UNIVERSITY OF WITWATERSRAND, SCHOOL OF ARCHITECTURE AND PLANNING

SOLAR PV FOR DECENTRALISED GENERATION FOR COMMERCIAL BUILDINGS IN NIGERIA: A CASE STUDY OF THE ARCHITECTURE BUILDING AT KOGI STATE POLYTECHNIC.

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DECLARATION

I declare that this research report is my own unaided work. It is being submitted for the degree of Master of Architecture in Sustainable Energy for Efficient cities to the University of Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at any other University.

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ABSTRACT

The centralised energy generation system has been constantly criticised for not meeting the demand of Nigerian consumers. Recent studies on Nigeria's energy crises suggest that there should be an urgent adoption of decentralized generation (DG) as a means of alleviating energy poverty in the country, and as a way of reducing greenhouse gas emission (GHG) from the popular fossil-fuel based standalone generators. However, businesses today are anxiously trying to find ways to lower their energy related expenditures.

In line with these assertions, and using a case study of the Department of Architectural Office Building (DAOB) to incorporate rooftop solar PV system, the study uses a Design Builder and Energy plus simulation software to model and analyse the DAOB. This study is based on primary and secondary data sources. The study assessed policy regulatory and market structures which could stimulate the increased deployment of such systems in Nigeria.

The electricity bills for one year reported an annual consumption of 12,407 kWh, at the cost of N297, 762 ($945) and likewise the cost of operating a building on diesel generator for a period of one year was calculated at N2, 688,000 ($8,513) while the status-quo baseline energy consumption of the building from simulation and the cost implication per annum was 69,733 kWh and ₦1,673,592 ($5,579) respectively. Optimisation of the baseline consumption through a combination of three feasible energy efficiency initiatives reduced the baseline annual consumption by 47% from 69,733kWh to 37,298 kWh.

The roof had the capacity to generate 155,347kWh which could cover for both the baseline and the optimised annual electricity consumption. The analysis revealed further that the roof could generate a surplus of 118,045 kWh/annum based on the optimised energy consumption. Using financial analysis tools of payback period, return on investment and net present value, the study undertook a number of business case scenarios to establish a viable business model. Based on the financial analysis performed, a Solar Power Purchase Agreement (SPPA) business model was identified as the most suitable to overcome the barrier of upfront cost.

Keywords: Business model, distributed energy generation, Energy efficiency, greenhouse gas, optimization.

Dedication

This work is dedicated first and foremost to God almighty, for without him, this work would not have been possible. I equally dedicate this work to my lovely wife and child, Mrs Ipinmoroti Rosemary and Miss Ipinmoroti Anabel for their understanding, support and unending love.

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Chapter 1

Introduction

1.1 Overview

Availability and access to affordable clean energy sources is the socio-economic back bone of any modern economy. The contemporary world is dependent on diverse energy supply to run economic activities like food production, processing and preservation, mining and industrial processes, transportation, communication and information technology, health care delivery services, education and research. An energy resilient country must among other things be able to identify the availability of renewable energy resources that are diverse in nature, sustainable in quality and quantity, affordable in prices, aid economic progress, support poverty reduction, and be sustainable to the environment. (Sambo, Garba, Zarma, Gaji, 2010:1).

Nigeria is Africa's most populated country with an estimated population of 182.2 million people (as at 2015), and is said to be the eighth most populated country in the world. The country is made up of six geopolitical zones which are subdivided into 36 states, and 774 local governments with Abuja as the Federal Capital Territory (FCT). The country falls between latitude 4^0 to 14^0 north and longitude 2^0 to 5^0 east, and stretches over an estimated area of 923,768 kilometres square (Centre for Renewable Energy Technology CRET 2015: un-paginated).

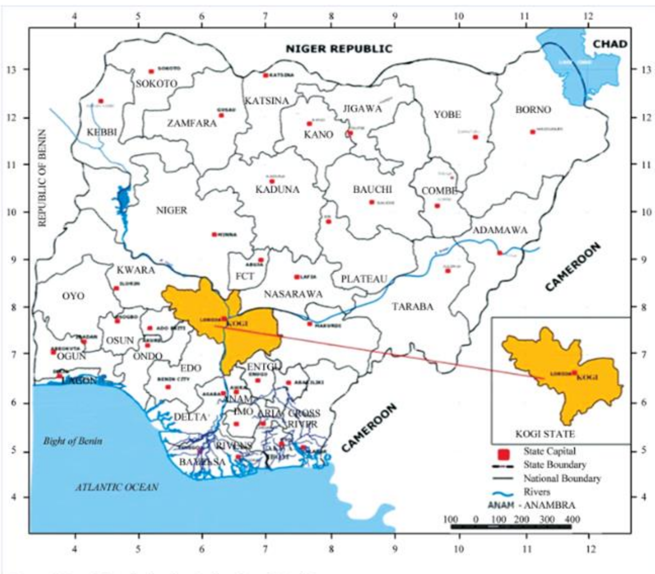


Figure 1: Map of Nigeria with the 36 States showing the map of Kogi State. Source: Kogi State Ministry of Land and Environmental (2008).

As in most developing countries, energy crisis in Nigeria has escalated hand in hand with population growth and urbanisation. Electricity demand in Nigeria is estimated at 24.4GW, while total installed power capacities is 12.07GW, and actual availability is 6.84GW. The actual generating capacity as of July 2015 was 4.06GW, mainly from hydro, gas, and thermal power plants (Centre for Renewable Energy Technology CRET 2015: un-paginated).

According to the CRET report, the population without electricity is estimated at 99 million out of a total of the 182.2 million. The challenges in the electricity sector has been attributed mainly to the following factors; over-centralised mode of generation, high dependency on one source of electricity, electricity lost in the cause of transmitting to other distance settlements, inadequate maintenance culture of the generating plants, vandalism, government policies and political factors amongst other causes (Borok, Aganda, Mangai, 2013: 1; CRET, 2015).

1.2 Background and context

A major diversification in power generation in most developed and developing countries has improved their power sectors and economies to move forward and decentralised generation is one of the key components of such diversification. A decentralized generation (DG) system is an affordable and accessible source (often clean electricity) that is usually generated close to its point of use. When generated from renewable sources, it equally aids in decarbonizing the society as guided by the Kyoto protocol of 1997. It includes but not limited to the following generation of fuel and technologies; biomass, industrial energy recycling and on-site power, combined heat and power (CHP), hydrogen fuel cell, solar energy, and turbine for wind energy (Aliyu, Dada, Adam, 2015; Mohammed, Mustafa, Bashir, and Mokhtar, 2013).

In a bid to mitigate the electricity crisis in Nigeria, most households, small and medium scale enterprises (SMEs), industries and cooperate organisations, as well as government institutions in need of electricity to run their day to day activities have resorted to self-generation, using petrol/diesel stand-alone generators. This type of power source is mostly off-grid, expensive and not sustainable owing to its large scale greenhouse gas emission (GHG) (Nduka, 2012:16).

1.2.1 Motivation

The performance of energy in buildings is of vital significance to building owners/users because it transforms to cost. Energy efficiency simply implies that the quantity of energy needed for the provision of services will be utilized in a way that optimises its usage. However, it does not translate to complete elimination of energy usage (Moshen, 2011). Instead it allows for the possibility of reducing the energy requirement as well as mitigates the demand on grid supply and related centralised generation sources.

Currently, solar energy exploitation in Nigeria is highly restricted to a few households in urban centres, some organisations or government institutions, and a few rural electrification projects under the Millennium Development Goals (MDGs) with examples such as a few automated street lights in some rural areas. Nevertheless, research shows that the country has enough solar radiation to sustain its energy demand especially in rural and sub-urban areas due to their low energy demand (CRET, 2015). This study aims at appraising the potential of DG at building scale level through the use of building integrated PV system technology, and by developing a business model that could enhance its scale-up in Nigeria in general.

1.3 Problem statement

Recent studies on Nigeria's energy crises have begun to prioritise decentralized generation (DG) as a means of alleviating energy supply constraints as well as poverty in the country. DG is also viewed as a way of mitigating greenhouse gas emission from the popular diesel/petrol stand-alone generators. However, the mechanisms for the systematic implementation of DG (design and financial models, as well as responsive regulatory and policy frameworks) have not emerged as yet. For years, the centralised energy generation has been constantly criticised for not meeting the demand of Nigeria consumers. Obadote (2009:1) argues that only 10% of rural households and 40% of the country's total population have access to electricity which is also characterised by erratic and limited supply for the rapidly growing and transforming economy.

With regards to energy consumption in buildings, Nigerian buildings are usually poorly designed in terms of exploiting passive design approaches. For example, some office buildings lack enough illumination to be functional with optimised daylight and end up using artificial means even in daytime. Equally, office space often becomes too hot, as a result of excessive solar heat gain thus necessitating other methods of cooling such as mechanical ventilation and HVAC (heating, ventilating and air-conditioning).

1.4 Rationale of the study

Although, research and innovation on DG (especially PV) has broken through the critical barriers such as financial constraint, maturity in technology, and the ongoing dilemma on whether DG is economically feasible or not, the question of what hinders its scaling-up towards mitigating energy crisis still needs to be answered. The focus of this study will therefore be to identify strategies for energy efficiency measures for the Department of Architecture Office Building (DAOB), which will allow for optimisation in energy consumption and evaluating the potential of building-integrated PV retrofit to meet the optimised energy demand.

The study will contribute towards assessing the potential for reduced cost of energy consumption in office buildings thus freeing up money that can be spent in other budget items of owners/users or organisations such as the polytechnic. The study also aims at conceptualising and evaluating viable business models that would help in addressing some existing barriers now inhibiting the proper scale-up of building-integrated PV (BIPV) in both new and existing buildings in Nigeria. The proposed study will also explore case studies from South Africa as well as other developed and developing countries of the world in order to gain insight on prevailing PV-based DG business model practices under entities such as ESCos (energy services companies) with a view towards adaptation to Nigerian context.

1.5 Research Question

The process of the study was guided by a key research question and five sub-questions as listed in the following sub-section.

1.5.1 Main research question

What is the potential of solar PV electricity generation through a retrofitting of the Department of Architectural Office Building (DAOB) as a case-study towards enhanced energy security, and what would be the responsive business model and policy framework to open up a wider transformation towards distributed energy generation with building integrated solar PV in Nigeria?

1.5.2 Sub questions

- What is the current energy baseline consumption patterns and levels as well as related cost for the DAOB?
- How can energy efficiency optimised interventions with integrated PV-based DG reduce the energy consumption of DAOB?

- How would the cost of retrofitting DAOB compare to the status-quo coping mechanism of the building in the short and long term?
- What are the viable business model options for a PV retrofit of the DOAB building?
- What would be the related insights for scale-up of the related interventions for commercial building (new and existing) for Nigeria?

1.5.3 Working hypothesis

The study was guided by a working hypothesis stating that the DAOB building has the potential to generate electricity through Solar PV system and export surplus to the grid. Also, through an innovative business model, the DAOB could serve as a prototype for similar buildings and pioneer the scale up of DG based solar systems in Nigeria. In turn, this could attract potential investors in DG and best address the persistent power outage, its unsustainable status quo coping mechanisms, and lead to mitigation of greenhouse gas emissions (GHG). The study has demonstrated that the DAOB building can generate electricity through Solar PV system and export surplus to the grid.

1.6. Research approach

The research question was addressed using a case study approach from which primary data was obtained. On-site visual survey was performed to assess the study area first-hand while online secondary databases were utilized to reinforce data obtained from the site. Primary data collected includes the different office appliances, equipment, computers and lighting with their corresponding wattages used in the building. Building and construction drawings, electrical and mechanical drawings were collected as secondary data. Building occupancy and operation pattern were equally documented. The site was also examined for any obstruction occurring on the rooftop surface because only by understanding the conditions of the rooftop surface was it possible to determine the rooftop area available for solar PV deployment. Design builder software was also utilized to determine the status-quo electricity consumption of the building.

Secondary data used in this research report was obtained from the university library and internet searches including experts' reports, conference proceedings, web-based information systems, journal articles, specialist surveys, and case study reports.

1.7 Limitations and delimitations of the study

This report examines the potential of solar PV electricity generation through a retrofitting of the Department of Architectural Office Building (DAOB) as a case-study towards enhanced energy security in Nigeria. The study further evaluates the responsive business model and policy framework to open up a wider transformation towards distributed energy generation with rooftop solar PV in Nigeria. It was considered necessary to set this study within a case study context from which data could be gathered and analyzed. However, the key findings presented in this study (especially on business model and policy framework) are established from secondary data as well as methodology that utilized certain assumptions that can have significant implications when adapting the results to other contexts. Generalizability of these results is subject to certain limitations. Limitations encountered when conducting this study are highlighted below.

The study is limited by a lack of information on the existing business model within the energy service company's practices in Nigeria. To address the related sub-question "what are the viable business model options for a PV retrofit of the DOAB building?"

However, it was important to first understand the existing business model practices for DG within energy service provider in the country. This implies that much of the information provided to answer this question were based on existing business model practices within energy service companies in other countries. This lack of information has prevented a comparison to be made between the business model practices in Nigeria and other countries to ascertain the authenticity of the viable business model options for a PV retrofit of the DAOB.

The second limitation is around policy on feed in tariffs. Although, there is an existing policy that support a grid-tied renewable energy generation except solar energy (FMP, 2015), however, apart from grid unreliability as well as unavailability of smart technologies like net-metering, there is no clear intention or policy on whether energy generated from solar PV will benefit in the nearest future, from the feed in tariff implementation or not. This implies that the discussion on the possibilities of exporting excess energy generated by the building to the grid for revenue purposes is theoretical and as such cannot be directly transferred for use in other studies without customization to contextual conditions in this regard.

The third limitation is that rooftop solar PV generation potential is highly influenced by contextual factors such as topography and weather conditions (National Renewable Energy

Laboratory, 1992). For this reason, it is important to note that rooftop solar PV generation potential estimates in this study cannot be directly transferred for use in other studies without customization to contextual conditions in this regard. Further, the cost estimates presented in dollar in the report was based on the exchange rate at the time of this report. Dollar to naira rate at the time of this report was 1$ USD to ₦315.37 (naira).

1.8 Definition of key concepts.

Distributed generation: This is an approach that employs small-scale technologies to produce electricity close to the end users of power. DG technologies often consist of modular (and sometimes renewable-energy) generators, and they offer a number of potential benefits. In many cases, distributed generators can provide lower-cost electricity and higher power reliability and security with fewer environmental consequences than can traditional power generators (Lasseter, 2007, Wong et al, 2017).

Debnath et al. (2015) argues that in contrast to the use of a few large-scale generating stations located far from load centres, the approach used in the traditional electric power paradigm-DG systems employ numerous but small plants and can provide power onsite with little reliance on the distribution and transmission grid. DG technologies yield power in capacities that range from a fraction of a kilowatt [kW] to about 100 megawatts [MW]. Utility-scale generation units generate power in capacities that often reach beyond 1,000 MW (Debnath et al, 2015). The concept of DG has been applied in this study to represent electricity generation next to the point of use (utilized by the host (DAOB) of the facility first).

Rooftop solar PVs: A rooftop photovoltaic power station or rooftop PV system is a photovoltaic system that has its electricity-generating solar panels mounted on the rooftop of a residential or commercial building or structure (Razykov et al, 2011). The various components of such a system include photovoltaic modules, mounting systems, cables, solar inverters and other electrical accessories (Razykov et al, 2011).

Rooftop mounted systems are small compared to ground-mounted photovoltaic power stations with capacities in the megawatt range. Rooftop PV systems on residential buildings typically feature a capacity of about 5 to 20 kilowatts (kW) while those mounted on commercial buildings often reach 100 kilowatts or more (*ibid*).

In this study, this concept refers to the technology that uses energy from sunlight to generate electricity via modules mounted on the DAOB building rooftop. This electricity generated is first consumed within the DAOB building. This concept is contrasted from other technologies such as building integrated photovoltaic (BIPVs) and solar thermal technologies. BIPV technologies substitute conventional building materials in the climate envelope of the building and makes them power generators (Jelle and Breivik, 2012) while solar thermal technologies harnesses the solar energy and convert it to thermal energy.

Energy efficiency interventions: This concept refers to the strategies (both passive and active) to reduce the baseline electricity consumption of the building without reducing the quality of the electricity supplied. In this study these energy efficiency interventions are those that are technically viable for the DAOB building case study.

Improvements in energy efficiency are generally achieved by adopting a more efficient technology or production process or by application of commonly accepted methods to reduce energy losses (Rujula et al, 2017).

There are many motivations to improve energy efficiency as revealed by Debnath et al (2015) and Sharma et al (2015). Firstly, reducing energy use reduces energy costs and may result in a financial cost saving to consumers if the energy savings offset any additional costs of implementing an energy efficient technology. Secondly, reducing energy use is also seen as a solution to the problem of reducing greenhouse gas emissions.

Business case: This concept refers to a financial justification made for a precise planned investment. In this study, the concept is used to make comparison of the opportunity cost of undertaking alternative energy efficiency interventions applied to the DAOB building and that of installing the solar PV system.

Business model in this study describes the rationale of how a third-party driven rooftop solar PV project captures and creates value for the institution as the owner of the building and the investor through the three structures of ownership, operation and financing. (Frantzis et al., 2008:4-2). The essence of the business model as described in this study was to be responsive to the policy, regulatory and market environment while addressing the key barriers in order to drive the required increased deployment of decentralized rooftop solar PV electricity generation from buildings in Nigeria.

Baseline energy consumption: This concept is used interchangeably with "baseline electricity consumption". In this study, the concept refers to the simulated minimum annual electricity consumption of the equipment and operations of the DAOB building.

Optimized energy consumption: This concept refers to the annual electricity consumption of the DAOB building that maximizes the use of energy efficiency interventions to lower the annual baseline consumption.

Grid-tied system: In this study, this concept has been used interchangeably with grid- integrated system. It refers to the system of electricity generation from the rooftop solar PVs that assumes that the system is connected to the utility grid via a bi-directional meter. The concept assumes that the solar PV facility is able to feed into and tap from the grid. In addition, it assumes exclusion of the battery for simplicity in connection.

Feed-in-tariff: In a grid connected rooftop photovoltaic power station, the generated electricity can sometimes be sold to the servicing electric utility for use elsewhere in the grid. This arrangement provides payback for the investment of the installer (Rujula et al, 2017). This concept refers to a payment for the surplus electricity generated by the DAOB rooftop solar PV system and exported to the utility grid (as off-takers) fixed by policy in Nigeria to run for a period of 25 years.

1.9 Proposed structure and chapter outline of the research report

The proposed study is structured into chapters. The chapters are sectioned into different themes and sub-themes. Chapter 1 contains the background and context of the study, chapter 2 comprises of literature review, chapter 3 deals with research methodology, data analysis and data interpretation, while chapter 4 contains discussion of findings.

Chapter 1 provides the context, background, problem statement, rationale, main research question and working hypothesis of the proposed study. This chapter also highlights the challenge of energy crisis in Nigeria, existing coping mechanism, and the importance of decentralised generation through building integrated photovoltaic technology

Chapter 2 of the study reviews literature on the potential and challenges of renewable energy in Nigeria and energy efficiency principles for retrofit interventions in existing buildings. Also, the chapter review literatures on viable, trending and emerging business models globally for the purpose of adaptation into Nigerian context.

Chapter 3 provides an overview of the research methodology, research design approach, data analysis and interpretation. The chapter also reveals the derivation of findings form optimising and simulating the selected building (DAOB). Further, the chapter discuses findings from various business models appraised through primary and secondary data collected.

Results from simulation were discussed and interpreted in chapter 4. Also, the status-quo baseline consumption of the building as well as the related cost were established in this chapter, while chapter 5 looked at the various passive and active energy efficiency interventions to be retrofitted in the building to optimise it's energy consumption. The chapter also discusses the financial implication of such measures to know their viability.

