TECHNICAL AND ECONOMIC FEASIBILITY OF UTILIZING EFFICIENT PHOTOVOLTAIC SYSTEMS TO POWER RURAL HEALTH CENTRES IN THE FEDERAL CAPITAL TERRITORY (FCT) OF NIGERIA

By

Jimento Aikhuele

A Thesis Presented to

The Faculty of Humboldt State University

In Partial Fulfillment of the Requirements for the Degree

Master of Science in Environmental Systems: Energy, Technology, and Policy

Committee Membership

Dr. Arne Jacobson, Committee Chair

Dr. Charles Chamberlin, Committee Member

Dr. Peter Alstone, Committee Member

Dr. Margaret Lang, Graduate Coordinator

Dr. Rock Braithwaite, Graduate Dean

July 2018

ABSTRACT

TECHNICAL AND ECONOMIC FEASIBILITY OF UTILIZING EFFICIENT PHOTOVOLTAIC SYSTEMS TO POWER RURAL HEALTH CENTRES IN THE FEDERAL CAPITAL TERRITORY (FCT) OF NIGERIA

Jimento Aikhuele

Delivering reliable electricity to rural health centres in Nigeria has long been a challenge. This study presents a technical and economic feasibility analysis involving a comparison between efficient solar photovoltaic systems, small gasoline generators, and the (unreliable) grid as power supply sources for rural health centres in Nigeria. Twenty-eight rural health centres were visited in the Federal Capital Territory (FCT) in Nigeria whereupon an assessment was taken to know their energy needs and how these needs are met. Ibwa 1 Primary Health Centre (PHC), one of the health centres audited, was used as a case study for technical design and economic analysis.

Two scenarios were considered for the design and economic analysis for the Ibwa 1 Primary Health Centre. A lead acid deep cycle battery was used in Scenario 1 for the system sizing, and a lithium-iron phosphate battery was used for Scenario 2. The daily energy demand for both scenarios was reduced by 52% using demand-side energy efficiency measures such as efficient ceiling fans and LED light bulbs.

Based on the economic analysis from the results, Scenario 1 is more economically viable. The results reveal an initial cost of ₦13,828,000 ($38,411) and ₦35,949,160

($97,081) for Scenarios 1 and 2 respectively, and an annual operation and maintenance cost of ₦342,360 ($951) for Scenario 1 and 2 respectively.

The investment model developed for an independent investor, reveals that 20% and 55%margin on the outlay cost must be reached for the investor to break even within a 10-year repayment period for Scenarios 1 and 2 respectively. Given the outcomes of the two scenarios, an estimated 19 tCO_2e GHGs would be avoided per year from Ibwa 1 primary health centre.

ACKNOWLEDGEMENTS

I humbly wish to express my gratitude to God Almighty for keeping me alive, in good health, and sound mind during this project. My sincere gratitude goes to Dr. Arne Jacobson, Dr. Charles Chamberlin, and Dr. Peter Alstone for their indefatigable support and guidance during my studies and research.

I appreciate Dr. Jacobson for his counsel and the fatherly figure played throughout my degree program. I will always remember the smiles on his face and his diverse approach of proffering solutions to a problem. I am happy I took several hands-on courses with Dr. Jacobson which prepared me towards the success of my thesis. The skills developed will enable me to make a great impact to the outside world.

I am grateful to Dr. Chamberlin for his support, contributions, and review towards my thesis. I will always remember his advice, suggestions and books he lent me when I was preparing for my thesis fieldwork. I am glad I took a course he taught.

My honest appreciation also goes to Dr. Peter Alstone for his great contributions and review towards the success of my thesis. I remember his words during preparation for my thesis fieldwork, he said to me “What is going on? I heard you are having challenges getting response from health centres you are to audit for your fieldwork”. This added fire to my pursuit to come up with results. I am also grateful I took courses he taught which was very relevant to my thesis as well.

I say a big thank you to the Schatz Energy Research Center and the World Bank for sponsoring my thesis fieldwork collecting data from Nigeria. I appreciate all staff members of the Schatz Energy Research Center, USA.

My sincere appreciation goes to Dr. Steve Hackett and Dr. Kevin Fingerman at the Humboldt State University, USA, and Dr. Joseph Dioha of the Energy Commission of Nigeria. I also appreciate Meg Harper and Kristen Radecsky for their assistance during my thesis. I thank Kimberly Thorpe and Maia Cheli-Colando for their support during my stay at SERC. Meg, Kristen, and Kimberly: I will always remember the walk in the redwood forest picking berries. Kimberly, thank you for making me feel at home. I would want to express appreciation for Jeff Harkness, Derek Ichien, Keivan Branson, Michael Avcollie and other ETaP students. I also appreciate my few friends, Terry Alexander and Onomewerike Okumo.

I appreciate Tom and Nancy Sheen and all members of Christ the King Catholic Church (Mckinleyville, USA) for their encouragement and support during my stay in their community.

I appreciate with tears in my eyes Late Mrs. Susan Omagbemi (Mother in law) for her support and for being instrumental to my coming to the Humboldt State University to study. My appreciation also goes to Mr. Richmond Omagbemi for his encouragement.

I say a big thank you to Mrs. Justina Aikhuele (my mother), Mr. Alfred Aikhuele (father), Mrs. Uwaye Ideh (sister), Mr. Usi Aikhuele(brother) and Dr. Osemen Aikhuele (brother) who supported me throughout my studies and played a major role during my thesis fieldwork.

Finally, my profound appreciation goes to the most important people in my life, Mrs. Alero Aikhuele (Wife) and Gibrian Aikhuele (Son) for being there throughout my studies. Alero, my love, my confidant, my sister, and my friend. I appreciate you for your support and patience throughout my studies.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF APPENDIX TABLES

LIST OF APPENDIX FIGURES

ABBREVIATIONS

The abbreviations below were used in the thesis and may be found useful to readers.

AFDB	Africa Development Bank
AMAC	Abuja Municipal Area Council
ANC	Antenatal Care
BP	British Petroleum
CHC	Comprehensive Health Centre
FCT	Federal Capital Territory
GHG	Green House Gas
HP	Health Post
IEA	International Energy Agency
IIM	Independent Investors Model
KWH	Kilowatt Hours
LED	Light Emitting Diode
LGA	Local Government Area
MTCOE	Metric Tons of Carbon-dioxide Equivalent
MW	Megawatts
NPHCDA	National Primary Health Care Development Agency
O & M	Operation and Maintenance
PHC	Primary Health Centre
SEforAll	Sustainable Energy for All

UNDP	United Nations Development Programme
UNICEF	United Nations Children's Funds
UN	United Nations
WHO	World Health Organization

INTRODUCTION

The scope of this study is to analyze the energy needs of selected rural health centres in the Federal Capital Territory (FCT), Nigeria, and to use these data to make recommendations related to improving energy access for the health facilities. The work is intended to contribute to knowledge and inform development of a strategy to improve electricity supply and reduce greenhouse gas (GHG) emissions caused by use of fossil fuel (diesel or gasoline generators) at rural health clinics. An important motivation for this effort is the improved maternal and child health care that can occur if energy supply is improved at rural health centres (WHO, 2014).

Energy access continues to be a challenge in developing countries like Nigeria, affecting the lives of millions of people, including women, children, and newborns. While attention in the ongoing campaign of improving energy access is focused on household energy, less attention is given to social services like providing adequate energy in rural health centres. The World Health Organization (WHO), in the “Health of the People” African regional health report, found that in rural areas in Sub-Saharan Africa, only 11% have access to electricity (WHO, 2014). Nigeria, being one of the largest and most populous countries in Africa’s continent, is not an exception to the challenge of lack of energy access. If the health centres in the rural areas are not electrified to create energy and access to modern energy services, the economic and social well-being of women and children is jeopardized (AFDB 2014). The Sustainable Energy for All initiatives on “energy and women health” also sheds the same light that energy is a critical enabler for vital primary health care services, especially during maternal and childbirth emergencies, and that without electricity, mothers in childbirth are particularly at risk (SEforALL, 2017). In this context, the need to improve on energy access and modern energy services especially in rural areas becomes imperative. Therefore, tackling the lack of energy access in rural health centres in Nigeria can help reduce maternal and child/newborn mortality.

Providing solutions to this problem will also align with the Sustainable Energy for All goals on "Energy and Women". The goal is to increase access to, and the effective and sustained use of, energy-dependent health services, with an emphasis on women in low- and middle-income countries (SEforALL, 2017) The United Nations Children's Fund (UNICEF) and National Primary Health Care Development Agency, Nigeria (NPHCDA) also prioritizes the millennium development goal on the reduction of maternal, child, and newborn mortality and improved healthcare delivery (NPHCDA, 2017).

Considerable progress has been made in the health sector worldwide in reducing maternal, child and newborn mortality. Despite the effort made, maternity and child mortality are still a challenge that needs to be tackled. It was estimated that 303,000 women died each year from potentially avoidable problems in pregnancy or childbirth worldwide (WHO, 2015). Africa accounted for more than half of the global burden of maternal mortality, with women in this region having a 1 in 37 chances of dying in pregnancy or childbirth. Nigeria, which constitutes less than 1% of the world's population, accounted for 19% of global maternal deaths and had an estimated maternal mortality ratio of 814 maternal deaths per 100,000 live births in 2015 (WHO, 2015). This makes Nigeria the country with the second highest maternal death rate in the world (Premium Times, 2017). Most of these deaths are preventable if health care facilities are equipped with adequate resources for service delivery.

Reliable energy, which can reduce the challenges associated with service delivery in rural health centres, is inadequate in Nigeria. Despite the abundant primary energy resources in Nigeria, such as oil and gas, coal, and a potential for renewable energy use through sources such as solar, wind, hydro, fuelwood, municipal waste, animal waste, and energy crop and agricultural waste for biomass and biogas, electricity supply is still inadequate. Between 2011 and 2014, Nigeria generated between 3000 and 4500 MWh of electricity for its estimated 170 million people (UNDP, 2017). In 2013 the national electrification status of Nigeria's population was 45% connected to the grid, with only 55% in the urban area and 37% in the rural areas (ECOWAS, 2013). Currently, an estimated 55.6% of Nigeria's 186 million people are connected to the grid, with a reduction in connection rates of 34.4% in rural areas and increase to 83.6% in urban areas population growth (Lighting Africa, 2016). However, most customers that are connected to the grid are under-electrified (Lighting Africa, 2016). Broader and more relaible, access to energy is both a critical element for health care delivery and socio-economic development and well-being.

Furthermore, the Division of Sustainable Development of Economic and Social Affairs of the United Nations stated that energy is inherently linked to economic and social development (UN, 2014). Scaling up access to reliable and affordable modern energy services has proven an essential driver for increased access to electricity and better access are strongly associated with industrial development, increased wealth, and improved human development outcomes. Access to modern energy services can significantly contribute to efforts to eradicate poverty; increase food security; provide access to clean water; improve public health; and enhance education and income generation.

These challenges led the author to define the thesis goal, scope, objectives, and key questions which helped shape this research.

The goal is to contribute useful knowledge to the effort to improve access to modern, efficient, and reliable energy for rural health clinics in Nigeria. To implement the scope and objectives, the author focuses on three key research questions below:

1. What are the electricity needs of rural health clinics in the Federal Capital Territory (FCT) of Nigeria?
2. How are rural health clinics meeting their electricity needs now, and what are the associated challenges?
3. Can solar photovoltaic technology play a role in providing cost-effective and reliable electricity service to rural health clinics in the Federal Capital Territory (FCT)?

Throughout the thesis, the author strived to define and streamline terms that are used in this study. The research paper includes a literature review section, a method section to evaluate key research questions, results and discussion section, and conclusion, and policy recommendations for the delivery of energy to rural health clinics in Nigeria.

LITERATURE REVIEW

This section provides an overview of the demographics of Nigeria, the energy sector, and health care system in Nigeria.

The section provides:

1. a description of energy access and the challenges in Nigeria;
2. the causes of maternal and child mortality in rural health clinics in Nigeria and interventions that have been made to reduce it;
3. a description of the energy needs of rural health clinics in Nigeria, how these needs are met and their challenges, strategies to improve energy access in rural health clinic of Nigeria, and solar photovoltaic systems as a pathway to electrifying rural health clinics in Nigeria.

Demographics of Nigeria

Nigeria lies on the west coast of Africa, and its territorial boundaries are defined by the Republic of Niger to the north, the Republic of Cameroon and Chad on the east, and the Republic of Benin on the west. A summary of Nigeria's demographics is shown in Table 1 below. Figure 1 below also shows the map of Nigeria with its thirty-six (36) states, including the Federal Capital Territory, and its six (6) geopolitical zones.

Table 1. Demographics of Nigeria summarized. Sources: (World Bank, 2016a; Sambo et al., 2010)

Location	West Africa
Size of Nigeria(Area)	Total area = 923,768 sq. km, of which 98.6% (910,771 sq. km) of total area is land
Latitude and Longitude	Latitudes 4º16' to 13º53' north and longitudes 2º40' to 14º41' east.
Population	186 million people
States	36 states including the Federal Capital Territory (FCT)
Geo-political Zones	North West, North East, North Central, South West, South South, and South East
People Living in Rural Area	51.4% of population
Country's GDP	$405.308 billion
Annual GDP growth rate	1.17%
$C0_2$ annual emission per capita	0.546 metric tonnes
Life expectancy	52 years

Figure 1. Thirty-Six States Including the FCT and Six (6) Geopolitical Zones. Source: (National Population Commission of Nigeria, 2013)

The Federal Capital Territory (FCT), which is the area of focus for this study, has a population of approximately 1.4 million people (National Population Commission, Nigeria, 2006); Table 2 below shows the population by Local Government Area (LGA) and sex.

Table 2. Population of the Federal Capital Territory by Local Government Area. Source: (National Population Commission Nigeria, 2006)

Local Government Area (LGA)	Male	Female	Total Both Sexes
Abaji	28,860	29,782	58,642
Abuja Municipal Council (AMAC)	415,951	360,347	776,298
Bawri	115,346	113,928	229,274
Gwagwalada	80,182	78,436	158,618
Kuje	49,420	47,813	97,233
Kwali	43,413	42,761	86,174
Total	733,172	673,067	1,406,239

Overview of Energy Sector in Nigeria.

Nigeria's energy sector has been undergoing a massive transformation over the years, but rural areas still face challenges related to energy access such as energy generation, transmission, and power interruption.

Energy Access Definition

According to the International Energy Agency (IEA), "Energy access is about providing modern energy services to everyone around the world" (IEA, 2018). These services may be access to electricity in health facilities, households, etc.

Electricity Generation in Nigeria

The total installed capacity of the plants currently generating electricity in Nigeria is 7,876 MW and peak load forecast is 8,900 MW (Sambo et-al, 2010). Due to aging life and inadequate maintenance of some of the power plants, the current generating capacity in Nigeria is 6,803 MW with a wheeling capacity of 6,700 MW by the transmission company (Oladeinde, 2017). Despite the wheeling capacity of 6,700 MW, electricity supply is still inadequate considering the country's growing population rate of 2.6% per year (World Bank, 2016).

Nigeria is blessed with abundant natural energy resources, from fossil fuel to renewable energy sources. It is Africa's largest oil producer, and in 2012 Nigeria was the world's fourth-largest exporter of liquefied natural gas (LNG). Moreover, identified reserves of LNG are enormous (GIZ, 2015). Table 3 below shows the fossil fuel resources present in Nigeria.

Table 3. Summary of Fossil Fuel Resources in Nigeria. Source: (BP, 2013)

Items	Oil	Gas	Coal (total recoverable) (Million tons)
Reserves	37.2 billion barrels	5.2 trillion cubic metres	209.4
Production	2417 thousand barrels per day	43.2 billion cubic metres per year	n/a
Years of extraction remaining	42 years	120	n/a

Electricity Generation and Consumption in Nigeria

Figures 2 and 3, below, depict the electricity generation by fuel and consumption in Nigeria from the years 1971 to 2015 and 1980 to 2014, respectively.

Figure 2 below shows electricity generation in GWh per year from 1971 to 2015 in Nigeria from different energy sources

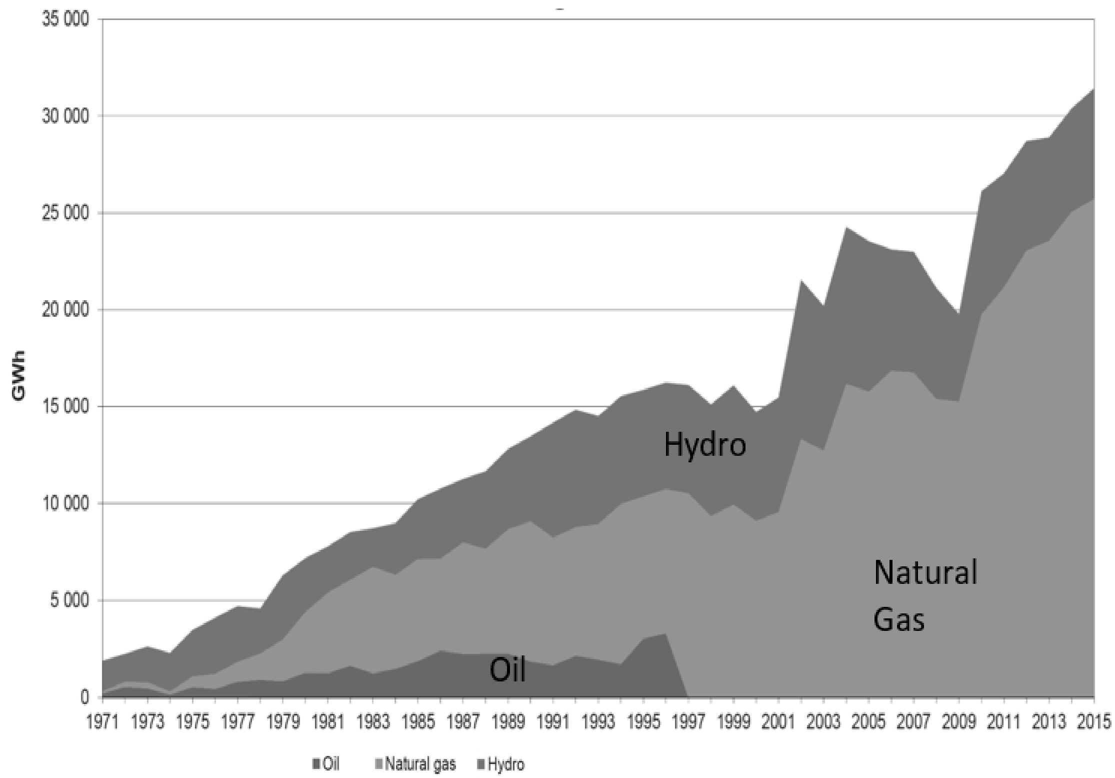

Figure 2.Energy Generation by Fuel in Nigeria (GWh/Year) from 1971-2015.
Source: (IEA, 2017)

Figure 3 below shows the average electricity consumption in Nigeria between 1980 and 2014. The consumption was 11.71 billion kilowatt-hours with a minimum of 4.7 billion kilowatt-hours in 1980, and in 2012 the maximum electricity consumption was 24.78 billion kilowatt-hours. Consumption has been rapidly increasing since 2002.

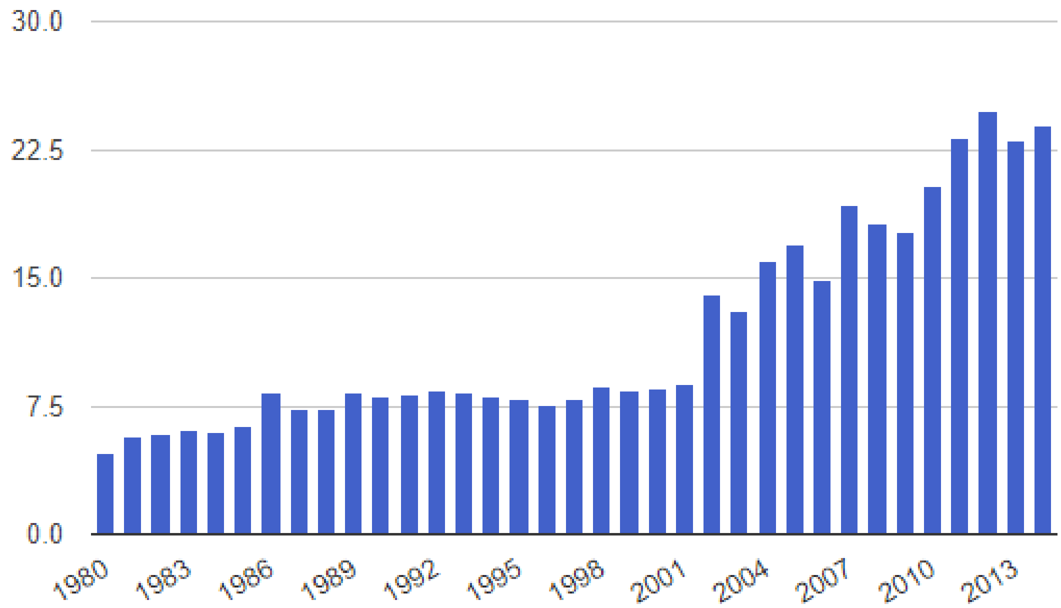

Figure 3. Electricity Consumption in Billion Kilowatt-hours/Year. Source: (EIA, 2017).

Electricity Interruption in Nigeria

Nigeria's energy sector has been undergoing a transformation towards improving electricity supply in the country. The generation and supply are not adequate to serve a growing population of 185 million people and only 45% of the population have connection to the grid. Sufficient and reliable energy is the lifeblood and driver of the modern economy and being without it might be one of the limitations to socio-economic development and economic growth in the country. The unreliability of electricity supply (not guaranteeing 24hours supply daily) has greatly hindered the development of economic activities in Nigeria (Akinlo, 2009).

Renewable Energy Potential in Nigeria

Nigeria is endowed with valuable renewable energy resources, including large and small hydroelectric power resources, solar energy, biomass, wind, and potentials for hydrogen utilization and development of geothermal and ocean energy. Table 4, below, presents estimated renewable energy resources in Nigeria.

Table 4. Renewable Energy Sources in Nigeria. Source: (Energy Commission of Nigeria (ECN), 2014a)

Energy Source	Capacity
Hydropower, large scale	11, 250 MW
Hydropower, small scale	3,500MW
Fuelwood	11 million hectares of forest and woodland
Animal waste	211 million assorted animals
Energy crops and Agricultural residue	28.2 million Hectares of arable land (30% of total land)
Solar radiation	3.5-7.0 kWh/m^2-day
Wind	2-4 m/s (annual average)

The experience gathered during the author’s field work for this study reveals that, Nigerian electricity supply can be best described as abysmal because of its frequently erratic power supply with an average of 11 hours supply daily, despite the endowed available energy resources enumerated in Table 4 above. The level of resource endowment, capacities to utilize specific technologies such as off-grid solar photovoltaic systems is dependent on cost, which is critical to the overall success in developing resource base.

Tables 5 and 6, below, present an overview of the levelized costs of off-grid electricity generating systems (both renewable and non-renewable energy generating systems) and a comparative assessment of operation and maintenance costs in Nigeria.

Table 5. Overview of cost of off-grid electricity generation, based on the levelized cost of energy (LCOE) in Nigeria. Source: (Nigerian Economic Energy Summit Group et al, 2017)

Technology (Engine Generator)	Levelized Cost of Energy USD (cents/kWh)
Gasoline	Over 60
Diesel	30
Small hydro	5
Off-grid Solar Photovoltaic (PV) (based on system size and component costs)	20
Onshore Wind	9

Table 6. Comparative assessment of operation and maintenance cost. Source: (Oladokun et-al., 2015, NERC, 2015, Nigerian Economic Energy Summit Group et-al., 2017)

Technology	O & M Costs USD ($/kW/Yr)
Diesel Generator of 10-100kw	22-33
Photovoltaic	50
Onshore Wind	18.5

Solar Energy Resource in Nigeria

The potential for solar energy in Nigeria is very encouraging because of solar radiation availability and distribution across the country. It is interesting to note that Nigeria lies within a high sunshine belt, and solar radiation is well distributed. The annual average of total solar radiation varies from about 12.6 MJ/m^2-day (3.5 kWh/m^2-day) in the coastal latitudes of the south to about 25.2 MJ/m^2-day (7.0kWh/m^2-day) in the northern arid regions, while the daily sunshine hours average of 4 to 9 hours, increasing from south to north. (ECN, 2014b). The potential for solar in Nigeria varies by location, but the cost of solar PV has fallen enough in recent years making it financially viable for coastal areas with relatively poor solar resource.

Solar Photovoltaic Technologies in Nigeria

The use of solar photovoltaic (PV) technologies in Nigeria is gradually gaining momentum, as the technology is widely accepted by Nigerians. However, despite advancement in local research, development efforts, and installations across the country, the market for photovoltaic (PV) products is small, due to lack of financial incentives and transmission upgrade (Omolola, 2017). Launching major national initiatives on these technologies requires a robust knowledge base and capacity. In all, solar PV systems are used in a wide range of applications in Nigeria like solar home systems in households, water pumping, general purpose refrigeration, vaccine refrigeration, and telecommunications. Most of these applications were seen in various health facilities during the author's fieldwork visit to Nigeria.

Overview of the Health Care System in Nigeria

Nigeria's first national health policy was formulated in 1988 and was done to achieve standard health care for all her citizens with regards to the pattern of population growth. Later, the challenges associated with the population growth pattern made a review of the national health policy imperative. Thus, the policy was later reviewed and established in 2004. The updated policy is referred to as the revised National Health Policy, and it outlines the goals structure, strategy, and policy direction of the healthcare delivery system in Nigeria (Federal Ministry of Health (FMOH), 2004). The policy framework emphasizes that a focus on primary health care is one of the leading strategies to improve the health care system in Nigeria. For example, the policy states that "Primary Health Care (PHC) will remain the basic philosophy and strategy for national health development" (FMOH, 2004). The objectives of the policy are to:

- Reduce newborn/child (i.e., ages 0-5 years) mortality rate by two-thirds between 1990 and 2015
- Reduce the maternal mortality rate by three-quarters between 1990 and 2015
- Reduce the spread of HIV/AIDS by 2015
- Reduce the burden of malaria and other major diseases by 2015
- Ensure environmental sustainability

The Healthcare system in Nigeria is grouped into three tiers: Primary, Secondary and Tertiary. Primary health care is the responsibility of the local government (LG), and secondary health care is the responsibility of the state government. The federal government is responsible for the tertiary health care and has full responsibility for policy development, regulation, and management of the healthcare system. These tiers fairly represent the Federal Republic of Nigeria's three-tiered system of government; the federal, state and local government levels. In the context of this study, the emphasis will be on the primary health care system.

Primary Health Care in Nigeria

Primary health care (PHC) is the bedrock of health policy in Nigeria and is the first point of contact for most Nigerians in the healthcare system. In Nigeria, the primary health care centres are known as the focal point for delivering effective, efficient, quality, accessible, and affordable health services to a broader proportion of the population, especially those in the rural areas. Primary health care has one of its core functions in the development of effective systems of supervision, monitoring, and evaluation based on national guidelines and standards. In a nutshell, the primary healthcare system is the foundation of the healthcare system in Nigeria (NPHCDA, 2007).

According to the National Primary Health Care Development Agency report on ward health care packages, PHC in Nigeria has four basic approaches. They are:

- Promote community participation in planning, management, monitoring, and evaluation;
- Improve inter-sectoral collaboration in primary health care delivery;
- Enhance functional integration at all levels of the health system; and
- Strengthen managerial processes for health development at all levels.

These four basic approaches to delivering health care services are through the ward system (NPHCDA, 2007). The ward system requires smaller groups of health facilities to cater to areas that are far from the ward health centre but within the same ward or catchment.

Types of Facilities under the Ward Health System

The primary health care facilities recognized under the ward health system are classified into three types:

- Health Post
- Primary Health Clinic and
- Primary Health Care Centres.

However, these health facilities are popularly known as health posts, primary health centres, and comprehensive health centres.

Health Post

The health posts are designed to deliver their services in either a settlement, neighborhood, or village level and are expected to have a coverage population of 500 people according to the National Primary Health Care Development Agency requirements (NPHCDA, 2007). The building structure ideally should have the following:

- Minimum Land Area: 1,200 square meters

- Two rooms with cross ventilation; walls and roof must be in good condition with functional doors and netted windows
- Functional separate male and female toilet facilities with water supply within the premises
- Availability of a clean water source: motorized borehole
- Be connected to the national grid or a regular alternative power source (NPHCDA, 2007)

Figure 4 below shows the blueprint of an ideal health post in Nigeria.

Figure 4.NPHCDA Blueprint of an ideal Health Post in Nigeria. Source: (NPHCDA, 2007)

Figure 5 below shows one of the health posts visited during the audit in Nigeria.

Figure 5. Ike Health Post, Kwali Area Council, FCT (Photo by Author)

Minimum Energy Load Found in a Health Post (NPHCDA, 2007)

The minimum electrical equipment for a health post include lighting sources, mobile phone(s) for communication, and a solar powered refrigerator.

Services Rendered by a Health Post (NPHCDA, 2007)

A health post is required to operate at the convenience of the community for at least 8 hours every day throughout the week from 9 am to 4 pm. The health post should be headed by at least a junior community health extension worker (JCHEW). The type of services provided by health posts are:

- Health education and promotion
- Health management information system
- Routine home visit and community outreach
- Maternal newborn and child care
- Family planning
- Promotion of nutrition and proper food education
- Immunization
- HIV/AIDS (education on prevention and misconception, community/home-based care and support, male and female condom distribution)
- Tuberculosis (contact tracing, education on prevention and misconception)
- Malaria preventive and curative care
- Water and sanitation
- Oral health and community mental health
- Referral
- Maintenance of PHC records, monitoring and supervision
- Waste disposal

Primary Health Centre's (PHC's) (NPHCDA, 2007)

Primary health centres are designed to deliver their services in either a settlement, neighborhood, or village level and are expected to have a coverage population of about 2,000 to 5,000. The building structure ideally should have the following requirements:

- Minimum land area: 2,475 square meters
- A detached building with at least five rooms
- Walls and roof must be in good condition with functional doors and netted windows
- Functional separate male and female toilet facilities with water supply within the premises
- Availability of a clean water source: at least motorized borehole
- Connection to the national grid and other regular alternative power sources
- A sanitary waste collection point and a waste disposal site
- A fence with a gate and generator houses
- Staff accommodation within the premises: 2-bedroom apartments

The building must have sufficient rooms and space to accommodate the following facilities: client observation area, consulting area, delivery room, first stage room, injection and dressing area, lying-in ward (4 bed), pharmacy section, record section, staff station, store, toilet facilities (or ventilated improved pit (VIP Toilet)) and waiting/reception area. Figure 6, below, shows an image of an ideal primary health centre in Nigeria.

