILKEN, S. K. 1992. Qualitative research for education: An introduction to theories and models. *Foundations of Qualitative research for Education***,** 1-11.

BOIE, I., KOST, C., BOHN, S., AGSTEN, M., BRETSCHNEIDER, P., SNIGOVYI, O., PUDLIK, M., RAGWITZ, M., SCHLEGL, T. & WESTERMANN, D. 2016. Opportunities and challenges of high renewable energy deployment and electricity exchange for North Africa and Europe–Scenarios for power sector and transmission infrastructure in 2030 and 2050. *Renewable Energy,* 87**,** 130-144.

BONY, L., DOIG, S., HART, C., MAURER, E. & NEWMAN, S. 2010. Achieving low-cost solar PV. *Rocky Mountain Institute (RMI), Snowmass, CO*.

BORTOLINI, M., GAMBERI, M., GRAZIANI, A., MORA, C. & REGATTIERI, A. 2013. Multi-parameter analysis for the technical and economic assessment of photovoltaic systems in the main European Union countries. *Energy conversion and management,* 74**,** 117-128.

BP. 2006. BP. Statistical Review of World Energy: Quantifying Energy June [Online]. *British Petroleum*. Available: http://www.rrojasdatabank.info/bpstats2006.pdf [Accessed 12 July 2015].

BP. 2013. BP. Statistical review of world energy [Online]. *British Petroleum.* Available: http://www.bp.com/content/dam/bp/pdf/statisticalreview/statisticalreviewofworldenergy2013.pdf. [Accessed 5 June 2015].

BP. 2016. British Petroleum statistical review of World Energy June 2016 [Online]. *British Petroleum*.Available:https://www.bp.com/content/dam/bp/pdf/energyeconomics/statistical-review-2016/bp-statistical-review-of-world-energy-2016-full-report.pdf [Accessed 25 June 2016].

BRADFORD, T. 2008. Solar revolution: the economic transformation of the global energy industry, MIT Press.

BRIANS, C. L. E. A. 2011a. Empirical Political Analysis: Quantitative and Qualititative Research Methods., Boston, MA: Longman.

BRIANS, C. L. E. A. 2011b. *Research Method Information: Quantitative Research.* [Online]. Available: http://apus.libguides.com/researchmethodsguide/researchmethodsquantitative [Accessed 28 November 2016].

BRISTOW, D. & KENNEDY, C. A. 2010. Potential of building-scale alternative energy to alleviate risk from the future price of energy. *Energy Policy,* 38**,** 1885-1894.

BROOKS, C. 1916. The rainfall of Nigeria and the Gold Coast. *Quarterly Journal of the Royal Meteorological Society,* 42**,** 85-106.

BURIAN, M. & ARENS, C. 2014. The clean development mechanism: a tool for financing low carbon development in Africa? *International Journal of Climate Change Strategies and Management,* 6**,** 166-191.

CAI, D. W., ADLAKHA, S., LOW, S. H., DE MARTINI, P. & CHANDY, K. M. 2013. Impact of residential PV adoption on Retail Electricity Rates. *Energy Policy,* 62**,** 830-843.

CANADA, N. R. 2004. Clean Energy Project Analysis with RETScreen® Software: Clean Energy Project Analysis Course. [Online]. *Minister of Natural Resources Canada* Available: http://www.aeei.bse.vt.edu/wp-content/uploads/2014/05/feasibility_ross.pdf [Accessed 13 May 2015].

CANMET, N. A. 2008. *Surface meteorology and Solar Energy a renewable energy resource web site.* [Online]. Available: https://eosweb.larc.nasa.gov/sse/RETScreen/ [Accessed 28 March 2015 2015].

CBER 2014. Solar powered growth in the UK: The macroeconomic benefits for the Uk investment in solar PV. *CBER.* Online: CEBR.

CBN 2010. CBN Statistical Bulletin. Nigeria: Central Bank of Nigeria.

CEC 2008. Commission of the European Communities: The support of electricity from renewable energy sources. *Commission Staff working Document.* Brussels: Commission of the European Communities.

CERC 2010. Central Electricity Regulatory Commission. *Petition No. 256/2010 (suo.motu).* New Delhi, India: Central Electricity Regulatory Commission.

CHARLES, A. 2014. How is 100% renewable energy possible for Nigeria. *Global Energy Network Institute (GENI), California*.

CHERRINGTON, R., GOODSHIP, V., LONGFIELD, A. & KIRWAN, K. 2013. The feed-in tariff in the UK: a case study focus on domestic photovoltaic systems. *Renewable Energy,* 50**,** 421-426.

CHINEKE, T. & IGWIRO, E. 2008. Urban and rural electrification: enhancing the energy sector in Nigeria using photovoltaic technology. *African Journal Science and Technology,* 9**,** 102-108.

CHINEKE, T. C. & EZIKE, F. M. 2010. Political will and collaboration for electric power reform through renewable energy in Africa. *Energy Policy,* 38**,** 678-684.

CHIRAMBO, D. 2014. The climate finance and energy investment dilemma in Africa: lacking amidst plenty. *Journal of Developing Societies,* 30**,** 415-440.

CHIRAMBO, D. 2016. Addressing the renewable energy financing gap in Africa to promote universal energy access: Integrated renewable energy financing in Malawi. *Renewable and Sustainable Energy Reviews,* 62**,** 793-803.

CHIRINKO, R. S. & WILSON, D. J. 2008. State investment tax incentives: A zero-sum game? *Journal of Public Economics,* 92**,** 2362-2384.

CHUHAN-POLE, P. 2016. *Africa's Pulse Spring 2016*, World Bank Publications.

CHUKWUEYEM, E. A. 2015. Analysis of energy market conditions in Nigeria. Online: Central Bank of Nigeria.

CHURCH, J. A. & WHITE, N. J. 2011. Sea-level rise from the late 19th to the early 21st century. *Surveys in Geophysics,* 32**,** 585-602.

CLAESSENS, S., DEMIRGÜÇ-KUNT, A. & HUIZINGA, H. 2001. How does foreign entry affect domestic banking markets? *Journal of Banking & Finance,* 25**,** 891-911.

CLAIRE 2010. "Presenting and Evaluating Qualitative Research." *American Journal of Pharmaceutical Education,* 74**,** 1-7.

COLPIER, U. C. & CORNLAND, D. 2002. The economics of the combined cycle gas turbine—an experience curve analysis. *Energy Policy,* 30**,** 309-316.

NIGERIA COMMISSION, 2010. Federal Republic of Nigeria, 2006 population and housing census priority table volume III; population distribution by sex, state, LGA and senatorial district. *National Population Commission, Abuja, Nigeria*.

COMPANY, M. 2014. Sustainability's Strategic worth: Mckinsey Global

Survey Results [Online]. Available: http://www.mckinsey.com/business-functions/sustainability-and-resource-productivity/our-insights/sustainabilitys-strategic-worth-mckinsey-global-survey-results [Accessed 18 June 2015].

CONSULTANT, G. S. 2013a. *Consultants boost renewable energy development in Nigeria* [Online]. Available: https://www.esi-africa.com/consultants-boost-renewable-energy-development-in-nigeria. [Accessed 24 July 2015].

CONSULTANT, G. S. 2013b. *German Mission in Nigeria: Inauguration of hybrid solar PV/wind plant at NAPTIN's Regional Training Centre in Kainji.* [Online]. Available: http://m.nigeria.diplo.de/vertretung/nigeria/en/0620wi2c20wz/wz/inauguration20of20Hybrid20plant20kainji.html [Accessed 22 August 2015].

CORVELLEC, H., CAMPOS, M. J. Z. & ZAPATA, P. 2013. Infrastructures, lock-in, and sustainable urban development: the case of waste incineration in the Göteborg Metropolitan Area. *Journal of Cleaner Production,* 50**,** 32-39.

CORY, K., COUTURE, T. & KREYCIK, C. 2009. Feed-in tariff policy: design, implementation, and RPS policy interactions. National Renewable Energy Laboratory (NREL), Golden, CO.

COUTURE, T. & CORY, K. 2009. State Clean Energy Policies Analysis (SCEPA) Project: An Analysis of Renewable Energy Feed-in Tariffs in the United States (Revised). National Renewable Energy Laboratory (NREL), Golden, CO.

COUTURE, T. & GAGNON, Y. 2010. An analysis of feed-in tariff remuneration models: Implications for renewable energy investment. *Energy policy,* 38**,** 955-965.

CPUC 2011. California Public Utilities Commission: California Solar Initiative Annual Program Assessment. *California Solar Initiative Annual Program Assessment.* California, USA: California Public Utilities Commission.

CRESWELL, J. 2009a. Research design: Qualitative, quantitative, and mixed methods approaches. *Handbook of mixed methods in social & behavioral research***,** 209-240.

CRESWELL, J. W. 2008. Educational research: Planning, conducting, and evaluating quantitative and qualitative research. . 3rd ed. Upper Saddle River: NJ: Pearson Education.

CRESWELL, J. W. 2009b. Research Design: Qualitative, Quantitative and Mixed Methods Approaches., Los Angeles, SAGE.

CRESWELL, J. W. 2013. Research design: Qualitative, quantitative, and mixed methods approaches, Sage publications.

D'AGOSTINO, A. L., SOVACOOL, B. K. & BAMBAWALE, M. J. 2011. And then what happened? A retrospective appraisal of China's Renewable Energy Development Project (REDP). *Renewable Energy,* 36**,** 3154-3165.

DADA, J. O. 2014. Towards understanding the benefits and challenges of Smart/Micro-Grid for electricity supply system in Nigeria. *Renewable and Sustainable Energy Reviews,* 38**,** 1003-1014.

DAMASCELLI, A., HUSSAIN, Z. & SHEN, Z.-X. 2003. Angle-resolved photoemission studies of the cuprate superconductors. *Reviews of modern physics,* 75**,** 473.

DARAMOLA, A. & IBEM, E. O. 2010. Urban environmental problems in Nigeria: Implications for sustainable development. *Journal of Sustainable Development in Africa,* 12**,** 124-145.

DAS, K. 2011. Technology Transfer under the Clean Development Mechanism: an empirical study of 1000 CDM projects.

DASAPPA, S. 2011. Potential of biomass energy for electricity generation in sub-Saharan Africa. *Energy for Sustainable Development,* 15**,** 203-213.

DAVID-WEST, A. 2014. *Nigerian Power Sector: Value investment opportunity or value trap* [Online]. Available: http://docplayer.net/38014739-Nigerian-power-sector.html [Accessed [Accessed 4 March 2017].

DECC 2009. The UK Renewable Energy Strategy (2009)presented to Parliament by the Secretary of State for energy and climate change. *In:* CHANGE, D. O. E. A. C. (ed.). Online: Parliament by the Secretary of State: Office of Public Sector Information.

DECC. 2013. *The feed-in tariff in the UK: A case study on domestic photovoltaic systems.* [Online].Available:http://www.academia.edu/8821367/Thefeed_in_tariff_in_the_uk_a_case_study_focus_on_domestic_photovoltaic_systems [Accessed 9 January 2015].

DECC, U. 2011. Renewable energy roadmap. Crown Copyright, Department of Energy & Climate Change, London.

DENZIN, N. K. & LINCOLN, Y. S. 2002. *The qualitative inquiry reader*, Sage.

DENZIN, N. K. & LINCOLN, Y. S. 2011. *The Sage handbook of qualitative research*, Sage.

DFID. 2007. Growth: Building jobs and prosperity in developing countries. Department for International Development. [Online]. Available: http://www.oecd.org/derec/unitedkingdom/40700982.pdf [Accessed 14 July 2017].

DIBIA, B. 2016a. Implementation and application of solar energy in Nigeria: Solar Radiation and Electricity Ouputs in Nigeria Locations (Abuja, Enugu-Nsukka, Awka and Lagos) Charts. PhD Research, University of Nottingham.

DOE, E. 2005. *International Electricity Installed capacity* [Online]. Online: Energy Information Administration and Department of Energy. [Online] Available:

http://www.eia.doe.gov/emeu/international/electricitycapacity.thml [Accessed 6 June 2014].

DOE, U. 2010. EIA, 2010,". Biosolids Equivalents Derived from Natural Gas. Washington, DC, USA.

EBELE, O. A. A., O. 2016. *Solar-powered vehicles, vehicles of the future* [Online]. Online: Vanguard Newspaper. May 2016 http://www.vanguardngr.com/2016/09/solar-powered-vehicles-vehicles-future-arthur-okeyika [Accessed 10 January 2017].

EBOHON, O. J. A. I., J. 2005. Nigeria' electric power sector reform: what should form the key Objectives? *Energy Policy,* Vol. 33**,** pp. 1213-1221.

ECN, 2006. Hydro Power Resources in Nigeria. A paper presentation at 2nd hydropower for today conference international centre on small hydro power (IC-SHP). . International, 2006 Hangzhou, China.

ECN 2009. Report of the Vision 2020 National Technical Working Group on Energy Sector. Online: Energy Commission of Nigeria.

ECN 2012. Renewable Energy Master Plan, Nigeria. Renewable Energy Master Plan. in Nigeria E. C. O. (ed). Nigeria

ECN, S. A. 2003. Energy Commission of Nigeria. *Energy Resources Review,* 4**,** 7-10.

EDOZIEN, E. A. 2016. Power sector needs more investment: The 5th Nigeria International Power Expo and Conference on ''Private Sector Partnership in Achieving Sustainability of Power Supply in Nigeria''. {Online}. Available: http://www.informationng.com/2015/11/untapped-opportunities-for-growth-abound-in-power-sector-fg.html [[Accessed 30 March 2017].