Chapter 6 explores the available roof area for solar panel installation. This chapter also looked at solar PV system sizing based on optimised energy demand as well as the available roof area for solar panel installation. Financial analysis was performed to determine the financial implications for the two scenarios in this chapter.

Chapter 7 consolidate findings from various data analysed and interpreted in the previous chapters. This will help in providing answers to the main and sub-questions in chapter 1. Also, this chapter concludes and summarises the proposed study.

Chapter 2

Literature review

2.1 Introduction

This section will focus on studies that address the following; overview of electricity sector in Nigeria, identification of the built environment as the industry where a huge GHG saving can be achieved, the potential and challenges of renewable energy in Nigeria, the need for energy efficiency, basic energy-saving techniques, energy strategies for new projects, principles of energy efficiency, and sustainable & energy efficiency strategies for retrofitting buildings. This section will also appraise studies on some trending and emerging PV-based business models globally in order to gain insight on the prevailing business model practices.

2.2 Overview of Electricity scenario in Nigeria

According to Obadote (2009) electricity history in Nigeria dates back to 1896 when it was first generated in Lagos, fifteen years after its introduction in England. This was through the installation of 2 small generating set to serve the then colony of Lagos Sambo, Garba, Zana, Gaji (2010). In 1946, the responsibility of electricity supply in Lagos was under the Public Work Department (PWD) and in 1950, Electricity Corporation of Nigeria (ECN) was created. Other authorised electricity supply companies includes Nigerian Electricity Supply Company (NESCO), and the Native Authority. Niger Dam Authority (NDA) was established to construct and maintain hydro dams and other works on the river elsewhere generating electricity by means of water. Power generated by NDA was sold to ECN for distribution and sales at utility voltage (Obadote, 2009).

A significant land mark in power sector of Nigeria was the coming together of ECN and NDA in 1972, to form a new organisation namely the National Electric Power Authority (NEPA) which was later renamed Power Holdings Company of Nigeria in 2004 due to the reform in Energy Sector of the country. NEPA, whose activities included electricity generation from production, distribution and transmission to billing monopolised the energy sector for years (Vicent and Yusuf 2014).

Various attempts made by NEPA to meet the challenges of electricity supply to the growing population of the country proved abortive (Vicent and Yusuf, 2014). The introduction of the National Electric Power Policy (NEPP) in 2001 was to aid in power sector reform. NEEP designed a road map for Nigeria's power sector privatization which was not signed into law immediately due to the bureaucracy of Nigerian government. However, it was later signed as Electric Power Sector Reform (EPSR) Act in 2005 (Vicent and Yusuf, 2014). A major part of EPSR duty was to create an enabling environment for potential local and foreign investors in energy sector especially renewable energy. The Act equally replaced NEPA with PHCN and within a short period of time PHCN became redundant and was later subdivided into several units, namely the Nigerian Electricity Supply Innovation (NESI) responsible for generation, Transmission Company of Nigeria (TCN), and the distribution companies comprising of eleven different electricity distribution companies (DISCO) across all the six geopolitical zones in the country.

The challenges of electricity in Nigeria include, generation, transmission, distribution and billing. According to a report by the Centre for Renewable Energy Technology CRET (2015), the existing fleet of power plants is a mix of plants built before the 1990's and plants built (or being built) since the mid-1990. Since the older thermal power stations suffer considerably from poor maintenance, the available generating capacity was just under 6,200 MW in 2012(CRET, 2015:15) and has risen to 6,840 MW in 2015. However, unavailability of gas, breakdowns, water shortages and grid constraints severely limit the power plant performance. This means that despite increases in the available installed capacity over the last years, only between 3,000 MW to 4,500 MW are actually being generated (CRET, 2015:15). The report reveals that Up to 2,700 MW of power generation capabilities are regularly lost due to gas shortage, up to 500 MW are lost due to water management, while several hundred megawatts are regularly lost due to line constraints (CRET, 2015).

The Maximum Peak Generation has remained below 5,000 MW for year 2015 (*ibid: 16*) because the fundamental problems bedevilling the national power systems have remained largely unsolved. These according to (CRET, 2015) include natural gas delivery constraints to the gas-thermal power plants, sub-par water resource management at the hydro-power plants and persistent losses through the dilapidated transmission/distribution lines (*ibid*).

Given the above hiccups, the outcome is poor distribution, voltage in most areas being relatively low and the billings do not in any way correspond with electricity consumption. Weak and inadequate networking, overload transformers and bad feeder pillars, substandard distribution lines, poor billing system, unwholesome practices by staff and very poor customer relations, inadequate logistic facilities such as tools working vehicles, poor and obsolete communication equipment, low staff morale and lack of regular training, insufficient funds for maintenance have been cited as part of the challenges facing the electricity sector (Vicent and Yusuf, 2014).

2.3 Stand-alone generating plants.

Since the country's goal of uninterrupted power supply seems almost impossible to achieve, different brand and capacities of individual self-generating electricity power plant in almost all residential houses and business outfits remains the order of the day for majority of Nigerians as far as electrical power supply is concerned. The cost of self-generation is as high as US$0.50 per kWh (Nduka, 2012) for a large class of the population. That is 5 times what the average American pays for electricity (Nduka, 2012; CRET, 2015). This is the situation in every part of the country including the study area. The effect of rampant use of individual house hold electricity generating plants includes anthropogenic source of carbon dioxide, carbon mono-oxide, particulate as well as (noise) emission which pose great danger to humans, the economy and promote factors that lead to environmental problems. These associated environmental, health and social hazards are major concerns to both the users and their neighbours (Nduka, 2012; CRET, 2015).

It is evident from these reports that adequate electricity generation would give rise to massive production at a low cost which then leads to low price for the demand. Such demand improves the aggregate demand thus adding positively to income which then leads to improve standard of living. There has been prolonged unreliable power supply in the country and this prolonged erratic power supply has the tendency to retard growth and even economic development (CRET, 2015).

This experience has been a major setback to the economy among all other African states. Nevertheless, looking at the coping mechanism, there is a willingness to embrace measures. Therefore, the reliable provision of clean and affordable electricity like rooftop solar PV has the potential to tackle these problems.

2.4 Institutional Set-up in the Nigerian Energy Sector

Over the years, a myriad of institutions and bodies have been created in Nigeria to steer the energy sector. This has led to overlapping mandates and regular conflicts amongst institutions and bodies adding to the already complex relation between the Federal and State levels which further affect the much needed coordination in the sector (Federal Ministry of Power FMP, 2015). The institutional set-up as a whole and many of its institutions have initiated a restructuring process to respond better to the needs of the newly liberalized power sector. This process is expected to improve the institutional coordination and complementarity. To ensure the sector's coordination, the Federal Ministry of Power (FMP) established the Inter-Ministerial Committee on Renewable Energy and Energy Efficiency (ICREEE) composed of the key power sector actors. The Committee has rather had a limited impact. The Nigerian Energy Support Programme (NESP) has supported the Federal Ministry of Power to re-activate it (FMP, 2015).

In addition to the Federal Ministry of Power (FMP) that is supposed to be the main actor in the sector responsible for policy formulation, planning, coordination and monitoring, the Presidency decided to be directly involved in the power sector reform with the creation of the Presidential Action Committee on Power (PACP) and the Presidential Task Force on Power (PTFP). The Federal Ministry of Power (FMP) is one of the institutions that is currently undergoing a restructuring process to adapt to the new structure of the liberalized power sector with the newly created Department of Renewable and Rural Power Access in the Ministry (*ibid*).

The Electricity Power Sector Reform Act (EPSRA) provided for a new institutional set-up for the reformed power sector. It created the Nigerian Electricity Regulatory Commission (NERC) in charge of regulating the sector (including licensing) and ensuring compliance of actors with market rules. It unbundled the former public utility and Power Holding Company of Nigeria (PHCN). As a result, a number of thermal power generation plants have been privatized (Ajayi, 2013; FMP, 2015). Others are awaiting privatization under the National Independent Power Producer (NIPP) Programme managed by the Niger Delta Power Holding Company Limited (NDPHC). The hydropower plants have been franchised. The transmission sector remains public under the control of the Transmission Company of Nigeria (TCN) managed by a private company (Manitoba Hydro International of Canada) (Ajayi, 2013; FMP, 2015). The distribution sector has been completely privatized with the creation of 11 zones that were sold to the private sector in an open competitive bidding process (Ajayi, 2013; FMP, 2015). With a view to ensure the transition towards a fully privatized power market, the Act also foresaw the creation of the Nigerian Bulk Electricity Trader (NBET) responsible for purchasing electricity from generation companies and selling it to distribution companies (FMP, 2015)

Due to the heavy reliance of power generation on gas and in order to ensure gas supply to the power generation companies, a Gas Aggregation Company of Nigeria (GACN) was established with the mandate to facilitate natural gas trade between suppliers and consumers (Ajayi, 2013; FMP, 2015). The Nigerian gas company in order to narrow down the gap between rural and urban electrification, the Electricity Power Sector Reform Act (EPSRA) also created the Rural Electrification Agency (REA), responsible for stimulating rural electrification through various instruments, including subsidization (*ibid*). Nonetheless, since the Rural Electrification Agency (REA) framework has not yet been fully finalized, the Agency carries out implementation of "constituency" projects, mostly main-grid extension, as well as off-grid renewable energies, upon requests from communities or political authorities using the monies of the federal executive which are directly allocated for specific projects. Other actors, like the Federal Ministry of Power (FMP), the Federal Ministry of Environment (FME) and the Energy Commission of Nigeria (ECN) also carried out constituency projects using off-grid renewable energy system (Ajayi, 2013; FMP, 2015).

The Constitution gives States the power to generate, transmit and distribute in areas that are not yet covered by the national grid. As a result, States and Local Governments also carry out electrification projects, mostly grid extension to rural areas using their own budgets. Nigerian Gas Company (NGC) was created to transport natural gas through its pipeline network (Ajayi, 2013; FMP, 2015).

2.4.1 Energy sector stakeholder analysis

Ministries, departments and agencies of the federal government play significant roles in the power sector in Nigeria. This is particularly so in the aftermath of the reform in the sector, which was ushered in by the Electric Power Sector Reform Act (EPSRA), 2005. The wider energy sector is equally overwhelmed by government presence. These MDAs and summary of their statutory roles are detailed below in table 1.

S/N	ENERGY STAKEHOLDER	STATUTORY FUNCTION
1	Energy Commission of Nigeria (ECN)	Energy sector planning and policy implementation. Energy Research and Development.
2	Federal Ministry of Power (FMP)	Developing electricity generation from all sources. Developing and deploying electricity related renewable energy policies.

3	Nigerian National Petroleum Corporation (NNPC)	Regulating, supervising and developing upstream and downstream activities in the oil industry.
4	Presidential Task Force on Power	Driving implementation, monitoring and performance evaluation of the power reform agenda.
5	Nigerian Bulk Electricity Trading Plc. (NBET)	Bulk purchase and resale of electricity from commercial-scale electricity generators.
6	Federal Ministry of Environment (FMENV)	Protecting the natural environment against pollution and degradation for sustainable development Includes a Special Unit on Renewable Energy.
7	Federal Ministry of Lands Housing & Urban Development (FMLHUD)	Driving policies and enforces regulation in the land, housing and building sector. Sets building codes for energy efficiency.
8	Federal Ministry of Water Resources (FMWR)	Providing sustainable access to safe and sufficient water for basic human needs including hydropower generation.
9	National Power Training Institute of Nigeria (NAPTIN	Training power sector personnel to serve Nigerian and the wider West African power sectors. Producer of the National Power Training Policy.
10	Nigerian Electricity Regulatory Commission (NERC)	Monitoring and regulating the electricity industry of Nigeria and ensuring compliance with market rules. Assesses applications for licenses to generate ≥ 1MW.
11	Rural Electrification Agency of Nigeria (REA)	Mobilizing capital for private-sector driven investment in electricity development and National Grid expansion.
12	Standards Organization of Nigeria	Monitoring and regulating standards of products (imported and locally made). Setting renewable energy and energy efficiency standards for solar lighting, PV panels etc.

Table 1: Stakeholders of the Nigerian Energy Market. Source: (NESP, 2014).

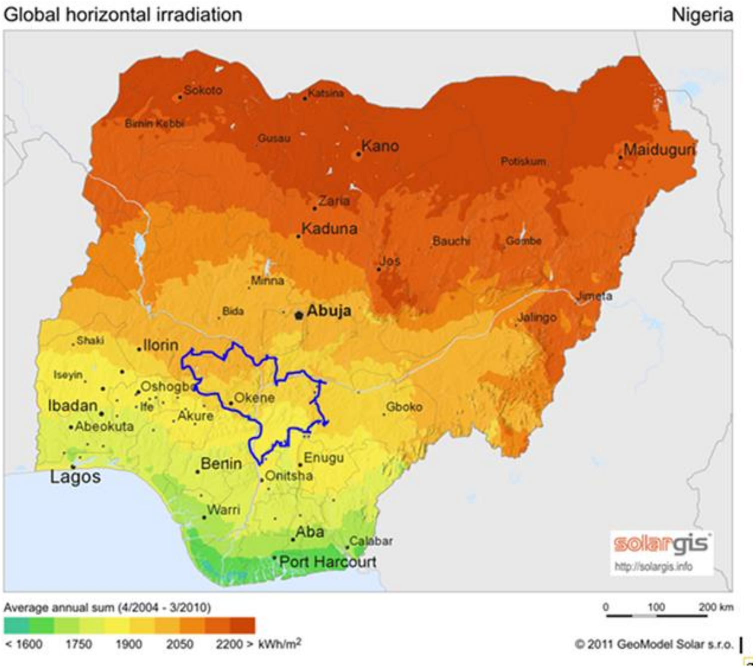
Although the improvements detailed in section 2.4.1 above have increased confidence in the future of Nigeria's power sector, large challenges remain in all phases of the power value chain if electricity supply is to meet electricity demand. The long-term viability of the sector is tied to the health and sustainability of all stages of the value chain from generation to payment by end users. Most importantly, the energy efficiency still needs to be embraced by stakeholders and the population at large as a cost-effective tool to save electricity and to improve the reliability of the power system. Awareness creation measures are as important as mandatory standards and voluntary pilot projects in order to demonstrate the viability of this approach.

2.5 Status of solar energy development in Nigeria

For decades, solar thermal has been constantly exploited by rural dwellers for agricultural processing purposes such as drying of agricultural products like grains, cassava (tubers or marsh), yam flakes, meat, fish, fruits, kernels, drying of manure, hides and skins. Other areas of solar energy utilizations include heating and lighting of animal pens, pumping of water and irrigation, food and vaccine storage (Yohanna and Umogbai, 2010). In addition to these, solar energy has also found wide usage in Nigeria in areas like solar street lightings, solar refrigerators, solar cookers, and solar-powered water pumps (Yohanna and Umogbai, 2010).

Different applications which exist in the form of solar thermal and solar PV. Solar energy devices (mainly solar thermal) have been designed, built or adapted by research institutes and tertiary institutions across the country (Sambo, 2010; Yohanna and Umogbai, 2010). Notable among the products in existence locally is the built 1000-litre (Sambo, 2010) capacity solar water heating system at the Usman Danfodiyo University Teaching Hospital, Sokoto in 1998 by the Sokoto Energy Research Centre (SERC), solar driers, solar chick brooders and solar absorption refrigerators developed at the National Centre for Energy Research and Development (NCERD) (Sambo, 2010). Solar PV found widespread usage in street lighting, but other pilot projects including water pumping, vaccine refrigerators, community lighting and few stand-alone mini grids installed and scattered across the country by the government or any of its agency like the Energy Commission of Nigeria (ECN), Federal Ministry of Power (FMP) and the Federal Ministry of Science and Technology (FMST) also exist (Sambo, 2010).

Figure 2: Global irradiation map of Nigeria showing the location of the study area. (2016).



List of some solar projects as carried out by ECN is given in Table 2. However, synergy does not exist among all the major energy players (ECN, FMP, FMST, other private donors and state parastatals that are involved in energy projects), hence, no comprehensive project database exist for renewable projects in the country. Additionally, all existing projects are either off-grid light applications of few kWp or stand-alone mini-grid at the moment; off-grid hybrid or grid connected solar projects do not exist across the country (Federal Ministry of Power, 2014).

Table 2: Solar power systems under development. (Source: CRET, 2015)

S/N	SOLAR ENERGY PROJECTS	STATE	CAPACITY (MW)	PROPONENT
1	PV GRID - TIED GENERATOR SYSTEM AT ATAKUMOSA WEST LGA	OSUN	50	ROOK SOLAR INVESTMENT LTD.
2	EVER POWER SOLAR POWER PLANT AT MANCHOK, KAURA LGA	KADUNA	50	QUAINT GLOBAL ENERGY LTD.
3	SOLAR FARM PROJECT AT NJUMTILO, MAIDUGURI	BORNO	200	BORNO STATE GOVERNMENT
4	SOLAR FARM AT KADO	KADUNA	59	SYNERGENT POWERSHARE NIG LTD
5	SOLAR INDEPENDENT POWER PROJECT , AT GANJUWA	BAUCHI	100	NIGERIAN SOLAR CAPITAL PARTNERS
6	ANJEED KAFANCHAN POWER AT ZIPAK, KAFANCHAN, JAMA'A LGA	KADUNA	50	ANJEED INNOVA LIMITED
7	SOLAR PHOTO-VOLTAIC POWER GENERATION PROJECT AT YABO LGA	SOKOTO	50	GEO ENVIRNMENTAL SERVICES

8	SOLAR FARM PROJECT AT KANKIA	KATSINA	30	KASTINA STATE GOVT
9	JAPANESE GRANT SOLAR POWER PLANT AT LOWER USMAN DAM	FCT, ABUJA	0.9	FED . MIN . OF POWER . ABUJA .
10	ON - GRID SOLAR POWER GENERATION AT USMAN DISTRICT	FCT, ABUJA	200	99 EFFECTS ENERGY LTD
11	PHOTOVOLTAIC SOLAR FARM PROJECT AT KANKIA	KATSINA	20	KATSINA STATE GOVERNMENT
12	SOLAR PROJECT AT DANMARKE, BUNGUDU LGA	ZAMFARA	75	SPGS POWER LIMITED
13	SOLAR POWER PLANT , PANYAM DISTRICT , MANGU LGA	PLATEAU	50	CT COSMOS LTD
14	SOLAR FARM AT RIKO, JIBIYA LGA	KATSINA	10	SINOSUN INVESTMENT LIMITED
15	SOLAR GENERATION PLANT IN DAMATURU	YOBE	1000	GOPA INT’L ENERGY CONSULTANT
16	PHOTO VOLTAIC POWER PLANT IN DUKPA/WUNA, GWAGWALADA	FCT, ABUJA	100	LR-AARON POWER LIMITED
17	SHIRORO SOLAR POWER PROJECT AT SHIRORO LGA	NIGER	300	NORTH SOUTH POWER COMPANY LTD
18	SOLAR POWER PLANT AT ABULE OLOKUTA VILLAGE , IREWOLE	OSUN	50	ROMIX ENERGIES LTD
19	SOLAR POWER PLANT IN LAMBA VILLAGE, BAKURA LGA	ZAMFARA	150	PV BAKURA LIMITED
20	SOLAR POWER PLANT AT USO, OWO LGA	ONDO	25	CECUSAFE LIMITED
21	SOLAR FARM AT GUSAU, GUSAU LGA	ZAMFARA	50	SINOSUN INVESTMENT LIMITED
22	SOLAR PANELLED POWER PROJECT , KEFFI LGA	NASSARAWA		AVENSOL SOLAR POWER NIG. LTD
23	SOLAR FARM AT KIRU LGA	KANO	40	BRAVOS ENERGY RESOURCES
24	SOLAR PROJECT IN KANKIYA LGA	KATSINA	125	NOVA SOLAR 5 FARMS LTD
25	SOLAR ENERGY PROJECT IN UDI LGA	ENUGU	1200	MOTIR SEASPIRE ENERGY NIGERIA LTD
26	SOLAR PLANTS IN DUTSE LGA	JIGAWA		NOVA SCOTIA POWER DEV LTD
27	SOLAR POWER PLANT (OROCERAM), ISOKUN OLOPAN, ILORIN SOUTH	KWARA	150	OROCERAM LIMITD
28	SOLAR POWER PLANT (OROCERAM), DOBWA JERE PAIKO LGA	NIGER	150	OROCERAM LIMITD
29	SOLAR POWER PLANT IN DUTSE LGA	JIGAWA	75	PAS DUTSE LTD
30	SOLAR POWER PLANT IN HADEJIA LGA	JIGAWA	75	PAS HADEJIA LTD
31	SOLAR ENERGY PROJECT AT GWAGWALADA AREA COUNCIL	FCT, ABUJA		SUPER SOLAR NIGERIA LTD.
32	SOLAR POWER PROJECT AT GWAGWALADA AREA COUNCIL	FCT, ABUJA	100	ENERLOG LIMITED
33	SOLAR POWER PROJECT IN YABO	SOKOTO	100	KVK POWER NIGERIA PVT LTD
34	SOLAR POWER PLANT IN KANKIA LGA	KATSINA	80	PAN AFRICA SOLAR LIMITED
35	SOLAR POWER PLANT AT LAMBAN VILLAGE, BAKURA LGA	ZAMFARA	300	BAKURA ENERGY LIMITED
36	SOLAR PLANT IN ONYI, KOKONA LGA	NASARAW A	50	AFRINGIA POWER LIMITED
37	SOLAR POWER PLANT AT NUMAN , NUMAN LGA	ADAMAW A	35	HILL CREST ENV. MGNT COY LTD .
38	RENEWABLE ENERGY AT OWO LGA	ONDO	10	GOTTPOWER LIMITED

2.5.1 Drivers and barriers to solar application and development

In order to meet up with the energy need by considering the escalating population growth and socio-economic activities, the planned Vision 2020 envisaged an increase in the country's electricity production from 4000 MW that had been attained since 2007 to 35,000 MW in 2020 (FMP, 2015). The contribution target from renewable resources by the FMP for 2020 is 1000 MW of capacity installed and expected mostly from large scale hydro power development (FMP, 2009). This actually shows government's desire to increase electricity generation and also the incorporation of renewable resources into the country's energy mix. Solar energy development can bring major benefits for economic and social development especially in rural areas through the different range of applications. The development of solar energy conversion systems can thus be driven by many factors as discussed in section 2.5.2 below. However, solar energy development also faces many obstacles in Nigeria. Some of these obstacles or barriers are presented in Section 2.6.3.