Figure 6. National Primary Health Care Development Agency (NPHCDA) Blueprint of an Ideal Primary Health Centre (PHC) in Nigeria. Source: (NPHCDA, 2007)

Figure 7 below shows one of the primary health centres visited during the audit in Nigeria.

Figure 7. Gbadalape Primary Health Centre, Abuja Municipal Area Council (AMAC), FCT (Photo by Author).

Minimum Electrical Equipment/Appliances found in a Primary Health Centre (NPHCDA, 2007)

The minimum required electrical equipment found in a primary health centre are enumerated below:

- Lighting source (at least a lantern)
- General purpose refrigerator and solar vaccine refrigerator
- Suction machine
- Sterilization machine (autoclave)
- Mobile phone and communication radio

Required Personnel and Services Rendered by a Primary Health Centre (PHC) (NPHCDA, 2007)

Primary Health Centres are expected to provide services on a 24-hour basis. The required personnel employed to carry on the affairs of a primary health centres include either a midwife or nurse midwife, a community health extension worker (CHEW), and a junior community health extension worker (JCHEW). Other common personnel on staff include support staff, such as health attendant/assistant and security personnel.

The services rendered are like those enumerated for a health post, but they are required to go more in-depth in the services they provide which may include administering treatment. The only addition is that they offer adolescent health services through counseling and support.

Comprehensive Health Centre (CHC) (NPHCDA, 2007)

The CHC's are more equipped with appliances/medical equipment and render more services than the primary health centres. They reach out to a broader population of about 10,000 to 20,000 in a political ward within a municipality. Their building infrastructures are like those of a primary health Centre except that the area is about 4,200 square meters. Additionally, the centre should include a detached building of about 13 rooms and staff accommodation consisting of at least two one-bedroom units. The rooms in the detached building should be able to accommodate the following:

- Waiting/reception areas for child welfare, absolute neutrophil count (ANC), health education and oral rehydration therapy (ORT) corner
- Staff station and two consulting rooms
- Adolescent health service room and pharmacy & dispensing unit
- Two delivery rooms, a maternity/lying-in section, and an in-patient ward section
- Laboratory and medical records area
- Injection/dressing area and minor procedures room
- Food demonstration area, kitchen, and store
- Toilet facilities (male and female)

Figure 8 below shows an image of an ideal comprehensive health centre in Nigeria.

Figure 8.Image of a comprehensive health centre (CHC). Source: (NPHCDA, 2007

Figure 9 below shows a photograph of a comprehensive health centre visited in Nigeria.

Figure 9. Pandagi Comprehensive Health Centre, Abaji Local Government Area Council, FCT (Photo by Author)

Minimum Electrical Equipment/Appliances Found in a Comprehensive Health Centre (NPHCDA, 2007).

The minimum required electrical equipment found in a comprehensive health centre are enumerated below:

- Angle poise lamp (a balanced arm lamp) and other lighting sources
- Blender and mill
- Ceiling fan and standing fan
- Centrifuge
- Electric microscope
- General purpose refrigerator and solar vaccine refrigerator
- Sterilization machine (autoclave)
- Suction machine
- Mobile phone
- Communication radio
- Computer
- Internet services

Required Personnel and Services Rendered by a Comprehensive Health Centre (CHC) (NPHCDA, 2007).

The CHC's are expected to be in operation 24 hours daily. The personnel required by NPHCDA to run the affairs of the health centre are enumerated below:

- Medical officer if available - 1
- Community health officer (CHO)- 1 (must work with standing order of 24hours of operation) -

- Nurse/midwife - 4
- Community health extension worker CHEW (must work with standing order) - 3
- Pharmacy technician - 1
- Junior community health extension worker (JCHEW (must work with standing order) - 6
- Environmental officer - 1
- Medical records officer - 1
- Laboratory technician - 1

Support staff:

- Health attendant/assistant - 2
- Security personnel - 2
- General maintenance staff -1

The services rendered by comprehensive health centres (CHC) are like those of primary health centres (PHCs), but the responsibilities of the CHC are more detailed. Core added services beyond those provided by PHCs are basic laboratory services that support the provision of other services.

Causes of Maternal and Child Mortality in Rural Health Clinics in Nigeria

Maternal, child, and newborn mortality in health clinics in Nigeria can be attributed to many factors. Researchers, scholars, and personnel in the medical field have found from research conducted globally that about 75% of maternal deaths are due to five major causes: severe bleeding, infections, high blood pressure during pregnancy (pre-eclampsia and eclampsia), complications from delivery, and unsafe abortion (Lale et al., 2014). In Nigeria, researchers also found that the causes related to maternal mortality are attributed to medical factors, reproductive factors, and socio-economic factors (Mojekwu and Uche, 2012). Other studies showed a different dimension to the causes of maternal, child, and newborn mortality. Related to energy access. For example, according to Magert, inadequate electricity as an infrastructural barrier to health services delivery and the use of traditional fuels are significant causes of maternal and child mortality (Magert, 2014). Inadequate lighting and communication systems in health facilities have also been linked to the causes of maternal, child and newborn mortality (We Care Solar, 2011). Therefore, improving lighting may allow health workers to identify and treat common complications (e.g. hemorrhage and obstetric lacerations, infections, hypertension, and emergency cesarean performed at night) and enhance promptness to emergency care to prevent women and children from dying.

Interventions to Reduce Maternal and Newborn Mortality

The solutions proffered to reduce maternal, child, and newborn mortality are centered on health services and policy inside and outside the health sector. Shyama et al., (2014) itemized some successes in reducing maternal and child mortality, enumerated below:

- Investments in health systems that support universal access to services, such as service delivery, health workforce, information, medical products, vaccines, etc.
- Investments and policies that are health-enhancing, such as promoting vibrant rural and urban communities, infrastructure development (e.g., electricity), ensuring universal enrollment and completion of primary education and expanded access to post-primary and higher education (e.g., girls' primary school enrollment). Improving environmental management (e.g., access to clean water) and building national capacities in science, technology, and innovation (e.g., number of scientific publications, global innovation index) are also relevant (Shyama et al., 2014).

Other possible interventions are centered around energy access technology. During field data collection by the author in health centres in Nigeria, it was evident that progress has been made in technology to combat the challenges associated with maternal and child mortality. Some of the health clinics had a solar vaccine refrigerator for immunization, solar PV for mobile phone charging and lighting, solar PV to power communication devices, and solar water pumping systems.

We Care Solar, a dedicated group that promotes safe motherhood and reduces maternal mortality in developing regions, has also contributed to technological innovations for healthcare delivery. Some of their portable power units provide health workers with highly efficient medical lighting and power for mobile communication, which allows a medical crew to be alerted when obstetric emergencies require immediate attention, laptop computers, small medical devices, and blood bank refrigerators that allow life-saving transfusions to occur without delay (We Care Solar, 2011).

Energy Needs of Rural Health Clinics in Nigeria

The energy needs of rural health clinics in Nigeria are dependent on the range of services they provide, which are related to the hours of operation, facility size, available medical equipment/appliances, and the population they serve. As enumerated above, the minimum requirements of a health post differ from a primary health centre, and those of a primary health centre also differ from a comprehensive health centre. For example, if the health facility provides a range of services like obstetrics care, immunization, minor ailment treatment, and/or minor surgical services like a hernia, then to efficiently provide these services, specific medical equipment and well-trained staff are required. The electricity need that is required to provide these services may fall under lighting, cooling (e.g. refrigeration for blood, vaccine, and/or drugs), powering of equipment/appliances (e.g. medical equipment, communication devices, mobile phones, etc.), thermal needs, and water pumping.

Research carried out in Nigerian hospitals by We Care Solar revealed that reliable electricity was crucial for life-saving obstetric care, and without reliable electricity and lighting health workers are unable to respond to obstetric emergencies quickly and cannot efficiently perform lifesaving procedures (We Care Solar, 2017). Their findings in the field also went further, revealing that mothers die every day in developing countries by giving birth in dark and unsafe conditions. Furthermore, mothers and their newborns often fail to receive timely care for emergencies due to an inadequate supply of electricity. Midwives struggle to work by kerosene lantern, candlelight, or only the dim light from their mobile phones, unable to adequately diagnose and treat medical conditions, and often postponing or canceling critical procedures. Cesarean sections are delayed, and critically ill patients are often turned away from hospitals that do not have electricity.

How Rural Health Centres Meet their Energy Needs in Nigeria and the Challenges

Most health clinics in rural areas of Nigeria tend to fall under the tier of ‘no access to electricity’ or ‘electricity supply is inadequate’ as described by the World Health Organization multi-tier framework system of health facilities (WHO, 2014). During field site visits by the author, it was discovered that most health centres were either off-grid or connected to the grid but were disconnected. Moreover, the health centres connected to the grid had unreliable electricity supply that could be as little as 3 hours of electricity supply daily. The challenges of having no electricity access or erratic power supply made most health centres depend on battery operated torch lights, mobile phone lights, candles, and kerosene lanterns. Few of the health centres had generators, and several that did hardly used them due to the operational and maintenance cost of running the generator. It was also revealed during the site visit that some health centres with the challenges mentioned ask patients, especially pregnant women, to come with a source of light when they are in child labor. They do this to have a backup light source in case the centre's lighting sources do not carry them all through the night hours as they work to deliver babies.

In a nutshell, the range of challenges observed during visits to rural health centres included:

- No access to electricity
- Unreliable electricity supply for those connected to the grid
- Disconnection from the national grid. The disconnection was reportedly because of negligence on the side of the appropriate authorities in paying existing electricity bills and unwillingness to pay for services that are unreliable.
- Lack of funds to maintain existing electricity supply system and run an alternative supply source such as a generator.
- Lack of cooperation from community members.

What Strategies Provide the Most Promising Pathways for Improving Access to Reliable Energy in Rural Health Centres in Nigeria?

Grid-based electricity supply over the years has been the norm for clinics in Nigeria. The National Primary Health Care Development Agency in Nigeria made it clear in its blueprint that health posts, primary health centres, and comprehensive health centres should be connected to the grid and any other reliable source of power supply. Generators, for example, have been used either as the backup to grid-tied systems or as a primary source of energy for off-grid systems to meet the electricity demand in health centres. The use of generators has helped some clinics secure a supply of electricity, but their use has contributed negatively to the environment by emitting greenhouse gases (GHGs), fine particulates, and other pollutants. Funds to continually fuel the generators is also a concern for health facilities in rural Nigeria.

Currently, in Nigeria, solar PV is also playing an important role in meeting the energy needs of health clinics. Solar vaccine refrigerators and solar water pumping systems are commonly found in health facilities in Nigeria. Small solar PV systems that are packaged in suitcases, an innovation of "We Care Solar," are found in some health clinics in Nigeria and other countries in Africa. A recent review, taking samples of over 4,000 public and private health facilities of energy supply patterns in 11 sub-Saharan African countries, found that hundreds of clinics and hospitals are using on-site solar photovoltaic (PV) power sources either as a primary or backup source. In Uganda, some 15% of hospitals and 2% of other health facilities used solar PV to complement grid electricity access, and in Sierra Leone 36% of all health facilities and 43% of hospitals used solar systems in combination with other electricity sources (Adair-Rohani et-al., 2013).

The Solar Nigeria Programme (SNP), an initiative of the Lagos State Government, has made a tremendous impact by installing solar PV in rural health centres. So far 11 installations have been done in health centres in Lagos State (SNP, 2016).

Also, Lighting Africa has contributed to health care services by deploying off-grid solar lighting products in thirty-six rural primary health centres across Adamawa, Nasarawa and Ondo states of Nigeria. So far, the number of working hours for midwives increased by up to 30% with the introduction of the quality-verified off-grid products (Louis, 2014). The products deployed are the micro solar home system (SHS) and portable lanterns for the midwives. Consequently, solar PV systems are gradually gaining momentum in Nigeria with support from both public and private institutes.

Figure 10 below shows the brands of the products deployed by Lighting Africa to Nigeria.

Figure 10. Solar Lighting Products Disseminated in 36 Health Centres in Nigeria. Source: (Louis, 2014).

Solar Photovoltaic (PV) Systems and Types

A photovoltaic system is a set of components that converts sunlight into electrical energy. The components of a system include solar PV modules, batteries, charge controllers, inverters and other accessories. A reasonably designed solar PV system gives reliability and optimum performance.

A solar system uses freely available sunshine. It does not even cost a dime to buy the input energy, unlike fuels such as premium motor spirit and diesel. Sun will continue to shine, but the same cannot be said about the petroleum products. The electricity a solar cell would produce depends largely on the surface area and efficiency of the cell and the strength of the sun. There are three main types of solar PV systems, namely:

- Grid connected solar photovoltaic(PV) systems
- Stand-alone or off-grid systems
- Hybrid solar photovoltaic systems (solar plus some other generation source)

Grid Connected Solar Photovoltaic (PV) Systems

A grid-tied solar PV system operates while being connected with the utility company's power supply. When the PV system produces less electricity than is required at the site, the utility power provides the remaining needed energy. Likewise, when the PV system generates more than is needed at the site, the utility company receives the excess (and in many arrangements, the utilities compensates the facility for this electricity). A controller is used to manage battery charging, while the metering system tracks energy flows in a grid tied battery system. Figure 8, below, shows a grid-tied system with battery backup. The battery allows the system to operate on a standalone-basis if needed, while also allowing the system to receive power to charge the battery from the grid or a generator when they are available. The type of inverter used to this kind of system is bi-directional, so that it converts DC to AC and AC to DC (SEI, 2013).

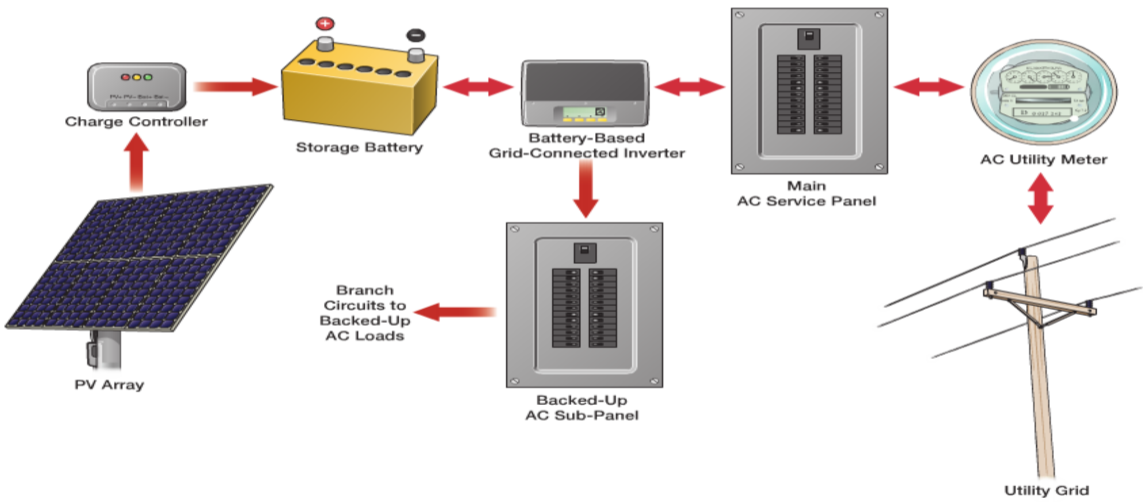

Figure 11. A Grid Tied Solar PV System. Source: (SEI, 2013)

Stand-alone Systems

The stand-alone solar PV system is also referred to as an off-grid system, and it can operate independently without connection to the grid. A stand-alone system requires a power storage facility such as batteries for times when sunlight is not available, e.g., cloudy days or when the system produces low levels of electricity. Figure 9 below shows a typical standalone system with battery backup (SEl, 2013).

2

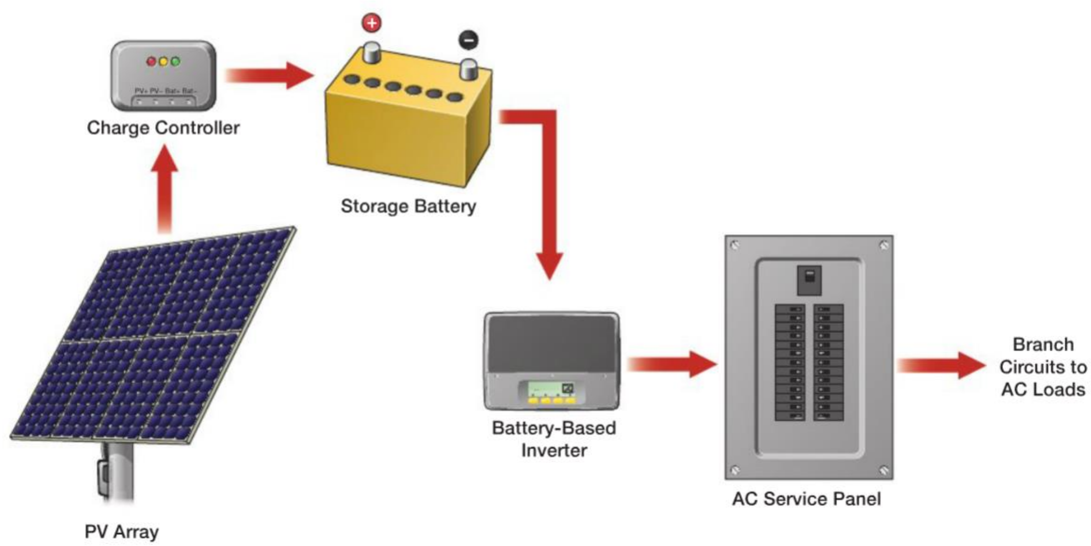

Figure 12.An Off-grid System with Inverter. Source: (SEI, 2013)

A Hybrid Solar Photovoltaic System (Thomas, 2015; TH-Energy, 2015)

A hybrid system combines solar and any other source of energy (wind, diesel, etc.) to produce electricity. This option opens a line of opportunities beneficial for both efficiency and monetary plan. The benefits are that one can operate entirely off-the-grid, may see a quick return on investment, and, can have the stability to generate power regardless of intermittent circumstances.

Solar PV systems have the following advantages:

- They are quiet, independent with minimal maintenance cost.

- They continue to supply electricity during grid power outages;
- They are environmentally friendly.

However, there are some drawbacks associated with solar systems.

- Their ability to supply electricity is limited by the solar resource.
- They do not produce electricity at night, and their production during the day is affected by clouds and haze.
- The initial cost of systems may be expensive, and systems may fail prematurely if they are not maintained properly.
- The cost of maintenance can be significant once periodic replacement of components is considered (e.g., battery bank replacement);

Definition of Solar Photovoltaic (PV) Components and Terms (SEI, 2013)

The components and terminologies used in an off-grid system design are defined in the sections below.

Deep cycle battery:

Batteries are used to store electrical energy for use during times when solar PV production is less than the electrical demand. Deep cycle batteries are preferred for solar applications because it has the ability to discharge up to 80% of the total battery capacity to energize loads over a long duration of time (SEI, 2013). Deep cycle batteries come in different chemistries, including lead acid, lithium iron phosphate, and other chemistry types. The most common batteries used for renewable application is the lead-acid battery, and within that category, there are both sealed lead-acid batteries and flooded lead-acid batteries. A deep cycle lead-acid may be designed to discharge to between 50% and 80% of its full capacity depending on the product design, manufacturer, and construction. Lithium ion phosphate batteries can be deeply discharged to 100% of their capacity. Deep cycle batteries are commonly used for off-grid solar and wind energy storage systems, especially in small installations for a single building.

Charge controller:

Charge controllers limit the rate at which electric current is added to or drawn from electric batteries. They prevent overcharging of the battery and may guard against overvoltage which can reduce battery performance or lifespan and may pose a safety risk. They can also protect against deep discharge (this is important for lead-acid batteries), and they may also have other features.

Inverter:

An inverter is an electrical device that converts direct current (DC) electricity to alternating current (AC). The converted AC power can be at any required voltage and frequency with the use of an appropriate transformer, switching, and control circuits.

Solar Panel:

Solar panels are also referred to as solar modules, and a collection of panels is called an array. They are made up of silicon cells that absorb sunlight in the form of photons and through the photovoltaic effect that convert the sunlight into electricity. The energy produced by the solar panel or array is DC electricity, and an inverter is required to convert it to AC.

Depth of discharge (SEI, 2013):

This is the limit of energy withdrawal to which you will subject the battery. It is expressed as a percent of the total capacity. For example, the more you discharge a lead-acid battery, the fewer the cycles that battery will be able to complete.

Days of autonomy (SEI, 2013):

Days of autonomy represents the number of days that the battery can carry the electrical loads of the system without significant input from a charging source. If by any means, one is unable to charge the battery and still need to draw power, one must provide this additional storage by increasing the size of the battery bank.

Solar Photovoltaic Systems as a Pathway to Electrifying Rural Health Centres.

Solar PV is being considered as an alternative to electricity generation in Nigeria because of the sporadic and limited grid electricity supply in the country. It has become a promising pathway for electrification of rural health centres that are on-grid or off the grid. Energy from the sun is free and relatively reliable, and Nigeria is endowed with a solar resource that ranges from 3.5 to 7.0 kWh/m^2 per day (ECN, 2014b). The Federal Government (FG) has enacted policies to support rural electrification initiatives using solar PV. According to the Renewable Electricity Policy of the Federal Ministry of

Power, Works and Housing (FMOPWH), “the nation shall aggressively pursue the integration of solar energy into the energy mix" (FMOPWH, 2006) with its objectives;

- To use solar energy as a complimentary energy resource in the rural and urban areas;
- To increase access to electricity services nationwide, especially in rural areas;
- To reduce air pollution and decrease greenhouse gas emissions, and thus contribute to improving health care and overall social development (FMOPWH, 2006).

Due to limited access to electricity supply, only 34% of the population is connected to the grid in rural areas of Nigeria. Solar photovoltaic systems, especially 'standalone’ systems, are a promising solution for rural health centres electrification. Other factors that may also make solar PV promising are the immediate need for energy, cost and time constraint for grid extension to rural health centres, and inadequate grid infrastructure.

During the author's visit/audit to some of the rural health facilities in Nigeria, it was noticed that health facilities that are grid-tied had limited supply daily due to power supply interruptions from the national grid. Most applications of solar PV found for rural electrification during data collection are solar street lights, solar water pumping systems, and solar vaccine refrigerator for rural health centres that are off and on the grid. It was also noticed that most health centres were off-grid and from information gathered, grid connection might not get to them in the next 5-10 years or more. It is therefore imperative to consider solar PV systems for off-grid and grid-tied facilities.

Challenges Associated with the Use of Standalone Solar PV Systems for Electrification of Health Facilities.

Despite the successes recorded in the use of solar PV systems for rural electrification in Nigeria, drawbacks are still evident in some of the audited sites. For example, during the audit of some health centres, the author observed system failures were due to inadequate provisions for operation and maintenance. These reason for failure also reflects the United Nations Foundation work in health clinics across Africa. For example, many health centres allocated insufficient budget funds for operation and maintenance costs and did not have adequately trained staff with the capacity to carry out maintenance tasks for the standalone solar PV systems (UNF, 2015a).

Other factors observed by the author include:

- Lack of standards for the components of the system. Often, there was no benchmark to monitor or measure the performance of the component. For example, installing system components (PV modules, batteries, charge controllers, and inverters) that are substandard or of poor quality or not in compliance with standards like International Electro technical Commission (IEC), or Institutes of Electrical and Electronics Engineers (IEEE) standards etc.
- The bureaucratic bottleneck or challenges the health facilities often encounter when reaching out to the higher governing body (e.g., the Area Council, NPHCDA) before reaching out to the donors or technicians that installed the system whenever the system breaks down. Also, the health facilities sometimes

reach out to the wrong technicians, i.e., those who are not skilled in solar PV installation and repairs contributed to the failure of some of the systems.

- Poor installation of systems and neglect in monitoring the systems after installation.
- Lack of community participation assisting with funding and supporting the health facilities on safety issues related to vandalism and theft of system components.

Additionally, the United Nations Foundation with its wealth of experience on standalone solar PV systems in health facilities around Africa (e.g., Ghana and Uganda) has also identified some fundamental failures. The maintenance of the systems was entirely the responsibility of the beneficiary institutions, leading to challenges around the sustainability of the systems. The cost of maintaining and replacing batteries on many small systems is quite expensive, which strains the budget of the respective health facilities. Low levels of training in energy management and lack of load limiting technologies and insufficient power availability for various uses make the systems unsustainable (UNF, 2015a).

Furthermore, one example of this lack of support is the audit carried out by the United Nations Foundation in Uganda. It revealed that almost all of the non-operating PV systems were donor-funded and lacked a long-term maintenance contract with suppliers and installers. Spare parts provision was not part of contracts for donor-funded systems. Also, no provisions were made by donors for maintenance service, spare parts or battery replacement. There were other challenges associated with insufficient records on origin, operational management, and maintenance schedule of the PV systems (UNF, 2015b).

METHODS

The research methodology presented in this chapter include the following:

1. Data collection/audit
2. Analysis of data collected using Excel spreadsheet
3. Design/sizing of a solar PV system for a selected health centre
4. Economic analysis and calculations on greenhouse gas emissions avoided.

First, a questionnaire was developed for data collection. This questionnaire was used to carry out a survey in twenty-eight (28) rural health centres across the six (6) different Local Government Areas (LGA) in the Federal Capital Territory (FCT). The information and data gathered were used to determine the health centre site characteristics, energy needs of the health centres, finance sources for energy system development, and the approach taken for maintenance of the existing energy sources (e.g., existing off-grid solar PV systems or generators). A copy of the questionnaire is included in Appendix A.

The second step involved site visits and carrying out audits of the health centres. A walk-through energy audit was carried out in twenty (20) health centres, and a comprehensive energy audit was carried out in eight (8) health centres in the six (6) Local Government Areas (LGAs) in Nigeria's Federal Capital Territory (FCT). The selected health centres for both the walkthrough and comprehensive energy audits extend across health posts, primary health centres (PHC), and comprehensive health centres. The selection criteria of the sites for the audit was based on the energy provision available and the needs at the various rural health centres. These are enumerated below:

1. Health centres without access to electricity (off-grid)
2. Health centres that are off-grid but have a primary or alternative source of electricity supply e.g., generator (diesel or gasoline) and solar PV system.
3. Health centres that are grid connected but with unreliable or erratic power supply without a backup
4. Health centres that are grid connected with unreliable power supply but have a backup electricity supply, e.g., generator (diesel or gasoline) or solar PV system.
5. Health centres that fall under category 1, 2 and 3 with a bore hole (handpump, AC pump or solar pump) that iseither functional or non-functional.

Furthermore, most of the load information which includes lighting, fans, appliances /medical equipment, and other devices at the facility were collected by talking with staff and through the nameplates of the devices. Some of the loads like solar vaccine refrigerators were measured using the compact Extech clamp meter, model 380942 30Amp mini AC/DC meter range with 0.1mA (AC) and 1mA (DC), AC and DC volts ranging from 0-400volts, to determine the current in amperes; the current was used to estimate the power consumption of the device.

A 60m measuring tape was used to measure the size (both interior and exterior) of the health centre buildings. The data was used to determine the area of both interior and exterior of the building.

A Canon G9x camera was used to take photographs of the health centre buildings, appliances, and medical devices. The camera was also used for short video recording.

A Solmetric Sun Eye 210 measuring device was used to determine the geographic coordinates, losses due to shading, solar resource, and tilt angle of the roof at each site. A clinometer app downloaded to a smart phone was also used to determine the roof tilt angle of each facility building.

An Apple iPad model A1823 tablet computer was used in some health centres to collect data/information as outlined in the questionnaire during the interview. The iPad was also used to take photographs and videos recording.

A Dell Inspiron 5000 series laptop was used to collect data/information as outlined in the questionnaire during the interview/audit.

A drawing sheet was used to sketch the buildings of each facility and a record sheet was utilized to take notes during the entire audit.

The audit included an assessment of the site characteristics to meet the energy requirements. To carry out design calculations for the solar PV system for the selected health centre, the following data were collected:

- The average solar resource, losses due to shading, and geographic coordinates (latitude and longitude) using a Solmetric Sun Eye tool model 210.
- Mobile telephone network signal strength to assess whether it would be possible to carry out remote monitoring using a mobile phone signal.

- Available space for mounting or installing the solar system (i.e., panels on the roof or the ground, locations for batteries, inverters and other system equipment).
- Safety concerns including requirements to prevent vandalism and theft when the system is installed.

Once these data were in hand, a detailed analysis was carried out for one of the rural health centre sites. The analysis here included solar PV system design, installation requirements, and economic life cycle cost assessment.

Economic Scenarios Included in the Analysis

The critical assumptions made during the design are also outlined in this section, including assumptions related to the load analysis, shading and system losses, the efficiency of the system, and the economic analysis. The economic analysis carried out for the pilot solar system designed is divided into two scenarios, with each scenario having two cases each.