EERE, D. 2013. Building Technologies Program: Appliance and Equipment Standards.

EIA. 2009. *Annual Energy Outlook 2009 with Projections to 2030 March 2009. Office of Integrated Analysis and Forecasting.* [Online]. Online: Energy Information Administration. Available: http://large.stanford.edu/publications/coal/references/docs/0383(2009).pdf [Accessed 8 May 2014 2014].

EJIOGU, A. R. 2013. Gas Flaring in Nigeria: Costs and Policy. *Energy & Environment,* 24**,** 983-998.

EKUNDAYO, S. 2010. The Energy Market in Nigeria and Business Opportunities.

ELLIS, T. J. & LEVY, Y. 2008a. Framework of problem-based research: A guide for novice researchers on the development of a research-worthy problem. *Informing Science,* 11.

ELLIS, T. J. & LEVY, Y. 2008b. Towards a framework of problem-based research: A guide for novice researchers. *Information Sciences***,** 1-19.

ELLIS, T. J. & LEVY, Y. 2012. Data sources for scholarly research: towards a guide for novice researchers. Proceedings of Informing Science and IT Education Conference, 2012.

ELLIS, T. J. A. Y., L.N 2008. Framework of Problem-Based Research: A Guide for Novice Researchers on the Development of a Research-Worthy Problem. *Informing Science: the international journal of an emerging transdisciplinary,* 11.

ELLISTON, B., MACGILL, I. & DIESENDORF, M. 2010. Grid parity: A potentially misleading concept? Proc. Solar, 2010. 1-11.

ELOCHUKWU, C. 2015. *Senate Paper Meeting* [Online]. University of Nigeria. Available: http://www.unn.edu.ng/wpcontent/uploads/2015/11/DegreeResultsA1%282014-2015%29.pdf [Accessed 14 February 2016].

EMODI N.V AND EBELE, N. E. 2016. Policies Enhancing Renewable Energy Development and Implications for Nigeria. *Sustainable Energy, 4, 4-16.*

EMODI, N. V. 2016. Results and Discussions. Energy Policies for Sustainable Development Strategies. Springer.

ENCYCLOPAEDIA, 2016a. Capital Investment Appraisal: Appraisal Techniques. [Online]. Available: http://www.capital-investment.co.uk/capital-investment-appraisal.php [Accessed 21 February 2016].

ENCYCLOPAEDIA, B. 2016b. Payback method: Payback period formula. [Online]. Available: https://www.accountingtools.com/articles/2017/5/17/payback-method-payback-period-formula [Accessed 21 July 2017].

ENERGY Outlook, 2014. Solar Energy Company (De Green Rhino Energy) has embarked on a 2,500 megawatt project aimed at easing Zimbabwe's power shortages. [Online]. Green Rhino Energy Available: https://www.evwind.es/2014/04/10/solar-energy-company-de-green-rhino-energy-has-embarked-on-a-2500-megawatt-project-aimed-at-easing-zimbabwes-power-shortages/44735 [Accessed 10 June 2015].

ENERGY, G. R. 2016a. Zimbabwe: De Green Rhino Energy solar plant delays [Online]. *Green Rhino Energy.* Available: https://www.esi-africa.com/news/Zimbabwe-de-green-rhino-energy-solar-plant-delays/ [Accessed 16 January 2017].

ENERGY, G. R. 2016b. Zimbabwe: De Green Rhino Energy solar plants delay*s* [Online]. *Green Rhino Energy.* Available: https://www.esi-africa.com/news/zimbabwe-de-green-rhino-energy-solar-plant-delays/ [Accessed 16 January 2017].

ENGELBRECHT, C. J. & ENGELBRECHT, F. A. 2016. Shifts in Köppen-Geiger climate zones over southern Africa in relation to key global temperature goals. *Theoretical and applied climatology,* 123**,** 247-261.

EPIA 2011. Solar Generation V-2008: Greenpeace and European Photovoltaic Industry Association. European Photovoltaic Industry Association: Greenpeace and European Photovoltaic Industry Association.

ERONINI, N. 2014. The adoption of solar photovoltaic systems among industries and residential houses in Southern Nigeria.

ESMAP 2011. Unleashing the potential of renewable energy in India; Design and Performance of Policy instruments to promote the Development of Renewable Energy: Emerging experience in selected developing countries. Washington DC: World Bank: World Bank.

EZUGWU, C. 2015. Renewable Energy Resources in Nigeria: Sources, Problems and Prospects. *Journal of Clean Energy Technologies,* 3**,** 68-71.

FASHOLA, B. 2016a. The Nigeria Electric Power Sector: Opportunities and Challenges. *Journal of Multidisciplinary Engineering Science and Technology. ,* 4**,** 1-67.

FASHOLA, B. 2016b. Policy making and energy infrastructure change: A Nigerian case study of energy governance in the electricity sector. *Energy Policy, 102, 1-67.*

FCDA. 2014. Federal Capital Development Authority: Abuja Geography [Online]. Federal Capital Development Authority. Available: http://www.fcda.gov.ng/index.php?option=comcontent&view=article&id=32&itemid=68 [Accessed 8 May 2015].

FELTON, J. and KENNET, M. 2012. The Green Built Environment: A Handbook. UK. ISBN: 978-1-907543-06-7 © 2012. The Green Economics Institute, November 2012.

FILANI, M. O., CITIES, C. A. U. & GOVERNMENTS, L. 2011. A City in Transition: Vision, Reform, and Growth in Lagos, Nigeria. *Cities Alliance United Cities***,** P107221.

FINANCE, U. Y. 2017. £2.2 Million Solar Powered Luxury Yatch [Online]. Uk Yahoo Finance. Available: https://sg.finance.yahoo.com/.../p-solarwave-64-launched-last-photo-123249345.html [Accessed 18 March 2017].

FMOP 2014. Federal Ministry of Power: 2014 Annual Report of the Federal Ministry of Power Draft Report. Online: Federal Ministry of Power.

FMOP 2015. *National Renewable Energy and Energy Efficiency Policy,* Online, Ministry of Power and Federal Republic of Nigeria.

FRELING, R. A. & RAMSOUR, D. L. 2010. Shining Light on Renewable Energy in Developing Countries.

FRN 2010. Federal Republic of Nigeria: Aids, National and Assessment Spending. Vol. 3**,** pp. 2007-2008.

FTHENAKIS, V. 2009. Sustainability of photovoltaics: The case for thin-film solar cells. *Renewable and Sustainable Energy Reviews,* 13**,** 2746-2750.

FTHENAKIS, V., MASON, J. E. & ZWEIBEL, K. 2009a. The technical, geographical, and economic feasibility for solar energy to supply the energy needs of the US. *Energy Policy,* 37**,** 387-399.

FTHENAKIS, V., WANG, W. & KIM, H. C. 2009b. Life cycle inventory analysis of the production of metals used in photovoltaics. *Renewable and Sustainable Energy Reviews,* 13**,** 493-517.

GAGNEROC. 2016. History of Lagos Island east local council Government Area [Online]. Gagneroc. Available: http://lagosislandeastlcda.org/history [Accessed 12 September 2016].

GEIGER, K. A. 2015. The Nigerian Energy Sector: An Overview with a Special Emphasis on Renewable Energy, Energy Efficiency and Rural Electrification [Online]. *GIZ.* Available: https://www.giz.de/en/downloads/giz2015-en-nigerian-energy-sector.pdf [Accessed12 September 2016].

GEVORKIAN, P. & GEVORKIAN, P. 2008. Solar power in building design: the engineer's complete design resource: A GreenSource Book McGraw-Hill, copyright©2008. UK. ISBN: 13978-0415-56308-6.

GIBBONS, C. 2014. Introduction to quantitative and qualitative research. *short courses.* University of Nottingham.

GIRAUD, F. & SALAMEH, Z. M. 2001. Steady-state performance of a grid-connected rooftop hybrid wind-photovoltaic power system with battery storage. *IEEE transactions on energy conversion,* 16**,** 1-7.

GISMETEO. 2016. *Awka Weather* [Online]. *Gismeteo.* Available: https://www.gismeteo.com/city/daily/6814/ [Accessed 5 September 2016].

GORDON, R. H. & HINES, J. R. 2002. International taxation. *Handbook of public economics,* 4**,** 1935-1995.

GOSWAMI, Y.D. and KREITH, F. 2016. Energy Efficiency and Renewable Energy: Handbook. U.S.A ISBN: 13: 978-1-4665-8508-9 © 2016. Taylor & Francis Group CRC Press.

GREENICLES. 2016. Going Solar Just Easier. [Online]. *Greencles: The Solar Company*. Available: https://www,greenicles.com [Accessed 4 January 2017].

GREENPEACE, E. 2011. Solar generation 6. Solar photovoltaic electricity empowering the world. *European Photovoltaic Industry Association, Greenpeace Report*.

HAINES, A., SMITH, K. R., ANDERSON, D., EPSTEIN, P. R., MCMICHAEL, A. J., ROBERTS, I., WILKINSON, P., WOODCOCK, J. & WOODS, J. 2007. Policies for accelerating access to clean energy, improving health, advancing development, and mitigating climate change. *The Lancet,* 370**,** 1264-1281.

HEAL, G. 2009. The economics of renewable energy. National Bureau of Economic Research.

HERNÁNDEZ-MORO, J. & MARTÍNEZ-DUART, J. 2013. Analytical model for solar PV and CSP electricity costs: Present LCOE values and their future evolution. *Renewable and Sustainable Energy Reviews,* 20**,** 119-132.

HERRANDO, M., MARKIDES, C. N. & HELLGARDT, K. 2014. A UK-based assessment of hybrid PV and solar-thermal systems for domestic heating and power: System performance. *Applied Energy,* 122**,** 288-309.

HONSBERG, B. A. 2013. *PV Education and Awareness Campaign.* [Online]. Available: http://www.pveducation.org/pvcdrom/pn-junction/movement-of-carriers-in-semiconductor [Accessed 18 March 2014].

HOPPMANN, J., PETERS, M., SCHNEIDER, M. & HOFFMANN, V. H. 2013. The two faces of market support—How deployment policies affect technological exploration and exploitation in the solar photovoltaic industry. *Research Policy,* 42**,** 989-1003.

HOPPMANN, J., VOLLAND, J., SCHMIDT, T. S. & HOFFMANN, V. H. 2014. The economic viability of battery storage for residential solar photovoltaic systems–A review and a simulation model. *Renewable and Sustainable Energy Reviews,* 39**,** 1101-1118.

HUENTELER, J., NIEBUHR, C. & SCHMIDT, T. S. 2016a. The effect of local and global learning on the cost of renewable energy in developing countries. *Journal of Cleaner Production,* 128**,** 6-21.

HUENTELER, J., SCHMIDT, T. S., OSSENBRINK, J. & HOFFMANN, V. H. 2016b. Technology life-cycles in the energy sector—Technological characteristics and the role of deployment for innovation. *Technological Forecasting and Social Change,* 104**,** 102-121.

IBANICHUKA, E. A. L. & JAMES, O. K. 2014. Just-In-Time Cost Accounting System and Social Economic Factors Affecting Its Adoption by Nigerian Firms. *Journal of Empirical Economics,* 2**,** 116-128.

IBITOYE, F. & ADENIKINJU, A. 2007. Future demand for electricity in Nigeria. *Applied Energy,* 84**,** 492-504.

IEA-PVPS 2007. Trends in Photovoltaic applications: Survey report of selected IEA countries between 1992 and 2006. IEA Photovoltaic Power Systems Program. Online: International Energy Agency.

IEA. 2009. Nigerian Power Sector Guide: Total installed electricity net generation in Nigeria.

IEA. 2010a. International Energy Agency: World Energy balances. {Online}: *International* Energy Agency. Available: http://www.iea.org [Accessed 8 May 2017].

IEA. 2011a. 2009 Amendment of the Renewable Energy Sources Act-EEG: Global Renewable Energy Policies and Measures. [Online]. *International Energy Agency*. Available: http://www.iea.org/textbase/pm/?mode=re&id=4054&action=detail [Accessed 5 March 2014].

IEA. 2016a. *Nigeria Feed-in Tariff for Renewable Energy Sourced Electricity* [Online]. Nigeria. Available:https://www.iea.org/policiesandmeasures/pams/nigeria/name-154529-en.php [Accessed 26 April 2016.

IEA 2016b. A Snapshot of Global PV. *IEA PVPS T1-29 Report.*

IEA, 2012. emissions from Fuel Combustion. *International Energy Agency*.

IEA, 2011b. World energy outlook 2011. *Int. Energy Agency*, 666.

IEA, 2010b. OECD and World Bank. 2010. Analysis of the Scope of Energy Subsidies and Suggestions for the G-20 Initiative, 26-27.

IKE 2012. Climatological Effects of total solar radiation in Awka. *Journal of Applied Physics (IOSR-JAP),* 5, 51-54.

IKE CHINELO, U., OKEKE, C. C. & OKEKE, S. 2013. Technical Report on The Design and Installation of a 1KVA Solar Energy Powered Security Light in The Dora Akunyili and Stella Okoli Female Hostels of Nnamdi Azikiwe University, Awka, Using Monocrystalline Panels.

IKE, D., ADOGHE, A. U. & ABDULKAREEM, A. 2014. Analysis of telecom base stations powered by solar energy. *International Journal of Scientific & Technology Research,* 3, 369-374.

IKEME, J. & EBOHON, O. J. 2005. Nigeria's electric power sector reform: what should form the key objectives? *Energy Policy,* 33, 1213-1221.