2.5.2 Motivations or drivers for solar power development

Apart from the advantage of good solar radiation and its abundance across the country, Ohunakin, Ojolo, and Ajayi (2006) cited several other drivers propelling solar energy development in Nigeria as discussed in this section. The enactment of the Electric Power Sector Reform Act (EPSRA) in March 2005, made provision by law for an individual to construct, own or operate an undertaking for generating electricity not exceeding 1000 kW in aggregate at a site without a license and/or own or operate an undertaking for distribution of electricity with a capacity not exceeding 100 kW in aggregate at a site without a license (FMP, 2005; Ohunakin, et al, 2006). This exemption to holding a license favors energy generation from renewable resources.

This law empowers individual or group of individuals to invest in standalone or off-grid power generating systems (Ohunakin, et al, 2006). The legislation also made way for the establishment of the Rural Electrification Agency (REA) whose major objectives are to: (i) extend the national grid (ii) facilitate independent off-grid systems (iii) generate renewable energy power and (iv) coordinate renewable electricity activities among the state and federal agencies. Solar energy will thus play a major role in achieving these objectives in both the grid-connected and independent off-grid systems because of the abundance of solar radiation in Nigeria (Ohunakin, et al, 2006).

2.5.2.1 Reduction of CO_2 footprint

According to Ohunakin, Fagbenle and Adaramola (2014), climate protection is one of the major drivers for solar energy development in Nigeria. Nigeria has a coastline that is 800 km long, sea level rise of about 0.2 m will inundate approximately 3400 km sq. of the coastline; several kilometers of arable lands have also been found to be lost annually to desert encroachments. Rise in sea level and desertification are consequences of changing climate as propelled by rapid greenhouse emissions. Solar applications produce no emission, thus meeting or exceeding emission standards around the world. Energy generation through various solar applications will thus reduce the industry's carbon footprint and will also be an excellent means of reducing carbon dioxide (CO_2) emission thereby mitigating climate change across the country (Ohunakin, Fagbenle and Adaramola, 2014). The lowering of the water table in the North through desertification will continue to also make solar water pumps a relevant choice in water supply (Ohunakin, Fagbenle and Adaramola, 2014).

2.5.2.2 Energy demand

Population projection of Nigeria was expected to grow from 115.22 million in 2000 to 268.81 million by 2030 at an average annual rate of 3.86% between 2000 and 2030. Population growth is a major driver of energy demand while its most important determinant is the level of economic activity measured by the total GDP alongside with its shares by the various sectors and subsectors of the economy (Ohunakin, 2010). The rapidly growing demand for energy will create opportunities for solar energy development because conventional energy sources will not be enough to meet the need of the ever increasing population in a flexible manner. Furthermore, the expanding economic opportunities in the rural areas will also demand an aggressive deployment of renewable energy options (most especially the vast solar resources) due to grid non-availability needed to evacuate generated conventional power to the respective primitive locations (Energy Commission of Nigeria ECN, 2005).

2.5.2.3 Energy security and access for rural electrification

It was estimated that only 10% of the rural population in Nigeria have access to electricity services (ECN, 2005). Even in semi-urban and urban areas, there is also an 80% demand-supply gap in electricity in the country making most businesses to run on self-generated electricity using diesel- or gasoline-powered generators. In addition, the transmission network is overloaded resulting in a poor voltage profile on most parts of the network. There are occurrences of frequent system collapse and exceedingly high transmission losses (Ohunakin, OJolo, and Ajayi, 2006) often in the range of 30–35% (Ohunakin, 2010). However, the official transmission losses are reported as less than 10% (Ohunakin, 2010). Particular issues identified include stagnated power generation capacity growth, inadequate maintenance procedures, and a lack of human capacity development. Currently, power mix in the country is dominated by fossil fuel based generating plants. Since the off-grid power needs are enormous in Nigeria, standalone PV and solar thermal systems thus constitute a safe, reliable and to a large extent an affordable alternative to the widely spread self-powered generator sets (Ohunakin, 2010). Every part of the country is very relevant for modern off-grid solar products, even in grid-urban areas that are characterized by a highly unreliable network (Ohunakin, Fagbenle and Adaramola, 2014). Solar energy is thus a stabilizing factor for the energy supply system in Nigeria; energy generation through various solar energy developments will therefore be a high potential source for diversifying energy sources and increasing the share of domestic energy supply in the country, thereby meeting the objective of security of supply (Ohunakin, Fagbenle and Adaramola, 2014).

2.5.2.4 Conflict neutral energy sources

One of the major problems of fossil-fuel plants in Nigeria is the lack of/or irregular supply of gas for the gas-powered plants. In most cases, the problem is due to sabotage and destruction by the youth restive groups (militancy) and oil pipeline vandalism in the Niger Delta region of Nigeria (Okoli, Oriya, 2013). Solar technologies do not incorporate conflict relevant materials. The resource is abundant and inexhaustible, and will not give rise to conflicts about right usage. This may serve as an important pushing factor for solar technologies, more so that it addresses the same market segment in the country as fossil plants (Okoli, Oriya, 2013).

2.5.2.5 Increasing demand for local added value

Ohunakin, Fagbenle and Adaramola (2014), posits that solar technologies will support the needs of developing countries like Nigeria through added local values. Only about 30% of the entire Nigeria population is connected to the national grid and the majorities (mostly rural dwellers) are left to the use of biomass and fuel wood for their energy needs. Most of solar applications can be developed locally by the rural dwellers for energy in various forms (solar cookers, solar chicken brooders etc.) (Ohunakin, Fagbenle and Adaramola, 2014). Majority of solar based applications belong to technologies with a high potential for local added value; some have a little fraction of high-tech components substituted with other parts that easily subject themselves to local fabrication. This will promote socio-economic stability, skill acquisitions and employment generation (Ohunakin, Fagbenle and Adaramola, 2014).

2.5.2.6 Job creation

Promotion of solar technologies across the country will contribute immensely to poverty reduction through local communities benefiting from employment opportunities, skills development, investment opportunities and technology transfer (Ohunakin, Fagbenle and Adaramola, 2014). Many renewable energy pilot projects in developing countries give anecdotal evidence of the role that renewable sources can play in energy-poor communities (Nnaji, 2013; Labo, 2010). Therefore, increased investment in solar applications will lead to the development of indigenous expertise in repairs, installations and manufacture of the various solar devices across the country and in particular the rural, off-grid communities thus leading to vast job creation (Ohunakin, Fagbenle and Adaramola, 2014).

2.5.3 Barriers to solar PV uptake in Nigeria

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

2.5.3.1 Variability and intermittency of radiation

Solar energy is a variable resource and its availability as an energy source fluctuates. Sunshine duration in Nigeria ranges from a minimum of 8 hours in the South to 12 hours/day in the Northern part of the country (ECN, 2005). As a result, electricity output from solar power plants across the country will vary accordingly while its demand does not follow similar pattern (Ohunakin, Fagbenle and Adaramola, 2014). Grid connected and hybrid solar electricity can only be realizable in the North where solar insolation is highest. Whereas off-grid solar applications (solar lantern, solar battery charger etc.) can be a viable option in the Southern part of the country. However, this shortcoming can be overcome by the development of appropriate solar energy storage technologies for storage purposes when solar energy is available, and then re-use when the energy is not available (Ohunakin, Fagbenle and Adaramola, 2014).

2.5.3.2 Grid unreliability

Grid unreliability portends a barrier for grid-connected solar power. Currently, the transmission grid in Nigeria operates at 132 and 330 kV with a coverage that is limited to about 30% of the populace that are mostly spread in the urban/semi-urban regions of the country (Ohunakin, Fagbenle and Adaramola, 2014). The transmission network is found to be a weak link in the electricity supply chain in the country. The current transmission capacity of the national grid is less than 6000 MW (Ohunakin, 2010). Most of the transmission equipment across the country are aged, obsolete, poorly maintained and the construction of new lines is not in view thus making the operational transmission capacity to be presently below 5000 MW (Ohunakin, 2010). In addition, utility-scale solar power plants are often located more remotely than fossil-fueled plants due to the requirement for wide land area in primitive locations with no grid access. At the moment, the country's national grid is not designed to handle intermittent electricity generating system; therefore, grid connected solar applications will require the construction of new and expensive transmission lines which have hitherto been proving very difficult in Nigeria due to the associated cost (Ohunakin, Fagbenle and Adaramola, 2014).

2.5.3.3 Lack of awareness and information

The level of awareness about the immense socio-economic and environmental benefits derivable from solar energy among the citizens and decision-makers at different political and administrative levels is very low in Nigeria (Ohunakin, Fagbenle and Adaramola, 2014; Ohunakin, 2010). The current flow of information about the development, various applications, dissemination and diffusion of solar energy resources and technologies are also inadequate (Ohunakin, 2010). There is inadequate and insufficient education of consumer/solar applications users. Solar projects (mainly solar street lights) across the different states of the country had been executed by inexperienced technicians/practitioners using sub-standard solar products; most of the facilities are therefore no longer functional (Ohunakin, Fagbenle and Adaramola, 2014; Ohunakin, 2010). This has established poor confidence of the technology among the public, private and financing sectors on the adoption of technology in the country.

2.5.3.4 High initial investment cost

A basic barrier to the development of solar energy technology in Nigeria as a developing country lies in the high initial costs, including high installation costs with long payback times (Ohunakin, 2010). High initial costs may also reflect high-risk perceptions of investors and a general lack of financing instruments as well as fragmented or underdeveloped financial sectors (Labo, 2010; Karekezi, 2003). There is also lack of incentives on import or local manufacturing of solar devices in the country. Import duties are not allowed on solar PV in Nigeria; when the PV to be imported into the country forms a part of the complete solar device including battery storage, it attracts a 21% import duty (Ohunakin, Fagbenle and Adaramola, 2014; Ohunakin, 2010). This has forced the initial investment cost of solar devices to tower high above other conventional energy sources (such as diesel generators whose duties are stable, regular, and the products readily available when needed) (Ohunakin, Fagbenle and Adaramola, 2014; Ohunakin, 2010).

This challenge further becomes more pronounced in the country because of the high transaction costs since most solar projects are decentralized and within the small scale range. The solar energy projects thus become too costly in the long-run for local banks in Nigeria to consider for financing. The banks are always in a haste to recover funds and hence contemplate long-term solar projects too risky to finance (Ohunakin, Fagbenle and Adaramola, 2014; Ohunakin, 2010). Furthermore, with the view that most of the populace belong to the low-income range, it is thus generally difficult for an average individual to invest in solar energy systems.

3.5.3.5 Operation and maintenance costs

Solar technologies have been viewed as the energy supply option for the remote and rural poor areas in the country. At the moment, the operation and maintenance costs are appreciably high in the country, due largely to lack of technically skilled personnel. Hence, potential users of the technologies (occupying largely the remote locations) may be prevented from the adoption of SECs due to fear of failure in the absence of technical supports (Ohunakin, Fagbenle and Adaramola, 2014; Ohunakin, 2010).

3.5.3.6 Government policy and incentives

Policies instituted by the government have not supported the profitable exploitation of renewable energy resources (generally and particularly solar energy) for any intending investor

(Emodi and Yusuf, 2015). High supports in the form of subsidies are given to encourage energy generation from conventional energy sources leading to a fall in their prices and thereby creating an unfair competitive environment for solar energy exploitation; this has led to a slow in the growth demand for solar energy devices (Emodi and Yusuf, 2015). Furthermore, production of electricity in developed countries from solar resources is largely driven by Feed-in-Tariffs (FiT) (France, Germany, Spain, etc.) and government personal income tax credit solar PV-targeted tax incentives (e.g., in the USA and Australia) (Emodi and Yusuf, 2015; Moosavian, Rahim, Sevaraj, Solangi, 2013). For instance, the German government in 1991 introduced the Electricity Feed Act in Germany, which regulates the feed-in to the grid of electricity generated from renewable resources (Emodi and Yusuf, 2015).

This Act made it mandatory for utility companies in Germany to purchase electricity generated from renewable resources at set rates (feed-in tariffs). Due to this Act, the PV installed capacity has increased from about 90 MW in 2000 to 17370 MW in 2010 in Germany and similar trend was reported for countries with favorable government policies (Emodi and Yusuf, 2015; Moosavian, Rahim, Sevaraj, Solangi, 2013). The proposed FiT incorporated into energy policies in Nigeria is not attractive for investors and this must be reviewed to encourage private investment into solar infrastructures. The proposed FiT ranges from 68 NGN/MWh (US$0.4366) to 93 NGN/MWh (US $0.5970) between 2012 and 2016 for solar plant in the country; this is very high to allow for profitable investment by any intending investor (Emodi and Yusuf, 2015; Moosavian, Rahim, Sevaraj, Solangi, 2013; Ohunakin, Fagbenle and Adaramola, 2014; Ohunakin, 2010).

2.5.3.7 Ineffective quality control of products

Absence of national technical standards and effective quality control units in the country were identified as a major institutional challenge to the adoption of renewable energy in households. This absence is due to lack of appropriate training and personnel (Emodi and Yusuf, 2015). Most of the solar products are imported from China through various nation's borders into the market (Ohunakin, Fagbenle and Adaramola, 2014; Ohunakin, 2010). There are no existing standards and specifications regulating these products; products are also without trademark certificates and certificates of analysis from manufacturers (most of the products in the market have no brand name). These led to the influx of large quantities of sub-standard/poor quality of solar components; systems and services are also poorly installed by technicians with inadequate expertise. Confidence reposed on the technology has thus been undermined since the high initial cost of investment into these products cannot be justified (Ohunakin, Fagbenle and Adaramola, 2014; Ohunakin, 2010).

2.5.3.8 Insecurity of solar plant infrastructure

Most locations that are very suitable for the development of solar energy system in the country had played hosts to militant insurgency in the past. Insecurity has affected power plants constructions and other infrastructures through kidnaps and killing of workers in various parts of the country. General insecurity of solar infrastructures especially in the northern region of the country where there are abundant solar insolation can be a potential threat that will stall future investment in large scale grid-connected solar infrastructure (Ohunakin, Fagbenle and Adaramola, 2014; Ohunakin, 2010; Emodi and Yusuf, 2015).

2.5.3.9 Competition with land uses

Land issues may be very complicated especially when the intending project to be sited on such land, is non-governmental. There may be a major challenge in siting and securing of permits for solar power plants in new locations (Ohunakin, Fagbenle and Adaramola, 2014; Ohunakin, 2010). Most land in rural communities are for agriculture being the major occupation of the inhabitants; ownership of such piece of land may also belong to families or communities. Most communities are preventing foreigners from owning land for fear of total destruction of their heritage (e.g. Niger Delta oil spillage that has destroyed aquatic lives). Since solar projects on a large scale will involve private participation, prohibiting foreigners from owning land will constitute barriers to their involvement in bilateral solar project development and hence may be a major barrier to solar applications especially solar PV on a large scale (Ohunakin, Fagbenle and Adaramola, 2014; Ohunakin, 2010).

2.6 Renewable Energy Policy scenario in Nigeria

The National Renewable Energy and Energy Efficiency Policy (NREEEP) of 2015 provides an overarching framework for renewable energy and energy efficiency, thereby functioning as an umbrella policy for the various existing documents and serving as a reference document (anchor) for concrete implementation measures.

The level of productive use of energy in an economy, coupled with the mix and efficiency of conversion of primary and secondary energy resources to useful energy and the efficient use of energy, are directly indicative of the level and rate of development of the economy (Federal Ministry of Power, 2015). It is therefore essential to put in place a coordinated, coherent and comprehensive renewable energy policy linked to an equally coherent and comprehensive energy efficiency policy (FMP, 2015)

The evidence from the significant body of literature on renewable energy adoption and deployment suggests that given the intricacies of renewable energy, policy is a game changer. Appropriate policies are therefore needed to create the right incentives, regulation and standards to advance the adoption of renewables. The renewable energy policy will serve as a blue print for the sustainable development, supply and utilization of energy resources within the economy, and for the use of energy resource in international trade and co-operation.

2.6.1 The National Renewable Energy and Energy Efficiency Policy (NREEEP)

The NREEEP outlines the global thrust of the policies and measures for the promotion of renewable energy and energy efficiency. NREEEP seeks to bring to the attention of policymakers the economic, political and social potential of renewable energy. It recommends that an appropriate strategy should be developed to harness these potentials in order to add value to the ongoing changes in Nigeria's power sector.

Even though the existing policies lack a coherent and all-encompassing framework that drives the sector, an integrated renewable energy and energy efficiency policy which will serve as a useful vehicle that limits conflicts in the future and promotes development and deployment of renewable energy technologies in Nigeria is required (FMP, 2015; GIZ, 2015).

This policy encourages the development of a national renewable energy action plan and a national energy efficiency action plan which will facilitate the overall achievement of the objectives it sets out (FMP, 2015; GIZ, 2015). The NREEEP recognises the multi-dimensional nature of energy and therefore addresses diverse issues such as renewable energy supply and utilisation, renewable energy pricing and financing, legislation, regulation and standards, energy efficiency and conservation, renewable energy project implementation issues, research and development, capacity building and training, gender and environmental issues, planning and policy implementation (FMP, 2015; GIZ, 2015).