Scenario 1: In this scenario, a lead acid deep cycle battery was specified for use with the system, and a comparison was made for powering the health centre with the utility grid, a generator, or a solar PV system. Two funding sources were compared under Scenario 1, and an independent investor’s model was also developed. The funding sources are:

- **Case 1:** Self-funded system with all initial costs covered by the health centre, and the health centre also takes responsibility of the operation and maintenance costs as well as the equipment replacement costs.
- **Case 2:** Grant or subsidy-funded system where the support is used to cover the entire upfront cost of the system, but the health centre takes responsibility of the operation and maintenance costs and the equipment replacement costs.
- **Independent Investors Model 1 (IIM 1):** The investor's model is completely independent of Case 1 and 2. The model is designed by choice, if an individual or organization is willing to invest to make a return (turn over) on the investment. The terms of the contract in this kind of investment will cover the initial cost of the system, and operation and maintenance costs up to a certain period or year after repayment. The repayment will be with a markup for the investment to be profitable.

Scenario 2: In the second scenario, a lithium iron phosphate battery was specified for use with the system. This scenario involved the same analysis with respect to the comparison of generation sources and the system economics as Scenario 1, but in this context the cases and model are numbered **Case 3, Case 4 and Independent Investors Model 2 (IIM2)**, respectively**.**

Audted Health Centres Location on Google Map

This section presents the locations of the audited health centres on a map (Figure 10), including the location of the selected health centre chosen for the detailed design analysis

Figure 13 below shows the location of the 28 rural health centres audited in the six (6) Area Councils of the Federal Capital Territory (FCT), i.e., Abaji, Abuja Municipal Area Council (AMAC), Bawri, Gwagwalada, Kuja, and Kwali. The health centres are represented in Table 7 according to their tiers (Health Post (HP), Primary Health Centre (PHC) and Comprehensive Health Centre (CHC).

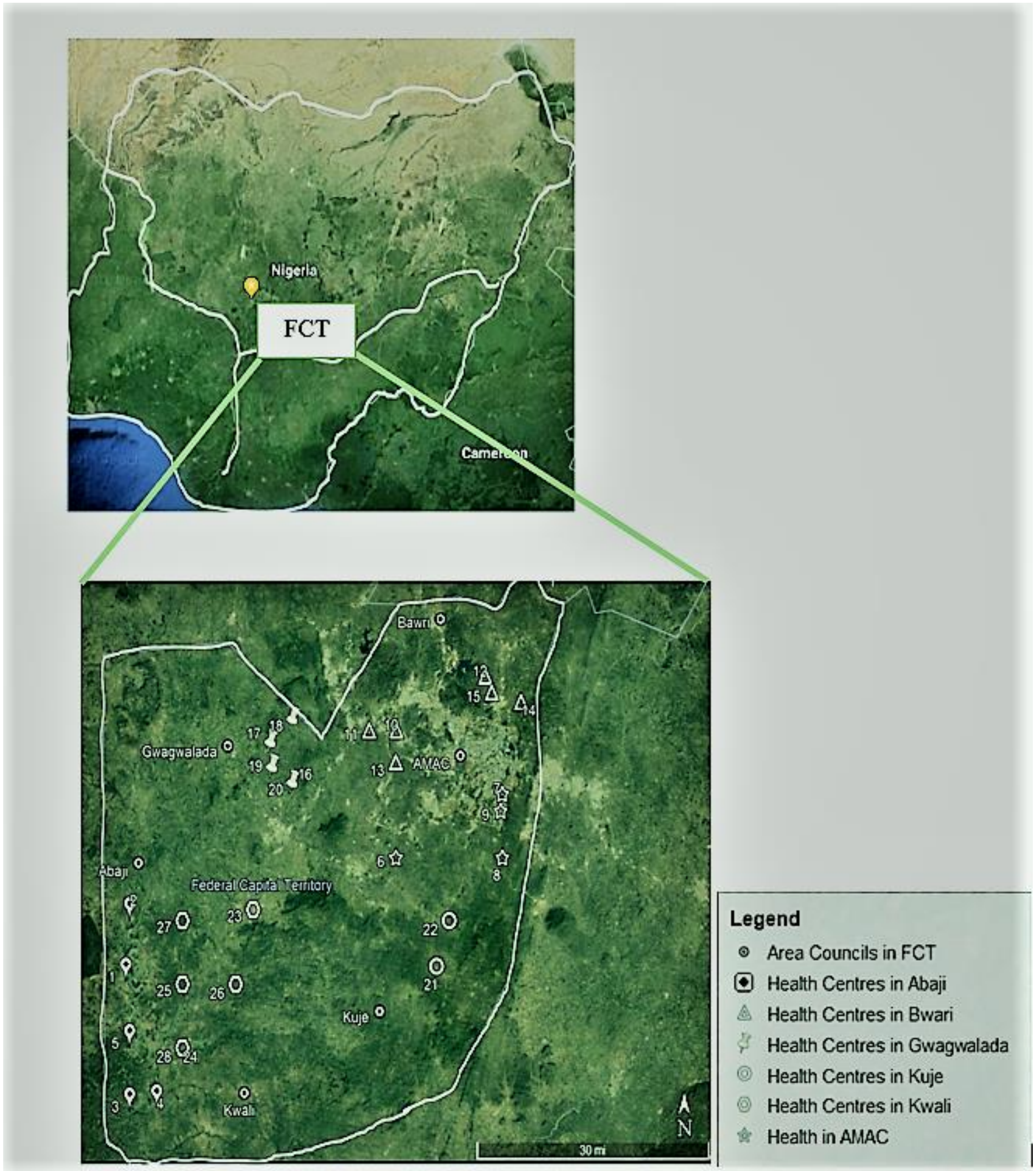

Figure 13. Geographical Distribution of 28 Surveyed Health Centres in FCT, Nigeria
Source: (Google Earth).

The total area of the Federal Capital Territory where all health centres are located is about 7314 km^2

Table 7. Health Centres by Location at Various Area Councils in the Federal Capital Territory (FCT), Nigeria

Abaji Area Council	AMAC Area Council	Bawri Area Council
1. Adagba PHC 2. Gurdi PHC 3. Model Naharati Sabo PHC 4. Pandangi CHC 5. Yaba PHC	6. Gbadalape PHC 7. Kpeyegyi PHC 8. Kurudu PHC 9. Damagaza PHC	10. Dei de CHC 11. Dei de PHC 12. Gudupe PHC 13. Dakwa PHC 14. Dutse Alahji PHC 15. Mapa PHC
Gwagwalada Area Council	Kuje Area Council	Kwali Area Council
16. Dukpa PHC 17. Ibwa 1 PHC 18. Ibwa 2 PHC 19. Rfin-Zurufl PHC 20. Wuna PHC	21. Kabi Mongoro PHC 22. Kasada PHC	23. Kwali CHC 24. Ike HP 25. Dafa PHC 26. Kamadi Tsho PHC 27. Tunga Sariki HP 28. Wako PHC

Criteria for Selecting a Rural Health Centre for a Pilot Design

The criteria for selecting the health centre chosen for a pilot design is broken down below:

- The primary health centres (PHC) were prioritized for selection over health posts and a comprehensive health centres because they are the first point of health care in every community in Nigeria. PHC's are available in almost community across Nigeria. Also, it must be one of the health centres that a detailed audit was conducted on.

- The energy needs and primary source of energy supply of the health centre; i.e., the health centre must be off-grid, have basic existing and future appliances and medical equipment's like fans, already wired for light bulbs even if bulbs are not available, centrifuge, and electronic microscope; additionally, the centre must have need for the use of a solar vaccine refrigerator and mobile phone charging.
- The number of outpatients served per day must be ten (10) and higher.
- Hours of operation per day; a health centre where installation of a solar power system will enable an increase in the hours of operation is preferred, because the expanded operation will improve health care delivery. Priority was therefore given to health care facilities that reported operating for less than 24 hours daily.
- The number of staff members present at the health centre should be at least two (2). In such cases, additional of solar PV systems may help create more jobs for health workers and help ameliorate staff productivity.

After carefully following the above-set criteria, Ibwa 1 Primary Health Centre (PHC) emerged an excellent fit for the pilot design.

Assumptions Made Designing a Solar System for IBWA1 Primary Health Centre.

The analysis includes assumptions as outlined below related to appliances:

- In cases where inefficient lights and fans were installed, they will be replaced with more efficient versions. Many of the lights were 60-W and 75-W incandescent bulbs, and I assume these will be replaced with 10-W and 13-W LED bulbs. The ceiling fans were models that consumed 100 W, and these were replaced with fans that consumed 62 W. Table 8, below, gives a description of the energy efficient appliances.

Table 8. Energy Efficient Appliances that Replaced Existing Appliances

Parameters	Values	Source
10 W LED Light Bulb 13 W LED Light Bulb	900 lumens 1125- 1170 lumens	(Rapid table, 2018)
62W Fans	246 revolution/min 155 Air Velocity (m/min) 200 Air Delivery (m^3/min)	Product Spec Sheet. (KDK for Middle East and Africa)

- The required power (W) and daily energy use (kWh) to run the devices/appliances for 24hours were increased by 15% in order to allow for future expansion of the system and to ensure a conservative system design. The author assumed that Ibwa 1 health centre runs a 24-hour service. Phantom load power consumption of 2.3 W for a 6 W mobile phone charger operating for 8hours per day was also considered.

Other assumptions were made on the solar system design as shown given in Table 9, Table 10, and Table 11, below.

Table 9. Assumptions Made on Battery Design

Parameter	AGM Lead Acid Deep Cycle (Scenario1)	Lithium Iron Phosphate Battery (Scenario2)	Source
Nominal Battery Voltage	6 V	12V	Specification sheet of Lithium Ion Company and Surrette Rolls (Lead-acid) Batteries
Days of Autonomy (DOA)	3 days	3 days	Author
Depth of Discharge (DOD)	50%	80%	Author
Ambient Temperature of Room for Battery	27^0C	27^0C	(NMI, 2018)
Temperature Multiplier @ 27^0C (81^0F)	1	1	(Solar Direct, 2018)

The measured/calculated values and assumptions made on the pilot solar system design for Ibwa 1 primary health centre are tabulated in the Table 10 below.

Table 10. Measured/calculated values and assumptions made on the solar system design

Parameters	Values	Source
Average Percentage of Solar Access Considering Shading Loss	98%	Measured from site
Solar Panel Tilt Angle and Azimuth	Tilt 21^0 and Azimuth 206^0	Measured from site
Total Area of Roof (ft^2)	188 m^2	Calculated
Average Daily Radiation for the Month the Smallest Solar Resource	4.15 kWh/m^2/day	Estimated using PV Watts Tool
Losses Due to Inefficiencies (battery, wires, inverter, voltage drop, array mismatched, charge controller losses and soling(dust)	32%	(SEl Handbook, 2013)

The assumptions made for Ibwa 1primary health centre during the design for other solar components are presented in Table 11 below.

Table 11. Assumptions on Other Components

Parameters	Values/Description	Source
Inverter Efficiency	84%	Estimated from Ibwa1 PHC load profile and Cotek SP1000-248 inverter spec sheet, 2018
Charge Controller Type	MPPT	MidNite Solar Classic SL 150 charge controller spec sheet, 2018
Solar Module Type	Monocrystalline (17.78% efficiency at STC). 17.78% was used only to estimate for the solar module efficiency.	Seraphim solar panels SRP-345-6MA company spec sheet
Wiring	Sizing to U.S Code	Calculated

Solar System Design

The metrics below were used to determine the system size of a solar system and energy produced:

Solar Array Size (KW) = Average Daily Demand kWh ÷ Average Daily Solar Radiation kWh/m^2/day for the Month with the Smallest Solar Resource ÷ System Efficiency

Annual Energy Produced by System (KWh/Year) = Solar Array Size (KW) x System Efficiency (%) x Average Solar Radiation (kWh/m^2/day) at Tilt Angle x 365 days-yr.

Other metrics used for the sizing of the system components based on the assumptions presented in Tables 8, 9, and 10 are summarized in Appendix Tables C-1 to C-9. The assumptions made during the economic analysis of the system and the information collected by the author during audit are presented in Table 12 and 13, below.

Table 12. Assumptions used in the economic analysis of the proposed system

Economics Assumption	Values and Description	Source
Project Life of System	20 years	Solar module life span is 25 years. Seraphim monocrystalline panel spec sheet, but author assumes 20 years for project life.
Construction Contingency	15%	Author's assumption
Value Added Tax (VAT) & Import Duty	5% each	(FIRS, 2018; Prince, 2018)
Target Inflation	10%	Central Bank of Nigeria, 2018
Nominal Interest Rate	12%	Central Bank of Nigeria, 2018
Installation + BOS (wire, breakers and accessories)	40% of component cost	Szabo et al., 2011
Operations and Maintenance of Solar System	2.5% of initial cost	Szabo et al., 2011; ECN, 2017
Battery Replacement: Lithium Iron Phosphate Battery: Lead Acid Deep Cycle Battery:	10 years 10 years	Battery specs sheet gives a warranty of 10 years, and author assumes a 10-year replacement period with proper maintenance.
Inverter Replacement	10 years	MidNite Inverter spec sheet
Cost of Utility Electricity	$0.10/KWh	(NERC, 2017) Nigeria
Generator Size and Model	1.2KVA Sumec Firman - ECO-1990S	Sumec generator spec sheet
Generator Cost	$150	Retail Market Price, Nigeria
Generator fuel tank size	50 litres	Sumec generator spec sheet
Liters of Gasoline Used per Hour on Full Load	1.22 litres	Victor et al., 2017
Installation Cost (Wire and Labor)	10% of Generator Cost	Victor et al., 2017
Maintenance Cost of Generator	10% of Generator Cost Per Year	Victor et al., 2017

Table 13. Author Collected Information During Audit

Economics Assumption	Values and Description	Source
Cost to Reconnect the Health Centre	$125	Author (collected during audit)
Cost Expended on Battery Torch Light Annually	$50	Author (Data was collected during the health centre audit)
Operation and Maintenance Cost the Health Centre is Willing to Pay Monthly	$28	Author (Information collected during audit)
Cost of Gasoline per Liter	$0.56	Author (During Site Audit)

Value and Health Benefits from Improved Electricity Supply and Reliability

A limitation of this study is not placing a value on the losses associated with the unreliability of electricity in the off-grid health centres. The study does quantify the cost of the energy generated by the system in the form of the initial cost of the solar system for the selected health centre (Ibwa 1 primary health centre) and the levelized cost of energy (LCOE) ($/kWh). The benefits that may be derived from this study on improving the unreliable supply of electricity at Ibwa 1 primary health centre and others reflecting the same significant energy insecurity are enumerated below.

- The improved reliability of electricity supply using a solar PV system at the Ibwa 1 primary health centre will enhance basic lighting and communications for maternal delivery and emergency procedures. It will also allow for the elimination of the use of inferior battery torch lights and kerosene lamps. Other medical diagnostic devices like those related to the detection of HIV, breast cancer, and cervical cancer where women have a particularly heavy burden would be improved upon. These and other similar applications of the electricity to power medical devices could contribute to saving lives and/or reducing the burden of disease.

- If it is maintained properly, the improved reliability of a solar PV systems can reduce occurrence of outrages or power interruptions experienced by grid-tied systems and provide reliable or adequate electricity supply for off-grid health centres. For example, damage to critical medical equipment or diagnostic devices may be prevented.
- Improved electricity supply and reliability at the Ibwa 1 primary health centre can help improve service delivery by expanding the hours of operation to 24 hours per day, assisting in the retention of health workers, allowing nighttime diagnostics, supporting mobile phone charging for communication, and preventing vaccines from going bad.
- Other areas of benefit are on GHG emissions and local air pollution reductions

Economic Feasibility of the Proposed Solar System for IBWA 1 Primary Health Centre

The solar system economic feasibility of Scenarios 1 and 2 (i.e. scenarios with deep cycle lead-acid batteries and lithium iron phosphate batteries, respectively) has been assessed using the discounted cash flow technique. The approach involves an estimation of the system value of the cost of the capital investment or initial outlay cost for both scenarios (self-funded, subsidy and investor funded) over a 20-year period. The ongoing costs such as the operation and maintenance cost, and equipment replacement costs were estimated by bringing it to the present using the discounting technique. The discounted cash flow technique was also used to assess the viability of the project for a private investor. Other economic evaluation methods used include the levelized cost of energy (LCOE) to evaluate the net present value of the unit cost of electricity in ₦/kWh or $/kWh over the 20 years, the discounted payback period (DPP), and the internal rate of return (IRR) on the investment. These approaches are summarized below.

- **Net present value (NPV):**

The NPV is a metric used in assessing the economic feasibility of a project to determine whether or not an investment opportunity is a smart financial decision. The Corporate Finance Institute defined NPV as the value of all future cash flows (positive and negative) over the entire life of an investment discounted to the present (CFI, 2018). When the NPV results are positive, it means that - at the end of life of the investment - the discounted cash flows produced will have given greater returns than the cost of the initial investment. When the NPV results are negative, it means that -at the end of life of the investment – the discounted cash flows produced will have given lesser returns than the cost of the initial investment. With regards to this study, a 12% discount rate is used, having it in mind that it sets a high bar for the project success.

- **Internal rate of return (IRR):**

The internal rate of return is used to determine if an investment is profitable or not. The internal rate of return is calculated by adjusting the discount rate to find a rate that makes the net present value (NPV) of all cash flows from an investment in a project be equal to zero.

- **Discounted Payback Period (DPP):**

The discounted payback period is a metric used to determine when an investment will break even. It gives the number of years to break even. It is more accurate than the simple payback period because it discounts the future cash flow and takes into account the time value of money (Investopedia, 2018).

- **Levelized cost of energy (LCOE):**

This metric evaluates the net present value of the unit cost of electricity, in units such as $/kWh, over the lifetime of a generating asset (Master, 2004). It indicates the minimum price that the project must receive to break even. Equation 1, below, can be used to calculate the levelized cost of energy.

LCOE in $/kWh = {(Present value of customer costs) - (Present value of customer benefits)} / (Annualized generation in kWh) (Equation 1)

Estimation of the Greenhouse Gas Emissions

The guidelines used in determining the greenhouse gas emissions from the gasoline generator and utility supply for Ibwa1 primary health centre are based on the Intergovernmental Panel on Climate Change (IPCC) guidelines from 2006. The metric used in estimating the greenhouse gas emissions from the proposed generator set and utility grid are given in Equations 2 and 3 below:

GHG emissions from generator ($tC0_2e$/day) = Daily fuel use (gallons/day) * ((EF of CO_2 * GWP of CO_2) + (EF of CH_4 * GWP of CH_4) + (EF of NO_2 * GWP of NO_2))

(Equation 2)

GHG emissions from grid electricity ($tC0_2e$/day) = Daily Electricity Demand (kWh/day) * ((EF of CO_2 * GWP of CO_2) + (EF of CH_4 * GWP of CH_4) + (EF of NO_2 * GWP of NO_2)) (Equation 3)

where:

tCO_2e = Tons of carbon dioxide equivalent.

EF = Emission factors for different gases from gasoline combustion (g of emitted gas / gallon) and electricity use (g of emitted gas / kWh)

GWP = Global Warming Potential of the emitted gas relative to CO_2 (100-year basis).

The Nigeria grid mix includes 74% of energy generation from natural gas and 26% of energy generation from hydro power (Isaac, 2017; Chineme, 2017). Table 13 and 14 shows the emission factors for gasoline generator and electricity grid for Nigeria.

Table 14. Emission Factors for Gasoline Generator. Source (EPA, 2014)

Pollutants	CO_2	CH_4	NO_2
Emission Factor (EF) of Gasoline(g/gallon)	8780	0.5	0.22
Global Warming Potential(GWP) (100 years)	1	25	298

Table 15. Emission Factors for Nigeria Electricity Grid. Source (Mathew et al, 2011)

Pollutants	CO_2	CH_4	NO_2
Emission Factor (EF) of Gasoline(g/KWh)	440	0.010	0.0014
Global Warming Potential(GWP) (100 years)	1	25	298

RESULT AND DISCUSSION

This chapter includes results and discussion related the analysis of the potential to use solar power to improve energy delivery in health clinics in the Federal Capital Territory of Nigeria. Topics covered include the following.

- Key findings from fieldwork on the energy needs and electricity situation for rural health centres in FCT, Nigeria
- A solar system design and economic analysis for the Ibwa 1 Primary Health Centre
- Results from greenhouse gas emissions (GHG) assessment for electricity from utility and generator sources.

Key Findings from Fieldwork on the Energy Needs and Electricity Situation of Rural Health Centre's in FCT, Nigeria

The energy needs obtained during the audit extends across lighting and cooling sources, appliances, and medical equipment. Table 16 below, shows a percentage representation of the twenty-eight health centres tiers visited during the audits in FCT, and Table B-1 in Appendix B, shows a summary of all clinics audited and their features.

Table 16. Percentage Representation of Twenty-Eight Rural Health Centres Tiers Audited in FCT, Nigeria

Type of Health Centre	Representation by Percentage
Health Post (HP)	7%
Primary Health Centre (PHC)	82%
Comprehensive Health Centre (CHC)	11%

A summary of the demographics in the various types of health centres is outlined in Table 17, below.

Table 17. Summary of Demographic Features Found in Various Health Centres

Parameters	Health Post	Primary Health Centre	Comprehensive Health Centre
Number of Health Centres per Tier	2	23	3
Average Number of Patients per Day	5	12	23
Average Buildings per Facility	1	1	2
Average Number of Bed per Facility	1	4	11
Hours of Operation per Day	15	24	24
Days Opened per Week	6	7	7
Average Number of Staff Members	2	8	24

From Table 17 above, the type, size, and services rendered by each health facility determines the numbers of patients it can accommodate, the number of buildings in the facility complex, beds space, hours of operation and staff strength. Results from the audit showed that some health centres, especially off-grid facilities operated less than 24 hours daily and 7 days weekly. Their hours of operation and opening daily and weekly is contrary to the minimum requirement of rural health centres in Nigeria. Information gathered showed it was associated with challenges of an interrupted power supply and energy access for off-grid health facilities.

The Energy needs/loads found across various audited health facilities (health posts, primary health centres and comprehensive health centres) are tabulated in Table 18 below.

Table 18. Summary of existing electrical loads for the various health facilities audited

Facility Type	Energy Needs
Health Post (HP)	Lighting (Light Bulbs: Incandescent and CFL), Battery Torch Light, Kerosene Lantern, Mobile Phone, Radio
Primary Health Centre (PHC)	All of the above plus additional, Printer and Scanner, Television, Telephone (RTcom), Computer, Celling and Standing Fans, Air conditioner, General Purpose and Vaccine Refrigerator, Internet Router, Water Pumping, Autoclave, Centrifuge, Electric Microscope (Bright field white light), Electrophoresis Genotype Machine, and Hematocrit Machine for Packed Cell Volume (PCV).
Comprehensive Health Centre (CHC)	All of the above plus additional, Abacus 380 (Hematology machine for full blood count), Cd4 Machine for HIV, , Hot Oven, Photoelectric Calorimeter, and Water Bath

The audit showed that the three types of health centres shared certain energy loads, particularly among the primary and comprehensive health centres. These loads included; lighting, fans, mobile phones, computers, general purpose refrigerators, solar vaccine refrigerators, centrifuges, autoclaves, electric microscopes and, for those with a borehole in their premises, water pumping systems.

The categories of electricity status observed during the audit of the rural health centres in the Federal Capital Territory (FCT) included facilities that are on-grid, facilities that are on-grid but disconnected, facilities that are on-grid, but the grid is down, and facilities that are off-grid. Figure 14, below, illustrates a graphical representation of the electricity situation in the health centres audited in FCT.

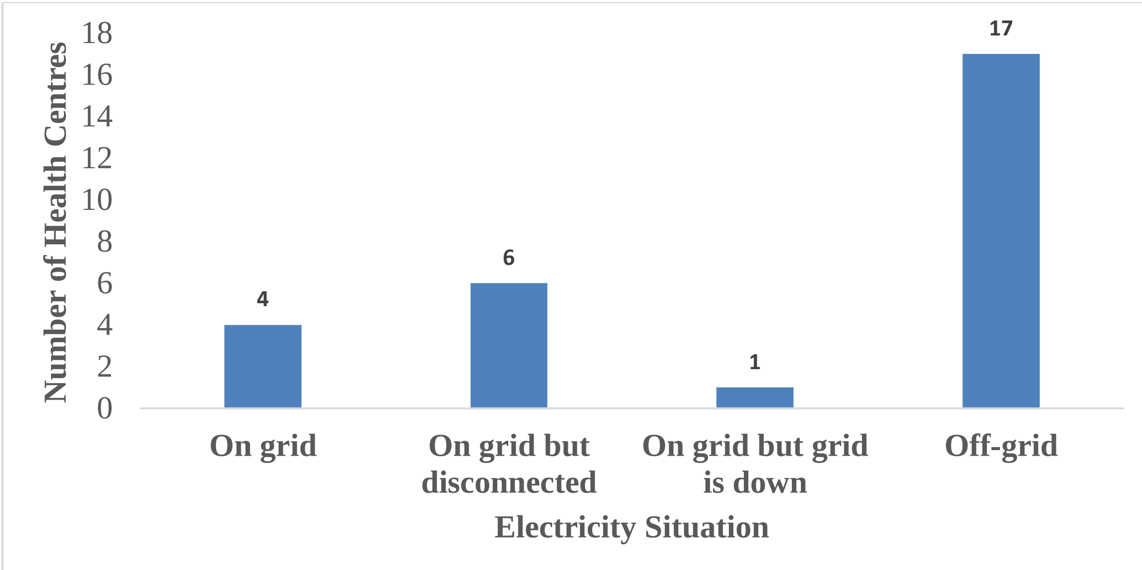

Figure 14. Electricity Situation in the Audited Rural Health Centres in the Federal Capital Territory FCT

From Figure 14 above, it shows that most of the health centres were off the grid and disconnected from the national grid. The prevalence of clinics without grid electricity explains the urgency of finding solutions to increase electricity access in rural health centres. The audit carried out by the author revealed that most of the off-grid health centres relied mainly on torch lights, disposable batteries, and mobile phones lights. They spend an average of $50 annually for torch light and battery expenses. A few of them used kerosene lamps and candles as a source for lighting.

Some of the off-grid facilities relied on a generator as a backup, but the clinics were constrained by the operation and maintenance cost of running the generator for about 12 hours daily. Considering the future of the off-grid facilities, more than 90% of the health centres audited were about 25 km from the existing electricity grid. Consequently, it may be many years before these centres are be connected to the grid.

The audit carried out by the author for grid-tied facilities revealed that most of the facilities experienced frequent and prolonged interruptions in electricity supply and/or erratic power supply. Most facilities were not assured of even three hours of power supply daily. These health centres that faced the predicament of erratic grid power supply were dependent on use of a generator. However, the health centres were financially constrained, which restricted their daily use of the generator.

The facilities that were disconnected from the grid had disconnection caused by backlogged or accumulated electricity bills and an unwillingness to pay high monthly bills that are not commensurable with the services (erratic power supply) rendered to the health facilities.

The facility with a grid connection that was down had lost their connection because of a faulty transformer. From the information gathered, they expected that it might take up to six months before the transformer was fixed.

Other Sources of Power and Amenities in Both On-grid and Off-grid Facilities

During the audit of the on-grid and off-grid rural health centres, commonly used equipment included generators, solar photovoltaic systems, solar-powered vaccine refrigerators, solar-powered borehole pumps, AC water pumps, and hand pumps. Figures 15 and 16, below, illustrate a graphical representation of common equipment found in health centres audited in the Federal Capital Territory (FCT).

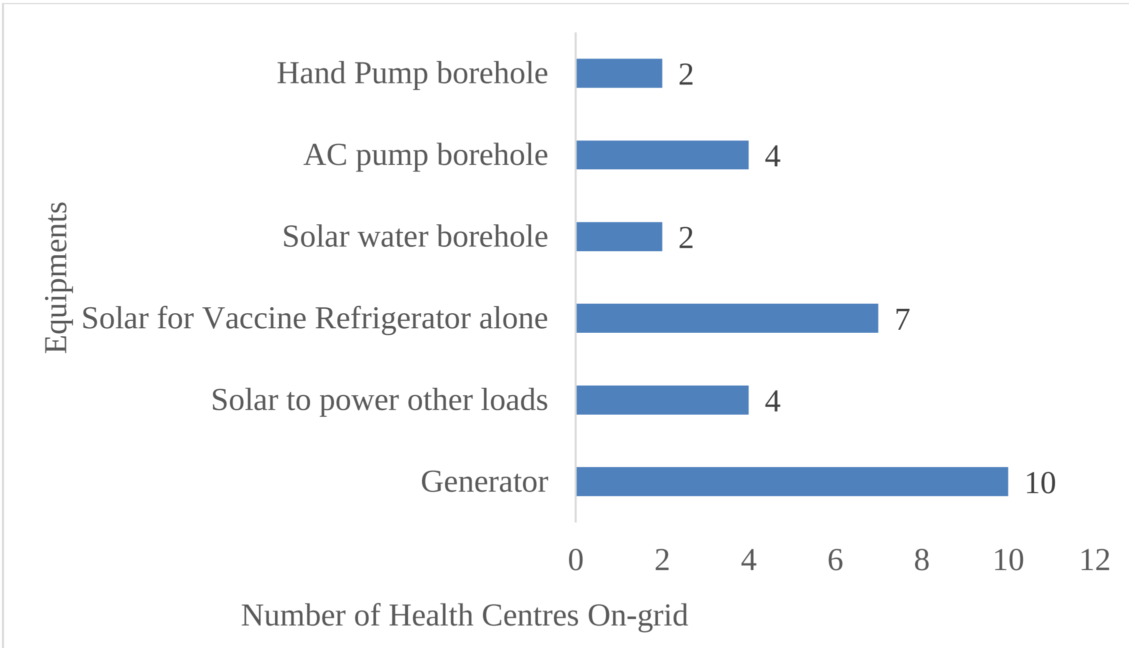

Figure 15. Common Equipment Found at Eleven Grid-Connected Health Centres in the Federal Capital Territory (FCT)

Despite the connection of the facility to the national grid, Figure 13, above, shows the dominance in the use of generators compared to other energy sources. The use of a generator as a backup source of power by ten out of eleven facilities indicates that the power supply from the grid is unreliable. Solar vaccine refrigerators are also very common even when facilities are connected to the grid because of the need for reliable electricity to power refrigerators that store vaccines for immunization purposes. Vaccines are critical for contributing to reduced child and newborn mortality. Other equipment like water pump/boreholes are an indication of the importance of water in rural health centres, and reliable energy is needed to enable its provision for patient and staff use (otherwise hand pumps must be used).