INCE, M., BASHIRE, D., ONI, O., AWE, E., OGBECHIE, V. & KORVE, K. 2010. Rapid assessment of drinking-water quality in the Federal Republic of Nigeria: country report of the pilot project implementation in 2004-2005. *World Health Organization: Geneva, Switzerland*.

INUGONAM, T. A. 2005. Challenges facing the Developments of Independent Power Producers in a Deregulated Power Sector: NEPA as a Case study. *The 6th International Conference on Power Systems Operation & Planning (ICPSOP) 2005.*

INUGONUM 2016. Charts on Installed Electricity Generation, Transmission and Distribution Capacity Nigeria: Transmission Company of Nigeria.

IPCC. 2008. The IPCC special report on renewable energy sources and climate change mitigation. [Online]. Intergovernmental panel climate change. Available: https://www.ipcc.ch/pdf/special-reports/srren/ipcc-srren-generic-presentation-1.pdf [Accessed 8 Noember 2011].

IRENA. 2013. IRENA: West African Power Pool: Planning and Prospects for Renewable Energy. [Online]. Available: https://www.irena.org/DocumentDownloads/Publications/WAPP.pdf [Accessed 4 August 2014].

IRENA. 2016. Policies and Regulations for Private Sector Renewable Energy Mini-grids; Joint Policies and Measures Database. [Online]. Available: http://www.iea.org/policiesandmeasures/renewableenergy/ [Accessed 27 February 2017].

ISMAIL, O. S., AJIDE, O. O. & AKINGBESOTE, F. 2012. Performance Assessment of Installed Solar PV System: A Case Study of Oke-Agunla in Nigeria. *Engineering,* 4**,** 453.

IWAYEMI, A. 2008a. Investment in electricity generation and transmission in Nigeria: issues and options. *International Association for Energy Economics***,** 37-42.

IWAYEMI, A. 2008b. Nigeria's dual energy problems: policy issues and challenges. *International Association for Energy Economics,* 53**,** 17-21.

IWUAGWU, O. 2009. Nigeria and the challenge of industrial development: The new cluster strategy. *African Economic History,* 37**,** 151-180.

IWUAGWU, O. 2011. The cluster concept: Will Nigeria's new industrial development strategy jumpstart the country's industrial takeoff. *Afro Asian Journal of Social Sciences,* 2**,** 1-24.

JACKSON, I. 1986. Relationships between raindays, mean daily intensity and monthly rainfall in the tropics. *International Journal of Climatology,* 6**,** 117-134.

JENKINS, D., FLETCHER, J. & KANE, D. 2008a. Lifetime prediction and sizing of lead–acid batteries for microgeneration storage applications. *IET Renewable Power Generation,* 2**,** 191-200.

JENKINS, D., FLETCHER, J. & KANE, D. 2008b. Model for evaluating impact of battery storage on microgeneration systems in dwellings. *Energy Conversion and Management,* 49**,** 2413-2424.

JENNER, S., GROBA, F. & INDVIK, J. 2013. Assessing the strength and effectiveness of renewable electricity feed-in tariffs in European Union countries. *Energy Policy,* 52**,** 385-401.

JESULEYE, O. A., SIYANBOLA, W. O. & ILORI, M. O. 2012. Policy Influence of Solar PV Diffusion into the Nigerian Rural Energy Mix. *Disruptive Technologies, Innovation and Global Redesign: Emerging Implications.* IGI Global.

JUNGBLUTH, N., STUCKI, M. & FRISCHKNECHT, R. 2009. Photovoltaics. et al., Sachbilanzen von Energiesystemen: Grundlagen für den ökologischen Vergleich von Energiesystemen und den Einbezug von Energiesystemen in Ökobilanzen für die Schweiz. Ecoinvent report.

KAFAYAT, A. & ABRAHAM, A. 2014. Improved Cook Stoves and Green House Gas Reduction in Uganda.

KAMAL, A. A., E AND ADEL, A. 2016. Performance analysis and investigation of a grid-connected photovoltaic installation in morocco. *Energy Reports,* 2**,** 261-266.

KARSTERN, L. G., J AND GHATIKAR, A. 2015. The Nigerian Energy Sector: An Overview with a Special Emphasis on Renewable Energy, Energy Efficiency and Rural Electrification., Germany, GIZ.

KAUNDINYA, D. P., BALACHANDRA, P. & RAVINDRANATH, N. 2009. Grid-connected versus stand-alone energy systems for decentralized power—A review of literature. *Renewable and Sustainable Energy Reviews,* 13**,** 2041-2050.

KHALID, A. & JUNAIDI, H. 2013. Study of economic viability of photovoltaic electric power for Quetta–Pakistan. *Renewable energy,* 50**,** 253-258.

KLEISSL, J. 2013. Solar energy forecasting and resource assessment, Academic Press.

KREYCIK, C., COUTURE, T. D. & CORY, K. S. 2011. Innovative feed-in tariff designs that limit policy costs. National Renewable Energy Laboratory (NREL), Golden, CO.

KUMAR, B. S. & SUDHAKAR, K. 2015. Performance evaluation of 10 MW grid connected solar photovoltaic power plant in India. *Energy Reports,* 1**,** 184-192.

KUTA, D. A. A. E. 2009a. A bill for an Act to Amend the Energy Commission of Nigeria Act to Grant Priority to the Promotion and Development of Renewable Energy Sources, and Provide for Other Matters Relating Thereto. [Online]. *Energy Commission of Nigeria*. Available: http://nass.gov.ng/document/download/1151 [Accessed 23 March 2014}.

KUTA, E. A. 2009b. Energy commission of Nigeria: Report of the Vision 2020 National Technical Working Group on Energy Sector. Online: Energy Commission of Nigeria.

LINCOLN, Y. S. & GUBA, E. G. 2000. The only generalization is: There is no generalization. *Case study method***,** 27-44.

LOR, P. J. 2015. Understanding Innovation and Policy Transfer: Implications for Libraries and Information Services in Africa. *Library Trends,* 64**,** 84-111.

MA, H., OXLEY, L., GIBSON, J. & LI, W. 2010. A survey of China's renewable energy economy. *Renewable and Sustainable Energy Reviews,* 14**,** 438-445.

MACKAY, R. & PROBERT, S. 1995. National policies for achieving energy thrift, environmental protection, improved quality of life, and sustainability. *Applied energy,* 51**,** 293-367.

MADUEME, T. C. A. O., O.I 2004. Solar energy investments in a developing Economy. *Nigerian Journal of Technology,* Vol. 29**,** pp. 1599-1610.

MAEHLUM, M. A. 2015a. *Energy Informative: 5 Mind-Blowing Solar Energy Facts* [Online]. Online. Available: http://www.Mind-Blowingsolarenergyfactsenergyinformative.mht [Accessed 10 August 2015 2015].

MAEHLUM, M. A. 2015b. Wind energy pros and cons. Energyinfomative.[WWW] http://energyinformative. org/solar-energy-pros-and-cons/(20.05. 2015).

MAGAZINE, P. 2013. Tested: SolarWorld Sunmodule Plus SW245 poly.

MAULEÓN, I. 2015. The cost of renewable power: A survey of recent estimates. *Green Energy and Efficiency.* Springer.

MCCRONE, A., USHER, E., SONNTAG-O'BRIEN, V., MOSLENER, U. & GRÜNING, C. 2012. Global trends in renewable energy investment 2012. *Frankfurt School UNEP Collaborating Centre for Climate and Sustainable Energy Finance*.

MCCULLOCH, C. E. & NEUHAUS, J. M. 2001. *Generalized linear mixed models*, Wiley Online Library.

MCKINLEY, B. 2014. Using REITs to Invest in Utility Scale Solar Projects Using REITs to Invest in Utility Scale Solar Projects. . 12**,** 60-68.

MCNABB, D. E. 2008. Research Methods in Public Administration and Nonprofit Management: Quantitative and Qualitative Approaches. 2nd ed. New York: ME Sharpe.

MEARA, J. G., LEATHER, A. J., HAGANDER, L., ALKIRE, B. C., ALONSO, N., AMEH, E. A., BICKLER, S. W., CONTEH, L., DARE, A. J. & DAVIES, J. 2015. Global Surgery 2030: evidence and solutions for achieving health, welfare, and economic development. *The Lancet,* 386**,** 569-624.

MENDONÇA, M. & JACOBS, D. 2009. Feed-in tariffs go global: policy in practice. *Renewable Energy World,* 12**,** 1-6.

MENDONCA, M., JACOBS, D. & SOVACOOL, B. K. 2009. *Powering the green economy: The feed-in tariff handbook*, Earthscan.

MENTIS, D., WELSCH, M., NERINI, F. F., BROAD, O., HOWELLS, M., BAZILIAN, M. & ROGNER, H. 2015. A GIS-based approach for electrification planning—A case study on Nigeria. *Energy for Sustainable Development,* 29**,** 142-150.

MILLS, A. & WISER, R. 2010. Implications of wide-area geographic diversity for short-term variability of solar power. Ernest Orlando Lawrence Berkeley National Laboratory, Berkeley, CA (US).

MOHAMMED, Y., MUSTAFA, M., BASHIR, N. & IBRAHEM, I. 2017. Existing and recommended renewable and sustainable energy development in Nigeria based on autonomous energy and microgrid technologies. *Renewable and Sustainable Energy Reviews,* 75**,** 820-838.

MONARI, A., ASSFELD, X., BELEY, M. & GROS, P. C. 2011. Theoretical study of new ruthenium-based dyes for dye-sensitized solar cells. *The Journal of Physical Chemistry A,* 115**,** 3596-3603.

MOULA, M. M. E., MAULA, J., HAMDY, M., FANG, T., JUNG, N. & LAHDELMA, R. 2013. Researching social acceptability of renewable energy technologies in Finland. *International Journal of Sustainable Built Environment,* 2**,** 89-98.

MUHAMMAD-SUKKI, F., RAMIREZ-INIGUEZ, R., MUNIR, A. B., YASIN, S. H. M., ABU-BAKAR, S. H., MCMEEKIN, S. G. & STEWART, B. G. 2013. Revised feed-in tariff for solar photovoltaic in the United Kingdom: A cloudy future ahead? *Energy Policy,* 52**,** 832-838.

MURCOTT, A. 1997. 'The PhD: some informal notes'. Unpublished paper. School of Health and Social Care. London: South Bank University.

MYERS, D. R. 2013. Solar radiation: practical modeling for renewable energy applications, CRC Press.

NAIBBI, A. I. & TUKUR, Y. M. 2017. Ensuring Optimal Electricity Generation and Supply: The Paradox of Nigeria's Situation.

NASA 2014. Solar Energy Pros and Cons by NASA: U.S Department of Energy (DOE) National Renewable Energy Laboratory (NREL), U.S Energy Information Administration (EIA) and European Union. Online: NASA, DOE, NREL, EIA and EU.

NBS 2012a. National Bureau of statistics (NBS) Economic Outlook 2012. *In:* STATISTICS, N. B. O. (ed.).

NBS 2012b. National Bureau of statistics reveals that 54% of Nigerian youths were Unemployed in 2012. Online. *National bureau of Statistics.*

NBS. 2012c. *National Bureau of Statistics: Economic outlook* {Online}. Available: http://nigerianstat.gov.ng/pdfuploads/NBS%20Economic%20Outlook%202012-2015.pdf [Accessed 24 April 2016].

NEBO, C. A. W., M. 2014. Nigerian Power Sector: Limited Access to Electricity and Overview of the power sector in Nigeria [Online]. Available: http://www.power.gov.ng/Press%20Briefing/ministerial%20press%20briefing%202014.pdf [Accessed 23 August 2015].

NEP. 2003. National Energy Policy: The Presidency Energy Commission of Nigeria [Online]. The Presidency Energy Commission of Nigeria. Available: http://wacee.net/getattachment/21cca4e4-ef1b-4c59850198b3e8624b88/National_Energy_Policy_Nigeria.pdf.aspx [Accessed 24 March 2014].

NERC. 2013. Nigeria Electricity Regulatory Commission Regulations on National Content Development for the Nigerian Electricity Supply Industry. [Online]. *Nigeria Electricity Regulatory Commission.* Available: http://www.nercng.org/nercdocs/Regulations%20on%20National%20Content%20Development%20for%20the%20Nigerian%20Electricity%20Supply%20Industry%202013.pdf [Accessed 13 March 2016].

NERC 2014. Regulations on National Content Development for the Power Sector. Online: *Nigerian Electricity Regulatory Commission*.

NERC. 2015. *Nigerian Electricity Regulatory Commission: Electricity on demand (MYTO 2015)* [Online]. *Nigerian Electricity Regulatory Commission.* Available: http://www.nercng.org/index.php/myto-2/discos [Accessed 24 March 2016].

NERC. 2016. *Nigeria Feed-in Tariff for Renewable Energy Sourced Electricity.* [Online]. Available: http://www.nercng.org/index.php/document-library/func-startdown/486/ [Accessed 26 April 2016].

NERLOVE, M. & ARROW, K. J. 1962. Optimal advertising policy under dynamic conditions. *Economica*, 129-142.

NESP, G. A. 2015. The Nigerian Energy Sector: An Overview with a Special Emphasis on Renewable Energy, Energy Efficiency and Rural Electrification. Nigerian Energy Support Programme (NESP). , Nigeria, Nigerian Energy Support Programme.

NEVIN, R. 2010. Energy-efficient housing stimulus that pays for itself. *Energy Policy,* 38, 4-11.

NEWSOM, C. 2013. Can renewable energy turn Nigeria's lights on? . *International Institute for Environment and Development*, 1-4.

NEWSPAPER TIMES, 2015. Gross UP Clauses in Commercial Leases within the Context of withholding Tax Regime in Nigeria. . *ThisDay*, 13 January 2015, Nigeria.