2.6.2 The NREEEP focus

The overall focus of the policy is on optimal utilisation of the nation's energy resources for sustainable development. This policy on renewable energy and energy efficiency sets out a framework for action to address Nigerians' challenge of inclusive access to modern and clean energy resources, improved energy security and climate objectives. It aims at raising the national significance of renewable electricity generation activities by providing for the development, operation and maintenance, and upgrading of new and existing renewable electricity generation activities (FMP, 2015; GIZ, 2015).

While meeting the Economic Community of West African States' (ECOWAS) regional policy targets for renewable electricity generation and energy efficiency for 2020 and beyond, the policy declares energy efficiency to be a major, low-cost, and under-utilised source of energy offering savings on energy bills, opportunities for more jobs, improving industrial competitiveness, and lowering air pollution (FMP, 2015; GIZ, 2015). As poverty mitigation and environmental protection are hindered by the continued predominance and inefficient use of oil and natural gas in meeting targeted energy needs, the policy broadens the definition of energy security to include renewable energy and energy efficiency as equally important indigenous sources of energy, in addition to oil and gas (FMP, 2014; FMP, 2015; GIZ, 2015)

The policy includes provisions for renewable energy and energy efficiency generation activities into government policy statements and plans and thus recognizes the importance of enabling framework conditions for private investment in renewable energy and energy efficiency (FMP, 2015; GIZ, 2015). The Ministry of Power is set to develop an integrated resource plan (IRP) and ensure the continuous monitoring and review of the implementation and effectiveness of the action plans prescribed under the national policy statement. Furthermore, the FMP is to facilitate the establishment of a framework for sustainable financing of renewable energy and energy efficiency projects and programmes in Nigeria (FMP, 2014; FMP, 2015; GIZ, 2015).

2.6.3 NREEEP on funds

The funds required for the maintenance and refurbishment of the renewable energy supply infrastructure and for the expansion of capacity are enormous (GIZ, 2016; FMP 2015). It is believed that this policy will drive increased private sector participation and the on-going market reform especially as it relates to procurement of power in the renewable energy sub-sector and as such attract new investments, while the profit motive will assist in solving much of the management problems previously experienced(GIZ, 2016; FMP 2015). Incentives and regulations are needed to encourage power generating companies to expand the generation mix to include renewables. Such are also needed to enhance energy efficiency. Additionally, the energy efficiency technology and service market may be as well driven by already cost effective investment opportunities (GIZ, 2016; FMP 2015).

Private investment funds required by the renewable energy and energy efficiency sub-sector will be for instance foreign and local capital, private public partnership, environmental/green finance options (i.e. Emission trading) or financing mechanisms via Energy Service Companies (ESCOs) etc.(GIZ, 2016; FMP 2015). Thus, the environment must be made conducive to attract such investments and funding opportunities. It will hence be necessary to encourage and promote foreign as well as indigenous private sector participation in the sub-sector (GIZ, 2016; FMP 2015).

2.6.4 Hindrances to RE policy implementation

The follow-ups of all the Nigerian energy policies, strategies and targets are lacking, as well as commitment from the state and local government in renewable energy development. Some overlaps also exist in some activities of some ministries and government agencies, while duplication of the same activities is observed in some Federal ministries in the country. Alignment required in the Nigerian energy policies include the harmonization of National renewable energy, energy efficiency and rural electrification policy objectives, coordination of government agencies and effectiveness in the fulfilment of the mandate to coordinate policy issues. Nevertheless, looking at the various policies on RE development and utilization, Ajayi (2013) noted some certain issues that could be addressed to further the development as well as to fast-track the growth of RE in Nigeria. Some of these hindrances are discussed below.

2.6.4.1 Weak government motivation

According to Ajayi (2013), the policy statements and the documented intentions are clear evidence of the government to generate electricity from RE resources. However, the government may need to do more to actualize the intentions. This according to Mohammed et al (2013) and Ajayi (2013) may require releasing adequate resources and setting up implementation committee to oversee the establishment of renewable energy projects across the country. The government has made efforts to increase generation capacity from fossil fuel power plant. They may also need to focus more on RE development when consideration is given to the target dates. Although, recently, the government began to commit funds to renewable energy projects. For instance between 2011 and 2013, the federal government has approved budget proposals to fund three renewable energy projects. However, Ajayi (2013) pointed out that the budgets are minimal and the motivation needs to be improved.

2.6.4.2 Lack of economic incentives

Whereas the energy policy documents contain the road maps to translate the policy into implementation, it however lacks the selling point which is the part of a policy that is attractive to investors (Ajayi, 2013). What incentives are in place for RE marketers and how the government intends to aid or support willing investors should be clear (*ibid*). Mohammed et al (2013) and Ajayi (2013) suggest that the government needs to develop incentives such as tax holidays for RE investors, provide low or interest free loans to aid RE technology investment, develop appropriate feed-in tariff for grid connected renewable electricity, legalize the right to connect renewable electricity to the national grid, and the obligations for national electric utility to purchase RE.

2.6.4.3 Multiple taxations

In Nigeria, the occurrence of multiple taxations can be a hindrance to business development. Tax payment to federal, state and local governments can be harmonized and made payable at once through a central collecting organization (Mohammed et al, 2013; Ajayi, 2013). Such expenditures should also be insignificant to the extent that could aid interests and return on investments. Ajayi (2013) notes that tax chargeable on renewable energy projects should not be on the same rating as those from conventional sources. The value added tax and other tax payable by both consumers and marketers should be such that would aid the adoption and utilization of RE technology, especially wind and solar (Mohammed et al, 2013; Ajayi, 2013).

2.6.4.4 Non-existent favourable customs and excise duty act to promote renewable energy technologies

According to Mohamed et al (2013), at the moment, the custom and excise duty act of Nigeria lacks aspects that could improve imports of RE technology and equipment. Ajayi (2013) however notes that to aid RE development and attract foreign investors, the government may need to look into the customs and excise duty act with the aim of creating sections that will be

RE-specific. By doing so will make the revenue generation from RE technology imports be at variance from other imported goods. Marking RE technology imports as special for duty free or subsidized duty will encourage investors to import technologies to promote renewable energy development in the country (*ibid*).

2.6.4.5 Existing legislations that can facilitate the adoption and growth of renewable energy in Nigeria

According to Ajayi (2013), some existing legislations that can facilitate the adoption and growth of renewable energy in Nigeria are, land use Acts under which we have Environmental Impact Assessment, and Fiscal Incentives. Other legal related issues discussed in the study are grants for pioneer status, tax relief for research and development, capital allowances, and favourable investment vehicles. The study pointed out a market-oriented policy by government as one of the ways forward. The study emphasises the potential of a feed-in tariffs policy and regulations, investment tax credit, and renewable portfolios as a road map towards achieving RE in the country (Ajayi, 2013).

2.7 Energy efficiency strategies for retrofit interventions in existing buildings.

The highest percentage of our time is spent in buildings, either at home or at places of work. Hence residential and commercial buildings are the highest consumers of conventional energy supply. The rate and overall level of consumption is largely dependent on the extent of electrification, level of economic/human development, the micro climate for buildings, the amount of building area per capital, and the existing policies in promoting efficiency by the state (Moshen: 2011).

2.7.1 Potential for delivering significant and cost-effective GHG emission reductions via the building sector.

A report by the Sustainable Building and Climate Initiative SBCI (2009), posits that more than 40 percent of global energy use and one third of global greenhouse gas emissions, are alleged to have come from buildings, both in developed and developing nations.

The SBCI (2009) linked the main source of greenhouse gas emissions from buildings to energy consumption. However, buildings are also major emitters of other non-CO2 greenhouse emissions such as halocarbons (SBCI, 2009). Whereas, the bulk of emissions are from developed countries, it is expected that in the nearest future the rate of emissions from buildings in rapidly industrializing countries will be higher than from buildings in developed countries (*ibid*).

According to Graham (2003), and SBCI (2009), energy is consumed during the following activities:

- Manufacturing of building materials (embodied energy);
- Transporting these materials from production plants to building sites (grey energy);
- Construction of the building (induced energy);
- Operation of the building (operational energy); and
- Demolition of the building (and recycling of their parts, where this occurs).

The SBCI (2009) reveals that the building sector has the biggest prospects for providing a long-term, substantial greenhouse gas emissions that is cost-effective. With proven and commercially available technologies, the energy consumption in both new and existing buildings can be cut by an estimated 30 to 80 percent with potential net profit during the building life-span (SBCI, 2009). This potential for greenhouse gas emission reductions from buildings is common to developed and developing countries, as well as countries with economies in transition.

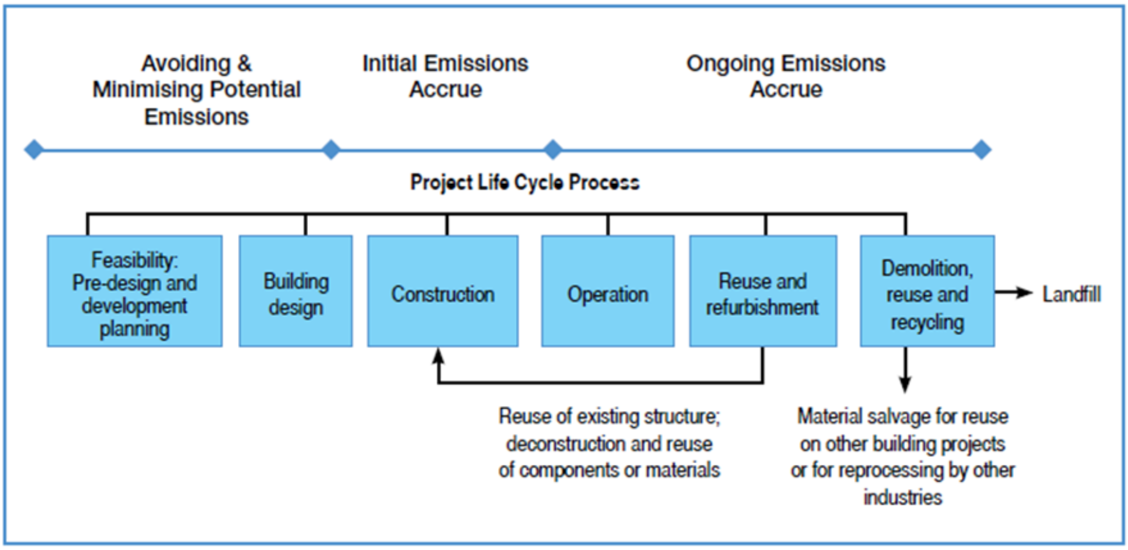
2.7.2 Assessing emissions through a Life Cycle Approach

Since buildings have a comparatively long lifespan, therefore actions taken or not taken now will continue to affect their greenhouse gas emissions over the medium-term either negatively or positively.

To understand the full extent of the life-time emissions of a building, Graham (2003) and SBCI (2009) engaged a life-cycle approach (LCA) which then reveals that over 80 percent of greenhouse gas emissions take place during the operational phase of buildings, when energy is used for heating, cooling, ventilation, lighting, appliances, and other applications (SBCI, 2009).

Graham (2003) uses a Life Cycle Approach to link emissions to the different stages of a building's life (Figure2.0).

Figure 3 Life Cycle Phases of Buildings. Source: Extracted from Graham (2003)



Graham (2003) posits that the greatest proportion of energy is used during a building's operational phase. Though figures vary from building to building, studies suggest that over 80 percent of greenhouse gas emissions take place during this phase to meet various energy needs such as heating, ventilation, and air conditioning (HVAC), water heating, lighting, entertainment and telecommunications (Junnila, 2004; Suzuki and Oka, 1998; Adalberth et al, 2001).

Nevertheless, between 10 to 20 percent, of the energy consumed can be linked directly or indirectly to materials manufacturing and transportation, construction, maintenance renovation and demolition (Junnila, 2004; Suzuki and Oka, 1998; Adalberth et al, 2001). Large numbers of buildings which will be standing in 2050 have already been erected, for this reason; policies should be made to inspire building owners to retrofit their buildings to optimize emission reductions through efficient consumption of energy. In developing countries, particularly those undergoing rapid urbanization, policies should encourage property developers and construction companies to incorporate energy and greenhouse gas emission considerations into the feasibility and design stages of buildings (Graham, 2003; SBCI, 2009).

2.7.3 Barriers to realizing emission reduction potentials

Although most developed countries and many developing countries are already steering towards reducing greenhouse gas emissions from the Building Sector, these steps have had a limited impact on actual emission levels (SBCI, 2009). This according to SBCI (2009) is as a result of some barriers which reflect the nature of the sector. Barriers such as the fact that there are many small reduction opportunities spread across millions of buildings; different stakeholders are involved at the various stages in a building's life; these stakeholders have different economic interests in terms of valuing investments in energy efficiency measures, energy efficiency investments are perceived to be costly and risky, and there is still a lack of practical knowledge about how to implement energy efficiency measures (*ibid*).

2.7.4 Existing policies, technologies and knowledge to overcome these barriers

To overcome these barriers, the report (Graham, 2003; SBCI, 2009) recommends that governments must take the lead by prioritizing the building sector in their national climate change strategies and putting in place a number of "building blocks" (SBCI, 2009).

Credible and comparable energy performance standards, accurate and comprehensive data and information about the Building Sector, the appropriate skills-base and capacity to assess energy performance and implement energy efficiency policies, and systems and frameworks for consultations with all major stakeholders have been cited as the essential tools for creating effective policies. Governments must work hand-in-hand with the building and construction industry, NGO and civil society organizations, research and educational institutes, and most importantly, the public, to achieve the common goal of reducing greenhouse gas emissions from buildings (*ibid*). With these "building blocks" in place, governments are well placed to select and design appropriate policies to reduce emissions from new and existing buildings (*ibid*).

The five key policy targets as put forward by the report includes; increase in energy efficiency of buildings, improvement in energy efficiency of appliances which use energy, encourage energy generation and distribution companies to support emission reductions in the Building Sector, change attitudes and behaviour towards energy consumption, and promote the substitution of fossil fuels with renewable sources of energy (*ibid*). Governments have a range of policy instruments like regulatory, fiscal, economic, informational and capacity building measures, to choose from. An appraisal by the Sustainable Building and Climate Initiative (2009) found that there are many policy instruments which are not only effective in achieving emission reductions, but can also result in net savings when the energy saved is factored into the assessment. At no other time has the case for international cooperation to address climate change been more pressing than now (SBCI, 2009).

Although, the United Nations Framework Convention on Climate Change offers the finest framework for facilitating this cooperation, however, if the Kyoto protocol in addressing greenhouse gas emissions from the Building Sector is to be achieved speedily, there is an urgent need to make the financing mechanism more flexible. As a result, the reason mentioned above, SBCI (2009) recommends that the current structure of the Clean Development Mechanism (CDM) must be reformed or additional mechanisms created to support developing countries' efforts to reduce emissions from the Building Sector (*ibid*).

Further recommendation from the report establishes that energy efficiency and greenhouse gas emission reduction programs in the Building Sector should be recognized as a Nationally Appropriate Mitigation Action (NAMA). At the same time, sufficient incentives to reduce emissions from buildings will bring multiple benefits to both the economy and to society (SBCI, 2009).

Given that the construction, renovation, and maintenance of buildings (offices and residential) enhance 10 to 40 percent of countries' Gross Domestic Product (GDP), Graham (2003) and SBCI (2009) maintains that a carefully planned, greenhouse gas mitigation strategies for buildings can stimulate the growth of new businesses and jobs, as well as contribute to other equally pressing social development goals, such as better housing and access to clean energy and water (Graham, 2003; SBCI, 2009). Decision-makers should seize the opportunity offered by the climate change crisis to build the foundation for sustainable development today, and for the future to attract private sector financing must be put in place.

Table 3: Major Barriers to Energy Efficiency in the Building Sector. (UNEP-SBCI, 2007).

Barrier categories	**Definition**	**Examples**	**Countries**	**Possible remedies**
Economic/ financial barriers	Ratio of invest-ment cost to value of energy savings	Higher up-front costs for more efficient equipment. Lack of access to financing. Energy subsidies Lack of internalization of environmental, health, and other external costs	Most coun-tries Especially developing, but also developed countries	Fiscal and economic instruments such as tax rebates, Kyoto Flexibility Mechanisms, subsidized loans, regulatory instruments. Or increase energy price, remove

				energy price subsidies
Hidden costs/ benefits	Cost or risks (real or perceived) that are not captured directly in financial flows	Costs and risks due to potential incompatibilities, performance risks, transaction costs etc. Poor power quality, particularly in some developing countries	All countries	Appliance standards, building codes (to overcome high transaction costs), EPC/ ESCOs, public leadership programs
Market failures	Market structures and constraints that prevent a consistent trade-off between specific EE investment and energy saving benefits	Limitations of the typical building design process Fragmented market structure Landlord/tenant split and misplaced incentives Administrative and regulatory barriers (e.g. in the incorporation of distributed generation technologies) Imperfect information Unavailability of energy efficiency equipment locally	All countries	Fiscal instruments and incentives Product standards Regulatory-normative Regulatory-informative Economic instruments Technology transfer, mechanisms
Behavioural and organizational barriers	Behavioural characteristics of individuals and companies that hinder energy efficiency technologies and practices	Tendency to ignore small energy saving opportunities Organizational failures (e.g. internal split incentives) Non-payment and electricity theft Tradition, behaviour and lifestyle, Corruption Transition in energy expertise: Loss of traditional knowledge and non-suitability of Western techniques	Developed countries Developing countries	Support, information and voluntary action: Voluntary agreements Information and training programs
Information barriers	Lack of information provided on	Lacking awareness of consumers, building	Especially developing, but also	Awareness raising campaigns,

	energy saving potentials	managers, construction companies, politicians	developed countries	Training of building professionals, regulatory-informative
Political and structural barriers	Structural characteristics of political, economic, energy system which make efficiency investment difficult	Process of drafting local legislation is slow Gaps between regions at different economic level Insufficient enforcement of standards Lack of detailed guidelines, tools and experts Lack of incentives for EE investments Lack of governance leadership/ interest Lack of equipment testing/ certification Inadequate energy service	Most developing (and some developed) countries	Enhance implementation of standards Incentive policy encouraging EE building design, Enhance international cooperation and technology transfer, Public leadership programs

2.7.5 Energy efficiency development in Nigeria

Of the electricity generated in Nigeria, it is estimated that households account for the largest share of consumption (about 78%) (Nigerian Energy Sector NES, 2015). This is a significant contrast with countries such as South Africa and Brazil where the majority is used in industry, and suggests that lack of power is hampering industrial growth in Nigeria (FMP, 2016).

An estimate of total energy consumption in Nigeria is challenging because a large percentage of the electricity consumed is generated on-site from private petrol/diesel generators. The World Bank estimates that the capacity of off-grid diesel and petrol generators totals 3 GW and 1.3 GW respectively. This is nearly equivalent to the total installed power plant capacity estimated at 6.2GW in 2011 (NESP, 2014). Due to fuel price rises and shortages, generating electricity with these small generators is not only inefficient in carbon emission terms, but also very expensive and unsustainable as discussed in section 2.3.

According to a report by the FMP, (2016), there is a shortage of reliable data on energy consumption in buildings, partly due to poor metering of mains electricity and also due to the fact that most buildings also generate electricity using petrol and diesel generators which complicates assessments (FMP, 2016). In late 2014, the former Minister of Power, Professor

Chinedu Nebo estimated that 55% of Nigerian electricity users are not metered (Nebo, 2014). This is recognized as a major barrier to energy efficiency, and efforts are underway to ensure appropriate meters are installed (FMP, 2016).

In 2013, GIZ commissioned a study on energy consumption in seven office buildings in Nigeria (NESP, 2013). The study suggested that office air-conditioning (AC) accounted for 40-68% of electrical consumption, with the other important uses being lighting (13-37%) and office equipment (12-25%) (GIZ, 2015). This is probably fairly typical for an air conditioned office in Nigeria, although office equipment consumption will depend heavily on the number and type of computers and other equipment in the building.