The equipment found in the off-grid health centres in the Federal Capital Territory (FCT) is illustrated in Figure 16 below.

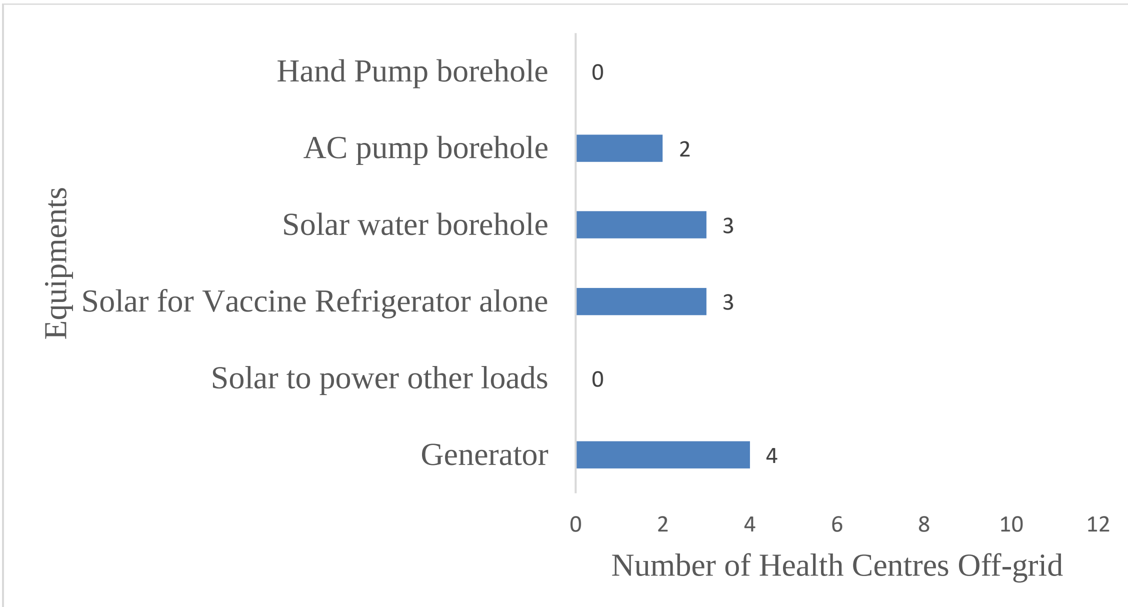

Figure 16.Common Equipment Found at Seventeen Off-grid Health Centres in the Federal Capital Territory (FCT)

Despite the energy challenges the off-grid health centres are facing and available technology for basic service, Figure 16 shows that the use of solar PV systems to power loads like light bulbs, appliances, and medical equipment (other than vaccine refrigerators) is currently negligible. The lack of access to electricity through solar power or any other sources emphasizes the need to support development for improved energy access for the off-grid facilities. Providing a reliable power supply to these facilities will enhance their ability to render health care in their service territories.

Furthermore, the use of solar power for vaccine refrigerators and borehole pumps in the 17 off-grid health centres audited is low compared to the use of solar power for these applications at grid-connected facilities. The solar vaccine refrigerators and borehole is low in numbers in off-grid facilities because most unreliable grid-tied systems are in the urban areas, they are easy to access and tend to be the first beneficiary from donors. These, again, highlights the need for improved energy service provision in off-grid facilities. The use of a generator in the off-grid facilities was observed in about 25% of the 17 audited sites. The use of generators is higher than the use of solar power, in spite of the fact that the generators poduce environmental pollution (noise and carbon emissions). Nonetheless, generator use is relatively low in the off-grid facilities compared to the grid-connected centres. The lower level of generator use in the off-grid facilities could be due to the high cost of operation and maintenance, suggesting that they may have limited access to resources to cover costs compared to the grid-connected facilities.

Solar System Design and Economic Analysis for IBWA 1 Primary Health Centre

In this section, results related to the load analysis and solar system sizing for the IBWA 1 primary health centre are presented, including analyzed results for the following items:

1. The results for an analysis of electric loads without considering energy efficiency upgrades,
2. A summary of solar PV system size and energy production calculations, and
3. An estimate of the initial cost of the solar PV system using a deep cycle battery.
4. Presentation of results for analysis of the loads for the health centre once energy efficiency measures have been applied.
5. Associated system characteristics and economic cost analysis.

6. An estimate of greenhouse gas emissions from the various system types.
7. A sensitivity analysis for selected parameters.

A comparative analysis is included for scenarios with and without the use of energy efficiency measures. A similar presentation of results is repeated for Scenario 2, which involves use of a lithium-iron phosphate battery instead of a lead-acid battery, and a comparative analysis is included showing differences between Scenarios 1 and 2.

Load Analysis without Energy Efficiency Upgrade for Scenarios 1 and 2

The existing and future loads for Ibwa 1 PHC and daily use pattern are presented in Table 19 below. An additional tolerance (contingency) of 15% on the power to be used for 24hours daily was considered for the solar system to ensure a conservative design. A detailed analysis of the load for the system is found in Appendix B, Table B-2.

Table 19. Existing and Future Loads and Use Pattern for Ibwa 1 PHC

Load Type	Power (W)	Daily use pattern (Hours)
Existing Loads		
Incandescent Light Bulbs	60 W to 75 W	8 hours interior lighting, 12 hours exterior lighting
Ceiling Fan	100 W	10 hours
Desktop Computer	100 W	5 hours
Mobile Phones and Tablets (Charging and Phantom Load)	54 W	5 hours
Future Loads		
Solar Vaccine Refrigerator	82 W	24 hours
Centrifuge	110	2 hours
Bright Electric Microscope	30	3 hours

The estimated daily load profile for Ibwa 1 PHC without energy efficiency upgrade applied is represented in Figure 17 below.

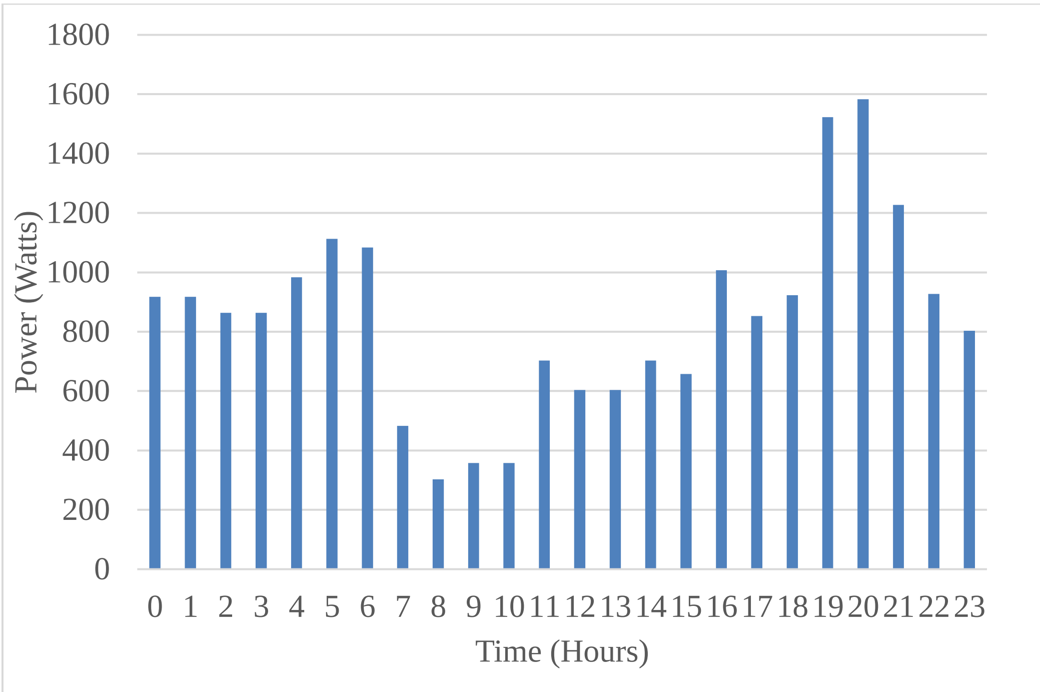

Figure 17. Estimated Daily load Profile for Ibwa 1 PHC Without Energy Efficiency Upgrade Applied

Table 20 below presents a summary of the load analysis without energy efficiency measures applied

Table 20. Summary of Load Analysis without Energy Efficiency Measures

Parameter	**Value/Units**
Load from Lighting & Fans (kW)	1.4kW
Other Equipment's/Appliances (kW)	0.2kW
Future Loads (kW)	0.5kW
Peak Power (Lighting, Fans, Other Equipment's, and Future Loads) (kW)	2.1kW
Daily Energy Demand (kWh)/day	22kWh/day
Yearly Energy Demand (kWh/Yr.)	7994kWh/year

System Design Outcomes and Associated Costs without Energy Efficiency Measures Applied for Scenario 1

The system design outcomes are summarized in terms of the size of the solar array for the system and the energy produced by the system. The associated costs included the installed cost of solar PV to meet the load and the other initial outlay cost of the system, including value added tax (VAT) of 5% and an import duty of 5% added. The summarized result is presented in Tables 21 and 22, below. The costs of individual system components can be found in the bill of engineering measurement and evaluation sheet (BEME) in Appendix C.

Table 21. Summary of System Design Outcomes and Associated Costs

System Size (KW)	**Energy Produced (KWh-year)**	**PV Cost Per Watt ($) USD/Watt**	**Initial Cost of System ($) USD**	**Initial Cost of System (₦) Naira**
8.3	1,0300	13	106,740	38,426,400

Load Analysis with Energy Efficiency Measures Applied for Scenario 1 and Scenario 2

Energy efficiency measures were applied to the existing load at IBWA1 PHC. A replacement of the 60 W incandescent light bulbs with 10 W LED light bulbs and the 75W incandescent bulbs with 13 W LED bulbs was included in the analysis. The replacement LEDs should produce the same level of light output, approximately 900 lumens and 1100 lumens, respectively, as the incandescent bulbs while consuming considerably less energy. Energy efficiency measures were also applied to the fans, reducing the power consumption from 100 W to 62 W. As discussed previously, the design load included an increase in the total load by 15% as a contingency. A detailed summary of the load analysis including the energy efficiency is found in Appendix C4, while Table 22, below, present's summary results for the load analysis for IBWA1 Primary Health Centre.

Table 22. Summary of Load Analysis with Energy Efficiency Measures Applied

Parameter	**Value/Units**
Load from Lighting & Fans (kW)	0.4 kW
Other Equipment's/Appliances (kW)	0.2 kW
Future Loads (kW)	0.3 kW
Total Loads (Lighting, Fans, Other Equipment's, and Future Loads) (kW)	0.9 kW
Daily Energy Demand (kWh)/day	10.5 kWh/day
Yearly Energy Demand (kWh/Yr.)	3,833 kWh/year

The estimated daily load profile is represented in a bar chart in Figure 18, below.

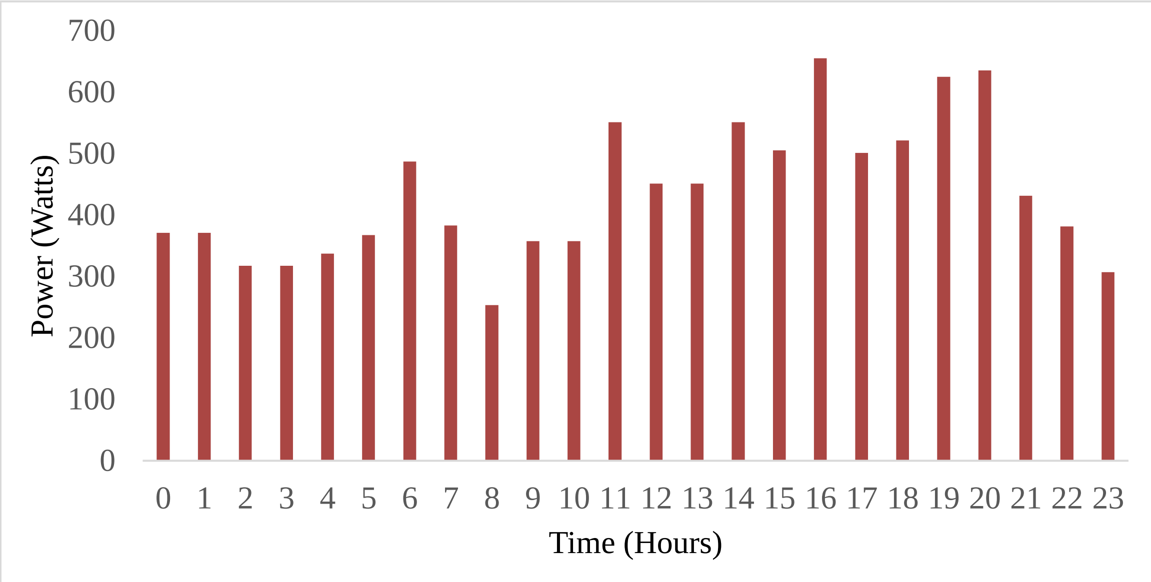

Figure 18.Estimated Daily Load Profile with Energy Measures Applied for IBWA 1 Primary Health Centre (PHC)

The estimated load profile for the IBWA 1 PHC in Figure 18 shows that the expected peak load hour is at 4:00pm, and the peak power at this time is 655 W. There is also a high-power draw at 11:00 am and 2:00 pm. The increase in load between 7:00 pm and 8:00 pm is expected, as this is the period when most appliances are in use. The decrease at 8:00 am and 11: 00 pm is expected, as the activities in the health centre reduces at this time of the morning and evening. The daily load profile also reflects the fact that most appliances are not in operation between 11:00 pm and at about 5:00 am. The typical appliances in use at these times are the vaccine refrigerator that run for 24 hours and security lights around those hours. Lighting in rooms between these periods may also contribute a small fraction, especially during emergencies like child labor. The daily load profile also indicates that the inverter used for the design will not operate at its highest efficiency at all times. In the design calculations a weighted average of the power consumption with comparison to the efficiency of the inverter curve was done to cater for inefficiencies. The actual efficiency of the inverter (Cotek SD 1000 248 > 1000-Watt Pure Sine Inverter 48Vdc/240VAC/50Hz) is 90%, but 84% efficiency was estimated for Scenario 1&2 with energy efficiency upgrade.

Solar Resource at IBWA 1 Primary Health Centre

The solar resource availability for IBWA 1 Primary Health Centre is illustrated in Figure 19, below.

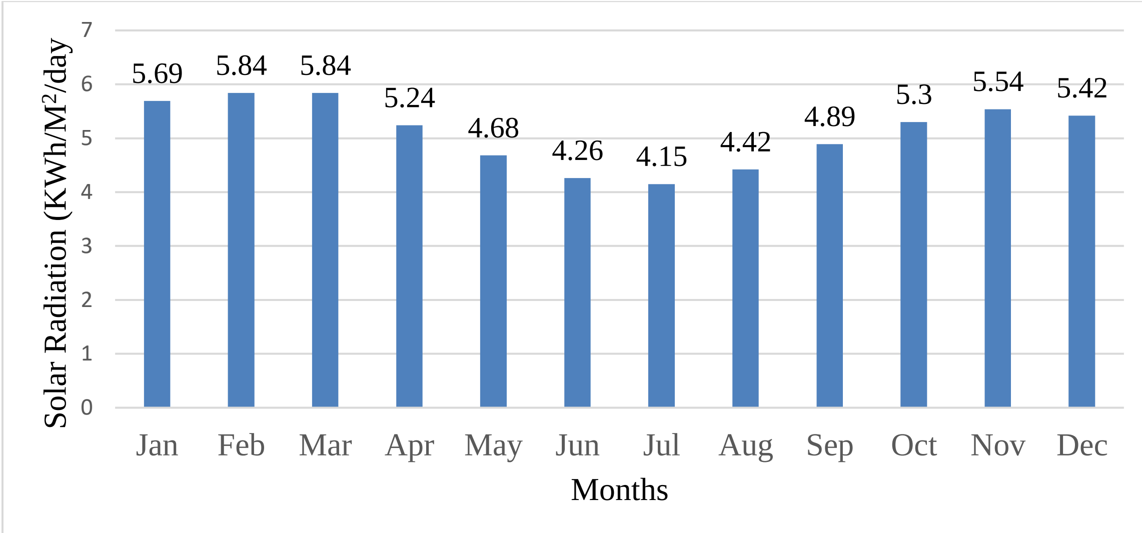

Figure 19. Average Daily Solar Resource per Month at IBWA 1 PHC

From Figure 19, July is close to the summer solstice in the Northern Hemisphere. Nigeria is close to the equator, so the amount of available sun does not change very much due to the tilt of the earth. Instead, weather patterns (rainy season) is the reason that there is less sun during June and July. The solar radiation in the month of July at Ibwa1 primary health centre is 4.15 kWh/m^2/day at roof tilt 21°. The sizing of the solar array is based on this month with the lowest solar radiation to ensure adequate energy even during cloudy periods.

Results from Solar Shading at Site

Losses due to solar shading contribute to the sizing of the solar array. Figure 20, below, illustrates the losses due to shading as measured by the Solmetric Sun Eye 210 instrument at the health facility.

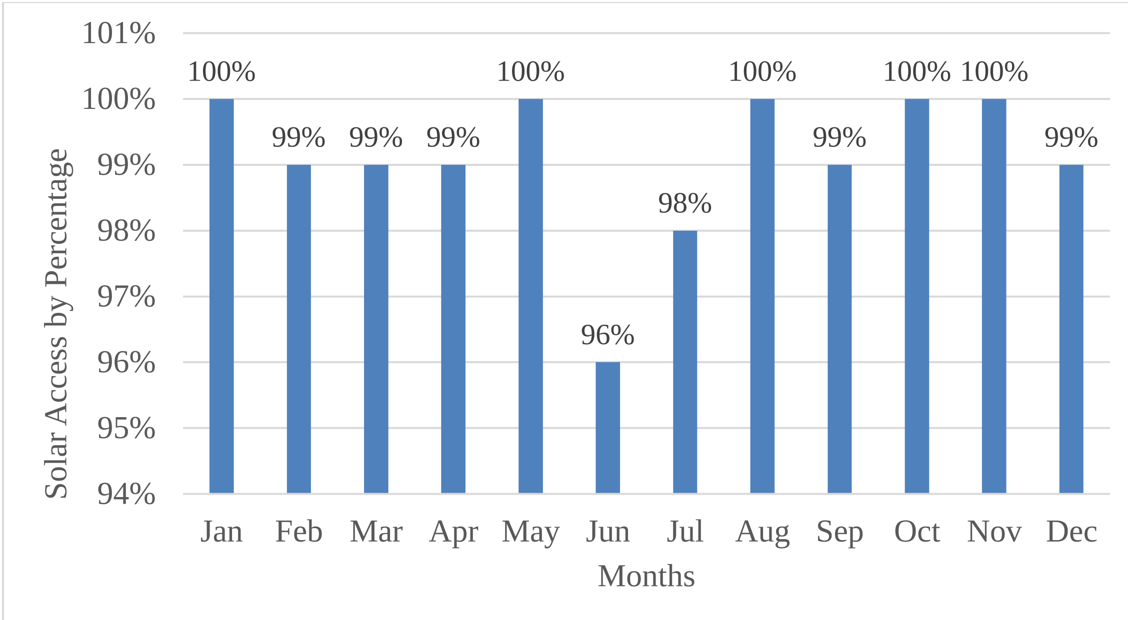

Figure 20. Percentage of Solar Access Available at IBWA 1 Health Facility

From Figure 17, July was used as the month with the highest shading loss and will reduce the efficiency of the system. In the design calculation, 98% shading in July was used instead of 96% in June to account for losses because the solar radiation at the month of June (4.26 kWh/m^2/day) is greater than that of July (4.15 kWh/m^2/day) at 21^0 tilt angles. Details results from the Solmetric Sun Eye tool used for the solar shading measurement are found in Appendix B, Figures B-1 and B-2.

<u>System Design Outcomes and Associated Costs with Energy Efficiency Upgrade for Scenario 1</u>

The results from system design outcomes and associated costs are summarized in Table 23, below. The costs of individual system components can be found in the bill of engineering measurement and evaluation sheet (BEME) in Appendix C, Table C-19, but a summary of the components used for the design is presented in Tables 23 to 25, below.

Table 23. Summary of System Design Outcomes and Associated Costs

System Size (KW)	**Energy Produced (KWh-year)**	**PV Cost Per Watt ($) USD/Watt**	**Initial Cost of System ($) USD**	**Avoided Cost from Utility Bill & O &M Cost of Generator $ (USD)**
4.1	5,150	9.2	38,411	4,347

Comparing results from Table 21 and 23

Tables 21 and 23 above shows that it is less expensive to install a smaller system than a larger one. The system size of 4.1 kW system (small system with energy efficiency upgrade applied) costs $ 9.2/watt, while the larger system (without energy efficiency upgrade applied) costs $13/watt for a system size of 8.3 kW. The result in this difference is because the cost of battery for the 8.3kW system is higher.

Table 24. Summary of Key Components Used for the Solar Design for IBWA 1 PHC

Item Description	**Quantity**
345 W Mono Crystalline Solar Module, 24V, Model SRP-345-6MA	12
6V 820 Ah Flooded Lead-Acid Deep Cycle Battery	16
MPPT Charge Controller 80A, 48V	1
Cotek SP1000 > 1000 Watt 48 VDC Pure Sine Inverter 2300W/48Vdc/240VAC/60Hz	1

The wire sizing presented in Table 22 was done according to the American wire code standards.

Table 25. Summary of Wire Sizing for Ibwa 1 Primary Health Centre

PV Source Wire	Minimum Required #14 AWG USE-2. Marking Negative with White Electrical Tape.
PV Output Wire	#6 THWN-2. Red for Positives, White for Negatives, and then Green for Ground.
Battery to Inverter Cables	2/0 THW Cable. Mark Negative Cable White with Electrical Tape. Red should be used for positives.
Inverter Output Wire	#4 AWG Wire. Black for L1, White for Neutral, Green for Ground.

Other estimated costs under the energy efficiency case study are the cost for energy upgrade appliances and equipment's, operation and maintenance cost of the solar PV system, back-up generator, and the cost associated with use of the grid all operating inclusively in Ibwa primary health centre. These costs are presented in Tables 26 to 28, below.

Table 26. Cost Summary Applying Energy Efficiency Upgrade

Appliance/Equipment	Quantity	Cost ($)
Universal LED E27 Light Bulb 2835 SMD	9	$93
KDK-M56XG 56"	4	$272
GRAND TOTAL		**$365**

From Table 26 above, the total cost for energy efficiency ($365) upgrade is added to the initial design cost of the system, and it is expected to be paid for either by the health centre for the self-funded case or by an external source for grant/subsidy case.

Table 27. Costs Associated with Utility at Site. Source: NERC, 2015 and information from author's audit)

Cost of Utility or Tariff ($/KWh)	Grid Re-connection Cost ($)	Cost Expended on Battery Torch Light ($)/Year
0.10	125	50

Table 28. O & M Cost of Solar PV and Avoided Costs from Generator and Utility

Annual O & M Cost for Solar PV ($/KW-Year)	Avoided Cost from Using Generator ($)/Year	Avoided Cost from Utility for the first year ($)
951	3891	456.1

The grid re-connection fee and the cost expended on battery torch light from Table 27 above were determined during the site audit. The annual O & M cost of solar

PV, avoided costs from using generator, and avoided cost from utility were estimated. These estimated costs were relevant to determine the life cycle benefit of the solar system, the NPV, and the payback period during the economic analysis.

Funding Sources for Scenario 1

The possible funding sources to cover the initial cost of installation, and maintenance and equipment replacement considered for Scenario 1 are Case 1: self-funding, Case 2: funding from a grant/subsidy. An independent investor's model (IIM 1) was developed from an investor's perspective.

Self-funding (Case 1) requires the health centre to cover the total cost of buying and installing the solar PV system and also take responsibility of the monthly or annual maintenance cost and equipment replacement after 10 years of the solar PV system. The subsidy funding (Case 2) would come as either a grant or a donation covering 100% of the initial cost, but the monthly or annual maintenance cost and equipment replacement after 10 years would be the responsibility of the health centre. As said earlier, the Independent Investors Model 1is totally independent of Case 1 and 2, but it's designed from the investor's perspective under Scenario 1. In this model there would be a contract agreement between the investor and the health centre (customer). The initial cost of buying and installing the solar PV system would be borne by the investor, but the health centre would be on an annual repayment plan for up to 10 years with a markup on the initial cost. The equipment replacement cost after 10 years would be the responsibility of the health centre. The investor would also cover the maintenance cost only, for 10 years, but it would be open to negotiation after 10 years to either continue to maintain the system or include equipment replacement in the contract. Tables 29 and 30, below, present the different costs outcomes based on these three pathways. The results in Tables 29 and 30 were calculated at a discount rate of 12%.

Table 29. Summary of cost Analysis for a Solar System for Case 1 (Self-funded)

Parameter	**Values**
Initial Cost of System ($USD)	$38,411
Annual Maintenance Cost ($USD)	$951
Equipment Replacement Cost (inverter after 10years and battery after 13years) ($USD)	$17, 605
Life Cycle Cost of PV (LCC) ($USD)	$63, 203
Levelized Cost of Energy ($/KWh)	$1.6/kWh
Net Present Value (NPV) ($USD)	-$10,380
Internal Rate of Return (IRR, %)	7%
Simple Payback Period (Years)	13
Discounted Payback Period (Years)	Over 20 years of project life

Table 30. Summary of cost Analysis for a Solar System Case 2 (Subsidy/Grant Funding)

Parameter	**Values**
Initial Cost Covered by Grant ($USD)	$38,411
Annual O & M Cost	$951
Equipment Replacement Cost (inverter after 10 years and battery after 13years) ($USD)	$17, 605
Life Cycle Cost of PV (LCC) ($USD)	$24,800
Levelized Cost of Energy ($/KWh)	$0.6 /kWh
Net Present Value (NPV) ($USD)	$28, 031
Internal Rate of Return (IRR, %)	0
Simple Payback Period (Years)	0
Discounted Payback Period (Years)	0

Comparison of Results from Case 1 (Self-Funding Source) and Case 2 (Funding by Subsidy)

The estimated results presented in Tables 29 and 30 illustrate that the net present value is negative when the initial cost of the system is funded by the health centre, but when covered by subsidy, this affects every aspect of the analysis positively. For example, the levelized cost of energy (LCOE in $/KWh) is reduced by 63% and the life cycle cost is reduced by 64 %. The net present value increases positively when subsidy covers the initial cost. The payback period and the internal rate of return are zero when subsidy covers 100% of the initial cost and the facility covers the equipment replacement cost.

The Independent Investors Model 1(IIM 1) for Scenario 1

The independent investors model was developed in view of the investors perspective to invest and make return on investment. The model that was developed to ascertain how profitable the investment is, the best profit margin to set for health centre and desired payment method. Table 31 below summarizes the results obtained for the independent investors model (IIM 1).

Table 31. Summary of Results for the Independent Investors Model

Parameter	**Value**
Initial Cost ($USD)	$38,411
Annual O & M Cost ($USD)	$951
Annual Repayment for 10 Years ($USD)	$4, 610
Margin on Upfront Cost (%)	20%
Net Present Value (NPV)	$672
Internal Rate of Return (IRR)%	12%
Simple Payback Period (Years)	8
Discounted Payback Period (Years)	19

The results show an economically viable investment for the independent investor; this model may be beneficial to health centres relative to Case 1(self-funded) because of the repayment plan. It is economically viable for the investor because the net present value is positive, and the return on investment is 12%. The expected annual repayment cost for the health centre is $4, 610 for the next 10 years.

System Design Outcomes and Associated Costs without Energy Efficiency Upgrade to Scenario 2

The system design outcomes for Scenario 2 (lithium iron phosphate batteries) are presented using an approach that is similar to that used for the results for Scenario 1 (lead-acid batteries). The same, solar resource, and shading loss values are used. The summarized result is presented in Tables 32 and 33, below. The costs of individual system components can be found in the bill of engineering measurement and evaluation sheet (BEME) in Appendix C, Table C-19. The only difference in this Scenario is that the existing load was used for the load analysis without energy efficiency upgrade.

Table 32. Summary of System Design outcomes and associated costs without energy efficiency upgrade

System Size (KW)	**Energy Produced (KWh-year)**	**PV Cost Per Watt ($) USD/Watt**	**Initial Cost of System ($) USD**	**Initial Cost of System (₦) Naira**
6.7	9843	34.4	231,440	83,318,400

System Design Outcome and Associated Costs with Energy Efficiency Measures Applied to Scenario 2

The analyzed results from system design outcomes and associated costs are summarized in Table 33, below. The costs of individual system components can be found in the bill of engineering measurement and evaluation sheet (BEME) in Appendix C, Table C-19, but a summary of the components used for the design is presented in Tables 33 and 35 below.

Table 33. Summary of System Design outcomes and associated costs with energy efficiency upgrade

System Size (KW)	Energy Produced (KWh-year)	PV Cost Per Watt ($) USD/Watt	Initial Cost of System ($) USD	Initial Cost of System (₦) Naira
2.8	4,100	35	97,081	35,000,000

Table 34. Summary of Key Components Used for the Solar Design for IBWA 1 PHC

Item Description	Quantity
345 W Module, 24V, SRP-345-6MA. Mono Crystalline	8
12V 500Ah Lithium Ion Phosphate Deep Cycle Battery	8
MPPT Charge Controller 60A, 48V	1
Cotek SP1000 > 1000 Watt 48 VDC Pure Sine Inverter 2300W/48Vdc/240VAC/60Hz	1

The wire sizing presented in Table 35 is summarized below. The sizing is according to the American wire code and standard.