NGO, C. and NATOWITZ, J.B. 2009. Our Energy Future: Resources, Alternatives and the Environment. Canada. ISBN: 978-0-470-11660-9 © 2009 John Wiley & Sons Inc. All rights reserved.

NIGERIA COMMISSION, 2010. The Business, Trade and Investment Guide. *Corporate Guides International Publication,* 11**,** 190.

NIMET, W. A. 2008. World Meteorological Organisation: Statement on the status of the global *climate in 2008* [Online]. Available: https://library.wmo.int/opac/doc_num.php?explnum_id=3461 [Accessed 12 October 2015].

NNAJI, B. 2011. Power sector outlook in Nigeria: Challenges, Constraints and opportunities.

NPC 2010. National Planning Commission: Nigeria Vision 20:2020. Nigeria: National Planning Commission.

NPSG 2013. Nigerian Power Sector Guide: Total installed electricity net generation in Nigeria.

NREEEP 2015. National Renewable Energy and Energy Efficiency Policy approved by FEC for the Electricity Sector 4/20/2015 Ministry of Power, Federal Republic of Nigeria. . *In:* POLICY, N. R. E. A. E. E. (ed.). Online Ministry of Power, Federal Republic of Nigeria.

NREL. 2012. *Life-cycle GHG Emissions from Photovolataics* [Online]. National Renewable Energy Laboratory. Available: http://www.nrel.gov/docs/fy13osti/56487.pdf [Accessed 4 May 2015].

OBAMA, B. 2015. Power Africa: Annual Report July 2015. Online: USAID.

OBASI, S. A. A., C. 2015. *75 percent of Nigerians lack access to regular power* [Online]. Nigeria: Vanguard Media ltd Available: http://www.vanguardngr.com/2015/11/75-nigerians-lack-access-to-regular-power/ [Accessed 7 May 2016].

ODEBUNMI, K. A. F. 2016. Arnergy rolls out pay-as-you-go solar rental systems in Nigeria. [Online]. Arnergy Solar Company. Available: http://innovation-village.com/arnergy-rolls-pay-go-solar-rental-systems-nigeria [Accessed 25 June 2016].

ODOYI, E. 2013. Challenges and Opportunities of Sustainable Electricity Access in Nigeria.

OGUNLEYE, E. K. 2017. Political economy of Nigerian power sector reform. *The Political Economy of Clean Energy Transitions*, 391.

OGUNLEYE, I. & AWOGBEMI, O. 2011. Constraints to the use of solar photovoltaic as a sustainable power source in Nigeria. *American Journal of Scientific and Industrial Research,* 2, 11-16.

OHIARE, S. 2015. Expanding electricity access to all in Nigeria: a spatial planning and cost analysis. *Energy, Sustainability and Society,* 5, 8.

OHUNAKIN, O. S. 2010. Energy utilization and renewable energy sources in Nigeria. *Journal of Engineering and Applied Sciences,* 5, 171-177.

OHUNAKIN, O. S. 2014. Renewable and Sustainable *Energy Reviews,* Vol. 32 pp. 294-301.

OHUNAKIN, O. S., ADARAMOLA, M. S., OYEWOLA, O. M. & FAGBENLE, R. O. 2014. Solar energy applications and development in Nigeria: drivers and barriers. *Renewable and Sustainable Energy Reviews,* 32, 294-301.

OHUNAKIN, O. S., OJOLO, S. J. & AJAYI, O. O. 2011. Small hydropower (SHP) development in Nigeria: an assessment. *Renewable and Sustainable Energy Reviews,* 15, 2006-2013.

OJO, O. V. 2017. An Overview of the Legal and Regulatory Framework for Renewable Energy Projects in Nigeria: Challenges and Prospects.

OKAFOR, E. E. 2008. Development crisis of power supply and implications for industrial sector in Nigeria. *Journal of Tribes and Tribals,* 6, 83-92.

OKAFOR, K. 2009. "Geregu Power Station Enhancing Engineering best Practice in Power Generation". Nigeria: PHCN News.

OKANLAWON, L. 2016. *Solar Power: Gradually Becoming Nigeria's New Normal?* [Online]. Greenicles Solar Company. Available: http://www.greenicles.com/solar-power-gradually-becoming-nigerias-new-normal/ [Accessed 27/09/2016.

OKEKE, A. A. 2015. Nigerian Energy Sector: Legal and Regulatory Overview [Online]. Available: http://www.ajumogobiaokeke.com/assets/media/2b13946e4257859eb7988150d1c620a2.pdf [Accessed 22 May 2016].

OKEREKE, O. C. 2017. Causes of failure and abandonment of projects and project deliverables in Africa.

OKOLOBAH, V. & ISMAIL, Z. 2013. On the issues, challenges and prospects of electrical power sector in Nigeria. *International Journal of Economy, Management and Social Sciences,* 2**,** 410-418.

OKOLOYE, C., AISIOKUEBO, N., UKEJE, J., ANUFOROM, A. & NNODU, I. 2013. Rainfall variability and the recent climate extremes in Nigeria. *Meteorol. Clim. Sci,* 11**,** 49-57.

OKORO, O. & CHIKUNI, E. 2007. Power sector reforms in Nigeria: opportunities and challenges. *Journal of Energy in Southern Africa,* 18**,** 52-57.

OKORO, O. & MADUEME, T. 2004a. Solar energy investments in a developing economy. *Renewable Energy,* 29**,** 1599-1610.

OKORO, O. & MADUEME, T. 2004b. Solar Energy: A Necessary Investment in a Developing Economy. *Nigerian Journal of Technology,* 23**,** 58-64.

OLAOLUWA, R. 2015. Nigeria: Lagos Arnergy Solar receives Funding from Bank of Industry and UNDP. [Online]. *AllAfrica.* Available: http://allafrica.com/stories/201507210458.html [Accessed 10 June 2016].

OLATOMIWA, L., MEKHILEF, S., HUDA, A. & OHUNAKIN, O. S. 2015. Economic evaluation of hybrid energy systems for rural electrification in six geo-political zones of Nigeria. *Renewable Energy,* 83**,** 435-446.

OLAYINKA, O. S. 2012. Noise pollution in urban areas: the neglected dimensions. *Environmental Research Journal,* 6**,** 259-271.

OMISORE, B. 2011. Nigeria's Solar Projects yield both failure and success: The National Geographic Daily news [Online]. The National Geographic Daily news. Available: http://news.nationalgeographic.com/news/energy/2011/11/111102-solarpower-in-nigeria/ [Accessed 28 May 2014].

ONI, A. 2013. The Nigerian Electric Power Sector: Policy. Law. Negotiation Strategy. Business, AuthorHouse.

ONOCHIE, U., EGWARE, H. & EYAKWANOR, T. 2015. The Nigeria Electric Power sector (opportunities and challenges). *Journal of Multidisciplinary Engineering Science and Technology,* 2**,** 494-502.

OSENI, M. O. 2011. An analysis of the power sector performance in Nigeria. *Renewable and Sustainable Energy Reviews,* 15**,** 4765-4774.

OSENI, M. O. 2012a. Households' access to electricity and energy consumption pattern in Nigeria. *Renewable and Sustainable Energy Reviews,* 16**,** 990-995.

OSENI, M. O. 2012b. Improving households' access to electricity and energy consumption pattern in Nigeria: Renewable energy alternative. *Renewable and Sustainable Energy Reviews,* 16**,** 3967-3974.

OSUEKE, C. & EZUGWU, C. 2011. Study of Nigeria Energy resources and its consumption. *International Journal of Scientific & Engineering Research,* 2**,** 121-130.

OTTINGER, R. L. & BOWIE, J. 2015. Innovative Financing for Renewable Energy. *Pace Envtl. L. Rev.,* 32**,** 701.

OUYANG, X. & LIN, B. 2014. Levelized cost of electricity (LCOE) of renewable energies and required subsidies in China. *Energy policy,* 70**,** 64-73.

OYEDEPO, S. O. 2012a. Energy and sustainable development in Nigeria: the way forward. *Energy, Sustainability and Society,* 2**,** 15.

OYEDEPO, S. O. 2012b. On energy for sustainable development in Nigeria. *Renewable and Sustainable Energy Reviews,* 16**,** 2583-2598.

OYENEYE, O. 2004. Socio-economic Influences on Policies of Power Deregulation. Proc. 20th National Conference of the Nigerian Society of Engineers (Electrical Division), 2004. 1-15.

OZOR, N., MADUKWE, M., ENETE, A., AMAECHINA, E., ONOKALA, P., EBOH, E., UJAH, O. & GARFORTH, C. 2012. A framework for agricultural adaptation to climate change in Southern Nigeria. *International Journal of Agriculture Sciences,* 4**,** 243.

POLICY, E. & FINANCE, P. C. 2011. Fuel for Thought 22–6 (Late May to Mid-July 2011). *Energy & Environment,* 22.

PV.TV, 2017. The true dawning of the sector age-outlook for solar PV in 2017 [Online]. *Solar PV.tv.* Available: http://www.nortonrosefulbright.com/knowledge/publications/146966/the-true-dawning-of-the-solar-age-outlook-for-solar-pv-in-2017 [Accessed 16 March 2017].

PVPS, I. 2016. A Snapshot of Global PV. *Report IEA PVPS T1-29*.

QAZI, S. 2016. Standalone Photovoltaic (PV) Systems for Disaster Relief and Remote Areas, Elsevier.

RAUGEI, M. & FRANKL, P. 2009. Life cycle impacts and costs of photovoltaic systems: current state of the art and future outlooks. *Energy,* 34**,** 392-399.

REED, S. & DE FREITAS, N. 2015. Neural programmer-interpreters. *arXiv preprint arXiv:1511.06279*.

REHFUESS, E. & ORGANIZATION, W. H. 2006. Fuel for life: household energy and health.

REKIOUA, D., BENSMAIL, S. & BETTAR, N. 2014. Development of hybrid photovoltaic-fuel cell system for stand-alone application. *International Journal of Hydrogen Energy,* 39**,** 1604-1611.

REN21, R. 2011. global status report. 2011.

REPORT, A. P. 2015. Power People Planet seizing Africa's energy and climate opportunities. Online: Africa Progress panel.

RET SCREEN INTERNATIONAL, 2005. *Clean Energy Project Analysis Software.* [Online]. Natural Resources Canada. Available: http://www.RETScreen.com [Accessed 19 February 2015].

RICHARDS, G., NOBLE, B. & BELCHER, K. 2012. Barriers to renewable energy development: A case study of large-scale wind energy in Saskatchewan, Canada. *Energy Policy,* 42**,** 691-698.

SALAMI, L. & ELEBIJU, A. 2004. Investment Incentives for the Electricity Business in Nigeria. *Journal of Energy & Natural Resources Law,* 22**,** 94-100.

SAMBO, A. Electricity demand from customers of INGA hydropower projects: The case of Nigeria. WEC Workshop on Financing INGA Hydropower Projects, 2008a. 21-22.

SAMBO, A. 2008b. Matching electricity supply with demand in Nigeria. *International association for energy economics,* 4**,** 32-36.

SAMBO, A. 2010. Renewable energy development in Nigeria. Energy commission of Nigeria paper presented at the World's future council and strategy workshop on renewable energy, Accra, Ghana, 2010.

SAMBO, A. S. 2008c. Paper Presentation at the National Workshop on the Participation of State Government in the Power Sector: Matching Supply with Demand. *National Workshop Paper.* Ladi Kwali Hall, Sheraton Hotel and Towers Abuja.

SAMBO, A. S. 2009a. The Place of Renewable Energy in the Nigerian Energy sector. Presented at the World Future Council Workshop on Renewable Energy Policies. . *The World Future Council Workshop on Renewable Energy Policies.* Addis Ababa, Ethiopia.

SAMBO, A. S. 2009b. Strategic developments in renewable energy in Nigeria. *International Association for Energy Economics,* 16**,** 15-19.

SAMBO, A. S., GARBA, B., ZARMA, I. H. & GAJI, M. M. 2012. Electricity generation and the present challenges in the Nigerian power sector. *Journal of Energy and Power Engineering,* 6**,** 1050.

SCHMALENSEE, R. 2015a. The future of solar energy: a personal assessment. *Energy Economics,* 52**,** S142-S148.

SCHMALENSEE, R. 2015b. *The Future of Solar Energy: An Interdisciplinary MIT Study*, Energy Initiative, Massachusetts Institute of Technology.

SCHMIDT, M. 2016. Cumulative average growth rate CAGR and other growth metrics. Retrieved from Business Encyclopedia.

SCHMIDT, M. J. 2002. *The business case guide*, Solution Matrix.

SCOTT, A. & SETH, P. 2012. Infrastructure services post-2015. *London: ODI Research Report*.

SHAABAN, M. & PETINRIN, J. 2014. Renewable energy potentials in Nigeria: meeting rural energy needs. *Renewable and Sustainable Energy Reviews,* 29**,** 72-84.

SHARMA, V. & CHANDEL, S. 2013. Performance analysis of a 190 kWp grid interactive solar photovoltaic power plant in India. *Energy,* 55**,** 476-485.

SHIVA, K. A. S., K. 2015. Performance evaluation of 10 MW grid-connected solar photovoltaic power plant in India. *Energy Reports,* 1**,** 184-192.

SHYU, C.-W. 2014. Ensuring access to electricity and minimum basic electricity needs as a goal for the post-MDG development agenda after 2015. *Energy for Sustainable Development,* 19**,** 29-38.

SIEMINSKI, A. 2014. International energy outlook. *Energy Information Administration (EIA)*.