2.7.6 Energy Efficiency in the Nigerian Building Sector.

A report by the GIZ (2015) revealed that the concept of Energy Efficiency was not introduced in Nigeria until 2009. So energy efficiency, standards and labelling and Minimum Energy Performance (MEP) are still relatively new in the country. The legislation required to promote and enforce such concepts has not yet been adequately created (GIZ, 2015). So far, the Standards Organization of Nigeria (SON) published standards related to energy efficiency, such as a code of practice for the deployment of outdoor solar lighting systems, and standards for self-ballasted lamps, electrical installations of buildings and for safety and performance of CFLs (FMP, 2016). Standards for refrigerators, air conditioners, energy management in industry and an energy building code are under development, supported by GIZ, UNDP and UN Habitat.

In the past, the Federal Government of Nigeria made several policies in the energy sector that aimed to encourage uptake of renewable energy (RE) and energy efficiency (EE) (FMP, 2005; FMP, 2012; GIZ, 2013). However, these were limited in their scope and only mentioned general issues without giving a detailed framework (FMP, 2015, GIZ 2016). It is hoped that the recent approval of the first ever RE and EE policy for Nigeria will provide better guidance to the industry. Within the building sector, this policy proposed developing energy efficiency building codes so that buildings are designed in line with bio-climatic design concepts and incorporate other energy saving measures (FMP, 2015).

A National Energy Efficiency Action Plan is currently being developed by stakeholders with the aim of promoting energy efficiency in Nigeria (FMP, 2016). This action plan supports the implementation of the recently approved RE and EE policy (2015) and sets its own targets for energy savings in the building sector amongst others and proposes concrete measures and actions that would contribute to meeting the targets (GIZ,2016; FMP, 2015).

The ECOWAS Directive on Energy Efficiency in Buildings (2013) also requires action from national governments to promote the improvement of energy efficiency of buildings. The Nigeria National Building Code (2006) does not currently include detailed energy efficiency requirements, but is under revision to include those energy efficiency aspects that are easy to implement, cost-effective, and would lead to energy savings (FMP, 2016).

The Nigerian Building Energy Efficiency Guideline (NBEEG) was created in response to the Nigeria RE and EE policy target of producing guidelines on all the key components of energy efficiency by 2020 (FMP, 2016). The guideline provides practical information on the design and construction of energy efficient buildings, and will be disseminated to all major stakeholders in the construction industry.

2.7.6.1 Barriers to Energy Efficiency Development in Nigeria

The following has been cited as the barriers to the development of energy efficiency in Nigeria by (Oluwafemi et.al, 2015; Etiosa et.al, 2009);

- Lack of Policy and Legislation:

Lack of policy and legislation to address the inefficient use of energy is a very key barrier to the development of energy efficiency. Policy and legislation will help to change behavior towards an energy efficient economy. Private and public institutions should also be encouraged to make their own policy to promote the efficient use of energy. The government can make it mandatory for public, large and small scale private organizations to establish an energy management department or unit (Oluwafemi et.al, 2015; Etiosa et.al, 2009).

- Lack of trained EE Professionals and research materials on EE

Inadequate trained personnel and professional is another factor inhibiting the development of energy efficiency. Nigeria as a country lack adequate energy efficiency experts that will drive the development of the concept and policy that will promote energy efficiency. Also, there is lack of research materials and data that will guide the development of policy that will strengthen the efficient use of energy. Similarly, there is lack of material to conduct training on energy efficiency (Oluwafemi et.al, 2015; Etiosa et.al, 2009).

- Importation of used machines:

As mentioned earlier, the proliferation of imported secondhand appliances may hinder the use of efficient appliances. The reason is that, this second-hand equipment are cheap and easily available, the new and efficient ones may be unable to compete with them in the market (Oluwafemi et.al, 2015; Etiosa et.al, 2009).

- Inefficient metering system and low electricity pricing:

The metering system in Nigeria is very inefficient and does not encourage consumers to pay the correct amount for the energy they consume. Many people that still use the old meters are now on estimation since these meters are faulty. The use of prepaid meters which was recently introduced by the PHCN will help change the behavior of consumers to use energy efficiently (Oluwafemi et.al, 2015; Etiosa et.al, 2009).

- Proliferation of inefficient equipment and desire to minimize initial cost:

The desire to minimize initial cost force many consumers to purchase cheap and inefficient appliances. For example, the cost of energy saving bulbs in the Nigerian market is about N800 compared to an incandescent bulb which cost about N40 (GIZ, 2014; GIZ, 2016). Many consumers will prefer to go for the cheaper ones not minding the long-term benefit of using efficiency bulbs. Furthermore, about 70% of Nigerians live below the poverty line of $2 per day. Many are not able to afford the cost of efficiency appliances which are sometime more expensive than the less efficient ones (Oluwafemi, et.al, 2015; Etiosa et.al, 2009).

2.7.6.2 Existing Energy Efficiency Projects in Nigeria

Measures in the sense of centrally planned or coordinated programmes are not yet in place, although some policies exist through ECN, the National Centre for Energy Efficiency and Conservation (NCEEC) and The Federal Ministry of Environment (FMENV). That said, the National Centre for Energy Efficiency and Conservation (NCEEC) attached to the University of Lagos has been conducting research into energy efficiency and conservation and under this mandate has conducted studies into the promotion of energy efficient appliances and light bulbs. The insights have not yet been fed into tangible measures (GIZ, 2014; GIZ, 2016).

The Energy Commission of Nigeria (ECN) in partnership with the Cuban government and with support from ECOWAS has been distributing one million Compact Fluorescent Lamps (CFL) in Nigeria free to residents in organised estates across the country (GIZ, 2014; GIZ, 2016). Under the aegis of Federal Ministry of Environment’s National Clean Cooking Scheme

(NCCS) run by the Renewable Energy Programme Unit, the Rural Women Energy Security (RUWES) has started production and distribution nationwide of a purpose designed bio-fuel stove in partnership with pot-makers Tower and energy firm Envirofit (GIZ, 2014; GIZ, 2016).

The Rural Energy Access Project (REAP) was initiated by the Federal Ministry of Environment's Renewable Energy Programme Unit to address the need to source and deploy alternative and sustainable sources for lighting purposes, whereby energy efficiency spells empowerment as it brings light to the rural poor who suffer most from a dearth of electricity (GIZ, 2014; GIZ, 2016). REAP hinges on reducing power consumption by using clean, energy efficient LED bulbs (light-emitting diode) and introducing household stand-alone solar kits to replace incandescent bulbs, single-wick kerosene and oil lamps as well as small diesel generators (GIZ, 2014; GIZ, 2016).

Julius Berger of Nigeria (a Nigerian based German construction company) introduces energy efficient buildings to the country. In 2013, the company completed the office building of the Central Bank of Nigeria in Lagos and has ongoing projects, like the Rose of Sharon Building, Nestoil Towers, and Akwa Ibom Stadium Complex (GIZ, 2016). According to the GIZ (2016), the company has the specialised knowhow needed to construct buildings that meet the Leadership in Energy and Environmental Design (LEED) standards for certification. However, these pilot projects are high-cost measures and cannot be regarded as common practice in the building industry (GIZ, 2016). The Energy Efficient Housing Scheme is a partnership between the FMENV and Aso Savings And Loans Plc, a leading mortgage bank with the objectives of providing affordable energy efficient housing for staff of the Ministry by micro generation mainly from solar and Bio-energy (*ibid*).

The project was recently launched in Kaduna with the prospect of containing 2000 housing units and many more on the pipeline from different states across the nation. Projects looking at energy efficiency in the industrial sector are not existent so far. To a limited extent, a few industries implemented energy audits. This involves identifying in each state all manufacturing hubs and major areas of industrial production. The estimated energy needs of all industrial manufacturing hubs will be included in Nigeria's energy dispatch considerations, and used in planning the electric power sector (*ibid*).

The project "Promote Energy Efficiency in Nigeria's Residential and Public Sectors" (2011 – 2015) aims to introduce energy efficiency policies and measures, including standards and labels for refrigerators and lights in Nigeria (*ibid*). Managed by the UNDP, the project is being implemented by an Energy Efficiency Unit, which has its head office on the premises of the Energy Commission of Nigeria. It is going to receive financing in the amount of approximately USD 4.8 million for a period of 5 years (*ibid*).

2.7.6.3 Planned Energy Efficiency Projects in Nigeria

The Abuja Green City: The Abuja Green City is an initiative of the Renewable Energy Programme of the Federal Ministry of Environment, together with Green Carbon Afrique Creation Environmental Services and Integra Integrated Renewable Energy Services (GIZ, 2014; GIZ, 2016; FMP, 2015). The low-carbon development is using a combination of local electricity generation, improved insulation, and energy efficient devices for the apartments. (GIZ, 2014; GIZ, 2016; FMP, 2015).

Abuja Centenary City: Being planned by an investor from the Gulf and designed by Julius Berger International, this city will feature an array of sustainable energy measures (GIZ, 2016).

With support from the Global Alliance for Clean Cook-stoves, the International Centre for Energy, Environment and Development (ICEED) is establishing the Nigerian Clean Cook-stoves Design and Testing Centre at Afikpo, Ebonyi State. The centre will provide stove producers and users, and other relevant stakeholders the opportunity to confidently compare stove performance and safety. In addition, it will provide a common set of terminology for wood stoves for easier understanding and communication; give stove producers, marketers and users assurance of product quality (GIZ, 2014; GIZ, 2016).

Furthermore, the Nigerian Clean Energy Access Programme NCEAP, in line with the quest to reduce the global impact of climate change and as part of the solution to the epileptic power supply in Nigeria through plan to distribute 150 million bulbs over the next five years under the Clean Development Mechanism (CDM) (GIZ, 2014; GIZ, 2016).. This is part of FMENV's initiative to ensure energy efficiency is private sector driven (GIZ, 2014; GIZ, 2016).

The European Union and German Government funded Nigerian Energy Support Programme (NESP) in cooperation with the FMP, the FMLHUD and the FMITI focuses on energy efficiency in the building and industrial sector (GIZ, 2014; FMP, 2015; GIZ, 2016). Pilot projects will be implemented for apartment buildings, for the application of solar water heaters and with regard to energy management systems in selected industries (GIZ, 2015). Experiences are used for up-scaling into policy development and the development of support mechanisms such as financing schemes, introduction of ISO standards and standards and labels for household appliances (GIZ, 2014; FMP, 2015; GIZ, 2016).

2.7.6.4 Potential for GHG reduction at Building scale within Nigerian context.

A study by the Centre for Renewable Energy Technology CRET (2015) put the current residential housing needs in the country to about 18 million. There is a dire need to build these new homes and ensure they all have adequate power supply. Building power-integrated homes is definitely the best way forward. Investors should take full advantage of this opportunity. Affordable energy-efficient mass housing is appealing to large classes of the population (CRET, 2015).

The buildings must be designed and built to naturally cool themselves and to make maximum use of day lighting. Active electrical power will be derived principally from solar energy (roof-integrated solar PV panels) and other renewable energy sources (e.g., wind, hydro, biomass, geothermal etc.) should be deployed if and when necessary (*ibid*).

Therefore, important considerations for the energy efficient buildings include: Net-Zero Energy (ability to self-generate at least all the energy each building needs); Natural Lighting (use of sky lighting and glazed glass windows); Insulation (e.g., compressed earth, expanded polystyrene, polyurethane etc.); Solar Water Heating; and Natural Cooling (e.g., introduction of strategically placed vents to achieve maximal natural ventilation).

2.8 Estimating Project Value

Understanding the benefits of energy efficiency and the risks of the status quo provides a compelling argument for energy efficiency upgrades (Weimin et.al, 2011). Once motivated, building owners will need to develop a project-specific business case that will ensure that the project meets long-term cost-effectiveness requirements (Weimin et.al, 2011; USEPA, 2007). Weimin et.al (2011) in their studies reveal the following analysis methods to quantify a project's overall financial impact in different ways, and summarizes the benefits and drawbacks of each approach.

2.8.1 Simple Payback Method

According to Weimin et.al, (2011) the most simple and commonly used financial analysis method is the simple payback. Simple payback is defined as the time, in years, for a project's cumulative annual savings to equal its upfront cost (Weimin et.al, 2011; USEPA, 2007). However, the simple payback does not take into account any benefit or cost that occur after the initial investment has been recouped (Weimin et.al, 2011). A project can firstly appear to be unattractive when looked at within the context of a simple payback period, while a more complete economic analysis reveals it to be a highly profitable investment (Weimin et.al, 2011; USEPA, 2007). Further, Weimin (2011) posits that a Life-cycle cost (LCC) analysis is more effective at identifying the best project option, once the costs and benefits of each alternative are carefully analysed and expressed in present value terms.

2.8.2 Net Present Value (NPV)

According to Weimin et.al (2011), Net Present Value (NPV) offers a more rigorous analysis than simple payback by not only extending the analysis to include all cash flows over the useful life of the project, but also accounting for the time value of money. The project's cash flows include the first cost, energy cost savings (which may be assumed to increase with rising energy prices), and all other costs and benefits, such as O&M costs and any salvage value at the end of the analysis term (Weimin, 2011). The calculation of a project's NPV depends on the discount rate selected as well as the length of the analysis term (Weimin et.al, 2011).

Discount rate is often defined as ''the investor's minimum acceptable rate of return for an investment whose length and risk profile match those of the project being evaluated.'' (Weimin et.al, 2011). In an NPV analysis, the discount rate is used to determine the present value of each cash flow, adjusting all cash outflows and inflows over the life of the project to comparable dollar amounts today(ibid). The choice of a discount rate is critical; the chosen rate should reflect the rate of return that could be earned on an investment of similar risk and duration (ibid).

Weimin et.al (2011) and USEPA (2007) argues that a positive NPV indicates that the present value of the cash inflows is greater than the present value of the cash outflows over the analysis term. A negative NPV indicates that the investment required is greater than the project's return, once all of the cash outflows and inflows are reduced to their present values and summed (Weimin et.al, 2011; USEPA, 2007). NPV is the primary metric used for economic analysis of the measures presented in this guide (Weimin et.al, 2011).

2.9 Financial Assistance for Energy Efficiency Projects

Defining an approach for financing is a key step in creating the business case for an energy efficiency project (*ibid*). The approach to financing includes determining the source of funds to pay upfront costs and identifying incentives that may substantially reduce those costs (*ibid*). This section provides an overview of the most common purchase options and some of the incentives available that may improve a project's financial attractiveness.

2.9.1 Purchase Options

A building owner has two primary means of funding the upfront costs of an energy efficiency project, either through the purchase of equipment and services required, or through a performance contracting. In addition, utility and government incentives can be leveraged to reduce total project costs (*ibid*). Most common finance options are discussed below;

2.9.1.1 Debt

While an owner may use cash to purchase the services and equipment associated with an energy efficiency project, the most common way to finance a project is through borrowing. When considering this option, it's recommended to research low-interest loans specifically tailored to energy efficiency projects *(ibid*). A good example of such low-interest loans is the utility incentives discussed below.

Government loans or loan guarantees are often available at multiple levels (local, state, and federal). Many of these loan programs were historically limited to energy retrofits in public buildings, but have recently been extended to commercial buildings (*ibid*)

2.9.1.2 Performance Contracting

Weimin et.al (2011) reports that performance contracting is a substitute to conventional project financing. Under a performance contract, an energy service company (ESCO) delivers turnkey energy efficiency projects, with the project cost recovered over time out of energy savings (Weimin et.al, 2011). The ESCO will typically complete an audit, obtain contractor bids, manage the installation, and finance the project (Landsberg, Lord and Carlson, 2009). Energy cost savings are then shared between the ESCO and the building owner, with the ESCO's share of savings paying for the ESCO's services, including the cost of capital.

Distribution of Energy Cost Savings through Performance Contracting

Performance contracting addresses many of the common barriers that delay projects. Some of the key benefits as reported by Weimin et.al (2011) include:

- Building owners avoid upfront project costs because the ESCO finances the project
- ESCOs provide technical expertise for implementing measures
- Risk may be reduced by including a savings guarantee in the project contract.

Weimin et.al (2011) argues that performance contracts are complicated by the technical nature of a large energy efficiency project and the complex and nuanced calculations they require. Measurement and verification of savings becomes a critical and sometimes controversial part of the contract and project, especially for larger investments where the contract term may exceed ten years (Weimin et.al, 2011).

The primary disadvantage of performance contracting according to Weimin et.al, (2011) is the inability of the owner to see the full benefit of reduced operating costs during the period of the contract. Further, Weimin et.al (2011) argues that the ESCO's cost of capital has a significant influence on the project economics. Some building owners may be able to secure financing at better rates than the ESCO, in which case the benefit of a performance contract is reduced. On the other hand, ESCOs have a wealth of knowledge about energy efficiency measures, and they may be a valuable project partner even without a performance contract (Weimin et.al, 2011; Landsberg, Lord and Carlson, 2009).

2.9.1.3 Utility and Government Incentives

Leveraging incentives available through utility programs can be an effective way to reduce a project's total cost. There are numerous programs available offering cash rebates to help make an energy efficiency project more financially attractive. The availability of incentives is highly time and location dependent (Weimin et.al, 2011; Landsberg, Lord and Carlson, 2009). Utility representatives are also often able to describe opportunities that relate to your facility. It's worth noting that the incentives usually are issued upon project completion, so the owner will still need to make the full upfront investment (Weimin et.al, 2011; Landsberg et al, 2009).

2.9.1.4 Utility "On-Bill Finance"

Weimin et.al (2011) reports that some utilities have started financing energy efficiency retrofits through On-Bill Finance. On-Bill Finance offers utility customers the opportunity to receive a utility payment for a retrofit and then repay the utility through a charge on the utility bill, which is typically offset by project savings (Weimin et.al, 2011). As with performance contracting, this can be a useful way to finance a project, but will result in the owner not seeing the full benefit of the savings until the financing is repaid (Weimin et.al, 2011).

2.9.1.5 Tax Relief

There are also financial incentives available in the form of tax relief, offered by all levels of government, but are dependent on location (Weimin et.al, 2011; Landsberg, Lord and Carlson, 2009). According to Weimin et.al (2011:) ‘’the primary tax relief offered by the federal government is the Commercial Buildings Tax Deduction, which offers up to $1.80/sf for projects that achieve at least 50% energy cost savings (extended through 2013 at time of publication).’’ To demonstrate 50% savings, participating buildings are required to be modelled in a qualifying software program like design builder for auditing (Weimin et.al, 2011)

An additional tax relief mechanism that has been tested in local government pilot programs throughout the U.S. according to Weimin et.al (2011) is the Property Assessed Clean Energy (PACE) financing. By allowing building owners to finance retrofit projects as a property tax assessment, PACE financing programs result in more favourable lending rates compared to traditional loans (Weimin et.al, 2011).

2.10 Access to financing energy efficiency projects in Nigeria

Building projects are capital intensive, and capital costs are high in Nigeria. Access to affordable financing instruments is paramount for a successful establishment of energy efficient buildings (FMP, 2016). In this sense, some of the remedial measures to mitigate scarcity of capital are financial collaboration/partnerships between the government and the private sector (PPP) and applying for some of the multilateral organizations calls for proposals (FMP, 2016).

Currently, an increasing number of international organizations are already active or planning to get involved in supporting the energy efficiency sector in Nigeria (FMP, 2016). For example, the French Agency for Development (FAD) is planning to establish a credit line for energy efficiency measures providing interest-reduced loans. On the international level, the Nationally Appropriate Mitigation Actions NAMA-facility provides funding to finance the transition towards sustainable growth in countries (FMP, 2016). In Mexico, a project with the duration

2013-2019 targets energy efficiency in the residential sector (FMP, 2016). It is their objective to promote the penetration of basic efficiency standards in the entire new housing market in Mexico by means of: (a) technical assistance to large public housing financiers and small and medium-sized housing developers and (b) financial incentives and project-related technical support for small and medium-sized developers and financial intermediaries. Another objective is to promote the upgrading of energy efficiency standards to more ambitious levels (FMP, 2016).