Table 35.Summary of Wire Sizing for IBWA 1 PHC

PV Source Wire	Minimum Required #14 AWG USE-2. Marking Negative with White Electrical Tape
PV Output Wire	#6 THWN-2. Red for Positives, White for Negatives, and then Green for Ground.
Battery to Inverter Cables	4 THW Cable. Mark Negative Cable White with Electrical Tape. Red should be used for positives.
Inverter Output Wire	#4 AWG Wire. Black for L1, White for Neutral, Green for Ground.

A summary of system components cost can be found in the bill of engineering measurement and evaluation sheet (BEME) in Appendix D2

Funding Sources for Scenario 2

The self-funding and subsidized funding cases are also considered for Scenario 2. Tables 36 and 37, below, present the analyzed results from costs outcomes for these funding sources. The results from Table 36 and were calculated at a discount rate of 12%.

Table 36. Summary of cost analysis for case 3 (Self-funded)

Parameter	**Values**
Initial Cost of System ($USD)	$97,081
Annual O & M Cost ($USD). Assumed to be same as that of Scenario 1	$951
Equipment Replacement Cost of Inverter and Batteries after 10 Years ($USD)	$51,949
Life Cycle Cost of PV (LCC) ($USD)	$156,222
Levelized Cost of Energy ($/kWh)	$5.2/ kWh
Net Present Value (NPV) ($USD)	-$81,050
Internal Rate of Return (IRR, %)	-6%
Simple Payback Period (Years)	Exceeds Project Life
Discounted Payback Period (Years)	Exceeds Project Life

Table 37. Summary of cost analysis for case 4 (Subsidy/Grant Funded)

Parameter	**Values**
100% Initial Cost of System Covered by Grant ($USD)	$97,081
Annual O & M Cost ($USD). Same as Scenario 1	$951
Equipment Replacement Cost of Inverter and Battery after 10 Years ($USD)	$51,949
Life Cycle Cost of PV(LCC) $(USD)	$59,140
Levelized Cost of Energy ($/KWh)	$2/ kWh
Net Present Value (NPV) $(USD)	$16,0302
Internal Rate of Return (IRR) %	0
Simple Payback Period (Years)	0
Discounted Payback Period(Years)	0

Comparison of Results from Case 3 (Self-Funding Source) and Case 4 (Funding by Subsidy) for Scenario 2

The estimated results obtained from Tables 36 and 37, above, illustrate that the investment can only be viable when the outlay or initial cost is covered by a grant or through subsidy. From Table 36, the net present value is negative right from the onset of the investment for the self-funded case study. The levelized cost of energy (LCOE, $/KWh) to the site operator for the self-funded case study is about 62% higher than the subsidy funded case study. The payback period and the internal rate of return is zero when subsidy covers 100% of the initial cost. The simple payback period and the discounted payback period for the self-funded case study exceeds the project life period of 20 years.

The Independent Investors Model 2 (IIM 2) for Scenario 2

The investors model 2 developed for Scenario 2 was used to test how economically viable for the investor, if they decide to use lithium iron phosphate battery as the second choice of their investment. On the other hand, it might also show if the customer (IBWA 1 PHC) will be willing to pick Scenario 2 as their choice. The summary of analyzed results for the business model is presented in Table 38, below.

Table 38. Summary of Results for the Independent Investors Model 2 for Scenario 2

Parameter	**Value**
Initial Cost ($USD)	$97,081
Annual O & M Cost ($USD)	$951/year
Annual Repayment for 10 Years ($USD)	$15,048/ year
Break Even Margin for the Investor (%)	55%
Net Present Value (NPV)	$1700
Internal Rate of Return (IRR)%	12.2%

Parameter	Value
Simple Payback Period (Years)	7
Discounted Payback Period (Years)	18

The results show an economically viable investment for the investor, but it is not very favorable for the customer (health centre) because of the high repayment fee, except there is financial assistance from the local government area council where the health centre is located or the community or any external source. The yearly installment re-payment fee is about $15, 048 /year. Extending the years of repayment might be a good option but doing so will also increase the margin on the upfront cost from the investor.

Comparison of Scenario 1 and Scenario 2

The comparison of Scenarios 1 and 2 (systems with lead-acid batteries and lithium iron phosphate batteries, respectively) is based on the goals of the system design and the economic viability of the design for the health centre (customer). A critical factor in both scenarios is to provide adequate power supply to meet the demand of the rural health centre at an affordable cost using available funding resources. Sustainability of the designed system is another factor considered to prevent an early failure of the system. The significant difference between both scenarios is the battery used. The advantages of the lithium iron phosphate over the lead-acid include the former battery type's charge-discharge efficiency, depth of discharge, and durability. However, the lead-acid battery can serve the same purpose as the lithium iron phosphate battery if adequately managed. For example, the lead-acid battery should not be discharged beyond 50% of its capacity to ensure a reasonable service life and if one or two staffs are trained or assigned to carryout simple maintenance and report any issues on time on the battery. Besides, the health centre is responsible for the ongoing monthly or yearly maintenance and can be contracted to a company who will take sole responsibility of the maintenance within a certain agreed period.

A significant disadvantage of the lithium iron phosphate battery is the cost, and it is not yet widely used in developing countries for off-grid systems. Another disadvantage is the scarcity of the technology in the market. Lithium iron phosphate is a new technology, and it has not been widely tested over the years for off-grid systems. Considering, IBWA 1 PHC income stream ($28 monthly payment on O& M) from Table 13, it is evident that Scenario 1 (Lead-acid deep cycle battery), Case 2 (grant/ subsidy funded) seems to be the best option for the health centre, because they will only be expected to pay for the O&M cost. Moreover, the willingness to pay $28 monthly is not enough to cover the anticipated 2.5% of initial cost of system for O&M. Succinctly, the grant funded Scenario only represents the ongoing O&M and replacement costs of the system.

Figures 21 and 22 below illustrate how using these battery types may affect the economics of the design in both Scenarios 1 and 2.

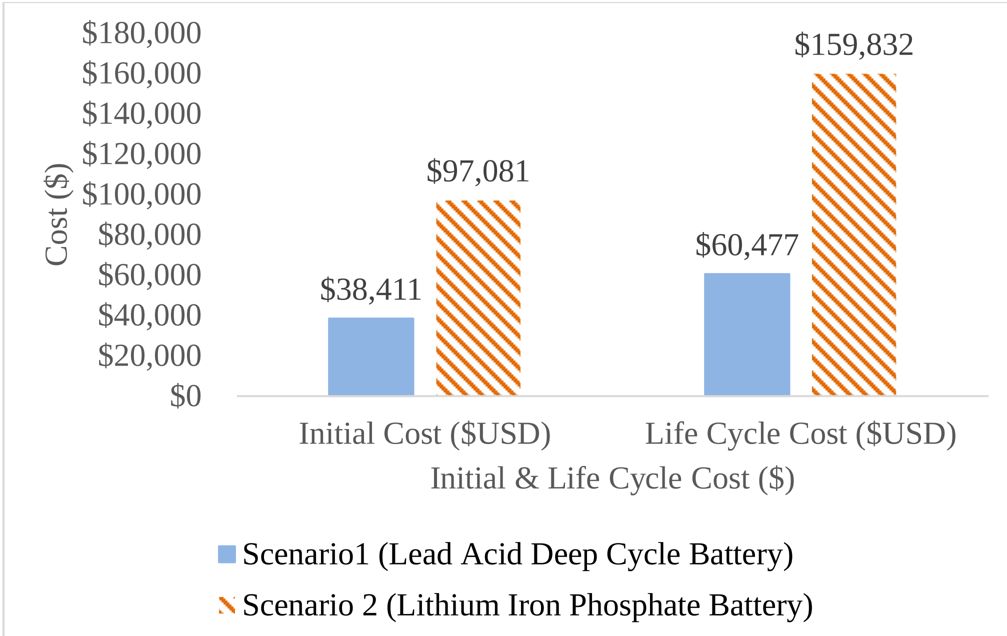

Figure 21. Shows Initial Cost of System and Life Cycle Cost for Scenario 1 and 2

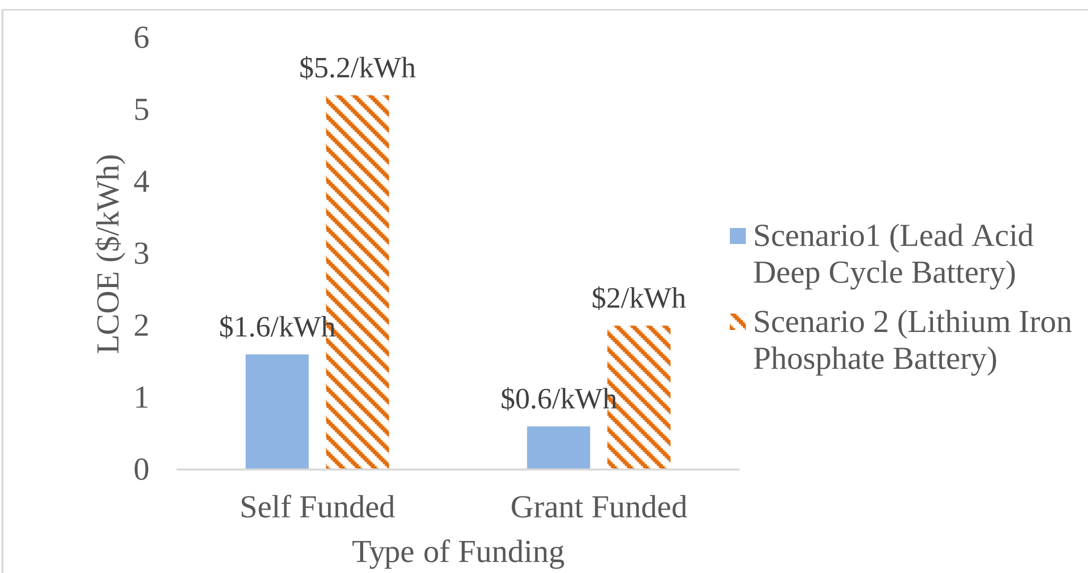

Figure 22. Levelized Cost of Energy ($/KWh) Versus Funding Type for Scenario 1 & 2.

From Figures and 21 and 22 above it is clear how the battery type considered for Scenarios 1 and 2 respectively affects the economics of the system. Both figures explain the cost estimated from energy efficiency measure applied to the load and the funding source is self-funded. The lead-acid deep cycle battery seems to be more favorable in all ramifications in terms of initial cost, life cycle cost and levelized cost of energy, except for the maintenance requirements or equipment's replacement costs they will have to deal with.

Figures 23 below illustrate the annual operation and maintenance costs and equipment of the system for both Scenarios 1 and 2 over the life time of the project and it also shows how using these battery types may affect the economics of the design in both Scenarios. Also, it is assumed that the same amount of O&M is used for both Scenarios 1 and 2.

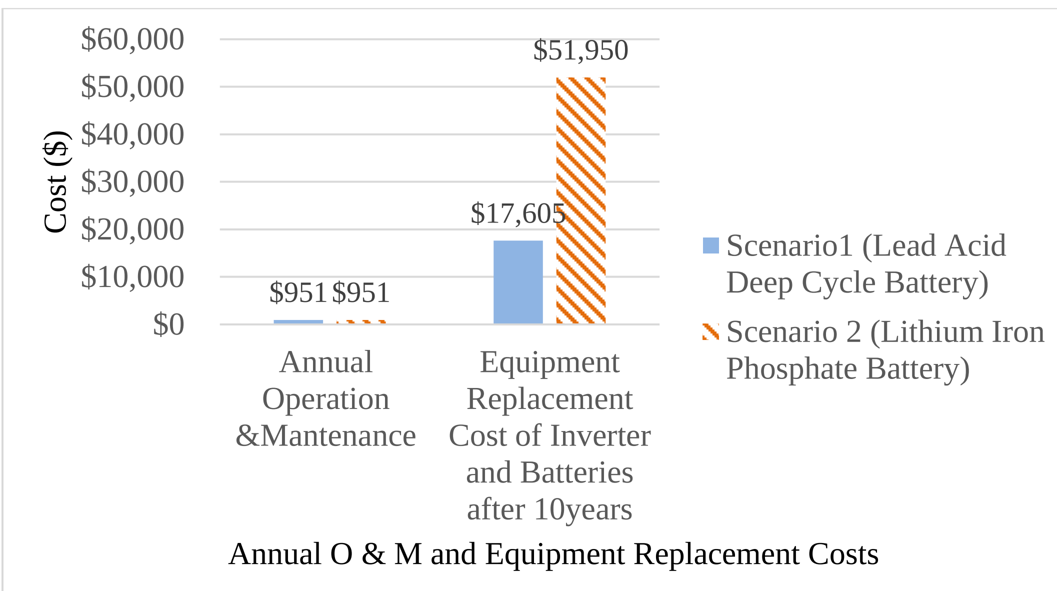

Figure 23. Annual Operation and Maintenance Cost for Scenario 1& 2

Sensitivity Analysis for Scenarios 1 and 2

The sensitivity analysis carried out for this study is based on varying the discount rates to see how it affects the economics of the system. Sensitivity analysis was carried for both battery-type scenarios as well as cases with and without subsidy support. The results of the sensitivity analysis are presented in Figures 21 to 28 below.

Sensitivity Analysis for Scenario 1

The results of the sensitivity analysis performed for Scenario 1 are presented in Figure 24 to 27.

Figure 24 below illustrates how discount rate varies with the life cycle cost (LCC) and net present value (NPV).

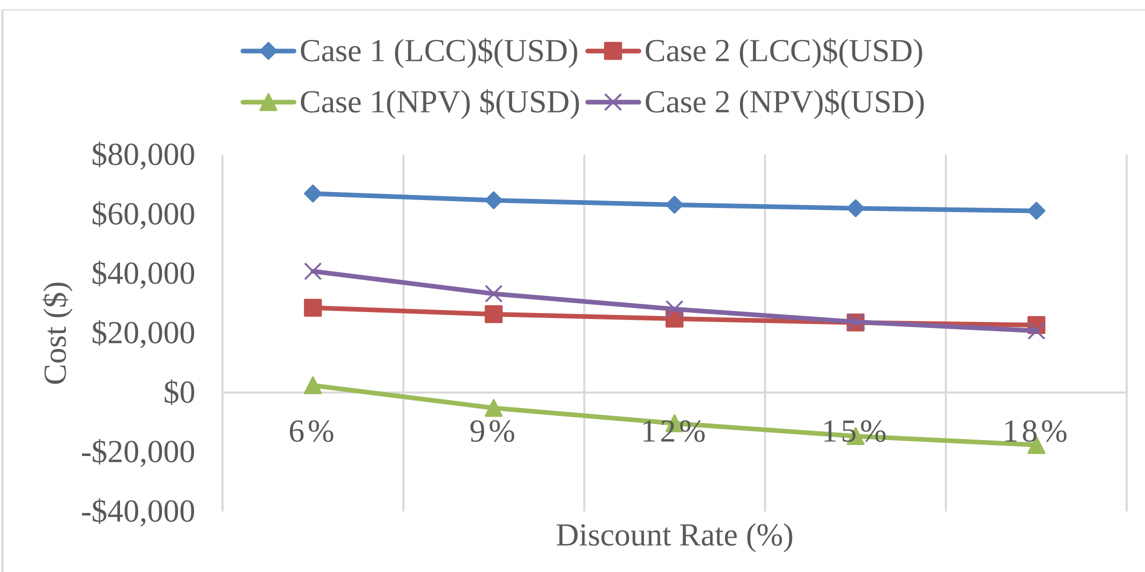

Figure 24. Sensitivity Analysis on the Life Cycle Cost and NPV as it Varies with Discount Rate for Case 1 (Self-Funded) and Case 2 (Grant Funded).

Figure 24, above, shows that as the discount rate decreases, the life cycle cost for both Case 1 (self –funded) and Case 2 (grant/subsidy funded) increases, but the overall life cycle cost of Case 1 is much higher in all cases. This is because the initial cost of the system is covered by a grant/subsidy in Case 2. The positive NPV value for Case 2 over the range of listed discount rates shows that it is more economically viable for the health centre than Case 1.

Figure 25 below shows how discount rate affects the levelized cost of energy (LCOE). The graph shows that the levelized cost of energy increases as the discount rate increases for both cases, but Case 2 has a lower LCOE because of the application of a grant or subsidy. Figure 25 below shows how discount rate affects the levelized cost of energy.

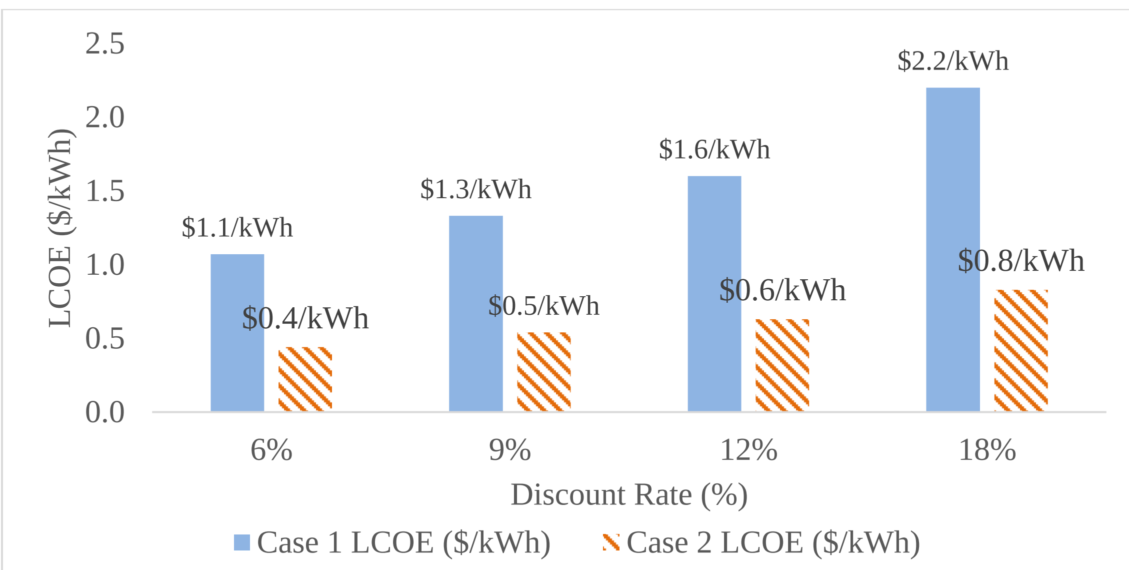

Figure 25. Shows How Levelized Cost of Energy ($/kWh) Varies with Discount Rate (%) for Case 1 & 2.

Sensitivity Analysis on the Independent Investors Model 1 for Scenario1

The sensitivity analysis result of the Independent Investor's Model 1 is presented in Figure 26 below.

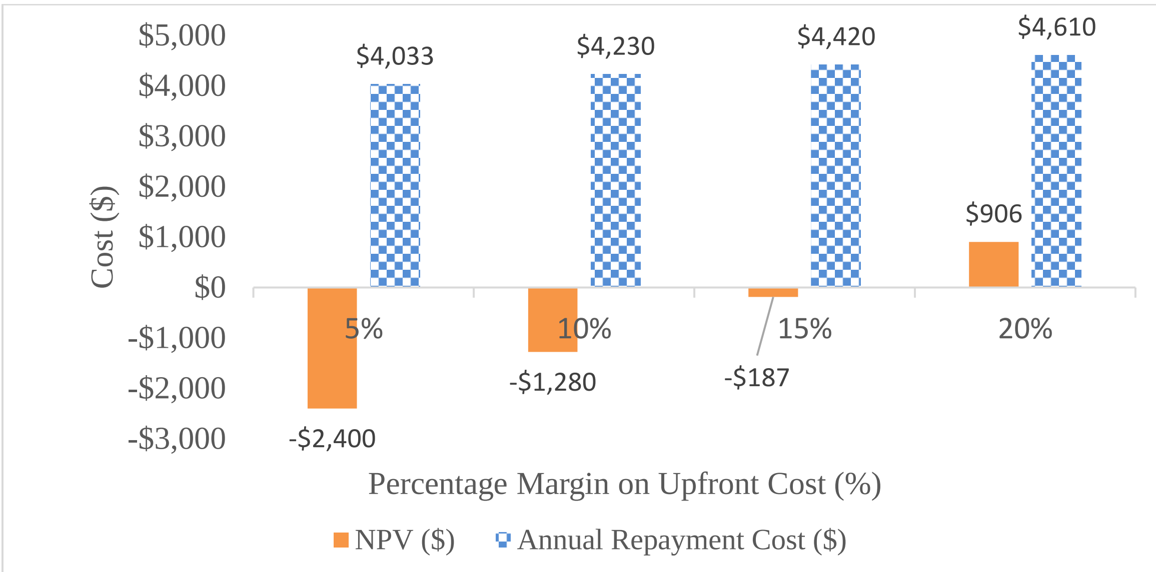

Figure 26. Sensitivity Analysis of Independent Investors Model 1 with Margin on the Upfront Cost.
'

From Figure 26 above, the result from the analysis shows that the investor will breakeven by adding a 20% margin on the upfront cost. The investment becomes economically viable at this point giving an NPV of $906 with a repayment cost of $4,610 per year for the health centre to remit the cost of the system within a 10 years period.

Figure 27 below shows the results of sensitivity analysis carried out for contribution towards the upfront cost and how it affects NPV. This contribution for example, may either be in a form of a joint venture/strategic alliance or public private partnership (PPP)

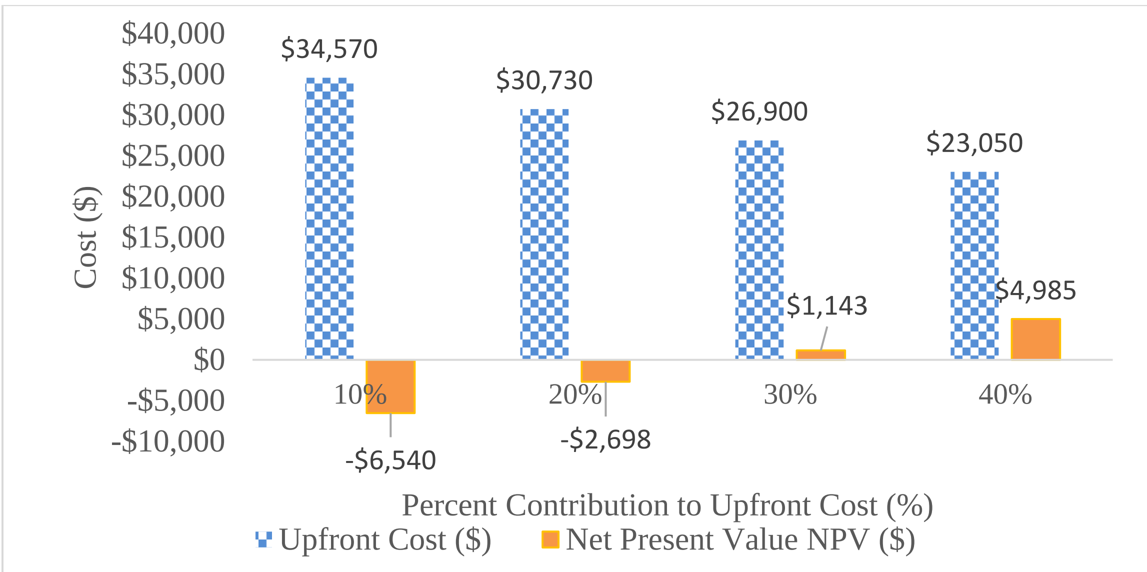

Figure 27.Sensitivity Analysis for Scenario 1on Strategic Alliance /Joint Venture at 10-40% Contribution towards the Upfront Cost and Effect on NPV.

The result from Figure 27 shows that, if 30% of the initial cost is covered by a subsidy then the investment would be profitable if the health centre is able to provide the remaining 70% of the initial cost.

Sensitivity Analysis for Scenario 2

The results of the sensitivity analysis performed for Scenario 2 is presented in Figure 28 to 31

Figure 28 below presents the sensitivity analysis done for the lifecycle cost and NPV for the lithium iron phosphate battery used for the design of the solar PV system. The analysis compares two cases; Case 3 (self-funded) and Case 4 (grant funded) for Scenario 2.

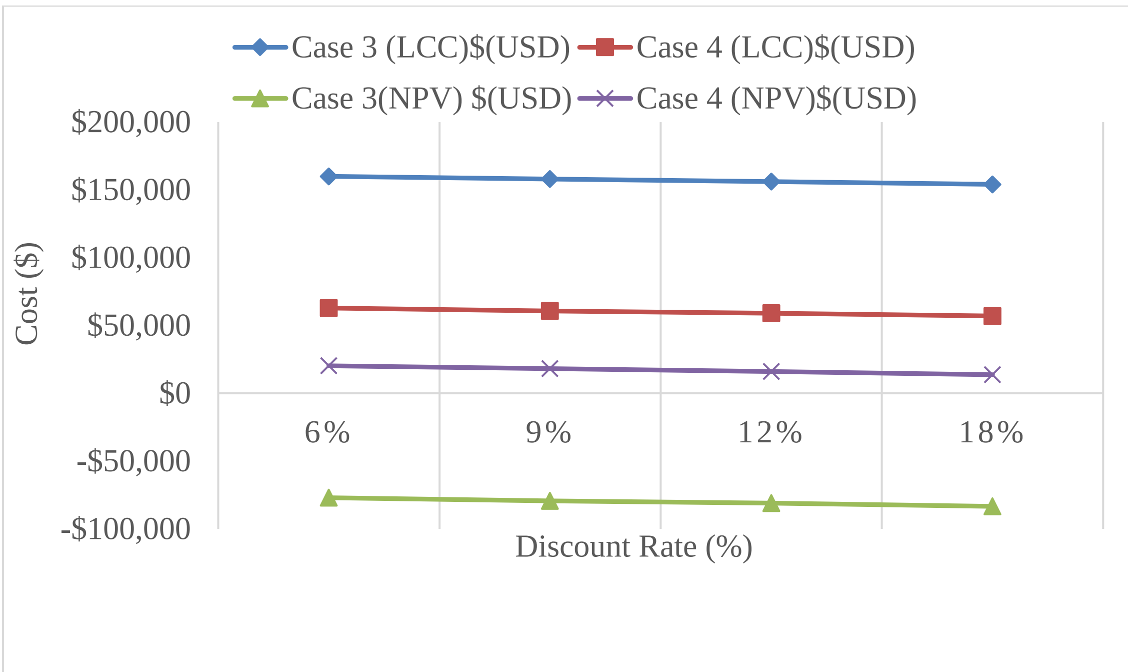

Figure 28.Sensitivity Analysis on Discount Rate on Life Cycle Cost (LCC) ($) and NPV ($) for Scenario2 Cases (3&4)

Figure 29 below, shows a sensitivity analysis of the levelized cost of energy for both Case 3 (self-funded) and Case 4 (grant funded) for Scenario 2 (lithium iron phosphate battery) for variations in the discount rate.

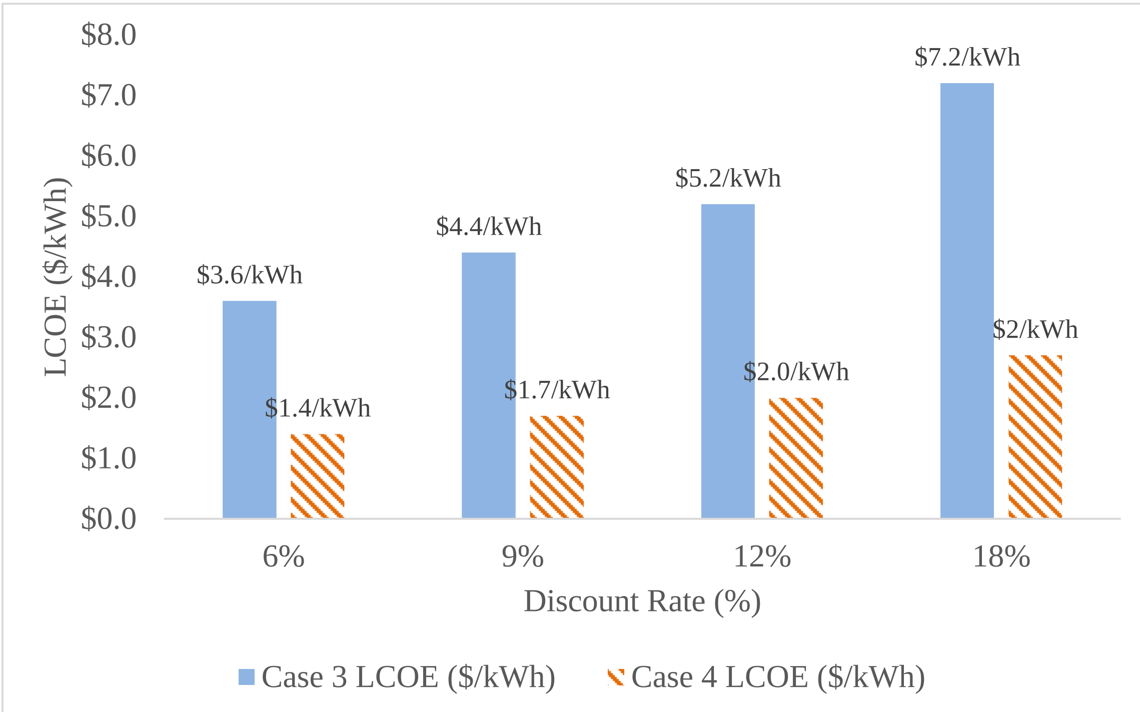

Figure 29.Sensitivity Analysis on Discount Rate on Levelized Cost of Energy (LCOE) for Scenario2 Cases (3 and 4).

Figure 30 below illustrate the sensitivity analysis carried out on the Independent Investor's Model 2, to ascertain at what margin the investor will break even, and the associated annual repayment cost for the health centre to pay for the system in10 years.