SILVERMAN, D. 2000. Doing Qualitative Research: a practical handbook. London: SAGE.

SINGH, K. 2007. Quantitative social research methods, Sage.

SÖSEMANN, F. 2007. EEG-The renewable energy sources act: the success story of sustainable policies in Germany. Berlin, Germany: Federal Ministry for the Environment. *Nature Conservation and Nuclear Safety*.

STERN, N. 2007. The Economics of Climate Change: The Stern Review. London, UK. ISBN: 13: 978-0-521-70080-1 © 2007. Cambridge University Press.

SULEIMAN, Y. 2016. Renewable Energy and Power Back-up Solutions [Online]. Blue Camel Energy. Available: http://bluecamelenergy.com.ng/wp-content/uploads/2016/04/BlueCamelBusinessProposal.pdf [Accessed 27 March 2016].

SUNDAY, O.O. 2014. Towards achieving energy for sustainable development in Nigeria. *Renewable and Sustainable Energy Reviews* 34, pages 255-272.

SUNDAY, O.O. 2012. Energy and sustainable development in Nigeria: the way forward.

SUNTECH. 2012. 240 watt Monocrystalline Solar Module (STP240S-20/Wd) [Online]. Suntech Company. Available: https://gr.krannich-solar.com/fileadmin/content/datasheets/solarmodules/greece/STP240S-20Wd.pdf [Accessed 12 September 2016].

TALLAPRAGADA, P. 2009. Nigeria's electricity sector-electricity and gas pricing barriers. *International Association for Energy Economics*, 29-34.

TEODORESCU, R., LISERRE, M. & RODRIGUEZ, P. 2011. *Grid converters for photovoltaic and wind power systems*, John Wiley & Sons.

TIMILSINA, G. R., KURDGELASHVILI, L. & NARBEL, P. A. 2011. A review of solar energy: markets, economics and policies.

TRIPATHY, M., SADHU, P. & PANDA, S. 2016. A critical review on building integrated photovoltaic products and their applications. *Renewable and Sustainable Energy Reviews,* 61**,** 451-465.

UNDP, E. A. 2012. Renewable Energy Master Plan. Nigeria: Energy Commission of Nigeria.

UNIDO 2014. Energy Poverty: Global Challenges and local solutions. *In:* HALFF, A. S., B.K AND ROZHON, J. (ed.) 1st ed.: UNIDO.

USAID. 2015. 2015 Global Education Summit the Office of Education of USAID's Bureau for Economic Growth, Education, and Environment (E3) [Online]. Available: https://www.usaid.gov/education/events/global-education-summit [Accessed 2 January 2016].

USMAN, Z. G. & ABBASOGLU, S. 2014. An overview of power sector laws, policies and reforms in Nigeria. *Asian Transactions on Engineering,* 4**,** 6-12.

USMAN, Z. G., ABBASOGLU, S., ERSOY, N. T. & FAHRIOGLU, M. 2015. Transforming the Nigerian power sector for sustainable development. *Energy Policy,* 87**,** 429-437.

UZOMA, C., NNAJI, C. & NNAJI, M. 2012. The role of energy mix in sustainable development of Nigeria. *Continental Journal of Social Sciences,* 5**,** 21.

VINCENT, E. N. & YUSUF, S. D. 2014. Integrating renewable energy and smart grid technology into the Nigerian electricity grid system. *Smart Grid and Renewable Energy,* 5**,** 220.

WALID, S. 2015. Schneider Electric commission off-grid solar energy solutions for six Nigerian states [Online]. Schneider Electric. Available: http://www.africanreview.com/energy-a-power/renewables/schneider-electric-commission-off-grid-solar-energy-solutions-for-six-nigerian-states [Accessed 12 September 2016].

WATKINS, L. 2016. *Nigerian Power Sector: Opportunities and Challenges for Investment in 2016* [Online]. {Online}. Available: https://www.lw.com/thoughtleadership/lw-nigerian-power-sector-opps-and-challenges [Accessed [Accessed 16 February 2017] 2017].

WHITE, P. 2008. Developing research questions: A guide for social scientists, Palgrave Macmillan.

WICKS, M. 2009. Energy Security: A national challenge in a changing world, DECC.

WIEMANN, M. & Ling N.G. 2014. Untapped Markets: Access to Energy Lies in Business Innovation. *IEEE Power and Energy Magazine,* 12**,** 42-49.

WISER, R. & BOLINGER, M. 2011. 2010 Wind technologies market report. National Renewable Energy Laboratory (NREL), Golden, CO.

YALA, A. & PALESTINE, L. O. Green Grabbing and the Economy of Repair.

YOUNG, ERNEST. 2011. UK solar PV industry outlook: The UK 50kW to 5MW solar PV market. [Online]. Available: http://www.oursolarfuture.org.uk/wp-content/uploads/The-UK-50kW-to-5-MW-solar-PV-market-190611-Final.pdf [Accessed 7 April 2014].

YOUNG, ERNEST. 2014. Financial report interim for the half-year ended 31 December 2014: An illustration of an Australian registered managed investment scheme's financial report Endeavour Managed Investment Scheme. [Online]. Available: http://www.ey.com/Publication/vwLUAssets/EY-endeavour-managed-investment-scheme/$FILE/ey-endeavour-mis-2014.pdf [Accessed 25 November 2016].

YUN, Y. S., LE, V.-D., KIM, H., CHANG, S.-J., BAEK, S. J., PARK, S., KIM, B. H., KIM, Y.-H., KANG, K. & JIN, H.-J. 2014. Effects of sulfur doping on graphene-based nanosheets for use as anode materials in lithium-ion batteries. *Journal of Power Sources,* 262**,** 79-85.

ZAMALLOA, C., VULSTEKE, E., ALBRECHT, J. & VERSTRAETE, W. 2011. The techno-economic potential of renewable energy through the anaerobic digestion of microalgae. *Bioresource technology,* 102**,** 1149-1158.

ZARMA, I. HYDRO POWER RESOURCES. 2nd Hydro Power Conference Hangzhou, China, 2006.

ZELAYA-ANGEL, O., HERNANDEZ, L., DE MELO, O., ALVARADO-GIL, J., LOZADA-MORALES, R., FALCONY, C., VARGAS, H. & RAMIREZ-BON, R. 1995. Band-gap shift in CdS: phase transition from cubic to hexagonal on thermal annealing. *Vacuum,* 46**,** 1083-1085.

ZYL, W. V. 2017. Solar energy is really our only answer for long-term sustainable energy. [Online]. Available: https://qz.com/987397/solar-power-is-the-only-answer-to-africas-electricity-problem/ [Accessed 5 August 2017].

APPENDICES

Appendix 1 from chapter1 provides additional information with table of the world electricity grid-connected generation supply with indication of poor state of Nigeria electricity generation and supply regarding the country statistics of electricity generation and per capita consumption around the world; the World net solar electricity generation from 2010-2040 (billion kilowatt hours) by region and country; the 2009 World electricity access aggregates; the population of Developing Countries without Access to Electricity (Million) and the Africa Population without Electricity (millions). Appendix 2 from chapter 1 provides additional information with table of Nigeria electricity distribution companies; the 2010 distribution of Households electricity supply access by types; the Electricity Grid-Connected Generation and trends in electrification rates per State in 2010-2020. Appendix 3 from chapter 3 provides additional information the selected methods pros and cons compared and analysed table and RET Screen Pros and Cons table and solar PV system advantages and disadvantages. Appendix 4 represents the administered designed questionnaire to the participants for collection of data from case study. Appendix 5 from chapter 4 provides additional information on solar PV system module specifications with selection of Sunpower and Suntech that mostly used for the installation from case study and both have good conversion efficiency performance. Appendix 6 represents RET Screen simulation cumulative cash-flow with example of 33 kW installed.

APPENDIX 1

Appendix 1a Table: Country Statistics of Electricity Generation and Per Capita Consumption around the world

Continent	Country	Population (Million)	Power Generation Capacity	Per- capital consumption
North America	United states	250.00 million	813,000 MW	3.20 kW
South America	Cuba	10.54 million	4,000 MW	0.38 kW
Europe Central	United Kingdom	57.50 million	76,000 MW	1.33 kW
Europe Eastern	Ukraine	49.00 million	54,000 MW	1.33 kW
Middle East	Iraq	23.60 million	10,000 MW	0.42 kW
Far east	South Korea	47.00 million	52,000 MW	1.09 kW
Africa	South Africa	44.30 million	45,000MW	1.015 kW
	Libya	5.50 million	4,600 MW	1.015 kW
	Egypt	67.90 million	18,000 MW	0.265 kW
	Nigeria	170.00 million	4,000 MW	0.03 W

(Source: Chrisdonasco 2013).

Appendix 1b Table: World net solar electricity generation by region and country from 2010-2040 (billion kilowatt hours).

Region/Country	Projections							Ave. Annual % Change 2010-2040
OECD	2010	2015	2020	2025	2030	2035	2040	2010-2040
OECD Americas								
United States	4	32	37	40	46	62	99	11.2
Canada	0	1	1	1	1	1	1	-
Mexico/Chile	0	0	0	1	1	1	1	-
Total Americans	4	33	38	42	48	64	101	11.1
OECD Europe	23	78	85	89	94	98	102	5.1
OECD Asia	5	12	22	33	39	50	50	8.1
Japan	4	7	14	23	29	39	39	8.1
South Korea	1	1	2	2	2	2	2	3.6
Australia/New Zealand	0	4	6	8	8	9	9	-
Total OECD	37	135	167	197	220	262	303	7.86
Non-OECD								
Non-OECD Europe & Eurasia								

Russia	0	0	0	0	0	0	0	-
Other	0	0	1	1	1	1	1	-
Total Non-OCED	0	0	1	1	1	1	1	-
Non-OECD Asia								
China	1	26	67	79	90	100	105	17.0
India	0	3	7	13	14	17	20	-
Other	0	2	2	2	3	3	4	-
Total Asia	1	31	76	94	107	120	129	17.2
Middle East	0	2	9	16	22	44	47	-
Africa	0	0	8	13	15	18	21	-
Central & South America								
Brazil	0	0	0	0	0	0	0	-
Other	0	1	1	1	1	1	1	-
Total Non-OECD	1	34	94	124	145	183	198	18.6
Total World	38	169	261	321	365	445	501	9.1

(Source: GIZ 2015).

Appendix 1c Table: World Electricity Access Aggregates (2009)

Country	Population without Electricity (millions)	Electrification Rate (%)	Urban Electrification Rate (%)	Rural Electrification Rate (%)
World	1317	80.5	93.7	68.0
Africa	587	41.8	68.8	25.0
North Africa	2	99.0	99.6	98.4
Sub-Saharan Africa	585	30.5	59.9	14.2
Developing Asia	675	81.0	94.0	73.2
China and East Asia	182	90.8	96.4	86.4
South Asia	493	68.5	89.5	59.9
Latin America	31	93.2	98.8	73.6
Middle East	21	89.0	98.5	71.8
Developing Countries	1314	74.7	90.6	63.2

Note: The World includes OECD and Eastern Europe/Eurasia (Source: Javadi et al, 2013).

Appendix 1d Table: Population of Developing Countries without Access to Electricity (Million)

	2009			2030 Projection		
Countries	Rural	Urban	Share of Population (%)	Rural	Urban	Share of Population
Africa	466	121	58%	539	107	42%
Sub-Sahara Africa	465	121	69%	538	107	49%
Developing Asia	595	81	19%	327	49	9%
China	8	0	1%	0	0	0%
India	268	21	25%	145	9	10%
Rest of Developing Asia	319	60	36%	181	40	16%
Latin America	26	4	7%	8	2	2%
Middle East	19	2	11%	5	0	2%
Developing Countries	1106	208	25%	879	157	16%
World	1109	208	19%	879	157	12%

(Sources: World Energy Outlook IEA Publishing © OECD/IEA 2011).

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Appendix 1e Table: Africa Population without Electricity (millions)

Country	Electrification Rate (%)	Population without Electricity (millions)
Malawi	9	12.7
Uganda	9	28.1
DR Congo	11.1	58.7
Mozambique	11.7	20.2
Tanzania	13.9	37.7
Burkina-Faso	14.6	12.6
Lesotho	16	1.7
Kenya	16.1	33.4
Ethiopia	17.1	68.7
Zambia	18.8	10.5
Madagascar	19	15.9
Togo	20	5.3
Benin	24.8	6.7
Eritrea	32	3.4
Namibia	34	1.4
Sudan	35.9	27.1
Gabon	36.7	0.9
Congo	37.1	2.3
Zimbabwe	41.5	7.3
Senegal	42.2	7.3
Botswana	45.2	1.1

Cote d'lvore	47.3	11.1
Cameroon	48.7	10
Nigeria	50.6	76.4
Ghana	60.5	9.4
Mauritius	99.4	0
Sub-Saharan Africa	30.5	585.2

(Source: Hailu, 2012).