2.11 Common Photovoltaic (PV) business model around the world

Wurtenberger, Bleyl, Menkveld, Vethman, Tilburg (2012) posit that business models for renewable energy in the built environment aim at providing policy makers and other market actors insight into the way new and innovative business models can stimulate the deployment of renewable energy technologies (RET) and energy efficiency (EE) measures in the built environment.

PV industries have moved a step further from customer owning and financing PV system to overseeing important aspect of installation. This aspect according to Frantzis, Graham, Katofsky, Sawyer (2008:5), is called ‘’Zero Generation PV business model’’ in which the attractiveness of this type of model is limited to a relatively small group of people (the pioneers) whose interest is on the benefit that comes with PV, namely ‘’environmental, energy security, and self-generation’’ (Frantzis et al, 2008: 5).

The first generation PV business model products gained much attention at a larger market which allowed for early ‘’adopter customer category’’ (*ibid*: 5). The second generation PV business model according to has emerged and includes a highly grid interactive PV system that is equipped with modern and emerging technology, and more ‘’regulatory initiatives’’ (*ibid*: 5) that give room for a viable and valuable integration. The ‘’2nd generation business models’’ (*ibid*: 5) is the centre of the forthcoming business models because, it is very important to potential stakeholders (*ibid*: 5).

The driving forces are no longer the technologies but the business models, nevertheless, ‘’leasing, Power Purchase Agreement system, and solar mortgage’’ Frantzis et al (2008:6) are some of the business models recently initiated in developed countries which are mainly related to grid-connected PV system. The potential of PV is highly challenged by upfront cost, which according to Frantzis et al (2008), is the most common problem in developing countries. Utility response to PV business has been limited to ‘’net metering, and standardized interconnection’’ (Frantzis et al 2008:6). It is believed that utility involvement in future PV business models will be highly impactful and will be motivated by grid interaction. Below are some common photovoltaic business models reviewed for the purpose of this study;

2.11.1 Solar Power Purchase Agreement (SPPA)

According to Wurtenberger et al (2012) SPPA is a financial arrangement in which a third-party developer owns, operates, and maintains the photovoltaic (PV) system, and a host customer agrees to site the system on its property and purchases the system's electric output from the solar services provider for a predetermined period. This financial arrangement allows the host customer to receive stable and often low-cost electricity, while the solar services provider or another party acquires valuable financial benefits, such as tax credits and income generated from the sale of electricity (Frantzis et al 2008; Meier, 2014).

With this business model, the host customer buys the services produced by the PV system rather than the PV system itself. This framework is referred to as the "solar services" model, and the developers who offer SPPAs are known as solar services providers (Frantzis et al 2008). SPPA arrangements enable the host customer to avoid many of the traditional barriers to the installation of on-site solar systems: high upfront capital costs, system performance risk, and complex design and permitting processes. In addition, SPPA arrangements can be cash flow positive for the host customer from the day the system is commissioned (Frantzis et al 2008; Wurtenberger, 2012).

A host customer agrees to have solar panels installed on its property, typically its roof, and signs a long-term contract with the solar services provider to purchase the generated power. The host property can be either owned or leased. Frantzis et al (2008) argues that for leased properties, solar financing works best for customers that have a long-term lease. The purchase price of the generated electricity is typically at, or slightly below, the retail electric rate the host customer would pay its utility service provider (Frantzis et al 2008; Meier, 2014). SPPA rates can be fixed, but they often contain an annual price escalator in the range of 1 to 5 percent to account for system efficiency decreases as the system ages; inflation-related cost increases for system operation, monitoring, and maintenance; and anticipated increases in the price of grid-delivered electricity (Frantzis et al 2008; Meier, 2014). An SPPA is a performance-based arrangement in which the host customer pays only for what the system produces. The term length of most SPPAs can range from six years (i.e., the time by which available tax benefits are fully realized) to as long as 25 years (Frantzis et al 2008; Wurtenberger, 2012; Meier, 2014).

The solar services provider functions as the project coordinator, arranging the financing, design, permitting, and construction of the system. The solar services provider purchases the solar panels for the project from a PV manufacturer, who provides warranties for system equipment (Frantzis et al 2008).

The installer will design the system, specify the appropriate system components, and may perform the follow-up maintenance over the life of the PV system. To install the system, the solar services provider might use an in-house team of installers or have a contractual relationship with an independent installer. Once the SPPA contract is signed, a typical installation can usually be completed in three to six months (Wurtenberger et al, 2012; Meier et al, 2014). Where financing and tax benefits are available, the investor is responsible to arrange the financing and possible tax benefits or subsidies, which will work in his favour as he reaps the benefit. Under certain circumstances, the investor and the solar services provider may together form a special purpose entity for the project to function as the legal entity that receives and distributes to the investor payments from tax benefits and the sale of the system's output (Wurtenberger et al, 2012; Meier et al, 2014).

The utility serving the host customer provides an interconnection from the PV system to the grid, and continues its electric service with the host customer to cover the periods during which the system is producing less than the site's electric demand. Certain states have net metering requirements in place that provide a method of crediting customers who produce electricity on-site in excess of their own electricity consumption. In most states, the utility will credit excess electricity generated from the PV system, although the compensation varies significantly depending on state polices (Wurtenberger et al, 2012; Meier, 2014).

This is similar to the solar roof rental, where large retailers rent the roof to PV companies who will pay rent to use the roof and sell the electricity back to the grid or the retailer. That is another variation of business model which may not be very applicable to the case study building.

The SPPA is a good, low risk business model. Even though there are currently no renewable energy companies in Nigeria offering this type of business arrangement. It would be the most appropriate model to respond to the barriers of this technology and leverage on the progressive support mechanisms.

2.11.2 Solar leases

Solar leases works in a similar to solar PPAs. In this case, you enter into an agreement with the solar leasing company that entitles you to the benefits of the system (i.e., the energy that the solar panels generate) for the term of the contract, which is generally around 20 years. Under these arrangements, the solar leasing company owns and maintains your solar panel system, so it is entitled to the rebates, tax breaks, and financial incentives that are available for the solar panel system. Consumers can indirectly benefit from those savings through lower electricity rates (Frantzis et al 2008; Wurtenberger et al, 2012; Meier, 2014).

While the terms "solar lease" and "solar PPA" are used interchangeably by so many people because of their similarity, in practice, there is a key difference between the two. With a solar lease, you agree to pay a fixed monthly "rent" or lease payment, which is calculated using the estimated amount of electricity the system will produce, in exchange for the right to use the solar energy system. With a solar PPA, instead of paying to "rent" the solar panel system, you agree to purchase the power generated by the system at a set per-kWh price (Frantzis et al 2008; Meier, 2014).

2.11.3 Public Private Partnership (PPP)

Public-private partnership (PPP) is a funding model for a public infrastructure project such as solar power plant. The public partner is represented by the government at a local, state and/or national level. The private partner can be a privately-owned business, public corporation or consortium of businesses with a specific area of expertise (Frantzis et al 2008; Meier, 2014). Different models of PPP funding are characterized by which partner is responsible for owning and maintaining assets at different stages of the project. Examples of PPP models summarised for the purpose of this report include:

- Design-Build (DB): The private-sector partner designs and builds the solar infrastructure to meet the public-sector partner's specifications, often for a fixed price. The private-sector partner assumes all risk.
- Operation & Maintenance Contract (O & M): The private-sector partner under contract, operates a publicly-owned solar infrastructure for a specific period of time. The public partner holds ownership of the assets.
- Design-Build-Finance-Operate (DBFO): The private-sector partner designs, finances and constructs a new infrastructure component and operates/maintains it under a long-

term lease. The private-sector partner transfers the infrastructure component to the public-sector partner when the lease is up.

- Build-Own-Operate (BOO): The private-sector partner finances, builds, owns and operates the infrastructure component in perpetuity. The public-sector partner's constraints are stated in the original agreement and through on-going regulatory authority.
- Build-Own-Operate-Transfer (BOOT): The private-sector partner is granted authorization to finance, design, build and operate an infrastructure component (and to charge user fees) for a specific period of time, after which ownership is transferred back to the public-sector partner.
- Buy-Build-Operate (BBO): This publicly-owned asset is legally transferred to a private-sector partner for a designated period of time.
- Build-lease-operate-transfer (BLOT): The private-sector partner designs, finances and builds a solar facility on leased public land. The private-sector partner operates the solar facility for the duration of the land lease. When the lease expires, assets are transferred to the public-sector partner.
- Finance Only: The private-sector partner, usually a financial services company, funds the infrastructure component and charges the public-sector partner interest for use of the funds.

2.11.4 Solar mortgage

The solar mortgage is a concept that enables a homebuyer or mortgage refinancer to add a solar system after the mortgage loan has closed. This is done by allowing up to 15 percent of the “as completed” home value to be used to pay for the cost of a solar system with funds escrowed by the lender, and gives the homeowner 180 days after the closing date to have the solar system installed (Frantzis et al 2008; Meier, 2014). The new mortgage requires a home energy report to determine the cost-effectiveness of the solar improvement. The report must show that the present value of energy savings is greater than the cost to install. The homeowner must also have an as-completed appraisal, which includes value for the not-yet-completed solar system (Frantzis et al 2008; Wurtenberger et al, 2012; Meier, 2014).

Adding solar when purchasing a home or refinancing a mortgage has the potential to become the default choice, like repainting a room, doing new landscaping, or any other minor improvement a homeowner makes when completing a new real estate transaction.

2.11.5 Feed-In Tariffs

A Feed-in Tariff (FiT) is an energy supply policy that promotes the rapid deployment of renewable energy resources. A FiT offers a guarantee of payments to renewable energy developers for the electricity they produce. Payments can be composed of electricity alone or of electricity bundled with renewable energy certificates. These payments are generally awarded as long-term contracts set over a period of 15-20 years (Karlynn, and Toby, 2012).

FiT policies are successful around the world, notably in Europe. Currently there are six U.S. states (California, Hawaii, Maine, Oregon, Vermont, and Washington) that mandate FiTs or similar programs. A few other states also have utilities with voluntary FiTs. There is growing interest in FiT programs in the United States especially as evidence mounts about their effectiveness as framework for promoting renewable energy development and job creation (Karlynn, and Toby, 2012).

2.12 Overview of trending business models in selected countries.

A number of interesting and successful business models, such as leasing, PPP systems, PPA systems, and solar mortgage, have recently been developed in industrialized countries mainly related to grid-connected PV systems. While these business models may be replicated in grid-connected areas of developing regions, different models are needed in off-grid areas. Some of these regions and their emerging business models are discussed below.

2.12.1 Kenya

A business model currently gaining ground in Kenya as highlighted by Meier (2014) was financed through the Public Private Partnership (PPP). About 40 water projects in Kenya have increased the sale of PV through innovative solutions for water supply in arid and semi-arid region of the country. The project which consists of boreholes, water pumps, water dispensers and water-card for customers is being undertaken by Grundfos Lifelink.

A PV system is installed in each of these locations to generate electricity that runs the whole system from pumping water into a reservoir to operating the dispenser. Customers load money into their water card with the help of M-pesa (a successful mobile phone payment developed by safaricom), which is used to purchase water from the dispenser. The dispenser debits the amount and releases water equivalent to the debited amount (*ibid*).

2.12.2 United States

In the United States, an online solar market place that connect investors to solar projects in need of financing has emerged for some time now. This is known as Mosaic. It has a web site called joinmosaic.com and the projects to be financed are all described into detail in a prospectus. Interested investors create an account online on the company's web page (Meier, 2014:17). The prospectus is prepared to conform to the Security and Exchange Commission's (SEC) requirements. Investors recover their capital and interest over a stipulated period of time. The interest rate ranges from 4.5-6.5% per year. The sizes of the project range from 50 kW to 1MW (*ibid*: 17). Mosaic business model is designed to operate like an effective renewable energy bank, lobbying investment for solar developments and making loans to be paid back over a period of about 10 years.

Mosaic is taking an upfront fee of 2 to 3% of the loan they are making. And then they charge an annual fee of 1% on the principal of the investment, meaning if they make a loan for 7%, they are offering it on the platform for 6% net of fees. So what investors see on their webpage is the real rate of return. The solar projects funded typically consist of rooftop or ground-mounted installations that either (a) generate on-site electric power for small businesses or other organizations or (b) generate power for sale to an electric utility or other "off-taker" (*ibid*).

Mosaic is providing the loans to Special Purpose Entities (SPE), controlled by local developers. The SPE typically repays the loan primarily out of cash flow generated by the sale of electricity to the solar customer or off-taker and, in many cases, the sale of Solar Renewable Energy Certificates (SRECs) to local utilities or other purchasers. Further, the loans are secured by the assets of the project owned by the SPE as well its contractual rights with respect to the sale of electricity or SRECs. The 'roof provider' has the option to buy out the SPE at the end of the lease agreement and thus, own and operate the infrastructure as long as the system lasts (*ibid*).

2.12.3 Nepal

Gham Power in Nepal is a good example of urban hybrid PV micro grid interaction business model (Meier, 2014). In this case, Nepal's market population operates on a lot of fossil-fuel based stand-alone generators. However, ''PV is incorporated into the existing diesel grid, with or without power storage (*ibid: 21*). Projects of this nature are usually undertaken by institutions such as banks, hospitals, hotel, and big factories (*ibid: 20*) that can afford a lot of money operating on diesel plants.

Although urban hybrid PV business model was created by Gham Power, another holding company receives the funds from investors. The holding company acts as the investor and becomes the legal owner of the PV system that is installed. Gham is also responsible for sourcing and executing projects (*ibid*).

End users are often provided with a ‘’lease-to-own model’’ in which they are presented with an opportunity to buy and own the system at the expiration of the lease which is usually after 10 years. The system operates in a similar way with a bank loan from Nepal’s Clean Energy Development Bank (CEDB), which is the financing partner of Gham Power (*ibid: 21*). CEDB funds 70% of the project while the remaining 30% is usually provided by the holding company. In addition, the physical structure (*ibid: 21*) is used as collateral.

In Nepal, incentives such as investment subsidies, generation based incentives, tax incentive, and quota obligation have been provided by the state to encourage large scale uptake of RE. An Indian based company (SunEdison) developed a business model centred on these incentives, in which companies, industries and corporate organisations are encouraged to invest in, and own their solar pack without having to become solar experts (*ibid*). SunEdison is responsible for site selection, acquisition of permits, construction and installation of the system and operation and maintenance.

According to the author, ‘’the model is not based on feed-in-tariff but Accelerated Depreciation Benefits (tax incentive) and India’s Open Access Programme (quota obligations)’’ (*ibid: 22*). Incentives for 100% depreciation on solar assets are paid within the first year of purchase while the ‘’Open Access Programme allows the developer to sell renewable energy credit to large energy consumers with renewable purchase obligation’’ (*Ibid: 22*).

2.12.4 South Africa

In South Africa, several shopping malls have been investing massively in solar business. For example, Clearwater mall installed 500 kWp of PV in 2014 and has added another 1000kwp this year (2016) (Cooke, Prabu, Steele, 2016). This is due to the accomplishment made between the periods of two years. An average of 2500,000 kWh is generated per year; this corresponds to the consumption of 347 households and 10% of the energy consumed by the mall. Moreover, V&A waterfront produces an estimated 164,000 kWh per year of electricity which can serve approximately 310 households. The daily consumption rate is between 7 to 24% (Cooke et al, 2016).

Electricity in South Africa revolves mainly around Eskom. The company is the single buyer of electricity in the country. However a new model known as the willing-buyer, willing-seller model has emerged. The success of this model is shown in Amatola Green Power (Pty). According to Cooke et al (2016), Amatola partners with municipal entities to facilitate the development of this exceptional business model.

Amatola designed a system equivalent to international standards that enable companies to give account of GHG reduction resulting from every kilowatt of energy they generated. Currently, Amatola is the only company permitted to operate on this model. This is a sign of what the future ‘’voluntary market’’ holds, most importantly in collaboration with municipal governments in the country (Cooke et al, 2016: 31).

In order to support the first green power development in its area, Nelson Mandela Bay Municipality (NMBMM) agreed to purchase the power. In order not to fall foul of the MFMA (Municipal Finance Management Act) requirement that municipalities source the lowest cost service, NMBMM offered to buy the electricity at a rate below Eskom mega-flex rates. The developer was able to recoup its costs through selling the ‘green’ component of the power to a private company through a Green Credits Agreement (*ibid*).

In this arrangement, the company continues to buy their electricity from the municipality, but in addition buys the ‘green premium’ directly from the generator (*ibid*). This ‘green’ certificate can count towards triple bottom line accounting requirements and marketing of a green image. The municipality, though supportive, could not engage in the kind of long-term power purchase agreements (PPAs) so vital for raising development finance for ongoing renewable energy project development (*ibid*). In 2013, with the signing of a wheeling agreement between NMBMM and AGP, the possibility of long-term PPAs was opened up. AGP was licensed by NERSA in 2009 to trade green power - buying power from renewable energy generators and sell this on to willing buyers (*ibid*).

Customers of AGP pay between R0.80 and R1.40 per kWh of electricity purchased and generators are paid between R0.62 and R1.05 per kWh supplied. The customers enter into long-term (10, 15 to 20 years) contracts. AGP operate on a “take or pay basis” which means that if a customer says they will purchase a certain amount of green energy and actually use less, they will still be required to pay for the energy that they did not use. With a contract in place, committing a willing buyer to ten or fifteen years of power purchase from the generator, at an established price, the project risk for the developer is substantially reduced and financiers are more willing to loan the necessary funds for the project investment (*ibid*).

The trader (AGP) is charged directly by the municipality for the wheeling of the green power at the established use of network charge as set out in the Wheeling Agreement between AGP and NMBMM. NMBMM initially set this network charge at 7% of the value of the power delivered in the trading agreements (calculated on Eskom mega-flex rates). The municipality has since undertaken a detailed Cost of Supply study and have updated the Wheeling Agreement to set the network charge in the region of 20% of the value of the power wheeled over the grid. This will cover all network costs, but does not cover the full cost of service - billing and other services that raise revenue for the municipal rates and service accounts (*ibid*). The municipality has agreed to forfeit this portion of the traditional revenue generated as it strongly believes that the opening up of the grid to local power producers will compensate the loss through the stimulus to local economic development. The municipality's framework wheeling agreement is based on the idea of attracting and supporting local renewable energy development. The Coega Industrial Development Zone is situated within the NMB Municipality and has been established as the green technology manufacturing hub of South Africa and there are also plans to build up to 1200 MW of renewable energy here. These projects have the potential for job creation associated with parts manufacture, plant development and maintenance (*ibid*).

Although it took some years to get the broad framework in place, and enormous amounts of discussion and engagement with NERSA, this framework has the ability to now fast track renewable energy development in the area. The motivating force for NMBMM is that of local development. In addition the municipality believes that there are important, direct financial benefits of having a portion of its power coming from local, renewable source electricity: demand charge reductions on power purchased from Eskom, no environmental levy, and no carbon tax when that comes into effect. Grid stability is also improved (*ibid*).

Even though this is very interesting, it applies only to large scale solar generation. However, several shopping malls in South Africa have been investing massively in solar business. For example, clear water mall installed 500 kWp of PV in 2014 and has added another 1000 kWp in 2016. This was due to the accomplishment made between the periods of two years. An average of 2500, 000 kWh is generated per year; this corresponds to the consumption of 347 households and 10% of the energy consumed by the mall. Moreover, V&A waterfront produces an estimated 16, 40000 kWh per year of electricity which can serve approximately 310 households .The daily consumption rate is between 7 to 24% with the surplus sold back to the grid (Cooke, Prabu, Steele, 2016).

2.12.5 Conclusion

The cases discussed above shows that the formulation of successful business models is not an easy task that can be done in just a couple of days. It is possible to replicate these models in other developing region of the world like Nigeria, although, different prototypes are necessary in off grid regions. However, the specific regulatory, economic, social and cultural situation in a region has to be well understood and addressed in business models.