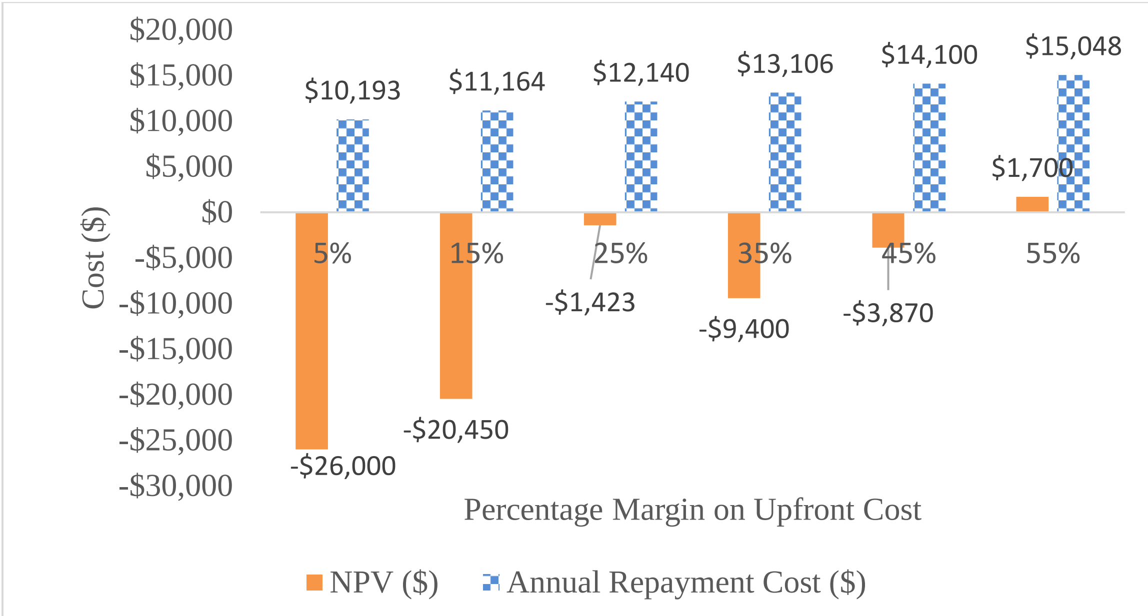

Figure 30.Sensitivity Analysis of Independent Investors Model 1 with Margin on the Upfront Cost.

From Figure 30 above, the result from the analysis shows that the investor will breakeven by adding a 55% margin on the upfront cost

Figure 31 below shows the results of sensitivity analysis for Scenario 2 carried out for either a joint venture/strategic alliance or public private partnership (PPP) contribution towards the upfront cost and how it affects NPV

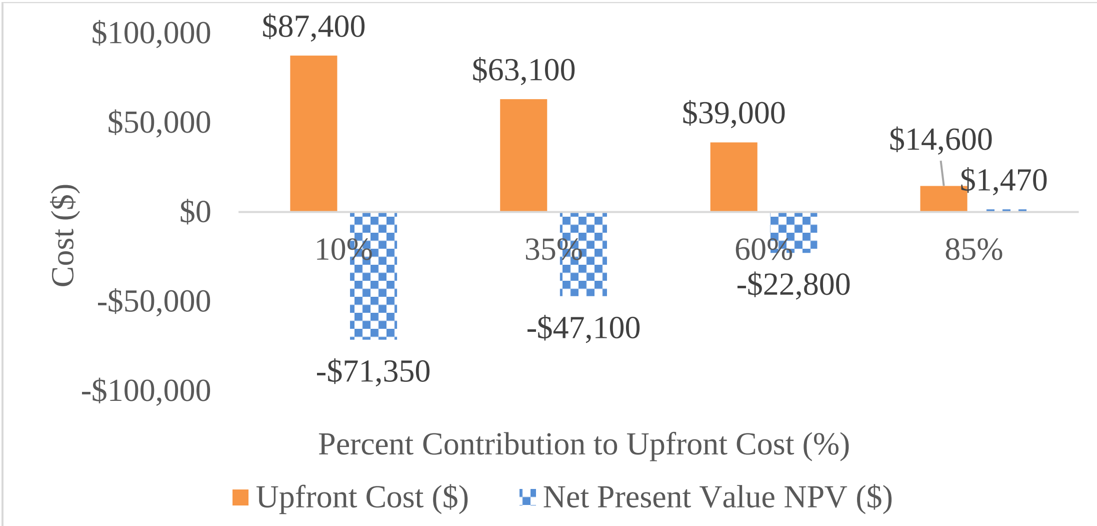

Figure 31. Sensitivity Analysis for Scenario 2 on Strategic Alliance /Joint Venture at 10-85% Contribution towards the Upfront Cost and Effect on NPV

Comparison of Sensitivity Analysis for Scenario1 and 2

The sensitivity analysis from Figure 24 to 31 shows that the preferred option for the IBWA 1 PHC is Scenario1, Case 2 (i.e. lead-acid battery with subsidized initial costs). The case compares favorably to Scenario2, Case 4 (i.e. lithium-based battery with subsidized initial costs) because the lead-acid battery is less expensive than the lithium iron phosphate battery. As the discount rate increases in both cases (Case 2 and Case 4), the life cycle cost, the levelized cost of energy, and the NPV all decline. Because it was assumed that the health centre received a grant to cover the upfront cost in both cases, the IRR on investment and payback time are not calculated. These subsidized cases are highly beneficial for the health centre, as the only costs incurred are for operation/maintenance and equipment replacement. The clinic may be able to obtain funding from the Local Area Council or use the savings from avoided utility bills and ongoing generator O & M costs of $4, 350 from Table 28 to cover the costs of replacement of key equipment, such as the inverter and batteries after 10 years. Besides, the health centre may borrow money from an international or local finance corporation at a low-interest rate from 6% below to make it more viable. Because from Table 24, NPV is positive at an interest rate of 6%.

The operation and maintenance cost of the solar PV system for IBWA1 primary health centre is an important aspect of this analysis. The O & M cost is not free; the cost requires a regimen of continual monitoring and inspecting of the system after installation. Keeping up to date on the monitoring and inspection should, help address issues that may arise in the future like repairs, and it may also enhance the system performance and ensures sustainability of the system. In this study, the O & M cost used for Scenario 1 was assumed for Scenario 2, because lithium iron phosphate batteries are durable and efficient and may require low maintenance costs. Figure 32 below shows a sensitivity analysis on O &M cost for both Scenarios 1 and 2 at different percentages on the upfront cost.

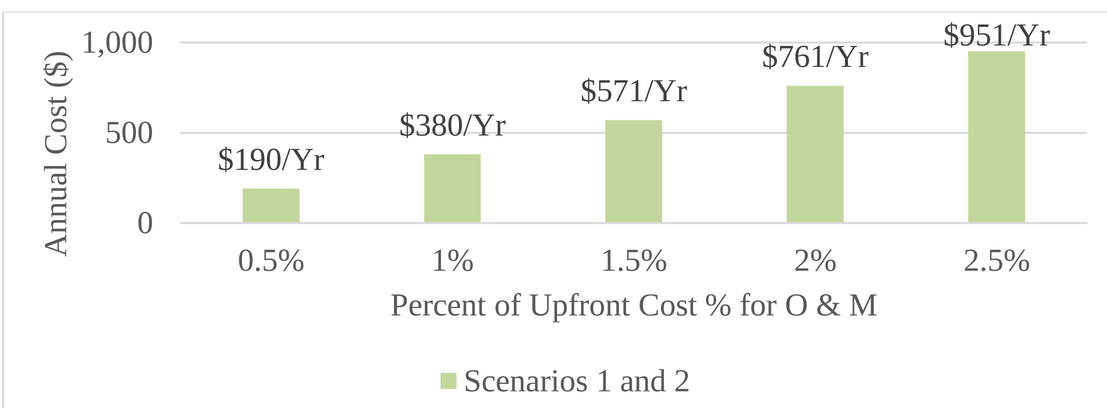

Figure 32.Sensitivity Analysis on O & M at Different Percentages on the Upfront Cost.

The percent on the upfront cost used for this analysis ranges from 0.5% to 2.5% (ECN, 2018; Electric Research Institute, 2010; European Commission, 2014; Thomas et-al, 2014; Szabo et, al, 2011). The information gathered from the audit presented in Table 13, shows that the health centre is willing to pay an O & M cost of $28 monthly resulting to about $336 annually. So, from Figure 32, above, the result from the sensitivity analysis shows that the health centre income for O & M falls in the range of 0.5% to 1% of the upfront cost. Furthermore, if other costs like expenses incurred on battery torch lights ($50 per annum) or costs from savings from use of generator maintenance or avoided cost of electricity bills for an unreliable grid, if connected, the health centre may be willing to pay up to 1.5% of upfront cost on O &M.

Avoided Green House Gas Emission (GHG) From Generator and the Electricity Grid

The results estimated for greenhouse gas emission from generator and the electricity grid for Ibwa1 primary health centre is presented in Table 39 and 40 below.

Table 39.Avoided Green House Gas Emission from Generator

tCO_2e from Generator Daily	0.047
tCO_2e from Generator Yearly	17
tCO_2e from Generator throughout the life of the project (20 years)	428

Table 40. Avoided Green House Gas Emission from Electricity

tCO_2e from Electricity Daily	0.01
tCO_2e from Electricity Yearly	3.7
tCO_2e from Electricity for the life time of the project (20 years)	91.3

CONCLUSION

Over the years, several initiatives have been proposed to reduce mortality among mothers and children and to solve the challenges of unreliable electricity supply and reduce greenhouse gas emissions in Nigeria. Despite the efforts made, poor maternal and child health indices, and unreliable electricity supply and greenhouse gas emissions have continued to be among the most serious development and environmental challenges facing the country.

It is an undeniable fact that energy access is a key factor in enhancing the delivery of healthcare services in Nigeria. In rural areas of the Federal Capital Territory (FCT), it is essential to provide improved energy service to health centers to improve the quality of health care service delivery.

The findings of this study indicate that efficient solar photovoltaic technology is a promising pathway, though expensive, for providing cost-effective and reliable electricity services to rural health centers in the Federal Capital Territory (FCT), including for health centres that are off-grid, disconnected from the grid, or on-grid with an unreliable power supply.

In addition, this study has shown the financial viability of solar photovoltaic systems PV systems for health centres. On the other hand, it supports the goals of the World Health Organization (WHO) and the Nigerian National Primary Health Care Development Agency (NPHCDA), which supports the use of solar PV systems to improve on energy access in rural health clinics and the reduction of maternal and child mortality that may occur through improved energy access in rural health clinics. Although not covered in depth within this research, this study also notes that the use of efficient solar photovoltaic systems has not only benefited the mitigation of maternal and child mortality, but it has also made contributions to immunization by providing electrical power to the vaccine cold chain. In this regard, the energy required by solar PV systems to power the cold vaccine chain was accounted for in the load analysis in the design of the solar system. Another key finding revealed in this study is the potential for reduction of greenhouse gas emissions from gasoline/diesel generators and the emission from the country's grid energy mix. The emissions reduction supports the Paris climate agreement, which was negotiated within the United Nations Framework Convention on Climate Change (UNFCCC) and covers greenhouse gas emissions mitigation, adaptation, and finance.

The comparison of Scenarios 1 and 2, in which systems with lead-acid deep cycle batteries were compared with systems with lithium iron phosphate batteries, confirmed that lead-acid batteries are more feasible for these systems at this time, but requires Significant grant funding and the O&M are a significant challenge. Scenario 1 (lead-acid batteries) proved viable for both the subsidy/grant and the self-funded case studies, as well as a business case that promotes public-private partnership. In contrast, Scenario 2 (lithium iron phosphate batteries) was not economically viable given current lithium iron phosphate battery prices.

All cost analyses for this study can be found in the results and discussion section of this report. As disclosed by the cost benefit analysis using the utility grid in addition to a generator as sources of energy compared to solar PV, Scenario 1 (the use of Lead-acid batteries), Case 2 (subsidy/grant funded for Scenario 1) is more cost effective than Scenario 2 (Lithium iron phosphate batteries). The total avoided cost from utility bills and ongoing generator operation and maintenance costs for the first year is ₦1,564,920 ($4,347).

Furthermore, the study also revealed that for the independent investor to break even, a 20% margin on the outlay cost must be added or the repayment period must exceed 10 years with a lesser margin. Scenario 1 favors the investor and the health centre (customer) because of the lower price of the lead-acid battery.

Succinctly, the technical and economic analysis of this study suggests that the initial cost of solar PV may be expensive at the beginning, but it is socially and economically more beneficial than a gasoline or diesel generator and unreliable grid electricity supply over the 20-year lifetime of the system. Another potential benefit, depending on the size of the system relative to the load and the effectiveness of O & M efforts, is the possibility of 24 hours of electricity supply from the solar PV to the health centre. The findings of this research can be utilized by policy makers in both the health and energy sectors. They can also be used to promote public-private partnerships involving private investors for the development of solar PV in Nigeria.

RECOMMENDATIONS

Based on this study's outcomes, the recommendations enumerated below may be utilized by the Nigerian Government, policy makers, researchers, and private investors for the development of solar PV in Nigeria.

1. Energy efficiency measure was a crucial element in achieving cost reductions in this analysis. Therefore, the government should provide opportunities to reduce energy costs through energy efficiency measures.
2. More research and pilots project installations should be done to evaluate the true cost within the Nigerian context of different sizes of solar PV systems.
3. To reduce the initial cost of installing a solar PV system in Nigeria, the government should consider introducing an incentive scheme in the form of a subsidy.
4. To create sustainability of solar PV systems, the Nigerian Government should create a mechanism to cover the cost of O & M and components replacement for off-grid solar systems at health centres and other medical facilities.
5. The government should introduce training programs related to the installation, operation, and maintenance of solar PV systems.

REFERENCES

Adair, R. H., Karen, Z., Sophie, B., Susan, W., Annette, C. K., Ryan, H., & Elaine, R.F. (2013) Limited electricity access in health facilities of sub-Saharan Africa: a systematic review of data on electricity access, sources, and reliability. *Global Health: Science and Practice*, 1(2), pp. 249–261.

African Development Bank (AFDB). (2014). The Importance of Energy in Improving Maternal and Child Health in Africa. Retrieved on from https://www.afdb.org/en/news-and-events/the-importance-of-energy-in-improving-maternal-and-child-health-in-africa-13089/.

Akinlo, A.E. (2009). Electricity consumption and economic growth in Nigeria: Evidence from cointegration and co-feature analysis. *Journal of Policy Modelling*. Retrieved from http://www.covenantuniversity.edu.ng/content/download/19617/126416/file/Electricity+consumption.pdf.

BP. (2013). Statistical Review of World Energy. Retrieved from http://large.stanford.edu/courses/2013/ph240/lim1/docs/bpreview.pdf

Central Bank of Nigeria (CBN). (2018). Data and Statistics: Money Market Indicators.

Chineme, K. (2017, October 18). Hydro Now Contributes 26% of Nigeria's Power Generation. Thisday Newspaper Online. Retrieved from https://www.thisdaylive.com/index.php/2017/10/18/fashola-hydro-now-contributes-26-of-nigerias-power-generation/

Corporate Finance Institute. (2018). Net Present Value (NPV). Retrieved from https://corporatefinanceinstitute.com/resources/knowledge/valuation/net-present-value-npv/

Economic Community of West African States (ECOWAS). (2013). Energy Situation Report-West Africa. Retrieved from http://e4sv.org/wp-content/uploads/2016/10/West-Africa-Energy-Report-AW-Draft-3-200516-V3_MT.pdf.

Electric Research Institute. (2010). Electricity Energy Storage Options.

- Retrieved from http://large.stanford.edu/courses/2012/ph240/doshay1/docs/EPRI.pdf.

Energy Commission of Nigeria (ECN). (2014). Retrieved from http://www.energy.gov.ng

Energy Commission of Nigeria (ECN). (2014). Draft National Renewable Energy and Energy Efficiency Policy. Retrieved from http://www.energy.gov.ng/

Energy Commission of Nigeria (ECN). (2018). Maintenance Cost for Off-grid Solar Photovoltaic Systems. Procurement Unit. Retrieved from http://www.energy.gov.ng

Energy Information Administration. (2017). Nigeria: Electricity Consumption. Retrieved from http://www.theglobaleconomy.com/Nigeria/electricity_consumption/

EPA. (2014). Fourth Assessment Report (AR4). Washington DC: IPCC. Retrieved from www.epa.gov/sites/production/files/2015-7/documents/emissionfactors_2014.pdf

European Commission. (2014). PV Status Report. Retrieved from https://setis.ec.europa.eu/sites/default/files/reports/PV-status-report-2014.pdf

Federal Inland Revenue Service (FIRS). (2018). Value Added Tax. Retrieved from http://www.firs.gov.ng/Resource-Centre/Pages/Frequently-Asked-Questions--on-VAT.aspx

Federal Ministry of Health, Nigeria. (2004). Revised national health policy. Retrieved from http://cheld.org/wp-content/uploads/2012/04/Nigeria-Revised-National-Health-Policy-2004.pdf

Federal Ministry of Power and Steel. (2006). Renewable Electricity Policy Guideline. Federal Republic of Nigeria.

German Cooperation (GIZ). (2015). The Nigerian Energy Sector: An Overview with a Special Emphasis on Renewable Energy, Energy Efficiency and Rural Electrification. Retrieved from https://www.giz.de/en/downloads/giz2015-en-nigerian-energy-sector.pdf

Jake, R. (2017). Assessment of Individual Photovoltaic Module Performance After 26Years of Field Exposure at the Telonicher Marine LAB in Trinidad, California. Unpublished Masters Project, Humboldt State University, Arcata, California. Retrieved from https://digitalcommons.humboldt.edu/cgi/viewcontent.cgi?article=1014&context=projects

International Energy Agency. (2017). Energy Statistics. Retrieved from http://www.iea.org/statistics/statisticssearch/

International Energy Agency (IEA). (2018). Uneven Progress on Achieving Access to Sustainable Energy for All. Retrieved from https://www.iea.org/topics/energypoverty/

Investopedia. (2018). Discounted Payback Period. Retrieved from https://www.investopedia.com/terms/d/discounted-payback-period.asp

Isaac, A. (2017, October 17). Nigeria Energy Mix Increases, As Grid Connected Gas Power Now 74%. *Business Day News online*. Retrieved from http://www.businessdayonline.com/nigerias-energy-mix-increases-grid-connected-gas-power-now-74-fashola/

Lale, S., Doris, C., Alison, G., Ozge., Tuncalp., Ann-Beth, M., Jane,D., Ametin, G., Marleen, T., & Leontine, A. (2014). Global Causes of Maternal Death: A WHO Systematic Analysis. *The Lancet Global Health.* Volume2, No. 6. Retrieved from http://www.thelancet.com/journals/langlo/article/PIIS2214-109X(14)70227-X/fulltext

Lighting Africa Nigeria. (2016). A program designed to impact Six (6) Million People. *An innovation of World Bank Group*. Retrieved from https://www.lightingafrica.org/country/nigeria/

Louis, G. (2014). Feedback on the Performance of Off-grid Lighting Products Deployed in 36 Health Centres in Nigeria. Lighting Africa Report. Retrieved from https://www.lightingafrica.org/wp-content/uploads/2015/08/Pilot-Intervention-in-Nigeria-Health-Sector.pdf

Margaret, N. Mc c. (2014). Energy as a Key Variable in Reducing Child Mortality: A Gender and Energy Perspective on Empirical Evidence on MDG 4. Retrieved from https://www.researchgate.net/publication/228987259_Energy_as_a_key_variable_in_reducing_child_mortality_A_gender_and_energy_perspective_on_empirical_evidence_on_MDG_4

Master, G. M. (2004). Renewable and Efficient Electric Power Systems (Vol. 156). Hoboken: John Wiley & Sons.doi:https://doi.org/10.1016/j.sbspro.2014.11.230

Mathew, B., Aman, S., Charlotte, W., Amy, H., Jessica, L., & Garry, D. (2011). Technical Paper: Electricity Specific Emission Factors for Grid Electricity. Retrieved from https://ecometrica.com/assets/Electricity-specific-emission-factors-for-grid-electricity.pdf

Mojekwu, J.N., & Uche, I. (2012). Maternal Mortality in Nigeria: Examination of

Intervention Methods. *International Journal of Humanities and Social Science* Vol. 2 No. 20. Retrieved from https://pdfs.semanticscholar.org/4436/feb1a319ded8644f2bbf6e4fd9607cd21ccc.pdf

Nigerian Economic Summit Group, and Heinrich Böll Stiftung Nigeria. (2017). Comparison of Costs of Electricity Generation in Nigeria. Retrieved from https://ng.boell.org/sites/default/files/true_cost_of_power_technical_report_final.pdf

National Population Commission, Nigeria. (2006). Data for National Planning and Development. Retrieved from http://population.gov.ng/core-activities/surveys/dataset/2006-phc-priority-tables/

National Population Commission, Nigeria. (2013). Nigeria Demographic and Health Survey. ICF International Rockville, Maryland, USA. Retrieved on 10/12/2017 from https://dhsprogram.com/pubs/pdf/FR293/FR293.pdf

National Primary Health Care Development Agency. (2016). Making A Difference with Midwives Service Scheme. Retrieved from https://www.nphcda.org/2016/03/01/making-a-difference-with-the-midwives-service-scheme/

National Primary Health Care Development Agency (NPHCDA) and World Health Organization (WHO). (2007). Ward Minimum Health Care Package in Nigeria, 2007 – 2012.

Norway Meteorological Institute (NMI). (2018). Abuja Weather Statistics. Retrieved from https://www.yr.no/place/Nigeria/Abuja/Abuja/

Oladeinde, O. (2017, August15). Nigeria's current electricity generating capacity. *Premium Times Newspaper*. Retrieved from https://www.premiumtimesng.com/news/more-news/240258-nigerias-current-electricity-generating-capacity-6803-mw-fashola.html

Oladokun, V. O., & Asemota, O.C. (2015). Unit Cost of Electricity in Nigeria: A Cost Model for Captive Diesel Powered Generating System. *Journal of Renewable and Sustainable Energy Reviews*, Vol 52, 35-40. Retrieved from https://www.sciencedirect.com/science/article/pii/S1364032115006759

Omolola, C. (2017). Nigeria's Renewables Market: Opportunity and Development for Solar PV. Retrieved from https://www.greenmatch.ch/en/blog/nigerias-renewables-market-opportunities-and-development-for-solar-pv

Premium Times. (2017, September 22). Experts React to Nigeria's High Maternal Mortality Rate.Retrieved from https://www.premiumtimesng.com/news/more-news/243885-experts-react-nigeria11/19/2s-high-maternal-mortality-rate.html

Prince, K. (2018, March 30). Operators Rue Customs' 10% duty on Solar Panels. *Vanguard Newspaper Online*. Retrieved from `https://www.vanguardngr.com/2018/03/operators-rue-customs-10-duty-solar-panel/

Rapid Table. (2018). Watts to Lumen Calculations. Retrieved from https://www.rapidtables.com/calc/light/watt-to-lumen-calculator.html

Solar Direct. (2018). Solar Electric System Sizing. Retrieved from http://www.solardirect.com/pv/systems/gts/gts-sizing-battery.html

Solar Nigeria Programme (SNP). (2016). At Lagos Clinic Solar Turns Health Around. Retrieved from http://www.solar-ng.com/2016/08/28/at-lagos-clinics-solar-turns-health-care-around.

Sambo, A.S., Garba, B., Zamar, I.H., & Gaji, M.M. (2010). Electricity Generation and the Present Challenges in the Nigerian Power Sector. *Journal of Energy and Power Engineering*, 6(7), 1050-1059. Retrieved from https://www.researchgate.net/publication/228399732_Electricity_Generation_and_the_Present_Challenges_in_the_Nigerian_Power_Sector

Shyama, K., Julian, S., David, B., Sadia, C., Daniele, C., Laura, F., Rafael, C., Bernadette, D., Andres, F., Taghreed, A., Robert, C.Y., Natalia, A., Jennifer, F., Seemeen, S., Beth, A.P., Beatrice, E., Sarah, B., Pritha, V., Rachael, H., John M., Sharon, A., Henrik, A., Blerta, M., Intissar, S., Rama, L., Troy, J., Susan, J., Elizabeth, M., Abdul, G., Nicholas, M., Carole, P, Flavia, B, & Success Factors for Women's and Children's Health study groups.(2014). Success Factors for Reducing Maternal and Child Mortality. *Bulletin of the World Health Organization (WHO).*

Solar Energy International. (2013). Photovoltaic Fundamentals and Applications. Second Edition.

Sustainable energy for all initiative (SEforAll). (2017). Energy and Women's Health. Retrieved from http://www.se4all.org/hio_energy-and-womens-health

Szabo, S., Bodis, K., Huld, T., & Moner-Girona, M. (2011). Energy Solutions in Rural Africa: Mapping Electrification Costs of Distributed Solar and Diesel Generation Versus Grid Extension. *Environment Resource Letters*, 6(3), pp.4002. Retrieved from http://iopscience.iop.org/article/10.1088/1748-9326/6/3/034002/pdf

Thomas, H., Arnulf, J.W., & Sandor, S. (2014). Mapping the Cost of Electricity from Grid Connected and Off-grid PV Systems in Africa. Retrieved from https://www.researchgate.net/publication/263221188_Mapping_the_Cost_of_Electricity_from_Grid-connected_and_Off-grid_PV_Systems_in_Africa

United Nations Children's Fund. (2017). Statistics and Monitoring. Retrieved from https://www.unicef.org/statistics/index_24304.html

United Nations Development Program (UNDP). (2017). Sustainable Energy Sources Enhances Health Care Provision in Rural Nigeria. Retrieved from http://www.ng.undp.org/content/nigeria/en/home/ourwork/environmentandenergy/successstories/sustainable-energy-sources-enhances-health-in-rural-nigeria-.html

United Nations Division for Sustainable Development Department of Economic and Social Affairs. (2014). A Survey of International Activities in Rural Energy Access and Electrification. Retrieved from: https://sustainabledevelopment.un.org/content/documents/1272A%20Survey%20of%20International%20Activities%20in%20Energy%20Access%20and%20Electrification.pdf

United Nations Foundation (UNF). (2014). Assessing the Enabling Environment for ICTs for Health in Nigeria: A Review of Policies Prepared by the United Nations Foundation in Support of ICT4SOML. Retrieved from http://www.unfoundation.org/assets/pdf/nigeria-policy-report.pdf

United Nations Foundation (UNF). 2015. Health Facility Energy Needs Assessment Ghana Summary Country Report. http://energyaccess.org/wp-content/uploads/2016/01/UNF-Health-Clinic-Electrification-Ghana-Country-Summary-Report.pdf

United Nations Foundation (UNF). 2015. Health Facility Energy Needs Assessment Uganda Summary Country Report. http://energyaccess.org/wp-content/uploads/2016/01/UNF-Health-Clinic-Electrification-Uganda-Country-Summary-Report.pdf.

We Care Solar. (2011). Maternal Mortality. Retrieved from http://wecaresolar.org/wp-content/uploads/2011/09/We_Care_Solar_FAQ-_Oct-1-2011.pdf

We Care Solar. (2017). We Care Solar Suitcase Program. Retrieved from https://wecaresolar.org/wp-content/uploads/2017/01/WCS-Facts-2017.pdf

World Health Organization (WHO). (2014). The Health of The People What Works. The African Regional Health Report. Retrieved from: http://apps.who.int/iris/bitstream/10665/137377/4/9789290232612.pdf

World Health Organization. (2015). Trends in Maternal Mortality: 1990–2015. Estimates by WHO, UNICEF, UNFPA, World Bank Group and the United Nations Population Division. Geneva. Retrieved from http://apps.who.int/iris/bitstream/10665/194254/1/9789241565141_eng.pdf?ua=1

World Bank (2016). Data for Nigeria. Retrieved from http://data.worldbank.org/country/nigeria

APPENDIX A: QUESTIONNAIRE USED FOR AUDIT OF HEALTH CENTRES

Appendix A Covers the questionnaire used for the audit of all rural health centres visited. Samples of the questionnaire are found from Table A-1 to Table A-25.

Table A-1, below shows the record information sheet.

Table A- 1: Audit Team Record

Auditing Team Record	**Notes**
Names of Auditors	
Date of Audit	
Time Start of Audit/Interview	
Time End of Audit/Interview	

Table A-2, shows the basic information sheet.

Table A- 2: Basic Information

Basic Information				**Notes**
Facility type	Health Clinic			
Location of facility	Country	District	Nearest Trade centre	
Name(s) of people contacted prior to site visit				
Corresponding people's titles				
Facility name				
Facility level/tier/type	Primary health care			
Dust conditions (Observe the environment/ask if it's rainy season)				
GPS coordinates (Detect with device upon arrival)	Latitude			
Name(s) of respondent				
Respondent(s) relationship(s) with facility (Title /Position)				
Contact email				
Contact phone number				
Name and title of staff in charge if different from respondent				
Service(s) provided				
Number of buildings in the facility complex				

Basic Information				**Notes**
Average number of patients served per day				
Number of beds present				
Number of staff present	Full Time/ Permanent/ Medical Staff	Support Staff	Number of staff present at time of site visit	
Opening time of facility per day				
Closing time of facility per day				
Basic Information				
Number of days open in a week				
Holidays closed per year				
Hours open per day/per week/per year				

Table A-3, below shows the sheet used for collecting electricity information in the health centres.

Table A- 3: Electricity Information

<table>
<tr><td colspan="9">Electricity Information</td></tr>
<tr><td colspan="3">Is there electricity present in this facility</td><td colspan="6">No</td></tr>
<tr><td colspan="3">IF YES</td><td colspan="5">IF NO</td><td>Notes</td></tr>
<tr><td>Do you have a backup/Secondary Source present?</td><td colspan="2">Yes</td><td colspan="5"></td><td></td></tr>
<tr><td>Do you have automatic shift/switch to back up?</td><td colspan="2"></td><td colspan="5"></td><td></td></tr>
<tr><td>Electricity Sources Details</td><td colspan="8">Capacity</td></tr>
<tr><td>* If electricity is present</td><td>Building Name</td><td>Room name/use</td><td>Sources</td><td>AC/ DC</td><td>Energy (Fill out for batteries, if applicable)

(kWh)</td><td>Power (Do not fill out for batteries)</td><td>Power Units</td><td>Comments/Additional details on electricity sources</td></tr>
<tr><td>Primary electricity</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Backup electricity (only used if primary is down)</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

Table A-4, below presents the audit sheet used for collecting information on electricity reliability in the health centres.