APPENDIX 2

Appendix 2a Table: Nigeria Electricity Distribution Companies

S/N	NAME	ADDRESS	AREAS COVERAGE	STATE LOCATED
1	Abuja electricity distribution company	Wuse Zone 4 Abuja	FCT, Niger, Kogi & Nasarawa	Abuja
2	Benin electricity distribution company	No. 5 Akpakpava street Benin-city	Edo, Delta, Ondo & part of Ekiti	Benin
3	Eko electricity distribution company	24/25 Marina Lagos	Lagos	Eko
4	Enugu electricity distribution company	No. 12 Station Road Okpara Avenue Enugu	Enugu, Abia, Imo, Anambra & Ebonyi	Enugu
5	Ibadan electricity distribution company	Capital Building 115 Ring Road Ibadan	Oyo, Ogun, Osun, Kwara & part of Ekiti	Ibadan
6	Ikeja electricity distribution company	Secretariat Road Alausa Ikeja	Lagos	Ikeja
7	Jos electricity distribution company	No. 9 Ahmadu Bello way Jos	Plateau, Bauchi, Benue & Gombe	Jos
8	Kaduna electricity distribution company	Nagwamatse Building Ahmadu Bello way Kaduna	Kaduna, Sokoto, Kebbi & Zamfara	Kaduna
9	Kano electricity distribution company	No. 1 Niger Street PMB 3089 Kano	Kano, Jigawa & Katsina	Kano
10	Port-Harcourt electricity distribution company	No.42 Obiwali Road Rumuigbo P/Harcourt	Rivers, Cross-Rivers, Bayelsa & Akwa-Ibom	Port/Harcourt

11	Yola electricity distribution company	No. 2 Atiku Abubakar Road Jimeta Yola	Yola, Adamawa, Borno & Yobe	Yola

Appendix 2b Table: Households Electricity Supply Access by Type

State	PHCN (NEPA) only	Rural Electri-fication*	Private Generator	PHCN / Generator	Rural Electricity / Generator	Solar Panel
Abia	89.6	0.9	0.5	5.0	4.1	0.0
Adamawa	89.5	2.9	1.9	4.8	1.0	0.0
Akwa Ibom	82.8	0.4	2.9	13.1	0.8	0.0
Anambra	81.0	1.7	1.0	15.6	0.7	0.0
Bauchi	77.5	8.0	1.4	9.4	3.6	0.0
Bayelsa	33.1	36.1	2.3	2.3	26.3	0.0
Benue	68.5	14.4	2.7	10.8	3.6	0.0
Borno	87.9	6.1	0.0	6.1	0.0	0.0
Cross River	91.7	6.2	0.5	1.6	0.0	0.0
Delta	93.6	2.7	1.5	1.5	0.8	0.0
Ebonyi	78.9	12.7	0.0	1.4	7.0	0.0
Edo	93.1	2.1	1.2	2.7	0.9	0.0
Ekiti	91.1	1.0	0.8	6.9	0.3	0.0
Enugu	75.0	16.9	1.3	5.9	0.8	0.0
Gombe	96.7	3.2	0.0	2.1	0.0	0.0
Imo	85.4	5.0	2.1	7.5	0.0	0.0
Jigawa	93.2	0.9	0.0	4.3	0.9	0.9
Kaduna	84.8	5.1	2.0	7.6	0.5	0.0
Kano	87.0	6.0	0.0	4.0	3.0	0.0
Katsina	80.4	14.7	0.0	4.3	0.0	0.6
Kebbi	86.4	1.6	3.8	7.1	1.1	0.0
Kogi	79.2	3.3	0.4	15.8	1.3	0.0
Kwara	92.8	1.8	0.3	2.4	2.7	0.0
Lagos	67.9	1.2	1.2	25.9	3.5	0.2
Nasarawa	76.0	0.6	7.2	13.2	3.0	0.0
Niger	75.2	1.8	0.9	21.7	0.0	0.4
Ogun	96.5	0.3	0.0	5.2	0.0	0.0
Ondo	87.5	0.8	2.9	2.9	5.8	0.0
Osun	90.5	0.0	0.4	7.1	2.0	0.0
Oyo	97.7	0.9	0.5	0.9	0.0	0.0
Plateau	92.5	1.3	1.3	3.8	1.3	0.0
Rivers	66.0	26.3	6.7	1.0	0.0	0.0
Sokoto	90.4	6.6	0.6	1.8	0.6	0.0
Taraba	85.7	0.0	0.0	14.3	0.0	0.0
Yobe	77.0	6.9	1.1	11.5	3.4	0.0
Zamfara	87.0	6.9	0.0	3.8	1.5	0.8
FCT Abuja	67.4	0.9	1.9	27.6	2.2	0.0
Sector						
Urban	83.2	2.7	0.8	11.3	2.1	0.0
Rural	81.5	7.5	2.0	6.2	2.6	0.1
National	82.2	5.5	1.5	8.4	2.4	0.1

Appendix 2c Table: Electricity Grid-Connected Generation

Year	Ave. Gen. Availability (MW)	Max. Peak Generation (MW)	Max. Daily Energy Generated (MWh)	Total Energy Generated (MWh)	Total Energy Sent Out (MWh)	Per Capita Energy supply (kWh)
2007	3,781.3	3,599.6	77,322.3	22,519,330.5	21,546,192.2	155.3
2008	3,917.8	3,595.9	86,564.9	18,058,894.9	17,545,382.5	120.4
2009	4,401.8	3,710.0	82,652.3	18,904,588.9	18,342,034.7	122.0
2010	4,030.5	4,333.0	85,457.5	24,556,331.5	23,939,898.9	153.5
2011	4,435.8	4,089.3	90,315.3	27,521,772.5	26,766,992.0	165.8
2012	5,251.6	4,517.6	97,781.0	29,240,239.2	28,699,300.8	176.4
2013	5,150.6	4,458.2	98,619.0	29,537,539.4	28,837,199.8	181.4
2014	6,158.4	4,395.2	98,893.8	29,697,360.1	29,013,501.0	167.6

Appendix 2d Table: 2010-2020 Trends in Electrification rates per State

No.	State	No. of Households as of 1997 (*1)	% of Household with Electricity as of 1997 (*2)	No. of Households with Electricity as of 1997	Annual growth rate of consumers (%)	% of Household with Electricity			No. of Household with Electricity		
						2006	2010	2020	2006	2010	2020
1	Taraba	432,880	12	50,301	7.80	17	21	34	98,888	133,542	283,012
2	Jigawa	823,164	12	99,685	7.77	18	22	35	195,520	263,766	557,554
3	Zamfara	593,479	13	77,924	7.71	20	23	37	152,101	204,752	430,492
4	Sokoto	686,178	13	90,095	7.71	20	23	37	175,859	236,734	497,734
5	Kebbi	592,137	13	77,807	7.71	20	23	37	151,866	204,431	429,794
6	Katsina	1,074,392	14	145,902	7.69	20	24	38	284,184	382,194	801,663
7	Gombe	426,284	17	72,553	7.49	25	30	46	139,031	185,628	382,367
8	Bauchi	819,259	17	139,438	7.49	25	30	46	267,198	356,753	734,857
9	Benue	788,111	17	135,003	7.49	25	30	46	258,565	345,146	710,537
10	Yobe	400,682	19	75,729	7.39	27	32	50	143,826	191,270	390,098
11	Ebonyi	416,196	25	102,759	7.06	39	46	69	189,857	249,413	493,343
12	Enugu	608,334	25	150,198	7.06	39	46	69	277,505	364,554	721,096
13	Cross River	547,224	29	159,954	6.80	40	47	68	289,196	376,273	726,572
14	Nassarawa	345,773	31	108,607	6.68	43	49	71	194,326	251,669	480,372
15	Plateau	602,456	31	189,231	6.68	43	49	71	338,583	438,495	836,973
16	Kano	1,663,337	32	538,256	6.62	44	51	72	958,709	1,239,106	2,353,218
17	Borno	725,970	34	248,935	6.51	46	53	75	439,310	565,469	1,062,926
18	Adamawa	601,745	35	210,069	6.48	47	54	76	369,621	475,140	890,189
19	Akwa-Ibom	689,703	36	246,638	6.43	47	55	77	432,200	554,578	1,034,327
20	Niger	693,215	42	288,932	6.10	54	61	83	492,124	623,542	1,126,789
21	Kaduna	1,126,632	43	479,607	6.05	55	62	84	813,402	1,028,655	1,850,037
22	Kogi	614,828	50	309,996	5.60	62	70	90	506,218	629,499	1,085,526
23	Bayelsa	321,102	52	167,069	5.51	64	71	91	270,706	335,469	573,511
24	Rivers	912,575	52	474,813	5.51	64	71	91	769,348	953,408	1,629,926
25	Abia	547,888	52	287,587	5.48	53	58	75	464,946	575,611	981,623
26	Imo	711,551	61	433,833	5.00	72	78	96	673,132	818,258	1,333,107
27	Delta	741,568	62	462,294	4.92	73	79	96	712,530	863,590	1,396,589
28	Edo	621,770	63	388,855	4.91	73	79	96	598,757	725,382	1,171,814
29	Kwara	443,257	68	299,509	4.63	77	83	98	450,021	539,288	847,795
30	Osun	617,802	71	436,539	4.45	80	85	99	646,094	769,082	1,188,952
31	Abuja	106,397	71	75,436	4.44	80	85	99	111,517	132,676	204,841
32	Ogun	668,065	72	483,813	4.35	81	86	99	709,928	841,842	1,289,056
33	Ekiti	439,644	72	318,698	4.35	81	86	99	467,484	554,265	848,386
34	Ondo	643,968	72	466,812	4.35	81	86	99	684,748	811,860	1,242,673
35	Anambra	800,534	78	621,295	4.06	85	88	99	888,786	1,042,097	1,551,263
36	Oyo	988,395	78	771,541	4.03	85	89	100	1,101,286	1,289,986	1,915,566
37	Lagos	1,638,903	96	1,577,936	3.00	96	96	97	2,058,848	2,317,252	3,114,193
	Total Nigeria	25,475,400	44	11,263,648	6.04	53	58	75	17,776,220	21,870,672	37,168,770

(Source: NERC Archive, 2014).

APPENDIX 3

Appendix 3a Table: Compared and Analysed Pros and Cons of Selected Methods

Methods	Advantages	Disadvantages
Quantitative	• Reliable and valid because they employ prescribed procedures. • Eliminate bias in a study because they involve many cases and few variables that prevent researchers from using subjects known to them. • Enable researchers to correlate independent and dependent variables to determine causality within a study framework. • Allow researchers to conduct a broad survey that involves many subjects and generalization of findings. • Yield accurate results.	• Rigid and less detail on the motivation, attitudes and behavior of study subjects.
Qualitative	• Explore wide array of dimensions of social world including texture and weave of everyday life • Understandings, experiences and imaginings of research participants.	• Involve small sample size • undermine opportunities to draw useful generalizations for broad policy recommendations upon findings (Dale Brubaker, 2008). • Non-consistent conclusions. • Data gathering and analysis often time consuming and expensive. • Requires high level of experience from researcher to obtain targeted

		information from the respondent.
Questionnaire	• Anonymously completed and less expensive. • Easily distributed and data compared and analysed.	• Inadequate feedback. • High possibility of low return. • Participants' response can be biased and the response may not reflect the research topic.
Interview	• Researcher or interviewer may develop good relationship with the interviewee. • Can cover a wide range of issues relating to the topic. • It provides high response rate.	• Difficult to remember all the information collected. • Costly to administer and transcribe the recorded information. • Interviewer may be bias for not understanding the interviewee responses.
Small Focus Group	• Useful when participants are more willing to discuss the topic in front of peers. • Participants' answers can inform others. • Group ideas generated may not be available in one-one interviews. • Researcher acts as facilitator/moderator but level of moderation depends on participants and Ethical considerations with regard to confidentiality (Glesne, 2006).	• Time constraints or accessibility an issue for a researcher. • Generally difficult to record and moderate and tape recording necessary with a separate note taker neither a researcher nor a participant.
Case Studies	• Provide detailed information about	• Difficult and time consuming to collect data and analyse.

	research topic, processes and results. • Powerful method of data gathering and reflective.	• Require patient.
Observation	• Event can be monitored as they occurs. • More detailed information can be gathered from data source.	• Behaviour from scenario may not represent the topic research.

(Source: Cathy Gibbons and Workshop, 2014).

Appendix 3b Table: Solar PV System Pros and Cons

ADVANTAGES	DISADVANTAGES
Renewable	Expensive
Abundant	Intermittent
Sustainable	Energy storage expensive
Environmentally Friendly	Associated with little pollution at manufacturing stage
Good Availability	Exotic materials at manufacturing stage
Reduces Electricity Costs	Requires space mainly for solar farm
Many Applications	
Shared Solar	
Silent	
Financial Support from Government/State	
Low Maintenance	
Technology is Improving	

(Source: Mathias Aarre, 2014).

Appendix 3c Table: RET Screen Software Compared and Analyzed Pros and Cons

RET Screen Model	Advantages	Disadvantages
RET Screen Software	• It evaluates energy production, life-cycle costs and greenhouse gas emission reductions for various types of energy efficient including renewable energy technologies. • It speeds up project analysis and test results are without weakness. • It is a great approach for decision making by the policy makers in making bold and confident decisions. • It also includes product, cost and weather databases as a detailed online user manual and free access. • The product Database provides users access to contact information for more than 1,000 clean energy technology manufacturers around the globe including direct websites and internet links within RET Screen software and this website (marketplace).	• Result of the simulation can be difficult to interpret. • The simulation modelling and analysis can be time consuming.

	• It currently have modules for evaluating wind energy, small hydro, solar PVs, combined heat and power, biomass heating, solar air heating, water heating, passive solar heating, ground-source heat pumps and refrigeration. www.retscree.net	

APPENDIX 4

Research Topic

Implementation and application of Solar Energy in Nigeria

Fieldwork

Fieldwork is an educational research process undertaken to administer questionnaire to participants in the case study. The questionnaire method for collection of data from the case study.

Methodology

Design questionnaire administered to participants during fieldwork used to assess installed PV system roof-top buildings or ground-mounted is sub-divided into three sections: Section 1: the general question for answer from participants by filling through ticking/circle the appropriate option on the dash spaces. Section 2: to address technical, economic and policy aspects based on people's perception about the subject matter. Section 3: compares the existing conventional energy plant and the installed solar PV system for electricity based on generation, cost and emissions. Section 2 and 3 focus mainly on group of participants with understanding of PV operation for feedback on the dash spaces.