Successful business models usually include a financing component. This is particularly important for the mass market in emerging regions where most people do not have access to commercial financing, or are overwhelmed in dealing with loan applications. Furthermore, to be attractive for potential customers, business models must appear to be clear and simple, even if sophisticated processes run below the surface.

Chapter 3

Research methodology

3.1 Introduction

This research work employed strategies that helped to meet the obligation for energy reduction. It is an evaluative kind of study that requires some retrospective assessments to establish the efficiency of energy and demand savings with the purpose of knowing their performances against specified accepted energy efficient measures or strategies. This chapter focuses on the methods used in collecting and analysing data. The chapter begins by examining the research method employed in the study as well as describe the case study area. Further, the chapter gives an outline of the data utilized in the study with details on how the data were collected, recorded and transcribed. Lastly, the chapter looks at the ethical considerations followed in the study.

3.2 Research Design/Approach

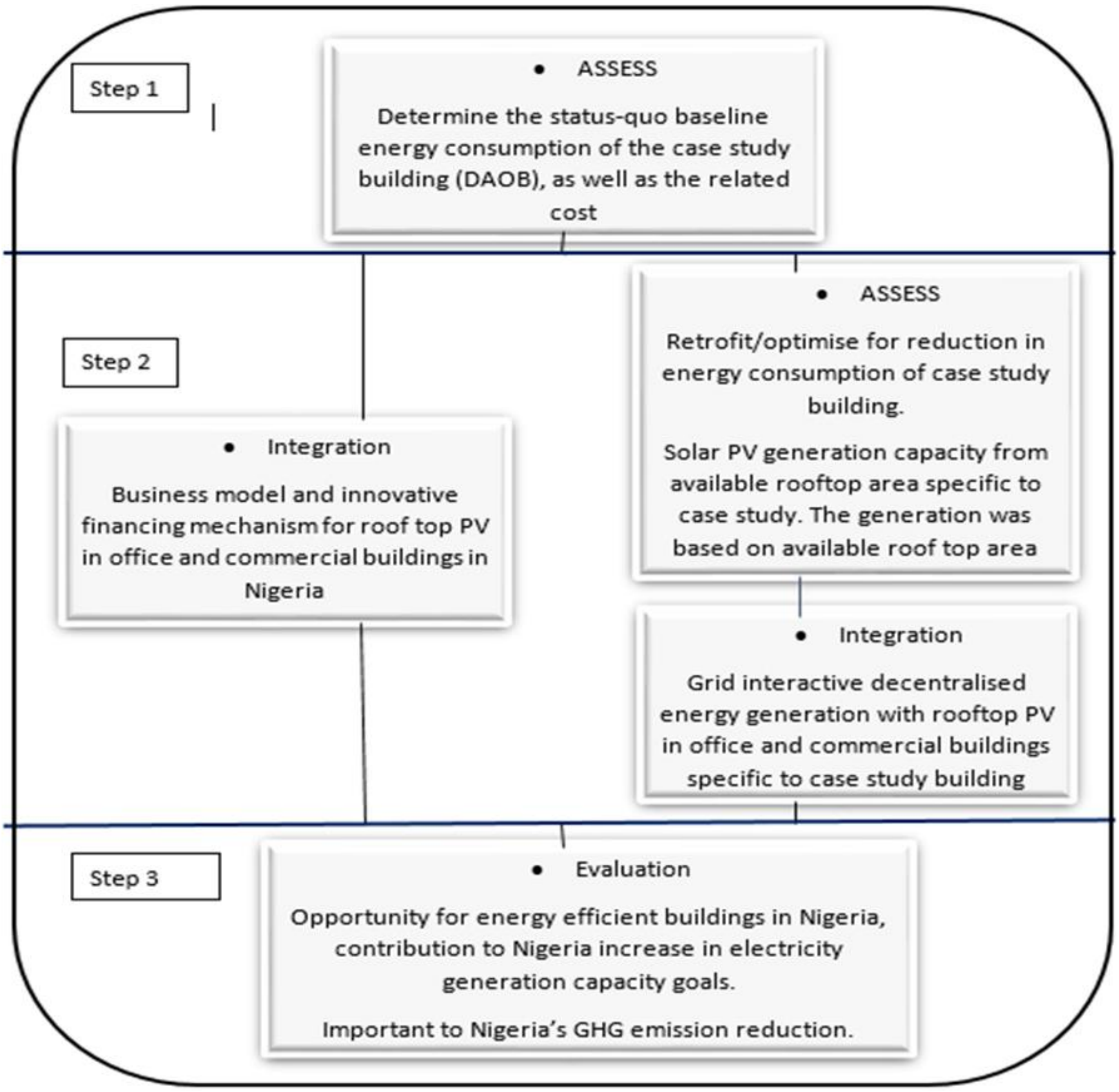
The study employed the qualitative type of research during the course of data collection and analysis. It also assessed various existing and emerging business models in PV globally, in order to gain acumen on predominant PV-based DG business models with a view towards adaptation to Nigerian context.

A case study research approach was applied. A case of DAOB was assessed, evaluated, and tabulated. Case study approach allows for a diagnostic exploration and in-depth knowledge of convoluted problem (Zaidah, 2009). It is perceived to be a direct type of approach most especially when it is subject to exhaustive scrutiny. In support of this assertion, Oluigbo (2011), highlights case study approaches that are applicable in architectural related research. For example, Illustrative, exploratory, explanatory, evaluative and critical approaches are most relevant to Architectural related studies. For the purpose of this research, the evaluative case study was employed.

Evaluative case study is appropriate for assessing the efficacy of status-quo so as to enable recommendations for the required amendments. For this research, purposive sampling was most suitable for assessing the effectiveness of energy consumption and demand reduction approaches to suggest relevant modifications.

The research question posed in the study seeks to know the potential of solar PV electricity generation through a retrofitting of an existing office building in Nigeria. The question also touch on formulating a responsive business model as well as policy framework that is capable of opening up a wider transformation towards decentralised energy generation with roof top solar PV in the country. In order to achieve the research objective, a three step procedure to answer the research question was followed. The overview of the procedure is outlined in the figure below.

Figure 4: Research design and overall approach.



The first step was to establish the status-quo baseline energy consumption of the Department of Architecture Office Building (DAOB). This was done by extracting the monthly electricity consumption of the building from the grid, and the related cost from the monthly electricity bill provided on request. The bill provided covers a period of one year (July 2015 to June 2016). A detailed presentation of the analysis and discussion around electricity from the grid is provided in chapter 4. Further, a software known as Design Builder (DB) was utilized for energy auditing of the building. This was done by modelling the building in the software, input all the necessary information and then simulate to determine the status-quo baseline energy consumption of the building. The simulation was done in line with the following; occupancy, operation pattern of the building, equipment/appliances load used in the building, and the prevailing climatic and environmental factor in the area. Detailed processes and information involved in the modelling, parameter input and simulation are provided in chapter 4 of this report. Comprehensive analysis of the result of the simulation are presented in the same chapter. Next is to determine the annual cost of operating the building on a standalone diesel generator due to the persistent power outage and load shedding in the case study area. Relevant data on load shedding schedule in the case study area, as well as cost of operating the building on a stand-alone generator to mitigate these crises are presented in section 4.5.3.

After this was done, the next step was to optimise the DAOB for energy efficiency. From the analysis of the results and outcome from the simulation, a thorough assessment of the results was done to determine certain areas of the building that require optimization in order to reduce the overall energy consumption of the building. Once these areas were identified, appropriate energy efficiency retrofit intervention were carried out in modelled building using DB software. Another simulation was done based on these interventions. The out-come of this simulation revealed a substantial reduction in energy consumption of the building. Detailed procedure involved in carrying out this optimization is presented in section 4.8.

The next step was to determine the solar PV potential of DAOB based on the reduced energy consumption of the building. Detailed procedure and calculations involved in these estimation are presented in section 4.8. The first procedure was to size the appropriate PV capacity that is suitable for the building based on the optimization carried out in the previous step. Second procedure was to estimate the available roof top area for solar PV installation. Next was to identify and select the appropriate business model for this study. Procedures that were followed include establishing the surplus electricity that could be exported to the utility grid based on annual electricity consumption patterns of the DAOB, identifying enabling mechanisms for rooftop solar PV generation, applying the mechanisms to render the business model financially viable.

Interpretations of the findings in step two are then presented in the third and final step. In this step, the cost of optimising DAOB and cost of installing solar PV are evaluated and compared to the cost of operating the building on a stand-alone diesel generator. Comparing the cost in a long run revealed that it is more expensive to operate the building on a stand-alone diesel generator. Analysis on this comparison is presented in section 4.9. Furthermore, solar PV is evaluated for its contribution to Nigeria's electricity generation capacity goals, and its significance to Africa's greenhouse gas emissions reduction, and the input of the intervention towards climate change mitigation.

3.2 Research data and data collection tools.

Both secondary and primary sources of data collection were engaged in the research as tabulated below

Table 4: Research data and data sources.

Step 1. Data required to establish the baseline energy consumption of DAOB			
	DATA COLLECTED	**SOURCES**	**DATA TYPE**
a.	Simulation results and outputs	Design builder software	Primary.
b.	Electricity bills for one year	Department of works, Kogi state Polytechnic, Lokoja.	Secondary.
Step 2. Data required to optimise the DAOB for energy efficiency.			
a.	Information on the following; massing, building orientation, wind direction, sunrise and sun- set, sizes and direction of the openings, existing landscape elements, types and characteristic of building material used, types and capacity of office appliances available, types and capacity of electrical fittings installed.	Visual survey of the case study building and its immediate environment.	Primary.
b.	Available spaces, functions and their dimensions were determined through physical measurement and enquiry	Physical task from the case study building.	Primary.
c.	Data on available types and capacity of energy efficient appliances and fittings in the market.	Brianok Engineering Nigeria Limited.	Primary.
d.	Data on types, capacity and cost of energy efficient appliances as well as strategies for retrofitting existing office building.	Literature reports and internet search. Advanced Energy Retrofit Guide. UNEP report on Building	Secondary

		and Climate Change. Deep Energy Retrofit report	
e.	Data on the appropriate types and costs of integrating roof top PV.	Brianok Engineering Nigeria Limited. Solid Green.	Primary.
Step 3. Cost comparison between retrofitting DAOB and the status-quo coping mechanism of the building in the short and long term.			
a.	The cost of retrofitting the building.	Analysis from stage two above	Primary.
b.	The initial cost and operating cost of running the building on generator.	Archival records	Secondary.
c.	The cost of operating the building on centralised power supply from the grid.	Electricity bills.	Secondary.
Step 4. Data on viable business model options for a PV retrofit of the DOAB building.			
a.	Information on a viable business model and finances.	energy experts, PV experts, property developers relevant units of the Local Government, and relevant units of the micro-finance banks	Primary
b.	Regulatory/policy framework on renewable energy in Nigeria.	Ministry of Power and Housing, Nigeria.	Primary.
c.	Regulatory/policy framework on renewable energy in Nigeria.	Literature report.	Secondary.
d.	Information from existing case studies/precedents within South Africa	Internet search. Literature reports.	Secondary
e.	Global emerging business model on PV.	Literature.	Secondary.
Step 5: Data on the related insights for scale-up of the related interventions for commercial buildings (new and existing) for Nigeria.			
a.	Data on insight gained from various South African business models on DG	Literature reports.	Secondary
b.	insight gained from various global business models on DG	Literature reports.	Secondary

3.2.1 Required data and procedure for step 1

In step 1, the data needed to determine the baseline energy consumption of DAOB includes the simulation output from Design Builder software as well as the monthly electricity bills of the building for a period of one year gotten from the Department of works, Kogi state Polytechnic, Lokoja. Design Builder is a state of the art software tool for checking energy consumption, carbon emission, lighting, and comfort performance. It's been developed to simplify the process of building modelling and simulation for maximum productivity, allowing it to rapidly compare the functional performance of building designs and delivery zones quickly and easily.

Prior to simulation, the following data were gathered and factored into the software's input; the building orientation, building size, gross and net floor area, building envelope, building occupancy and operation pattern, appliances and equipment load, prevailing climatic conditions of the case study area (temperature, relative humidity, solar radiation, and day lighting hours), and adjoining structures. This information was collected from visual survey, DAOB's architectural, mechanical and electrical drawings, archival records of the department, physical measurement, semi structured interview of the users and relevant literatures. Analysis of these data are presented in section 4.5.1

Also, the data required at this stage incudes the cost of operating DAOB on fossil fuel stand-alone diesel generator to mitigate the persistent electricity outage in the area. The cost comprises the fuelling cost, routine service cost, parts repairs cost and miscellaneous cost for a period of one year. Comprehensive data on the cost was provided by the Department of works, Kogi state Polytechnic, Lokoja. Detailed data on load shedding schedule in the case study area was gotten from one of the branch office of the Abuja Electricity Distribution Company (AEDC) serving the case study area. The data are presented in section 4.5.2

3.2.2 Required data and procedure for step 2

The required data at step 2 are the appropriate energy efficiency measures to be retrofitted into the building to help reduce its energy consumption. The data that presented opportunity for optimization in the following areas were gathered; building envelope, openings and fenestrations, lighting, appliances and equipment, user behaviour, operation and management. These data allowed for a re-designed prototype model of the building for simulation. The redesigned model incorporated energy efficiency retrofit for optimised energy consumption of the building.

3.2.3 Required data and procedure for step 3

Based on this optimised energy use, data on sizing for a suitable integrated roof top PV as alternative sources of generation were gathered and analysed. The preliminary analysis involved estimating the rooftop solar PV generation capacity in the DAOB. Generation capacity was defined as the amount of power that could be generated by rooftop solar PV in the DAOB using the available roof area.

Determining the generation capacity involved three stages namely: establishing the usable rooftop area for solar PV placement in the DAOB, determining the amount of solar radiation available in the area and finally estimating the generation capacity from the available rooftop area. The available rooftop area was calculated using detail-specific data collected from DAOB. The second procedure involved the use of secondary data to determine the average monthly solar radiation available in the area for 12 months (1st January to 31st December).

The cost of optimising the building, the cost of integrating the roof top solar PV and the cost of operating the building on a stand-alone, fossil fuel generator where obtained which allowed for comparison between the cost of retrofitting and cost of the status quo (baseline) of the building. This necessitated the establishment of the cost benefit analysis of PV-integrated building retrofit in terms of the Return on Investment ROI and the payback period.

The final analysis in this step utilised findings in Chapter 4 to establish how rooftop solar PV could be integrated into the DAOB using the appropriate business model. This involved five stages which are: establishing the quantities of surplus electricity generated from the rooftop solar PV system that could be exported to the grid, establishing the cost of installing the rooftop solar PV system in the building, identifying the appropriate framework for the business model. The annual electricity consumption patterns of the building was established via simulation as explained in section 4.8.1 Capital costs of installing rooftop solar PV in the DAOB were derived using secondary data.

3.2.4 Required data and procedure for step 4

The next procedure was to identify an appropriate enabling mechanism and business model for an existing office/commercial building retrofit as well as solar PV integration, followed by identifying an appropriate regulatory/policy frame work as well as existing case studies/ precedents within South Africa. Once the framework was established, key roles of the parties in the framework were also established including identification of the potential sources of innovative green finance for funding the project and the prevailing PV-based DG business model practices under entities such as ESCos. Appraisal of the prevailing business models provides for a recommendation for a scale-up of related interventions for commercial buildings in Nigeria. Two scenarios were analysed in this framework to establish an appropriate business model to use in the study. The appropriate scenarios were selected based on desirability using the net present value as a measure. NPV in this case was calculated by using a social discount rate deemed to be more appropriate for the project.

3.2.5 Required data and procedure for step 5

Once the business model was established, the final analysis was carried out to derive the key findings of the study. The analysis involved determining the extent to which savings made from optimising existing office building for energy efficiency and using electricity generated from the solar PV system could enhance energy security in the DAOB.

Results in this study were reviewed and interpreted within the context of previously published work to obtain general feel of how an existing office/commercial building optimisation and integrating rooftop solar pv in office/commercial building in Nigeria can contribute towards improving Nigeria's electricity generation capacity goals, Africa's GHG- emissions reduction, and climate change mitigation.

3.5 Ethical considerations

To ensure ethical considerations of the study, the proposed research was guided by the ethical standards of The University of the Witwatersrand. The researcher obtained formal permission from the Head of Department (HOD), Department of Architecture, Kogi state Polytechnic, Lokoja, prior to the commencement of field work to get access to the premises to conduct the research. The researcher also requested for information about electricity usage patterns in the form of monthly electricity bills for the DAOB from the Polytechnic's Works department.

Information on the operation pattern and occupancy of the building were gotten through a semi-structure interview with the H.O.D In this regard, participation information sheets with sufficient details about the purpose of the research were issued to the participants interviewed. All participants were informed of their rights to withdraw from the research at any time, and that they would not receive compensation for participation (Mouton & Babbie, 2001:523). The study ensured that no physical, psychological or social harm was caused to participants and everyone present in the study area during the investigation (Kimmel, 2007).

The contextual identity of the case study area was necessary to maintain valuable information about solar PV generation potential and location. In this regard however, no confidentiality concerns were raised by the department about using the actual name of the office in this study.

Chapter 4

Potential of roof top solar electricity generation in the Department of Architecture Office Building (DAOB)

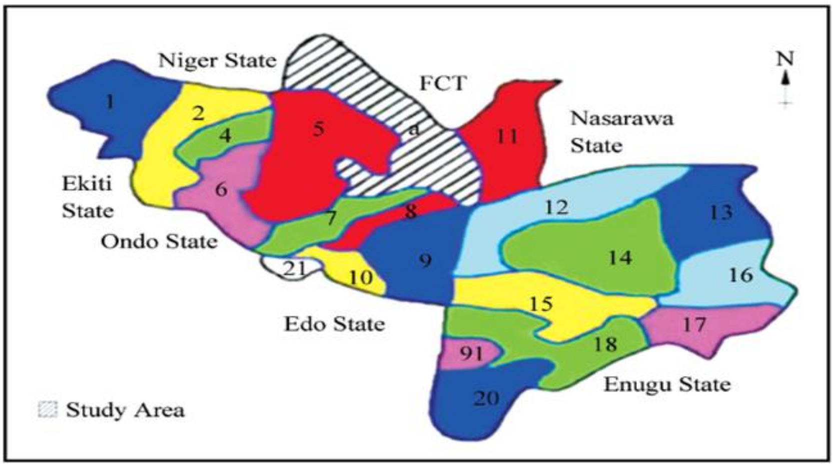
4.1 Introduction

The following chapter presents analysis carried out to derive preliminary findings of this study. The chapter is divided into three main sections. A description of the study area is presented in the opening section of the chapter followed by the analysis of DAOB. The next section contains analysis on modelling and simulation carried out to determine the status-quo baseline energy consumption of the building. The last section outlines methods followed to determine rooftop solar PV generation potential using the available rooftop area in the case study area.

4.2 Brief overview of Lokoja

The case study building is located in Lokoja town, Kogi state of Nigeria. Kogi state was created on august 27, 1991 with 21 Local Government Areas (LGA), and Lokoja as the state's administrative headquarter. The state was created along with eight others (Alabi, 2012; Kolabaje and Mustapha, 2012). It's about 165 km Southwest of Abuja, and 390 km Northeast of Lagos by same measure. Residential districts are of varying density, and the city has various suburbs such as Adankolo, Felele, Ganaja and Otokiti (Alabi, 2012).

Figure 5: Map of Kogi State showing Lokoja (in hatch) and all the other Local Government Areas. Source: (Kogi State Ministry of Land and Environmental, 2008).