Table A- 4: Questions on Reliability

Reliability and quality
Functional now?
Comments/Additional details on electricity sources (If non-functional, describe why)
Time(s) of day electricity is available from this source (e.g. 0900 hrs. to 1300 hrs.)
Total number of hours electricity is available from this source per day (hours)
Number of days electricity is available from this source weekly (days)
How often do you experience electricity supply interruptions (This may include battery or fuel run out, or grid outage), e.g.1/day, 1/week, 2/month? (per month)
Do you ever experience power interruptions? If so, on an average for how long does the supply interruption/outage occur? (This time is only during the facility operation hours) (hours)
Do you ever see your lights flicker (e.g. because of High or low voltage)?
Have you had any equipment damaged by your electricity source, e.g. voltage fluctuation?
Comments/Additional details on interruption/damaged equipment

Table A-5, below presents the audit sheet in collecting information on budget.

Table A- 5: Questions on Budget

Budgetary allocation	
Who is responsible for paying your bills? (electricity bills/fuel cost)	
Does your facility have a budget for fuel or electricity bills?	
Comments/Additional details on bills payment	
Who is responsible for paying for your maintenance or repair cost?	
Do you have sufficient funds/budget for carrying out maintenance or repairs?	
Comments/Additional details on maintenance/repairs	

Table A-6, below shows the audit sheet used for collecting information on bills and expenses.

Table A- 6: Questions on Bills and Expenses

Bills/Expenses	
Purchase (Upfront) cost of the system, if applicable (₦)	
Cost of rental or lease, if applicable (₦)	
Average Monthly Cost on Electric Bills (Only ask for non-fuel sources) (₦)	
Cost on per litre of fuel (e.g. Generator) (Only ask for fuel sources) (₦)	
Litres of fuel used (e.g. Generator) (Only ask for fuel sources) (per day)	
Average Monthly Expenses on Fuel (e.g. Generator) (Only ask for fuel sources) (₦)	
Average Monthly Expenditure on Maintenance/Repair (i.e. Generator/Solar) (₦)	
Comments/Additional details on Bills/Expenses	

Table A-7, below shows the sheet used to collect information on environmental sustainability

Table A- 7: Questions on Environmental Sustainability

Environmental Sustainability	
Air pollution	
Water /soil pollution, e.g. spilling	
Noise pollution	
Comments/Additional details on Air/Water/Soil/Noise pollution	

Table A-8, below presents the audited sheet for collection information on maintenance of existing systems in the health centres.

Table A- 8: Questions on Maintenance

Maintenance	
Is routine maintenance conducted?	
If routine maintenance is conducted, how frequently? [per year]	
Who is responsible for generation source operation and maintenance on site?	
Position of person responsible	
Would this person be available if we wanted to reach out?	
Contact details of the supplier (company / organization / technician name and contacts)	
Is there any type of contract or maintenance agreement with the supplier?	
What do you do when the system fails?	
Was anyone on site trained in maintenance of the system?	
If so, how many people and who (position and capacity) were trained?	
Are there manuals for this system in place at the site?	
Are there spare parts on site?	
Comments/Additional details including that of spare parts	

Table A-9, below shows the audit sheet for collecting information on electricity and facility information

Table A- 9: Electricity and Facility Information (Generator)

Generator Specific Data Collection	
Generator Type/Model	
Location of the generator in the facility (e.g. in a building room or separate building)	
Fuel type	
Fuel pump	
If Fuel Storage, then describe	
Power Factor (PF)	
Rated Current (A)	
Comments/Additional Details	
Date of installation	
Condition upon arrival	
Current condition	
Overhauled (e.g. Taking major or all parts apart; either by changing or repairing it)	
Overhaul date	
Comments/Additional Details on Overhaul	
Is the generator designed for standby or continuous operation?	
If the backup source is a generator, does it currently have fuel or a charged battery so that it could be used today?	

Table A-10, below shows the audit sheet used in collecting information on Solar PV. If present at the health centres.

Table A- 10: Electricity Information (Solar PV)

Solar PV (fixed) Specific Data Collection	
Solar System Identifier (Auditor can make up a name)	
Installing organization	
Supplier	
Date of system installation	
Condition Upon Arrival of the solar system	
Current condition of solar system	
Comments/ Additional details on Solar System condition	
System voltage (v)	
PV	
Power Rating of Single Module (kW)	
Module brand	
Number of modules	
Module model	
INVERTER	
Inverter brand	
Inverter model	
Inverter Wattage (W)	
State of inverter	
Battery	
Battery brand name	
Battery model	
Individual Battery Voltage (V)	

Solar PV (fixed) Specific Data Collection	
System Battery Voltage (V)	
Individual Battery Capacity (Ah)	
Number of Batteries	
Status of battery	
Charge controller	
Charge Controller Brand	
Charge controller model	
Rated Current of Charge Controller (A)	
Status of charge controller	
Comments/ Additional details on Solar System	

Table A-11, below is the audit sheet for collecting information on the health centre building and staff housing

Table A- 11: Questions on Facility Building and Staff Housing

Facility Building/Staff Housing			
Do you have a counselling block/waiting room?			
Do you have walkways or corridors or other areas where lighting is needed, either indoor or outdoor?			
Do you have staff housing?			
If Yes to Staff Housing			
Does your staff housing have electricity?			
IF Yes to Electricity in Staff Housing			
List the typical appliances in a staff's personal room	List additional rooms in the staff housing	Number of personal rooms in staff housing	Comments/Additional details

Table A-12, below cover audit questions on remote sensing.

Table A- 12: Questions on Remote Monitoring

Internet Service (Remote Monitoring)			
Internet provider	Is provider available at site? (asking around to interview participants)	Comments/Additional details	Internet provider used by facility

Table A-13, below presents audit sheet for collecting information on future load of the health centres.

Table A- 13: Questions on Future Needs

Future Energy Needs			
Do you have plans to purchase a new energy system /equipment's within the next 6 months?			
Would there be plans to add additional equipment's in the future, perhaps if there were access to adequate electricity?			
Would there be plans to extend operation hours in the future, perhaps if there were access to adequate electricity?			
What is the most important equipment your facility is lacking that would help to improve the services you offer?			
Who would be responsible for decisions about purchasing these additional appliances for the facility?			
IF No Grid at the Facility			
Are there plans for grid extension to your facility?			

Table A-14, below was used to collect information on vandalism, theft and safety.

Table A- 14: Questions on Safety

Vandalism/Theft/Safety	
Has there been any case of vandalism or theft of any kind within or close to the facility premises?	
Has there been any safety incidents with respect to the energy systems?	
Is there any security measure in place in general, specifically for energy equipment?	

Table A-15, below was used to collect information on water pumps in the various health centre's.

Table A- 15: Questions on Water Pump

Water Pump Specific Data Collection (If present at site)	
Source of water supply	
Location of where the water pump is in the facility (e.g main facility or other building in the facility)	
Type of pump used	
Date installed	
Condition upon arrival	
Present condition	
Date of last maintenance/repair (if any)	
Average Monthly Cost on Purchasing Water from other sources (₦)	
Average Monthly Cost on Purchasing Water from other sources (₦)	
Duration of water pumping per day? (h)	
Do you have any storage facility? Size of storage facility (L)	
Daily use (L)	
Use of water in the facility	
Basic Hygiene (Hand washing, Toilet, Bathing)	
Operating theatre/Maternity	
Drinking	
Cooking	
Cleaning medical equipment's	
Lab testing	
Laundry	
Others?	

Water Pump Specific Data Collection (If present at site)	
Is the water supply restricted to the facility alone or it is used by others?	
Comments/Additional Details on water pumping supply source, electricity source and use	
General Questions on Maintenance for Water Pump	
Water pump	
Is routine maintenance conducted?	
If routine maintenance conducted, how frequently? [per year]	
Who is responsible for generator operation and maintenance on site?	
Position of person responsible	
Would this person be available if we wanted to reach out?	
Contact details of the supplier (company / organization / technician name and contacts)	
Is there any type of contract or maintenance agreement with the supplier?	
What do you do when system fails?	
Was anyone on site trained in maintenance of the system?	
If so, how many people and who (position and capacity) were trained?	
Are there manuals for this system in place on site?	
Are there spare parts on site?	

Table A-16, below shows the measuring sheet used recording data measured for the facilities audited.

Table A- 16: Measuring Sheet for Facility Building

Building/Health Facility Data				
Building	**Room Name/Use**	**Length (m)**	**Width (m)**	**Area (m^2)**
Number of rooms in the health facility				
Area of building exterior [m^2]				
Roof overhang (m)				

Table A-17, below shows the sheet for recording solar shading data collected onsite.

Table A- 17: Questions on Solar Shading Data

Solar Shading	
General site observation	Comments/Additional Details
Session name	
Skyline Measurements (i.e. N, S, E, W, SE, SW, NE, NW)	
Sky condition	
Is the facility suitable for solar installation? (e.g space, condition of roof etc.	

Table A- 18: Questions on Remote Monitoring

Mobile Phone (Remote Monitoring)			
Network operator	Measured Signal Strength (dBm)	Operational?	Comments/ Additional Details

Table A-19, below present's observation sheet used during audit of the health facilities.

Table A- 19: Questions on Safety by Observing

Safety (Observation) - Can be filled out just after the interview is finished	
List unsafe equipment operation practices identified at site.	
What are the dangerous appliances identified?	
Are any fuel generators or batteries improperly installed? If so, please describe.	
Is there any fuel-filling of generators being done close to kitchen or other high-risk explosion areas/places?	
Identify any fuels that are not safely stored and describe.	
Other comments.	

Table A-20 below presents the audit sheet used for load measurement for recording all the loads and their use during the audit.

Table A- 20: Load Measurement

Load Details	
Building name	
Room name/use	
Load category	
Load	
Energy generation type	
Energy Generation Source	
Priority load when backup is in use	
Requires Generator on for use, i.e. if someone is getting a heart change and the grid goes down	
Additional details on load (for specific bulb type)	
Load count	
Times used during the day	
Estimated use per day (hours)	
AC/DC	
Power per load (W) (Ask for replacement bulb or ladder, if easy)	
Power for total (w)	
Status of equipment/appliance	
Comments/additional details	

Table A-21, below was used to collect information on community assessment during audit.

Table A- 21: Questions on Community Assessment

The Facility is within or at the edge a government institution (e.g office, school or police post) / trading center	
	Comments/Additional Details on the Number /Situation
Are there any government institution/small businesses/densely populated households close to the facility?	
Is there grid power in the community?	
Are there scattered households and small businesses near the health clinic?	
Is the health clinic 1km or further from any settlement or community?	

Table A-22, below was used to collect data on fuel pricing from each community visited.

Table A- 22: Questions on Fuel Pricing from Community

Local Prices for the following item (₦)	
1 Liter of Diesel	
1 Liter of PMS (petrol)	
1 Liter of LPG	
1 Liter of kerosene	

Table A-23 to A-24, below presents the audit sheet used to carryout quick audit of some of the health centre's.

Table A- 23: Audit Team Information and Record (Quick survey)

Auditing Team Record			
Names of auditors			
Date of audit			
Time start of audit/interview			
Time end of audit/interview			

Table A- 24: Basic Information Sheet

Basic Information				**Notes**
Facility type	Health Clinic			
Location of facility	Country	District	Nearest Trade center	
Name(s) of people contacted prior to site visit				
Corresponding people's titles				
Facility name				
Facility level/tier/type	Primary health care			
Dust conditions (Observe the environment/ask if it's rainy season)				
GPS coordinates (Detect with device upon arrival)	Latitude			
Name(s) of respondent				
Respondent(s) relationship(s) with facility (Title /Position)				
Contact email				

Basic Information				Notes
Contact phone number				
Name and title of staff in charge if different from respondent				
Service(s) provided				
Number of buildings in the facility complex				
Basic Information				
Average number of patients served per day				
Number of beds present				
Number of staff present	Full Time/ Permanent/ Medical Staff	Support Staff	Number of staff present at time of site visit	
Opening time of facility per day				
Closing time of facility per day				
Number of days open in a week				
Holidays closed per year				
Hours open per day/per week/per year				

Table A-25, below presents the checklist sheet used during the audit.

Table A- 25: Checklist

S/N	ITEMS	INFORMATION COLLECTED	NOT AVAILABLE	REMARKS
	Did you do these things?			
1.	GPS coordinate			
2.	Site and floor plans (sketched)			
3.	Photographs (Indoor/Outdoor, Equipment/Appliances)			
4.	Solar Shading			
5.	Mobile Phone signal			
6.	Primary and backup energy system sources sited and inspected			
7.	List of loads appliances/devices/equipment's (outdoor/indoor loads, lighting loads etc)			
	Did you ask for this documentation?			
8.	Utility Bills/ Invoices			
9.	Fuel Records (fuel use for facility/ from the community)			
10.	Fuel Records (fuel price for the facility/ from community assessment)			
11.	Site and floor plans			
12.	Relevant technical and maintenance manuals			

APPENDIX B: RURAL HEALTH CENTRES VISITED IN FCT AND LOAD ANALYSIS FOR IBWA 1 PRIMARY HEALTH CENTRE

Appendix B covers the rural health centres visited in the Federal Capital Territory FCT, Nigeria (Table B-1), load analysis (Tables B-2 and B-3) for IBWA 1 primary health centre with and without energy efficiency upgrade, estimated load profile (Table B-4), solar shading data (Figures B-1 to B2), and a photograph of IBWA 1 health centre building (Figure B-3)

Table B- 1: Health Centres Audited in the Federal Capital Territory, Nigeria

Name &Location of Facility	Current Electricity/Lighting Source	Solar Vaccine Refrigerator	Water Source Present/Type	patients served per day	Hours of Operation per day	Days Opened Per week
Adagba Primary Health Centre (Abaji Area Council, FCT)	Off-grid (No Electricity)	--	--	6	24	7
Gurdi Primary Health Centre (Abaji Area Council, FCT)	Off-grid (No Electricity)	Functional Solar for Vaccine refrigerator	--	6	24	7
Model Naharati Sabo Primary Health Centre Abaji Area Council (FCT)	On Grid but Disconnected (Generator + Solar PV)	Functional Solar for Vaccine refrigerator	Non-functional solar powered borehole.	12	24	7
Pandagi Comprehensive Health Centre (Abaji Area Council, FCT)	Off-grid (Generator)	--	Non-functional solar powered borehole.	12	24	7

Name & Location of Facility	Current Electricity/Lighting Source	Solar Vaccine Refrigerator	Water Source Type	patients served per day	Hours of Operation per day	Days Opened Per week
Yaba Primary Health Centre (Abaji Area Council, FCT)	Off-grid (non-functional Solar)	Non-functional Solar for Vaccine Refrigerator	--	10	24	7
Gbadalape Primary Health Centre (AMAC Area Council,FCT)	On Grid (Generator also available)	Non-functional Solar for Vaccine Refrigerator	Functional AC Pump Borehole.	12	24	7
Kpeyegyi Primary Health Centre (AMAC Area Council, FCT)	On Grid (Grid is down: Transformer is faulty)	--	Functional AC Pump Borehole.	9	24	5

Name & Location of Facility	Current Electricity/Lighting Source	Solar Vaccine Refrigerator	Water Source Type	patients served per day	Hours of Operation per day	Days Opened Per Week
Kurudu Primary Health Centre (AMAC Area Council, FCT)	On Grid (Generator available in the staff quarters)	--	--	13	8.5	5
Damagaza Primary Health Centre (AMAC Area Council, FCT)	Off-grid (But grid available in the community)	--	--	9	10	7
Dei de Comprehensive Health Centre (Bawari Area Council, FCT)	On Grid (Generator+ Functional Solar PV are available in the facility)	Non-functional Solar for Vaccine Refrigerator	Functional AC pump borehole.	25	24	7

Name & Location of Facility	Current Electricity/Lighting Source	Solar Vaccine Refrigerator	Water Source Type	patients served per day	Hours of Operation per day	Days Opened Per Week
Dei De Primary Health Centre (Bawari Area Council, FCT)	On Grid but Disconnected (Generator + Functional Solar PV)	--	Functional solar borehole	23	24	7
Gudupe Primary Health Centre (Bwari Area Council, FCT)	Off-grid	--	--	3	24	7
Dakwa Primary Health Centre (Bawri Area Council, FCT)	On Grid but Disconnected. (Generator is available)	--	--	12	7.5	5
Dutse Alahji Primary Health Centre (Bawri Area Council, FCT)	On Grid (20Kva Generator is available)	Functional Solar for Vaccine Refrigerator	Non-functional AC pump powered borehole.	40	24	7
MAPA Primary Health Centre (Bawri Area Council, FCT)	Off-grid	--	Non-functional AC Pump powered borehole.	7	24	7

Name & Location of Facility	Current Electricity/ Lighting Source	Solar Vaccine Refrigerator	Water Source Type	patients served per day	Hours of Operation per day	Days Opened per Week
Dukpa Primary Health Centre (Gwagwalada Area Council, FCT)	On Grid but Disconnected. (Generator is available)	--	--	8	6	7
Ibwa 1 Primary Health Centre (Gwagwalada Area Council, FCT)	Off- Grid. (Solar PV for internet is available)	Functional Solar Vaccine Refrigerator (Partially working)	Non-functional hand pump borehole	11	9	5
Ibwa 2 Primary Health Centre (Gwagwalada Area Council, FCT)	Off-grid	--	Non-functional solar powered borehole.	5	24	7
Rfin-Zurufl Primary Health Centre	Off-grid (Generator is available)	--	Non-functional solar powered borehole.	13	10	5

Name & Location of Facility	Current Electricity/Lighting Source	Solar Vaccine Refrigerator	Water Source Type	patients served per day	Hours of Operation per day	Days Opened Per Week
Wuna Primary Health Centre (Gwagwalada Area Council, FCT)	Off-grid (Generator is available)	--	--	10	24	7
Kabi Mongoro Primary Health Centre (Kuje Area Council, FCT)	Off-grid (Generator is available)	--	--	11	24	7
Kasada Primary Health Centre (Kuje Area Council, FCT)	Off-grid	--	--	13	24	7
Kwali Comprehensive Health Centre (Kwali Area Council, FCT)	On Grid but Disconnected. (Generator is available)	Functional Solar Vaccine Refrigerator (Partially working)	Non-functional hand pump borehole	35	10	7
Ike Health Post (Kwali Area Council, FCT)	Off-grid	--	--	3	24	7

Name & Location of Facility	Current Electricity/Lighting Source	Solar Vaccine Refrigerator	Water Source Type	patients served per day	Hours of Operation per day	Days Opened per Week
Dafa Primary Health Centre (Kwali Area Council, FCT)	On Grid but Disconnected. (Generator is bad)	Non-functional Solar for Vaccine Refrigerator			24	7
Kamadi Tsho Primary Health Centre (Kwali Area Council, FCT)	Off-grid	--	--	7	24	7
Tunga Sariki Health Post (Kwali Area Council, FCT)	Off-grid	--	--	6	6	5
Wako Primary Health Centre (Kwali Area Council, FCT)	Off-grid	Non-functional Solar for Vaccine Refrigerator	Non-functional AC pump powered borehole.	33	24	7

Table B- 2: Load Analysis without Energy Efficiency Upgrade

Area in Facility	**Load Type**	**Quantity**	**Wattage (W)**	**Total Power (W)**	**Daily Hourly Use (hr)**	**Daily Energy Use (Wh/day)**
Lighting and Fan						
Entry, sides and rear (Task Lights)	Incandescent Bulb	8	75	600	12	7200
Common Area	Incandescent Bulb	1	60	60	8	480
Consulting Area	Incandescent Bulb	1	60	60	8	480
Antenatal Unit (Labour/Delivery Room)	Incandescent Bulb	1	60	60	8	480
	Ceiling Fan	1	100	100	10	1000
Labor/Delivery Room	Incandescent Bulb	1	60	60	8	480
Cold Chain Room	Incandescent Bulb	1	60	60	8	480
Female Ward	Incandescent Bulb	1	60	60	8	480
	Ceiling Fan	1	100	100	10	1000
Male Ward	Incandescent Bulb	1	60	60	8	480
	Ceiling Fan	1	100	100	10	1000
Laboratory	Incandescent Bulb	1	60	60	8	480
	Ceiling Fan	1	100	100	10	1000

Area in Facility	Load Type	Quantity	Wattage (W)	Total Power (W)	Daily Hourly Use (hr)	Daily Energy Use (Wh/day)
Total Lighting and Fan				**1480**	**116**	**15040**
Other Equipment						
Cold Chain Room	Computer(Desktop)	1	100	100	5	500
Other Appliances/Phantom Loads (e.g Mobile Phones (3), Ipad Tablet)	Mobile Phones (4), Tablet and Laptop e.t.c	lots	54	54	8	162
Future Loads						
Cold Chain Room	Vaccine Refrigerator (Ice-Lined Vaccine Refrigerator TCW 2000 AC)	1	82	82	24	1968
Laboratory	Centrifuge	1	110	110	2	220
Laboratory	Bright Field White Light Microscope	1	30	30	3	90
15% of total load added for tolerance to run for 24 hours		lots	278.4	278.4	24	3650
Total Other Equipment				**654.4**	**66**	**6,860**
GRAND TOTALS				**2134**	**82**	**21900**

Table B- 3: (Load Appliances with Energy Efficiency Upgrade)

Area in Facility	Load Type	Quantity	Wattage (W)	Total Power (W)	Daily Hourly Use (hr)	Daily Energy Use (Wh/day)
Lighting and Fan						
Entry, sides and rear (Task Lights)	LED Bulb	8	13	104	12	1248
Common Area	LED Bulb	1	10	10	8	80
Consulting Area	LED Bulb	1	10	10	8	80
Antenatal Unit (Labor/Delivery Room)	LED Bulb	1	10	10	8	80
	Ceiling Fan	1	62	62	10	620
Labor/Delivery Room	LED Bulb	1	10	10	8	80
Cold Chain Room	LED Bulb	1	10	10	8	80
Female Ward	LED Bulb	1	10	10	8	80
	Ceiling Fan	1	62	62	10	620
Male Ward	LED Bulb	1	10	10	8	80
	Ceiling Fan	1	62	62	10	620
Laboratory	LED Bulb	1	10	10	8	80
	Ceiling Fan	1	62	62	10	620

in Facility	Load Type	Quantity	Wattage (W)	Total Power (W)	Daily Hourly Use (hr)	Daily Energy Use (Wh/day)
Total Lighting and Fan				**432**	**116**	**4368**
Other Equipment						
Cold Chain Room	Computer(Desktop)	1	100	100	5	500
Other Appliances/Phantom Loads (e.g Mobile Phones (3), Ipad Tablet)	Mobile Phones (4), Tablet and Laptop etc	lots	54	54	8	162
Future Loads						
Cold Chain Room	Vaccine Refrigerator (Ice-Lined Vaccine Refrigerator TCW 2000 AC)	1	82	82	24	1968
Laboratory	Centrifuge	1	110	110	2	220
Laboratory	Bright Field White Light Microscope	1	30	30	3	90
15% of total load added for tolerance to run for 24 hours				121.2	24	2908.8
Total Other Equipment				**497**	**66**	**6,118.8**
GRAND TOTALS				**929**	**182**	**10,487**

Table B- 4: Estimated Load Profile Analysis for Ibwa 1 Primary Health Centre

Time (Hours)	ANC Fan (W)	Male Ward Fan (W)	Female Ward Fan (W)	Laboratory Fan (W)	Microscope (W)	Centrifuge (W)
0	0	0	0	0	0	0
1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	0	0	0	0	0	0
4	0	0	0	0	0	0
5	0	0	0	0	0	0
6	0	0	0	0	30	110
7	0	0	0	0	30	110
8	0	0	0	0	30	0
9	0	0	0	0	0	0
10	0	0	0	0	0	0
11	62	62	62	62	0	0
12	62	62	62	62	0	0
13	62	62	62	62	0	0
14	62	62	62	62	0	0
15	62	62	62	62	0	0
16	62	62	62	62	0	0
17	62	62	62	62	0	0
18	62	62	62	62	0	0
19	62	62	62	62	0	0
20	62	62	62	62	0	0
21	0	0	0	0	0	0
22	0	0	0	0	0	0
23	0	0	0	0	0	0

Time (Hour)	Cold Chain Room Computer (W)	Common Area LED (W)	Laboratory LED (W)	Consultation Room LED (W)	Labor Room LED (W)	Common Room LED (W)	Female Ward LED (W)
0	0	0	0	0	10	0	0
1	0	0	0	0	10	0	0
2	0	0	0	0	10	0	0
3	0	0	0	0	10	0	0
4	0	10	0	0	10	10	0
5	0	10	10	0	10	10	10
6	0	0	10	0	0	0	10
7	0	0	0	10	0	0	10
8	0	0	0	10	0	0	0
9	100	0	0	0	0	0	0
10	100	0	0	0	0	0	0
11	100	0	0	0	0	0	0
12	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0
14	100	0	0	0	0	0	0
15	0	0	0	0	0	0	0
16	100	10	10	10	0	10	0
17	0	10	10	10	0	10	0
18	0	10	10	10	0	10	10
19	0	10	10	10	0	10	10
20	0	10	10	10	10	10	10
21	0	10	10	10	10	10	10
22	0	0	0	0	0	0	10
23	0	0	0	0	0	0	0

Time (Hours)	Male Ward LED (W)	Cold Chain LED (W)	Security LED (W)	Solar Vaccine Refrigerator (W)	Phantom load Mobile Charging (W)	Contingency Load (W)
0	0	0	104	82	54	121
1	0	0	104	82	54	121
2	0	0	104	82	0	121
3	0	0	104	82	0	121
4	0	0	104	82	0	121
5	10	0	104	82	0	121
6	10	10	104	82	0	121
7	10	10	0	82	0	121
8	0	10	0	82	0	121
9	0	0	0	82	54	121
10	0	0	0	82	54	121
11	0	0	0	82	0	121
12	0	0	0	82	0	121
13	0	0	0	82	0	121
14	0	0	0	82	0	121
15	0	0	0	82	54	121
16	0	10	0	82	54	121
17	0	10	0	82	0	121
18	10	10	0	82	0	121
19	10	10	104	82	0	121
20	10	10	104	82	0	121
21	10	0	104	82	54	121
22	10	0	104	82	54	121
23	0	0	104	82	0	121

Figures B-1 and B-2, below shows the percentage of solar access throughout the year, and the elevation and azimuth angles of the obstruction elevation at IBWA 1 primary health centre.

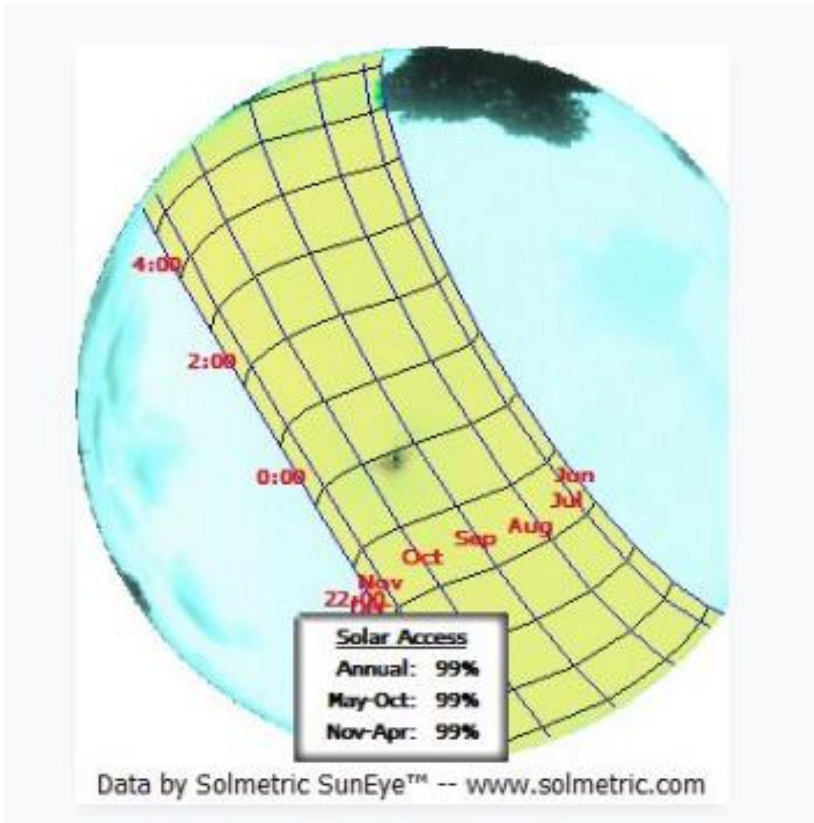

Figure B- 1: Solar Access/Shading Picture (source: Solmetric Suneye 210)

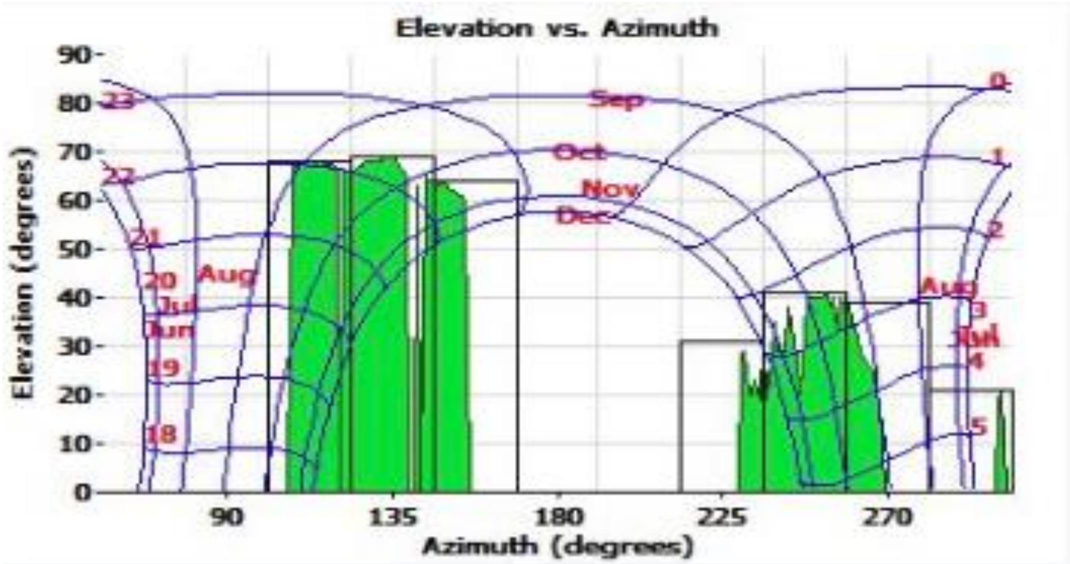

Figure B- 2: Figure B-2 Elevation and Azimuth at IBWA 1 PHC (Source: Solmetric Suneye 210)

Figure B-3, below show the proposed roof top area for solar panels mounting/ installation. The existing solar panel on the roof top is no longer is use.