Please kindly answer all the questions. The responses will be anonymous and strictly confidential.

Section One: General Question (Please tick/circle the appropriate box)

1. What is your sex? Male ☐ Female ☐
2. What is your age? 18 – 25 ☐ 26 – 40 ☐ 41 – 59 ☐ 60 and above ☐

3. What is your Occupation? Government staff…… Student…… NGOs…… Self-employed……. Others…… (Please specify)

4. Do you agree to the PV system installation in homes than commercial areas? Please specify Yes ☐ No ☐
5. Do you prefer PV system to the existing conventional energy? Yes ☐ No ☐
6. Do you think PV will help reduce your electricity consumption from the existing energy? Please specify Yes ☐ No ☐
7. Do you use the following items powered by installed PV system? (Please circle or tick)

	Home	Office
Radio	Yes No	Yes No
TV set	Yes No	Yes No
Video cassette recorder	Yes No	Yes No
Telephone	Yes No	Yes No
Refrigerator	Yes No	Yes No
Washing machine	Yes No	Yes No
Microwave	Yes No	Yes No
Lighting	Yes No	Yes No
Computer	Yes No	Yes No
Fan	Yes No	Yes No

Others (please specify)…….

8. What time of the day do you use these appliances? Morning ☐ Afternoon ☐ Night ☐ None of the above ☐
9. Which of the above appliances do you use more often throughout the day? (Please specify).....
10. What is the PV capacity (kW) installed in your building?
    <5 ☐ >5-20 ☐ >20-50 ☐ >50 and above ☐
11. Are there suppliers of PV system including cables, inverter and battery in Nigeria? Yes ☐ No ☐ if yes please specify……
12. Do you agree solar PV system depend on public funding? Yes ☐ No ☐ Please specify if

Yes……

……

13. Do you agree solar PV system depend both on public and private funding? Yes ☐ No☐
14. Do you think the citizens will profit more from use of solar energy in Nigeria? Yes ☐ No ☐
15. Would you be happy seeing renewable energy implemented and applied in Nigeria? Yes ☐ No ☐
16. Would you prefer solar energy use to other renewable energy sources in Nigeria? Yes ☐ No ☐ please specify if…….

yes……

Where would you want the PV system installed? (Please specify by ticking or circle)

17. Roof-top Yes No

Ground-mounted Yes No

Garden Yes No

Garage Yes No

18. What kind of application would you prefer most? (Please specify by tick or circle)

Standalone PV system with battery for storage Yes No

Grid-Connected PV system Yes No

19. How would you rate the overall quality and capacity of the PV system installed? (Please specify by tick) Poor performance ☐ Good performance ☐ Uncertain☐ Bad ☐ Very Bad ☐
20. Do you think there would be market for renewable energy including solar PV system in Nigeria? Yes ☐ No ☐Please specify if……..

Yes……

21. Is solar energy viable resource for investment in Nigeria? Yes ☐ No ☐

22. Is the country vulnerable to climate change to warrant solar application? Yes ☐ No ☐ Please specify if……yes……

23. Does the use of solar energy help solve the long term electricity shortage problem in Nigeria? Yes ☐ No ☐ Please specify if…….

yes……

24. Are the existing power generators causing inconveniences and environmental threats? Yes ☐ No ☐

25. Is it cheap to use PV module/panel in Nigeria? Yes ☐ No ☐

26. What is the power output generated from installed PV system for the following applications? (Please specify by filling the box below) Household ☐ Industry ☐ Commercial ☐ Institution ☐ Community ☐

27. What is the efficiency (%) used for the following systems? (Please specify by filling the boxes below)

	Stand-alone	Grid-connected
Monocrystalline	☐	☐
Polycrystalline	☐	☐
Amorphous	☐	☐
Inverter	☐	☐
Battery	☐	☐

28. Is there any insurance cover for PV system in Nigeria? Yes ☐ No ☐ if yes please specify……

29. Does the use of the PV system have any effect yet on your property tax in Nigeria? Yes ☐ No ☐ if yes please specify……

30. Do the manufacturers provide warranty on the PV system used in Nigeria? Yes ☐ No ☐

    if yes please specify years……..

31. Does your home have any of the following alternative sources of energy?

    Biomass Yes ☐ No ☐

    Hydropower Yes ☐ No ☐

    Solar electricity Yes ☐ No ☐

    Wind turbine Yes ☐ No ☐

32. Currently, which renewable energy sources you do not have and considered installing now? Please specify……

33. What do you think are the reasons properties have not yet installed a photovoltaic system? Please tick below relevant (1 = Huge influence 5 = No influence)

    Availability of energy in home 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

    Cost of installing a PV system 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

    Period too long to recover costs of installation 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

    Maintenance costs 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

    Little knowledge 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

    There are better alternatives 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

    Other (Please specify……

34. What factors would persuade you to install a photovoltaic system? Please tick below relevant option (1 = Huge influence 5 = No influence)

    Free installation of PV system 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

    Government subsidy towards cost of installing PV system 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

    Local public buildings installed with PV system 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

    Reduction of electricity costs 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

    Case studies from satisfied PV system customers 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

    Reduction in carbon emissions 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

More information 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

Other (Please specify……

35. Does government set targets for CO_2 reduction by 2020, 2030 and 2050 influence you to reduce carbon emissions by: Please tick (1 = Huge influence 5 = No influence)

    Adopting renewable energy sources 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

    Adopting solar energy source 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

36. Are you in any way aware that government supports the use of a PV system in Nigeria by:

    Making homeowners or generators to sell extra electricity Yes ☐ No ☐

    Generated from a PV system to the National-grid

    Pay generators for every kilowatt hour (kWh) of

    Electricity generated using a PV system Yes ☐ No ☐

Please kindly answer the following questions by filling the dash spaces

37. What are the home building measures with total ground floor area (i.e. gross floor area in m^2) in Nigeria? Please specify.....

38. What is the PV modules space on the roof of a building (i.e. Area of each module m^2) in Nigeria? Please specify……

39. What is the monthly power generated (kWh) from the installed PV system in Nigeria? Please specify……

40. What is the annual power generated (kWh) from the installed PV system in Nigeria? Please specify……

41. What is the peak power output from PV system generation (W)? Please specify the average daily output at peak power hour……

42. What is the total power required or consumed daily/monthly/yearly in Nigeria? Please specify……
43. Is there PV electricity sold to the National grid? Yes…….. No……. If yes please specify the rate in N/kWh……
44. What is the electricity purchase price in N/kWh? Please specify…….
45. What is the discount rate if sold to the grid? Please specify the percentage rate……
46. What is the capital cost of the PV modules/panels (N/m^2) used during and after the pilot projects in Nigeria? Please specify……
47. What is the current unit price of PV panel in Nigeria now? Please specify……
48. What is the cost of the following PV electrical materials used (N/m^2) and after the pilot project in Nigeria? Please specify for wiring……..
    Inverter……
    Control……Battery……
49. What are the system losses? Please specify in percentage the cabling……inverter……
    battery……
50. What is the cost of Installation……..O&M……Decommissioning
51. What is the percentage cost for minor repairs? Please specify……
52. What is the percentage cost for major replacement? Please specify……
53. What is the expected life-time of PV system? ……please also specify the appraisal

period……. payback period……

54. Is there any savings or net savings per day/month/year? Yes……..No……if yes please specify…….
55. What the best location hours for PV performance in Sahelian zone (Sokoto) of Nigeria? Please specify……
56. What best location hours for PV performance in Coastal zone (Lagos/Port-Harcourt) of Nigeria? Please specify……..
57. What best location hours for PV performance in Guinea-Savannah zone (Ibadan) of Nigeria? Please specify……..
58. What is the best location hours for PV performance in Midland zone (Abuja) of Nigeria? Please specify……
59. What is the best orientation for the performance in Abuja……Lagos…… ……..Ibadan……..Sokoto……
60. What is the tilt angle for installed PV system in Nigeria? Please specify……
61. Can you mention the most suitable sites for PV system in Nigeria? Please specify……
62. Are there any clear policy, investment and tax for the use of solar PV in generation? Yes……No……if yes Please specify……
63. Are there any other comments you wish to add relevant to the study? Please do.....

Section Two

Technical

1. What is the average conversion efficiency of PV system from DC to AC power output in Nigeria? (Please specify).....
2. What is the conversion efficiency of a stand-alone inverter (Please specify……an d grid-connected inverter…….
3. What PV module specification from the manufacturers is used in Nigeria? (Please specify……
4. Under standard testing condition (STC) what is the manufacturer's specification for PV panel efficiency? (Please specify)……..
5. What do you think can be used to improve the efficiency of the PV cells for use in Nigeria? (Please specify).....
6. How can solar energy be stored for night use? (Please specify).....
7. What is the energy balance in stand-alone operation? Please specify……
8. What are the technical challenges for solar energy development in Nigeria? (Please specify).....
.
9. Is there any proven technology that has been developed for large-scale disposal for solar PV systems in Nigeria? (Yes…….. No……if yes, please specify……
10. How are operational and technical issues addressed to ensure energy supply is continuous in Nigeria? (Please specify)…….

11. Is there any accidental damage or component failures to the installed PV system in Nigeria? (Yes…… No…… if yes please specify at what location……
12. What major role can solar PV cells play in addressing the problem of insufficient power supply in Nigeria? Please specify……
13. What are the factors (drivers and barriers) influencing the decision of consumers to install solar PV systems in the various sectors of Nigeria? Please specify Drivers……

……Barriers……

Economic

14. Please specify the current market unit price of solar PV modules (N/Wp) in Nigeria? Monocrystalline……Polycrystalline……

……. Amorphous……

Inverter…… ……..

Battery……
15. For solar energy development what are the economic challenges for electricity generation in Nigeria? (Please specify).....
.
16. What are the environmental and social benefits for using solar energy in Nigeria? Please
specify.....
.
17. Why is solar PV cost still more expensive than conventional energy cost? (Please specify).....
.....
18. Would the initial cost of PV installation affect the solar application and implementation in Nigeria? (Please specify).....
.....
..
19. At what time can solar energy be more profitable and competitive in Nigeria? (Please specify.....
.

20. How can the PV external cost be determined in Nigeria? (Please specify).....
.
21. What are the main drivers for solar power deployment and supply? (Please specify).....
.
22. How can solar energy be realised in a large scale and what is required in achieving its development? Please specify).....
23. What can lower the manufacturing cost to make solar PV more economically competitive in Nigeria? (Please specify).....
24. Are there financial institutions into loan financing for purchase of PV system in Nigeria? Please specify……
25. Are there green power marketing companies in Nigeria? Please specify
26. Does cost reduction encourage PV system adoption in homes more than commercial places in Nigeria? Please specify……

Policy

27. Would there be any negative effect from solar PV technology to affect the environmental sustainability in the future? (Yes…… No…… if yes, please specify……
28. Do you see solar PV system as the best choice to address the current environmental energy issue such as fossil fuel and GHG emissions? (Yes…….. No……
29. Does silicon use more prone to emission than aluminium? Yes..... No……

30. Judging from the environmental externalities do you think solar PV systems can compete favourably with fossil fuel based power generation? (Yes…… No……..if yes please specify……
31. What could be the energy policy barrier to solar application in Nigeria? (Please specify.....
32. Please specify what strategy to meet energy demand and energy policy goal in Nigeria……
33. Is there any subsidy available for the PV installation? Yes……. No……if yes please
    specify……
34. Is there any renewable energy strategy used so far like feed in tariff? Yes……. No……..if yes please specify……..
35. Is there incentive employed at both Federal and State level during and after the pilot projects? Please specify…….
36. Does the Renewable Energy Master Plan (REMP) for the short, medium and long-term measures developed by Energy Commission of Nigeria (ECN) for solving energy crisis approved in Nigeria? Yes……No……..if not please specify the reason for the
    delay……
37. Can government partnership with private sectors help bridge the gap in terms of power supply shortage and encourage solar energy implementation and application in Nigeria? Yes…… No……. if yes please specify……
38. What effort has been made for the future development of renewable power resources and solar use in generating electricity in Nigeria? (Please specify).....

39. What are the expected government's plans in addressing power supply to achieve renewable energy goal in Nigeria? (Please specify).....
40. What are reasons for the shortage in electric power supply in Nigeria? (Please specify).....
41. What major factors could prevent solar energy implementation plan in Nigeria? (Please specify).....
.
42. Why is solar energy so unique than other renewable energy resources for use in Nigeria? (Please specify)……
43. How do leadership traits impact solar energy implementation in Nigeria? (Please specify).....
.
44. Do solar energy implementation, application and investment be achievable soon in Nigeria? Yes…… No…… if yes please specify how soon……
45. What prompt PV technology to become a priority to the governments and many stakeholders in Nigeria (Please specify).....
.
46. What effort do the regulators make to promote renewable energy sources in terms of investment in Nigeria? (Please specify).....
47. How can renewable source be integrated into the conventional regulatory approaches in Nigeria? (Please specify).....
48. What will drive the stimulation of renewable energy growth in Nigeria? (Please specify).....
49. Is there any loan for generating electricity with installed solar PV system in Nigeria? Yes…….. No…… if yes please specify the financial institution……how

much…..with percentage……
……

50. Is there energy act in Nigeria? Yes……..No……if yes please specify them……
51. What efforts has Nigerian government made so far to eliminate obstacles hindering private sector investment to solar energy development by using PV system in Nigeria? Please specify……
52. What are government provisions to increasing private sector participation thereby encouraging renewable energy growth in Nigeria? Please specify……
53. How do different stakeholder groups perceive solar energy in Nigeria? Please specify……
54. Are there policies for hazardous waste control law in Nigeria? Please specify……
55. Are there any bills on installation targets tax incentives/debates addressing manufacturing or end of life hazards of PV system in Nigeria? Please specify……
56. Are there any existing government subsidies to the PV system adoption in Nigeria? Yes……..No……if yes please specify……
57. Is there any environmental regulations so far implemented in Nigeria? Please specify……
58. Have there been any environmental law reforms particularly in the energy or electricity sectors in Nigeria? Please specify……
59. Are there incentives for solar energy panels in Nigeria? Please specify……

60. Is individual allowed to generate their own power through PV installation in Nigeria? Please specify……
61. Is there climate change levy as a regulation in Nigeria? Please specify……

Section Three:

1. How much is the energy consumed or used in kWh in Nigeria from the existing power plants .....and from PV system
2. Existing power plants……..
3. Please specify the annual net electricity generated from the solar PV system yearly ..... and the existing electricity generated……
4. What is the electricity generation rate for the existing turbines (NGN/Wp) Monthly?…….. Yearly…… and from solar PV system Monthly…….. Yearly……
5. What is the average annual electricity generated from solar PV system? For Household consumption……. Industry…….. Commercial consumption…….. and the existing power plants from Household……. Industry……. Commercial consumption……
6. Please specify the price paid from the PV electricity.....and from the existing electricity in Naira & Kobo (NGN/kWh)…….

7. What are the initial capital costs for installing Solar PV system? …….. Conventional power turbines for Oil plant…… for Gas plant……..…….....and hydropower……
8. Is there payback cost analysis for the existing turbines Yes…… No……and Solar PV system Yes…… No……
9. What is the existing turbines construction costs for Operating?……..Decommissioning costs…… And solar PV system construction……..Operating…… and Decommissioning costs……
10. At what interest rate is electricity cost from existing turbines in Nigeria (NGN/Wp)?…….. and solar PV system……..
11. What is the life-cycle cost of electricity generation from the oil-fired turbine/plant……gas-fired plant……and hydropower plant……..based on the current market price per tonne in Naira kWh (equivalent to US$)…….
12. What is the current market price of fuel importation per tonne in Naira (equivalent to US$)?.....
13. What is the electricity export rate (N or $/MWh) for the installed PV system? (Please specify).....
14. What is the electricity export rate (N or $/MWh) for the existing or traditional system? (Please
    specify).....
15. What is the total annual GHG emission from solar PV system electricity based on (kWh/year) in Nigeria ……and the primary energy use…….year…….

16. What emissions by including Transmission & Distribution losses per g-CO_2/kWh from installed PV system?……Oil-fired turbine……Gas-fired turbine……
17. Is there release of emissions (GHGs such as Co_2, CH_4 & N_2O) during the life-cycle of the existing turbines in g-CO_2/kWh when T&D losses are included? (Yes…… No…… and from the PV system (Yes…… No……if yes please specify……

APPENDIX 5

Appendix 5a Table: Suntech PV System Specifications



Electrical Characteristics

STC	STP250S-20/Wd	STP245S-20/Wd	STP240S-20/Wd
Optimum Operating Voltage (Vmp)	30.7 V	30.5 V	30.2 V
Optimum Operating Current (Imp)	8.15 A	8.04 A	7.95 A
Open Circuit Voltage (Voc)	37.4 V	37.3 V	37.2 V
Short Circuit Current (Isc)	8.63 A	8.52 A	8.43 A
Maximum Power at STC (Pmax)	250 W	245 W	240 W
Module Efficiency	15.4%	15.1%	14.8%
Operating Module Temperature	-40 °C to +85 °C		
Maximum System Voltage	1000 V DC (IEC)		
Maximum Series Fuse Rating	20 A		
Power Tolerance	0/+5 %		

STC: Irradiance 1000 W/m², module temperature 25 °C, AM=1.5;
Best in Class AAA solar simulator (IEC 60904-9) used, power measurement uncertainty is within +/- 3%

NOCT	STP250S-20/Wd	STP245S-20/Wd	STP240S-20/Wd
Maximum Power at NOCT (Pmax)	183 W	180 W	177 W
Optimum Operating Voltage (Vmp)	27.9 V	27.8 V	27.7 V
Optimum Operating Current (Imp)	6.55 A	6.46 A	6.39 A
Open Circuit Voltage (Voc)	34.4 V	34.3 V	34.2 V
Short Circuit Current (Isc)	6.96 A	6.89 A	6.81 A

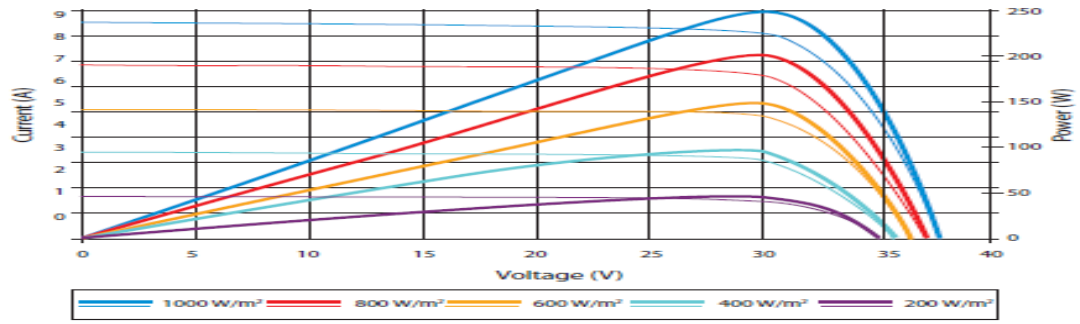
Temperature Characteristics

Nominal Operating Cell Temperature (**NOCT**)	45±2°C
Temperature Coefficient of Pmax	-0.45 %/°C
Temperature Coefficient of Voc	-0.34 %/°C
Temperature Coefficient of Isc	0.050 %/°C

Mechanical Characteristics

Solar Cell	Monocrystalline silicon 156 x 156 mm (6 inches)
No. of Cells	60 (6 x 10)
Dimensions	1640 x 992 x 50mm (64.6 x 39.1 x 2.0 inches)
Weight	19.1 kgs (42.1 lbs.)
Front Glass	3.2 mm (0.13 inches) tempered glass
Frame	Anodized aluminium alloy
Junction Box	IP67 rated (3 bypass diodes)
Output Cables	TUV (2Pfg1169:2007), UL 4703, UL44
	4.0 mm² (0.006 inches²), symmetrical lengths (-) 1000mm (39.4 inches) and (+) 1000 mm (39.4 inches)
Connectors	MC4 connectors

Current-Voltage & Power-Voltage Curve (250S-20)



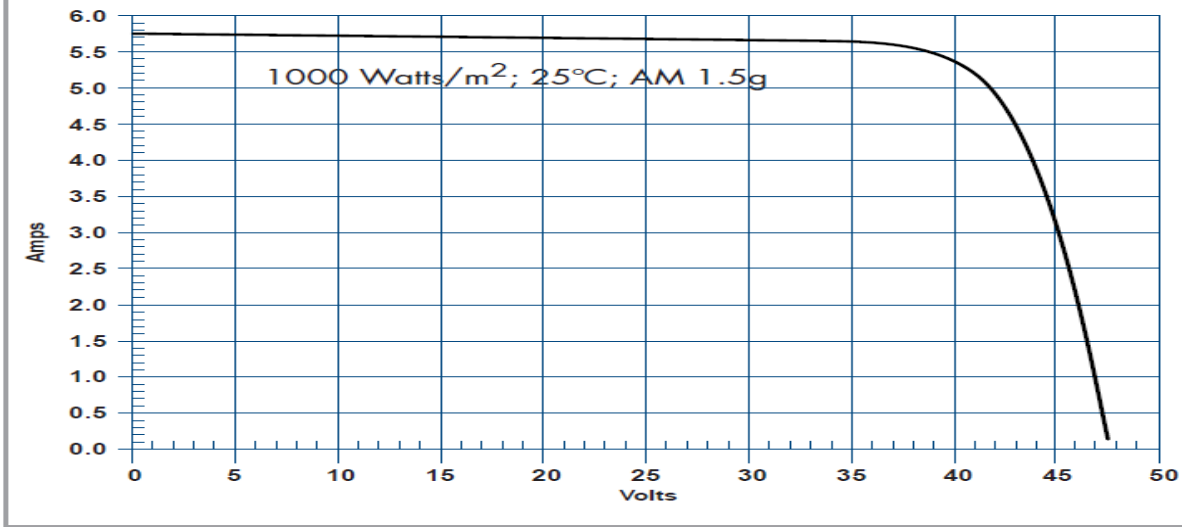
Excellent performance under weak light conditions: at an irradiation intensity of 200 W/m² (AM 1.5, 25 °C), 95.5% or higher of the STC efficiency (1000 W/m²) is achieved

Appendix 5b Table: Sun power PV Panel Specifications



ELECTRICAL CHARACTERISTICS AT STANDARD TEST CONDITIONS (STC) STC is defined as: irradiance of 1000W/m², spectrum AM 1.5g and cell temperature of 25°C		
Peak Power[1,2]	P_{max}	210W
Rated Voltage	V_{mp}	40.0V
Rated Current	I_{mp}	5.25A
Open Circuit Voltage	V_{oc}	47.7V
Short Circuit Current	I_{sc}	5.75A
Series Fuse Rating		15A
Maximum System Voltage		600V (UL)
		1000V (IEC)
Temperature Coefficients	Power	-0.38%/°C
	Voltage (V_{oc})	-136.8mV/°C
	Current (I_{sc})	3.5mA/°C
Module Efficiency		16.9%
Peak Power per Unit Area		15.7W/sq.ft. ; 169W/m²
PTC Rating		193.7W
MECHANICAL SPECIFICATIONS		
Length		61.39 in x 31.42 in [1559 mm x 798mm]
Thickness, including junction box		1.81 in [46 mm]
Weight		33 lbs [15 kg]

IV CURVE


1000 Watts/m2; 25°C; AM 1.5g
Amps
Volts
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
5
10
15
20
25
30
35
40
45
50

APPENDIX 6

Appendix 6 Table: 33kW Capacity with Retscreen Climate data, the Financial viability and Cumulative cash-flow

	Unit	Climate data location	Project location
Latitude	°N	9.2	9.2
Longitude	°E	7.2	7.2
Elevation	m	573	573
Heating design temperature	°C	18.3	
Cooling design temperature	°C	32.8	
Earth temperature amplitude	°C	13.6	

Month	Air temperature	Relative humidity	Daily solar radiation - horizontal	Atmospheric pressure	Wind speed	Earth temperature	Heating degree-days	Cooling degree-days
	°C	%	kWh/m²/d	kPa	m/s	°C	°C-d	°C-d
January	25.6	25.0%	5.88	95.6	2.4	28.0	0	485
February	26.7	29.9%	6.09	95.6	2.3	29.4	0	468
March	26.6	56.0%	6.27	95.5	2.6	28.9	0	515
April	25.5	76.8%	6.06	95.5	2.5	26.8	0	464
May	24.9	82.0%	5.58	95.6	2.5	25.8	0	462
June	24.0	84.6%	5.06	95.8	2.3	24.8	0	420
July	23.2	85.6%	4.44	95.8	2.5	23.8	0	408
August	23.0	85.6%	4.19	95.9	2.5	23.7	0	403
September	23.5	84.5%	4.73	95.8	2.4	24.3	0	406
October	23.8	80.0%	5.31	95.7	2.0	24.6	0	427
November	24.5	56.2%	5.98	95.6	2.4	25.5	0	434
December	25.3	30.6%	5.86	95.6	2.2	27.0	0	474
Annual	24.7	64.9%	5.45	95.7	2.4	26.0	0	5,365
Measured at					10.0	0.0		

Project costs and savings/income summary			
Initial costs			
Power system		NGN	0
Balance of system & misc.		NGN	0
Total initial costs	**0.0%**	**NGN**	**0**
Incentives and grants		NGN	14,828,000
Annual costs and debt payments			
O&M		NGN	0
Fuel cost - proposed case		NGN	0
Total annual costs		**NGN**	**0**
Periodic costs (credits)			
Annual savings and income			
Fuel cost - base case		NGN	0
Electricity export income		NGN	3,259
Total annual savings and income		**NGN**	**3,259**

Yearly cash flows

Year #	Pre-tax NGN	After-tax NGN	Cumulative NGN
0	14,828,000	14,828,000	14,828,000
1	3,259	3,259	14,831,259
2	3,259	3,259	14,834,517
3	3,259	3,259	14,837,776
4	3,259	3,259	14,841,034
5	3,259	3,259	14,844,293
6	3,259	3,259	14,847,551
7	3,259	3,259	14,850,810
8	3,259	3,259	14,854,068
9	3,259	3,259	14,857,327
10	3,259	3,259	14,860,585
11	3,259	3,259	14,863,844
12	3,259	3,259	14,867,102
13	3,259	3,259	14,870,361
14	3,259	3,259	14,873,619
15	3,259	3,259	14,876,878
16	3,259	3,259	14,880,136
17	3,259	3,259	14,883,395
18	3,259	3,259	14,886,654
19	3,259	3,259	14,889,912
20	3,259	3,259	14,893,171
21	3,259	3,259	14,896,429
22	3,259	3,259	14,899,688
23	3,259	3,259	14,902,946
24	3,259	3,259	14,906,205
25	3,259	3,259	14,909,463

Cumulative cash flows graph