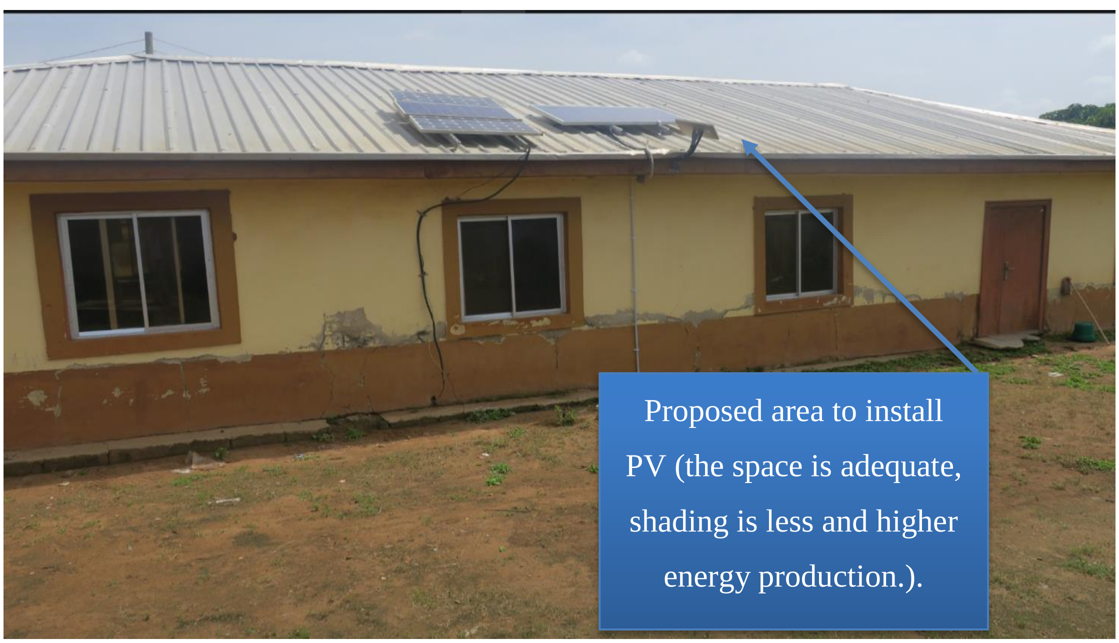

Figure B- 3: IBWA Primary Health Centre (Photo by Author)

APPENDIX C: DESIGN ANALYSIS AND BILL OF ENGINEERING MEASUREMENT AND EVALUATION FOR SCENARIO 1

Appendix C covers the design analysis carried out and costing (Bill of Engineering Measurement and Evaluation) for IBWA 1 PHC for Scenario 1. It is presented in Table C-1 to Table C-19 below.

Table C- 1: Parameters for Sizing

Parameters	Values	Units
System Voltage	48	Volts (V)
AC Daily Energy Demand	10,487	Watt-hour (Wh)
Inverter Efficiency	84%	Percent
Days of Autonomy(DoA)	3	Days
Ambient Temperature of Room for Battery	81	^{0}F
Temperature Multiplier @ 81^{0}F	1	--
Depth of Discharge(DoD)	50%	Percent
Number of Parallel Strings	2	--
Battery Storage Capacity	6	Volts (V)

Table C- 2: Battery Sizing

Average daily DC Watt-hour (Wh)	Battery Bank Capacity (Wh)	Battery Bank Capacity (Ah)
AC average daily watt-hour ÷ Inverter efficiency	Average daily DC Watts-hours x Days of Autonomy (DoA) x Battery Temperature Multiplier ÷ Discharge Limit (DoD)	Battery Bank Capacity (Wh) ÷ System Voltage
12,484	74906	1561

Table C- 3: Number of Batteries Needed

Minimum Battery Capacity (Ah)	Number of Battery in each Series String	Total Number of Batteries Needed	Reference
Battery Bank Capacity(Ah) ÷ Number of Parallel Strings	DC System Voltage(V) ÷ Battery Voltage (V)	Number of Series Strings(Parallel) x Number of Batteries in each series Strings	http://www.ecodirect.com/Surrette-Rolls-6-CS-25P-6V-820-AH-Battery-p/surrette-6-cs-25p.htm.
780	8	16	

Table C- 4: Site Location Coordinates

Latitude	Longitude
9.06362°N	7.05858°E

Table C- 5: Array Sizing Input Data and Calculations

Parameters	**Values**	**Unit**	**Sources**
Total Daily Energy Demand	10487	Wh	Calculated
Worst Monthly Solar Radiation Sun hours	4.15	kWh/m^2/day	**PV Watts.nrel.gov**
Typical losses due to Inefficiencies for a battery-based system (Soiling (Dust), Mismatched array, Voltage drop in wiring, Charge Controller Losses, Inverter and Battery Losses) excluding shading losses	32%	Percentage (%)	Solar Energy International Handbook 2013
Losses due to Shading	2%	Percentage (%)	Measured data for Ibwa 1 PHC using Solmetric Sun eye Solar Shading Tool
System Efficiency	67%		Calculated
Nominal Module Voltage	24	Volts	Module Specification

Table C- 6: Calculating Required Number of Module

Minimum Size (W)	Total Modules Needed	Module in Each Series String
Average Daily Wh ÷ Worst Solar Radiation ÷ System Efficiency	Minimum Array Size ÷ Selected Module Size	System Voltage ÷ Nominal Module Voltage
4140	12	2
Number of Parallel Strings	**Model Specification**	**Source**
Total Number Needed ÷ Number of Module per Series String	SRP-345-6MA (345-Watt Mono). 17.78% Efficiency.	https://www.altestore.com/store/solar-panels/seraphim-solar-panels-p40805/#SEP345SRP3456MA

Table C- 7: Calculating System Size

Size of System KW	Metric Used= Average Daily KWh ÷ Worst Case Sun hours ÷ System Efficiency	4.1

Table C- 8: Input Parameters and Calculating Roof Angle

Parameters	Values	Units
Length of Building	18	Meter (m)
Breath of Building	9.1	Meter (m)
Roof Overhang	0.5	Feet (m)
Roof Angle α	21	Degrees
Run(m)	Slope(m)	Area of Roof(m^2)
Breath ÷ 2	Run/Cosα	(Slope Overhang) x Length of Building
4.5	4.8	96

Table C- 9: Calculating Space Required for Installation of Panels on Roof

Size of each Panel m^2	Total Number of Panels	Number of Existing Panel on Roof	Total Area of Panel (Required + Existing) m^2	Total Area of Roof m^2
1.9	12	4	30.4	188

Table C- 10: Calculating Energy Produced by the System

Energy Produced by the System (KWh-Year)	Metric used= System Size(KW) x System Efficiency (%) x Average Solar Radiation (kWh/m2/day) at Tilt Angle x 365 days-Yr	5146

Table C- 11: Parameters for Sizing a Charge Controller

Parameters	Value	Unit
Open Voltage Current of Module(VOC)	46.8	Volts(V)
Short Circuit Current of Module(ISC)	9.43	Ampere(A)
Safety Factor	1.25	--
Total Number of Parallel strings of Module	2	--

Table C- 12: Sizing for Maximum Power Point Tracking (MPPT) Charge Controller

Total Wattage of Array (W)	Nominal Voltage of Battery (V)	Output Amps (A)
4140	48	86

Table C- 13: Fixtures Considered Selecting Inverter

Selecting Inverter for IBWA PHC
Features Considered in selection
Integrated AC charging (From Grid or Generator)
Automatic Generator Start
Inverter Transfer Switch and Display
Remote Controls (Web Monitoring or Monitoring at the health facility)
Stack ability (In case multiple inverter is needed to increase voltage or current. This might also be useful to conserve the battery by turning on only the inverter needed)
Rated Wattage with Surge Capacity
Inverter Voltage

Table C- 14: Inverter Sizing

Total AC Continuous Load in Watts (W)	System Voltage(DC) (V)	Maximum DC continuous Current in Amperes (Total Load(W)/System Voltage(V)) (A)
936.1	48	20

Table C- 15: Over-current Breakers (Protection) Input Data

Parameters	Value	Unit	Reference
Short Circuit Current of Panel(Isc)	9.43	Ampere	From Module
Current at Maximum Power (Imp)	9.11	Ampere	From Module
Voltage at Maximum Power	37.9	Volts	From Module
Over-irradiance	1.25	--	http://www.ieci.org/newsroom-and-insights/solar-photovoltaic-systems-and-the-2914-nec
3hours Continuous Factor (Oversize Amps)	1.25	--	http://www.ieci.org/newsroom-and-insights/solar-photovoltaic-systems-and-the-2914-nec
Combined Strings in Panel	5	--	Calculated

Table C- 16: Breakers between Panels and Charge Controller

Calculating Between Panels and Charge Controller	Calculated Value	Unit
Each Panel Strings x 1.25 over-irradiance x 1.25 3-hours	14.7	Ampere

Table C- 17: Table C- 17: Over Current Breakers between Inverter and Battery

Rated Wattage of Inverter / Lowest Battery Voltage x 1.25-3hours	26	Ampere

Table C- 18: Breakers between Inverter and AC Loads

Rated Wattage of Inverter/AC Voltage x 1.25 3-hours	5.4	Ampere

Wire Sizing was done according to the American Wire Code.

Table C- 19: Bill of Engineering Measurements and Evaluation (BEME) for Ibwa 1 PHC, Scenario 1

Item Description	**Quantity**	**Rate ($)**	**Total Cost ($)**	**Total Cost (₦)**
345 Module, 24V, SRP-345-6MA. Mono Crystalline	12	274	3,288	11,83680
6V 820Ah Flooded Lead Deep Cycle Battery	16	1,078.5	1,7256	6212160
MPPT Charge Controller 80A, 48V	1	590	590	2,12400
Cotek SP1000 > 1000 Watt 48 VDC Pure Sine Inverter	1	349	349	125640.00
Installation Cost + BOS (wires, breakers and other Accessories) 40% of components Cost	Lot	--	8593	3093480
SUBTOTAL			**30,076**	**108,273,60**

Item Description	**Quantity**	**Rate ($)**	**Total Cost ($)**	**Total Cost (₦)**
Contingency (5%)			4511	16,239,60
VAT (5%) + Import Duty (5%). Total = 10%			34560	12,441,600
GRAND TOTAL			**38,046**	**13,696,560**

APPENDIX D: DESIGN ANALYSIS AND BILL OF ENGINEERING MEASUREMENT AND EVALUATION FOR SCENARIO 2

Appendix D covers the design analysis carried out and costing (Bill of Engineering Measurement and Evaluation) for IBWA 1 PHC for scenario 2. It is presented in Tables D-1 to D-2 below

Table D- 1: Battery Sizing for Scenario 2

Parameters	**Values**	**Units**
System Voltage	48	Volts (V)
AC Daily Energy Demand	10826	Watt-hour (Wh)
Inverter Efficiency	89%	Percent
Days of Autonomy(DoA)	3	Days
Ambient Temperature of Room for Battery	81	^{0}F
Temperature Multiplier @ 81^{0}F	1	--
Depth of Discharge(DoD)	80%	Percent
Number of Parallel Strings	2	--
Battery Storage Capacity	12	Volts (V)

The metric used for order components design is the same used in Scenario 1 from Appendix Tables C-2 to C-18, but the bill of engineering measurement and evaluation (BEME) is presented in Table D-2, below.

Table D- 2: Bill of Engineering Measurements and Evaluation (BEME) for Ibwa 1 PHC Scenario 2

Item Description	**Quantity**	**Rate ($)**	**Total Cost ($)**	**Total Cost (₦)**
345 Module, 24V, SRP-345-6MA. Mono Crystalline	8	274	2,192	789120.00
12V 500Ah Lithium Ion Phosphate Deep Cycle Battery	8	6,449.98	41279.92	23,21992.8
MPPT Charge Controller 60A, 48V	1	470	470	169200.00
Cotek SP1000 > 1000 Watt 48 VDC Pure Sine Inverter 2300W/48Vdc/240VAC/60Hz	1	349	349	125640.00
Installation Cost + BOS (wires, breakers and other Accessories) 40% of components Cost	Lot	--	21844	78,63840
SUBTOTAL			**76,455**	**27,523,800**
Contingency (5%)			11468	4128480
VAT (5%) + Import Duty (5%). Total = 10%			8792.35	31,652,46
GRAND TOTAL			**96,716**	**34,817,760**

APPENDIX E: SPECIFICATION SHEETS OF DEVICE/SYSTEM COMPONENTS USED FOR DATA COLLECTION AND DESIGN

This Appendix covers major specification sheet of device/ components used during audit and for the solar system design. Figures E-1 to E-5 include specifications for the Solmetric Sun Eye 210, inverter, charge controller, solar PV panel, and battery, respectively

Figure E-1, below show the specification sheet of the Solmetric Sun Eye 210 used for determining geographical coordinates, losses due to shading, solar resource and tilt angle of the roof at each site during audit.

Figure E- 1: Solmetric Sun Eye 210 Specification Sheet.
Source: (http://resources.solmetric.com/get/SunEyePVD-DS-en.pdf)

Figure E-2, below show the specification sheet of the inverter used for the design

COTEK 1000W Pure Sine Wave Inverter **SP-1000 series**

Features:

- Pure sine wave output
- Power ON / OFF remote control (Green Terminal)
- Remote controller CR-8 / CR-16 (optional)
- Input & Output fully isolation
- Temperature & Load controlled cooling fan
- Built in advance microprocessor to provide friendly interface
- Output frequency 50 / 60 Hz selectable by DIP switch
- Output voltage DIP switch selectable
- Adjustable power saving mode by variable resister
- 3-color LED status indicators
- Input protection: Reverse Polarity (Fuse) / Under Voltage / Over Voltage
- Output protection: Short Circuit / Overload / Over Temperature
- E-13 / UL / CE / FCC approved

MODEL		SP-1000-112	SP-1000-124	SP-1000-148	SP-1000-212	SP-1000-224	SP-1000-248
Output	AC Voltage	100 / 110 / 115 / 120VAC			200 / 220 / 230 / 240VAC		
	AC Regulation	±5%			±3%		
	Rated Power	1000VA					
	Surge Power (1 Sec)	<1750VA					
	Maximum Output Power (1 Min)	>1000VA~1150VA (100%~115%)					
	Output Waveform	Pure Sine Wave (THD<5%@Normal Load NOTE1)			Pure Sine Wave (THD<5%@Normal Load NOTE2)		
	Frequency	50 / 60 Hz ±0.5%					
Input	DC Voltage	12VDC	24VDC	48VDC	12VDC	24VDC	48VDC
	Voltage Range	10.5 ~ 16.5VDC	21.0 ~ 33.0VDC	42.0 ~ 66.0VDC	10.5 ~ 16.5VDC	21.0 ~ 33.0VDC	42.0 ~ 66.0VDC
	NO Load Current	<1.5A@12VDC	<0.8A@24VDC	<0.5A@48VDC	<1.5A@12VDC	<0.8A@24VDC	<0.4A@48VDC
	Power Saving Mode	<0.1A@12VDC	<0.06A@24VDC	<0.05A@48VDC	<0.1A@12VDC	<0.05A@24VDC	<0.05A@48VDC
	Efficiency (Max.)	88%	89%	90%	88%	89%	90%
Protection	Input Under - Voltage Protection	10.5 ±0.3VDC	21.0 ±0.5VDC	42.0 ±1.0VDC	10.5 ±0.3VDC	21.0 ±0.5VDC	42.0 ±1.0VDC
	Input Under - Voltage Alarm	11.0 ±0.3VDC	22.0 ±0.5VDC	44.0 ±1.0VDC	11.0 ±0.3VDC	22.0 ±0.5VDC	44.0 ±1.0VDC
	Input Under - Voltage Recovery	12.5 ±0.3VDC	25.0 ±0.5VDC	50.0 ±1.0VDC	12.5 ±0.3VDC	25.0 ±0.5VDC	50.0 ±1.0VDC
	Input Over - Voltage Protection	16.5 ±0.3VDC	33.0 ±0.5VDC	66.0 ±1.0VDC	16.5 ±0.3VDC	33.0 ±0.5VDC	66.0 ±1.0VDC
	Input Over - Voltage Recovery	14.5 ±0.3VDC	29.0 ±0.5VDC	58.0 ±1.0VDC	14.5 ±0.3VDC	29.0 ±0.5VDC	58.0 ±1.0VDC
	Output Overload	Shutdown output voltage, restart to recover					
	Output Short	Shutdown output voltage, restart to recover					
	Over Temperature	Heat sink temperature over 80°C ±5°C, shutdown output voltage, recover automatically after heat sink temperature goes down to 60°C ±5°C					
	DC Input Reverse Polarity	By fuse					
Environment	Operating Temp.	-20°C ~ +40°C					
	Storage Temp.	-30°C ~ +70°C					
	Storage Temp. & Humidity	10 ~ 95% RH					
Safety & EMC	Safety Standards	Certified UL 458 NOTE3		—	Certified EN 60950-1		
	EMC Standards	Certified FCC class B			Certified EN 55022; EN 55024 EN 61000-3-2, -3-3 EN 61000-4-2, 3, 4, 5, 6, 8, 11		
	E-mark	—			Certified CISPR 25 ISO 11452-2; ISO 7637-2		
Control & Signal	Remote Control (Optional)	CR-8 / CR-16					
	LED Indicator	Input voltage level, output load level and faulty status					
	Dry Contact Terminal	By relay					
	Remote Control Terminal	6-port green terminal					
Others	Dimension (W x H x D)	200x83x372 mm / 7.87x3.27x14.65 inch					
	Packing	3.26kg; 4pcs / 14kg / 2.65CUFT					
	Cooling	Temperature & load controlled cooling fan					
	Application	Home and office appliances, portable power equipment, vehicle, yacht and off-grid Solar power systems ...etc.					
	Socket Type	North America (GFCI); North America (NEMA 5-15R)			Continental European (SCHUKO); Australia / New Zealand; United Kingdom; Universal		

Note1 - Normal Condition: Vin=12.5V / 25V / 50V Vo=100 / 110 / 115 / 120 VAC 80% Full load (PF=1.0)
Note2 - Normal Condition: Vin=12.5V / 25V / 50V Vo=200 / 220 / 230 / 240 VAC 80% Full load (PF=1.0)
Note3 - UL only for GFCI receptacles

COTEK 1000W Pure Sine Wave Inverter **SP-1000 series**

Mechanical Drawings:

Figure E- 2: Inverter Specification Sheet.
Source (https://www.ecodirect.com/Cotek-SP1000-248-1000-W-48V-Pure-Sine-Inverter-p/cotek-sp1000-248.htm)

Figure E-3, below show the specification sheet of the charge controller used for the design.

CLASSIC SL SPECIFICATIONS www.midnitesolar.com 360-403-7207 17722 - 67th Ave NE, Arlington, WA 98223

Classic SL 150, 200 or 250 MPPT Charge Controllers	
Nominal Battery Voltage	12 Through 72 volts on Classic SL's
Maximum Output Current	Classic SL-150 = 96A on 12V, 94A on 24V and 86A on 48V battery Classic SL-200 = 79A on 12V, 78A on 24+48V and 65A on 72V battery Classic SL-250 = 61A on 12V, 62A on 24V, 55A on 48V and 43A on 72V battery
PV Open Circuit Voltage VOC *(NOTE: See HyperVOC at bottom)*	Classic SL-150 = 150V + HyperVOC (battery voltage up to 48V) Example 150V + 48V = 198VOC Classic SL-200 = 200V + HyperVOC (battery voltage up to 48V) Classic SL-250 = 250V + HyperVOC (battery voltage up to 48V) (NOTE: See HyperVOC at bottom)
Power Conversion Efficiency	98% (Typical system)
Maximum Stand-By Self-Consumption (12V)	2.8W - 4W
Reverse Current At Night	Zero - Internal relay for reverse current
Low Battery Voltage	Low Battery voltage disconnect and re-connect of loads fully programmable with 2 Auxiliary outputs to control external load disconnect /re-connect switches
Hyper VOC *(NOTE: See HyperVOC at bottom)*	Standard all models - Extended VOC range for cold climates
Ground Fault Protection	Standard all models - resettable, no fuse to blow
Charging Regulation	Bulk, Absorb, Float as well as Equalization
Battery Voltage Regulation Set Points	10-100VDC
Equalization Charging	Adjustable Voltage and Duration, Manual or Auto
PV Reverse Polarity	Protected to Max VOC (Classic MPPT Charger Controllers are fully protected from reverse current on both input and output)
Battery Reverse Polarity	Fully protected (Classic MPPT Charger Controllers are fully protected from reverse current on both input and output)
Battery Short Circuit	Fully protected
Battery Temp Compensation	Automatic when BTS is installed, Adjustable mV per degree C per 2V cell
Programmable Auxiliary Control Output	2 Auxiliary outputs, Aux1 can be 12V out or dry contact, Aux2 is 12V out or Logic IN
Graphic Display	Graphical display
Networking Cabling	Standard 4 conductor phone cable, no hub needed
Communications	RS232 and ModBus openly published protocol
Remote Display	Display (MNGP) can be relocated and a second display can be added
Terminal Rating	75 C
Data Logging	380 days of daily history, 24 hours of data at 5 minute intervals
Positive Ground Applications	Requires 2 pole input and output breakers
Operating Temperature	Minimum of -40C to 50C - Controller will auto derate as temperature rises above 25C
Environmental Rating	Indoor type IP30 (The Classic is IP22 Rated to 60529 when used with Classic Drip Shield)
Conduit knock Outs	Single 1" conduit (35.05mm) on left and right sides. Two 1" conduit (35.05mm) on bottom. Two 3/4" conduit (27.76mm) on back.
Warranty	5 Year standard
Weight & Dimensions	12 Lbs. (5.45 kgs) - 14.9" x 6" x 4" (378mm x 152mm x 102mm)
Shipping Dimensions HxWxD	19" x 8.5" x 5.7" (482.6mm x 215.9mm x 144.78mm)
Options	MNGP graphical display, 3ft networking cable (NOTE: MNGP standard with all Classic SL models)

Figure E- 3: Midnite Charge Controller Specification Sheet.
Source (https://www.wholesalesolar.com/3900242/midnite-solar/charge-controllers/midnite-solar-classic-150-sl-charge-controller#downloads)

Figure E-4, below show the specification sheet of the panels used for the design.

Seraphim USA Solar Panels

SERAPHIM®
SOLAR USA MANUFACTURING

Seraphim USA is headquartered in Houston, Texas, with manufacturing operations in Jackson, Mississippi. They offer top-quality solar panels for the residential, commercial, industrial, government and military markets. Seraphim is a Bloomberg New Energy Finance (BNEF) Tier 1 Manufacturer - ranked above other USA Made Manufacturers. State-of-the-art, in-house manufacturing capacity and financial strength are what put them there.

Seraphim is the 1st company to pass the Thresher Test for solar panels.

FEATURES:

- Outstanding power output capability at low irradiance
- PID Free Modules
- Robust frame to withstand heavy snow load up to 5400 Pa
- 100% in-line Electroluminescence (EL) tests minimize breakage rate/cracks in the cells
- Qualify for the "Buy American" clause of the American Recovery and Reinvestment Act (ARRA)
- Certifications - ISO 9001, ISO 14001, OSHAS 18001
- Salt Mist Corrosion Test, Ammonia Corrosion Test, Fire Rating Class C
- 10 Year Workmanship Warranty, 25 Year Linear Power Output Warranty

ELECTRICAL CHARACTERISTICS:

Specifications:	SRP-290-6MB-BB	SRP-300-6MB-BB	SRP-345-6MA	SRP-360-6MA-40MM
Peak Power	290 Watts	300 Watts	345 Watts	360 Watts
Nominal Voltage	20 V	20 V	24 V	24 V
Voltage at Max Power (Vmp)	31.70 V	32.10 V	37.9 V	38.5 V
Current at Max Power (Imp)	9.15 A	9.35 A	9.11 A	9.36 A
Open Circuit Voltage (Voc)	39.30 V	39.70 V	46.8 V	47.40 V
Short Circuit Current (Isc)	9.44 A	9.65 A	9.43 A	9.70 A
Max System Voltage	1000 Vdc			
Module Efficiency	17.83%	18.44%	17.78%	18.55%
Dimensions	64.6" x 39" x 1.57"(1640 x 992 x 40 mm)		77" x 39" x 1.57"(1956 x 992 x 40 mm)	
Weight	41.9 lbs (19kg)	41.9 lbs (19kg)	50.7 lbs (23kg)	
Connectors/Cables	MC4 Compatible Connector/Cables			
Number of Cells	60 Monocrystalline cells		72 Monocrystalline cells	
Operating Temperature Range	-40C to + 85C			
Max Series Fuse Rating	20 A			

SEE DOCUMENTS TAB FOR DETAILED SPEC SHEETS AND DIAGRAMS OF EACH SOLAR PANEL

SERAPHIM®

Figure E- 4: Solar Panel Specification Sheet (Model SRP-345-6PA).
Source (https://www.altestore.com/store/solar-panels/seraphim-solar-panels-p40805/#SEP345SRP3456MA)

Figure E-5, below show the specification sheet of the Deep Cycle battery used for the design.

Surrette

DEEP CYCLE-SOLAR

SERIES 5000

BATTERY TYPE	**VOLTS**	**6**	**6 CS 25PS**			
DIMENSIONS						
LENGTH			559	MM	22	INCHES
WIDTH			286	MM	11 1/4	INCHES
HEIGHT			464	MM	18 1/4	INCHES
WEIGHT DRY			115	KG	254	LBS.
WEIGHT WET			145	KG	318	LBS.

CONTAINER CONSTRUCTION

INNER CONTAINER	POLYPROPYLENE
INNER COVER	POLYPROPYLENE - HEAT SEALED TO INNER CONTAINER
OUTER CONTAINER	HIGH DENSITY POLYETHYLENE
OUTER COVER	HIGH DENSITY POLYETHYLENE SNAP FIT TO OUTER CONTAINER
HANDLES	MOLDED

PLATES PER CELL		25			
ELECTROLYTE RESERVE	ABOVE PLATES	95	MM	3.75	INCHES
DESIGN CRITREA	10 YEAR WARRANTY	3300	CYCLES	15	YEAR LIFE
POSITIVE PLATE DIMENSION					
HEIGHT		273	MM	10.750	INCHES
WIDTH		143	MM	5.625	INCHES
THICKNESS		6.60	MM	0.260	INCHES
NEGATIVE PLATE DIMENSION					
HEIGHT		273	MM	10.750	INCHES
WIDTH		143	MM	5.625	INCHES
THICKNESS		4.57	MM	0.180	INCHES
SEPARATOR	SEPARATOR THICKNESS	0.105	INCH		

INSULATION	POSITVE PLATE ENVELOPED BY VERTICAL SLYVER GLASS MAT
TERMINALS	FLAG WITH STAINLESS STEEL NUTS AND BOLTS

COLD CRANK	CCA	0ºF / -17.8ºC	2088	**RESERVE**	1624
	MCA	32ºF / 0ºC	2610	**MINUTES AT 25A**	
CAPACITY	20 HR RATE		820		

		CAP / AH	CURRENT / AMPS
CAPACITY AT THE 100 HOUR RATE	1.265 SP. GR.	1156	11.6
CAPACITY AT THE 72 HOUR RATE	1.265 SP. GR.	1091	15.1
CAPACITY AT THE 50 HOUR RATE	1.265 SP. GR.	1009	20.2
CAPACITY AT THE 24 HOUR RATE	1.265 SP. GR.	853	35.5
CAPACITY AT THE 20 HOUR RATE	**1.265 SP. GR.**	**820**	**41**
CAPACITY AT THE 15 HOUR RATE	1.265 SP. GR.	763	51
CAPACITY AT THE 12 HOUR RATE	1.265 SP. GR.	713	59
CAPACITY AT THE 10 HOUR RATE	1.265 SP. GR.	681	68
CAPACITY AT THE 8 HOUR RATE	1.265 SP. GR.	640	80
CAPACITY AT THE 6 HOUR RATE	1.265 SP. GR.	582	97
CAPACITY AT THE 5 HOUR RATE	1.265 SP. GR.	549	110
CAPACITY AT THE 4 HOUR RATE	1.265 SP. GR.	508	127
CAPACITY AT THE 3 HOUR RATE	1.265 SP. GR.	394	131
CAPACITY AT THE 2 HOUR RATE	1.265 SP. GR.	394	197
CAPACITY AT THE 1 HOUR RATE	1.265 SP. GR.	279	279

Rev. 0 April - 04 SDSPECS 52

Figure E- 5: Battery Specification Sheet (Surrette Rolls 6-CS-21P > 6 Volt 683 Amp Hour Flooded Battery).
Source (http://www.ecodirect.com/Surrette-Rolls-6-CS-25P-6V-820-AH-Battery-p/surrette-6-cs-25p.htm)