4.3 Lokoja's climate description.

Lokoja is located between latitude 7° 45' N, 7° 51'N of the equator and longitude 6° 41' E 6° 45'E of the Greenwich Meridian. It is bounded in the west by the River Niger at an altitude of 45-125metres above sea level. It is also surrounded by pockets of hills of which the highest in the Patti ridge. The flat area is generally undulating at an altitude of 107metres below sea level.

The study area is categorized to be within the guinea savannah belt, even though what we really have now is derived savannah, only resistant vegetation still remains dominant due to anthropogenic activities of bush clearing and burning, lumbering, and most areas consist of secondary regrowth. The climate is characterized by wet and dry season. The rain begins in May and ends in October. With a maximum temperature of 37.9 0C, maximum temperature between December and April, average annual rainfall of about 1000mm and a relative humidity at 60% (Alabi, 2012; Kolabaje and Mustapha, 2012).

Table 5: Climatic data for Lokoja. Source: (Lokoja meteorological station).

Month	Temperature (° C)	Average rainfall (mm)	Average humidity
January	26.34	22.5	51.4
February	29.48	67.3	49.2
March	27.93	101.2	52.8
April	30.03	1186.7	57.6
May	28.19	1672.2	63
June	27.74	1475.4	66
July	26.89	2329.9	67.4
August	26.51	2076.8	68
September	27.04	2049.4	67.9
October	27.88	14.01	59.4

November	27.62	22.1	48.5
December	28.55	0	53.1

According to Alabi (2012), the rising heat emission and the impact of the increase built-up area on the heat budget and the emission of greenhouse gases (GHG) is increasing while the physical geography of the area stands as a challenge because the area is sandwiched between the Patti ridge (popularly known as Mount Patti) and the confluence of river Niger and Benue. These pose a tremendous impact on heat transfer and a dramatic effect on the micro climate (Alabi, 2012). This could be compared to the global trend elsewhere.

4.4 Description of case study building

The case study building (Department of Architecture Office Building) is located within the School of Environmental Technology, Kogi State Polytechnic Lokoja Campus, in Nigeria. The institution falls under Lokoja Local Government Area of the State, and is located along Lokoja/Abuja highway. The building is built on a relatively flat terrain, with flowers and shrubs around the building. The site of the building experiences moderate breezes. The building is a one storey building. The ground floor is made of 4 offices and 2 class rooms/drawing studios. The upper floor is an exact replica of the ground floor, also consisting of 4 offices and 2 class rooms/drawing studios. In total, the building is made up of 8 offices and 4 class rooms/drawing studios. All the offices and the class rooms/studios are cross ventilated.

The building's site measured approximately 270,000m^2 while the net area of the building is 1014.29m^2. The area of each office in the building is 16.8m^2 whereas the classrooms/studios in the building measured 103m^2 in area each.

Each office in the building is occupied by three lecturers, making a total of 24 lecturers occupying the 8 offices, while each of the class rooms/studios in the building is currently occupied by 30 students, making a total of 120 students occupying the 4 class rooms/ studios. In total, the building is occupied by 144 people consisting of students and lecturers.

To the North of the building is the Department of Urban and Regional Planning Office Building, it is a prototype of DAOB and is located approximately 300 meters across from the building (DAOB). The space between the two buildings is used as parking space. To the

Eastern side of the building is the School of Environmental Carpentry Work shop, which is a bungalow building and is located about 15 meters away from DAOB. The Southern side of DAOB is a large field that is occasionally used for convocation and other related activities by the Polytechnic. The Western side of the building is an uninterrupted view towards the Department of Science and Laboratory Technology, as well as the main access road to the School of Environmental Technology and the case study building (DAOB).

The DAOB was selected as the case study because it falls within the researcher's reach and is situated in hot climate region of Nigeria. Due to time and financial constraints, it was deemed suitable for the researcher to find a case study that is easily accessible. Another aspect that influence the purposeful selection of the case study is that it represents other similar office building within the case study area. Below is Figure 11 showing the aerial view of the SET marked in green colour and DAOB marked in red.

Figure 6: Aerial view of the case study building (DAOB). (Source: Adopted from Google Earth, 2015).

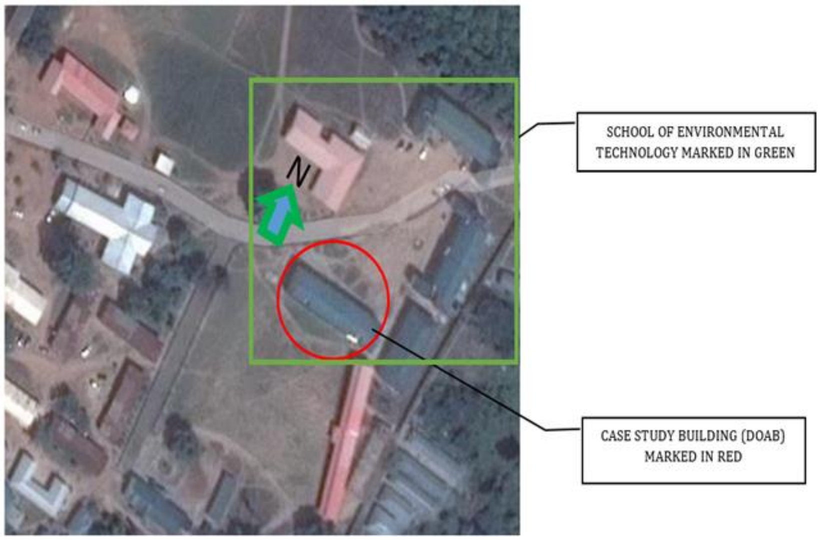


Table 6 below gives a summary of the case study building information

Table 6: General Building description

Owner	Kogi State Polytechnic, Lokoja
Climatic zone	Tropical hinterland
Site area	270,000m^2
Net floor area	1014.29m^2
Roof area	505.75m^2
Year of construction	2010
Year of major renovations	No renovations as yet
Building occupants	144
Building envelope	225 mm hollow block walls, with 15mm interior and exterior plaster.
Windows Material	6mm clear single glazing sliding window with aluminum frame.
Roof covering	0.55mm gauge long span roofing sheet, which slopes at approximately 20 degrees.
Doors material	Steel

Building Orientation.

The case study building is oriented longitudinally along the north and south axis. It is rectangular in shape and has more windows on the south and north facades.

The superstructure elements

The main external walls of the building comprise of 225mm hollow block walls with roughly 15mm interior and exterior plaster. The internal hollow block walls is 150mm thick with roughly 15 mm cement and sand plaster on both sides.

Ceilings and Floors.

The floor finishes in the building are granite tiles all through (in the offices, stores, toilets, walkways and class room/studios). In addition, there is no underfloor heating. The ground floor has a concrete ceiling painted with white all through the building. The upper floor has an asbestos ceiling painted with white. Also, there is no insulation in the roof.

Windows and Doors

Both the northern and the southern facing windows have single pane 4mm thick clear glazing fixed on Aluminium (sliding) framing. Also, the western and the southern windows are glazed in a similar way. All the entrance doors to the offices, stores and washrooms are made of hard wood polished panelled doors while the entrance doors to the class rooms/studios are made of double leaf, double swing aluminium doors fixed to aluminium framing.

Roof

The roof covering materials is made of 0.55mm gauge long span roofing sheet, which slopes at approximately 10 degrees. The approximate roof area is about 505.75 square metres.

4.5 The building user analysis

The building is predominantly occupied by lecturers and students. This indicates that the activities revolve around sedentary activity. The analysis shows that the active period ranges from 8am till 4pm giving a total average of eight hours for lecturers. However, students mostly remain in their classes for the purpose of studying beyond this hour. In fact, the class rooms and studios are mostly occupied from 8a.m in the morning to 10 pm in the evening.

Furthermore, giving the nature of the polytechnic academic calendar, the class rooms/studios are only occupied when the institution is in session, this is usually from the 1st week of February to 4th week of May for first semester, and 1st week of August to the 4th week of November for second semester. This implies that the whole building (offices, studios and class rooms) is occupied for a total period of 8 months in a year, while the studios/class rooms are unoccupied for a period of 4 months in a year, the offices are occupied throughout the 12 months of the year except on weekends.

4.6 Energy consumption

DAOB falls under Abuja Electricity Distribution Company (AEDC) thus the electricity consumption of the building is charged under AEDC. AEDC has a franchise for distributing electricity in four states, comprising the Federal Capital Territory of Abuja, Niger State, Kogi

State and Nasarawa State. Below is an extracted table of the 4 hours daily electricity supply to the building from the national grid. It is important to mention here that the 4 hours electricity supply to the building is as a result of load shedding that has been for a period of over one year in the State.

According to a respondent at the Abuja Electricity Distribution Company, AEDC Lokoja, branch has explained that the rationing of power in Lokoja and other areas of its coverage was necessitated by low volume energy available for distribution. The manager and public relations officer of the AEDC, furthered his explanation by revealing that the AEDC is being allocated 11.5 per cent of total energy available daily for distribution to customers nationwide. This volume, which reaches 450 megawatts even at peak generation periods, is insufficient to meet the demands of the company's customers in the Federal Capital Territory (FCT), Kogi State, Nasarawa State and Niger State. The AEDC is, however, optimising its load-shedding to address part of the problem in the short term. In the medium to long terms, the company is confident that the government's transformation plans would lead to actively increased levels of generation to meet the needs of electricity customers nationwide.

It is evident from the respondent above that, the issue of load shedding in the township of Lokoja is beyond the management of AEDC, and to the question of when or for how long this situation will continue, remain unknown to the management of AEDC or their customers. Table B1 in appendix B presents the daily interruption report for the case study area as extracted from the AEDC area office in Lokoja.

Table 7: Monthly electricity consumption pattern. Source: (Department of Works, Kogi State Polytechnic, Lokoja).

S/N	MONTHS	kWh	AMOUNT (₦)
1	JULY (2015)	773	18,534
2	AUGUST (2015)	1196	28,684
3	SEPTEMBER (2015)	1188	28,520
4	OCTOBER (2015)	1194	28,635
5	NOVEMBER (2015)	1199	28,778
6	DECEMBER (2015)	702	16,827

7	JANUARY (2016)	699	16,779
8	FEBRUARY (2016)	1198	28,759
9	MARCH 2016)	1185	28,445
10	APRIL (2016)	1196	28,712
11	MAY (2016)	1199	28,787
12	JUNE (2016)	679	16,304
TOTAL		**12,408**	**297,764**

The total annual electricity usage from the grid between July 2015 to June 2016 sum up to **12,408 kWh**, while the total cost in naira is estimated at **₦297,764**. The sharp differences and variations recorded in the months of July 2015, December 2015, January 2016, and June 2016 is as a result of the polytechnic calendar. Students are usually on break during these period, hence, less energy is required to run the offices occupied by lecturers. To establish whether the energy consumed by the building is high or low, it is important to show the kWh/m^2/annum for the DAOB by dividing 12,408 by 1,014 to get 12.24 kWh/m^2/annum. This is extremely low when compared to what an average building consumes in Johannesburg (which is 200kWh/m^2/annum). The low energy consumption of the building is due to the 2 hours daily electricity usage as well as the absence of HVAC in the building.

To establish the actual amount of electricity required to operate the DAOB from the grid for 8 hours in a scenario where there are no power interruptions for a whole year, since the daily energy consumed by the building for 2 hours as well the related cost is known, we simply multiply that by 4 for 8 hours. 54,416 kWh was estimated for the building in a year at ₦1,191,056 ($3777). Dividing the kWh by the net floor area of the building (kWh/m^2/annum) gave 53.66kwh/m^2/annum, again this implies that the energy utilised by the building is low as a result of the absence of HVAC.

The figure below shows the monthly consumption pattern of the building in kWh for a period of one year.

Figure7: Monthly electricity consumption in kWh

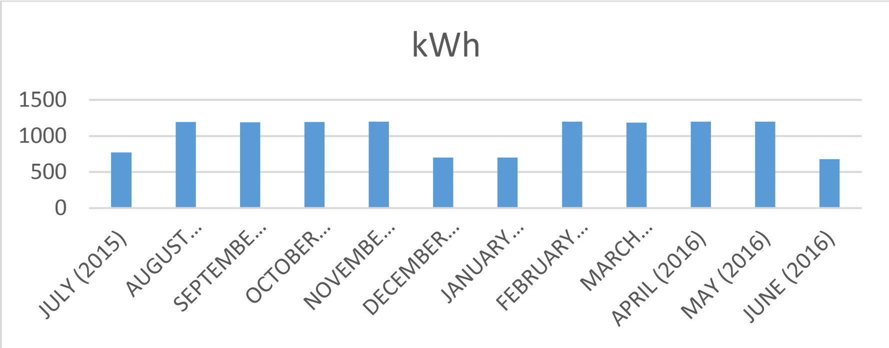
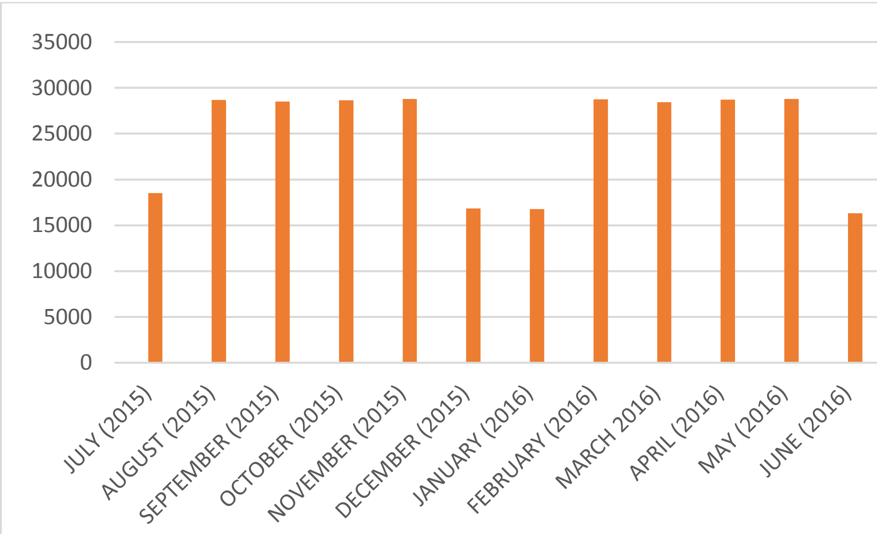


Figure 8: Cost of electricity consumption in Naira



4.7 Generator Analysis

Information gathered from the field revealed that the four hours electricity supply from the national grid is usually from 6am in the morning to 10am, and since office activities begins at 8am within the DAOB, this implies that the grid supply could only be useful for a period of two hours in a day (from 8am to 10am). To mitigate this power outage, the building is provided with an 80 KVA (Kilo Volts Ampere) diesel generator to run its day to day activities. As soon as the power from electricity company (AEDC) goes off by 10 am, the generator is then engaged to power the building from 10 am to 4 pm. Furthermore, the generator is engaged from Monday to Friday between the hours of 10am to 4pm, and 8pm to 11pm respectively to enable the students follow-up on their school work; also, the generator is in operation from 8pm to 11pm on Saturdays and Sundays for the same purpose.

Further information from the technician in charge of the generator revealed that the generator is alternatively used to power the concrete workshop as well as the carpentry workshop located about 20 -30m to the eastern side of the building for a period of 4hours weekly. Having given the capacity of the equipment in these workshops, it is assumed that the generator is working at 100% load at this point, and 50% when it is running the DAOB alone. At 100% load, the generator is still capable of 1 hour overload, this implies that at 100% load, additional load could still be added for 1 hour.

Based on the information gathered from the Polytechnic's works department, it is important to note at this point that the cost of powering DAOB using this generator depends on a number of factors. First is the initial cost of purchase, second is the cost of maintenance, third, is the cost of diesel which is not fixed in Nigeria, it depends on what is obtainable at the international market. Also, because of the durability of diesel engines, most maintenance is preventive in nature such as general inspection, lubricant services, cooling system service, fuel system service, servicing and testing starting batteries, and regular engine exercise.

Information on cost showed that the initial cost of purchase as at 2013 was ₦3, 123,360 (three million, one hundred and twenty three thousand, three hundred and sixty naira only) which according to the dollar to naira exchange rate at the time of purchase was $20,822.4 USD (in dollars at 2013). The generating set is mounted approximately 150 meters away from the eastern side of the building to prevent noise or fume pollution.

The following assumptions were adopted for the analysis:

a) The diesel generator was assumed to operate under ideal optimum conditions without breakdowns due to sabotage throughout its normal working life.
b) Maintenance is effective enough to minimize the effects of depreciation.

In addition to the ₦3,123,360 ($20,822.4) initial cost of purchase, the following is a breakdown cost of operating and maintaining the generating set monthly. Note that diesel price is estimated at an average of ₦165 ($1.9) per liter, which is the current price at the time the field work was carried out.

Table 8: Operation and maintenance of diesel generator.

S/N	DESCRIPTION	QUANTITY	RATE (₦)	COST (₦)	COST ($)
1	Fuelling (Diesel)	900 litres per month	160	144,000	456.6
2	Routine services	Once a month	25,000	25,000	79.27
3	Fuel filter	2	15,000	30,000	95.12
4	Oil filter	1	10,000	10,000	31.70
5	Water separator	1	15,000	15,000	47.56
6	TOTAL			**₦224,000**	710.27

4.8 Operating cost for energy consumption

The monthly cost of running and maintaining the generator is estimated at **₦224,000 ($710.3).** Therefore to arrive at the annual cost of running DAOB on diesel generator, we simply multiply 224,000.00 by 12 months which gives **₦2,688,000 ($ 8,524)/annual.** However, this figure may not be exactly accurate for two reasons, firstly, considering the period on weekends (Saturdays and Sundays) when the plant is only in operation for 4 hours, and secondly, given the period of 4months when the students are usually on holidays, nevertheless, for the purpose of this research, the amount (**₦2,688,000/annual)** was adopted.

To know the status-quo cost of operating the building, cost obtained from electricity bills from AEDC for a period of one year **(₦297,762.24)** was added to the cost of operating the building on diesel generator for one year (**₦2,688,000**) to arrive at **₦2,985,762 ($9,467)** as shown in the table below.

Table 9: Electricity sources and cost for the DAOB.

S/N	Source of electricity to the DAOB	Cost/year (₦)	Cost/year USD ($)
1	Electricity from the grid (AEDC)	297,762	944.16
2	Electricity from stand-alone diesel generator.	2,688,000	8,523.32
	Total cost of electricity in a year	**2,985,762**	**9,467.5**

It was important to model the building in a software called design builder and factor in a real life operation simulation of the building bearing in mind the occupancy, operation pattern, appliance, equipment, lighting and fittings available in the building.

4.9 Appliances, equipment, lighting and fittings in the DAOB.

Examples of appliances used in the building include printer, mini-fridge, coloured television, photocopier, and laptop. Furthermore, ceiling fans, desk- top computers, and lighting are part of the consumers of electricity in the building.

Table 10: Lighting, equipment and appliance in the 8 office only.

S/N	**Description**	**Quantity**	**Power (W)**	**Operating hour/day**
1	**External light**	**10**	**80**	**12**
2	**Veranda light**	**24**	**40**	**12**
3	**Office light**	**16**	**40**	**8**
4	**office laptops**	**24**	**74**	**5**
4	**Desktop**	**4**	**450**	**8**

5	**Ceiling fan**	**8**	**75**	**8**
6	**Fridge**	**2**	**400**	**8**
8	**Coloured TV**	**2**	**150**	**8**
9	**Photocopy Machine**	**1**	**250**	**3**
10	**Scanner**	**2**	**20**	**3**
11	**Printer**	**2**	**100**	**3**
12	**Toilet & Store light**	**24**	**60**	**9**

Table 11: Lighting, equipment and appliance in the 4 studios only.

S/N	**Description**	**Quantity**	**Power (W)**	**Operating hours**
1	**Studio Lights**	**48**	**40**	**15**
2	**Ceiling fan**	**36**	**75**	**15**
3	**Lap top**	**40**	**74**	**8**

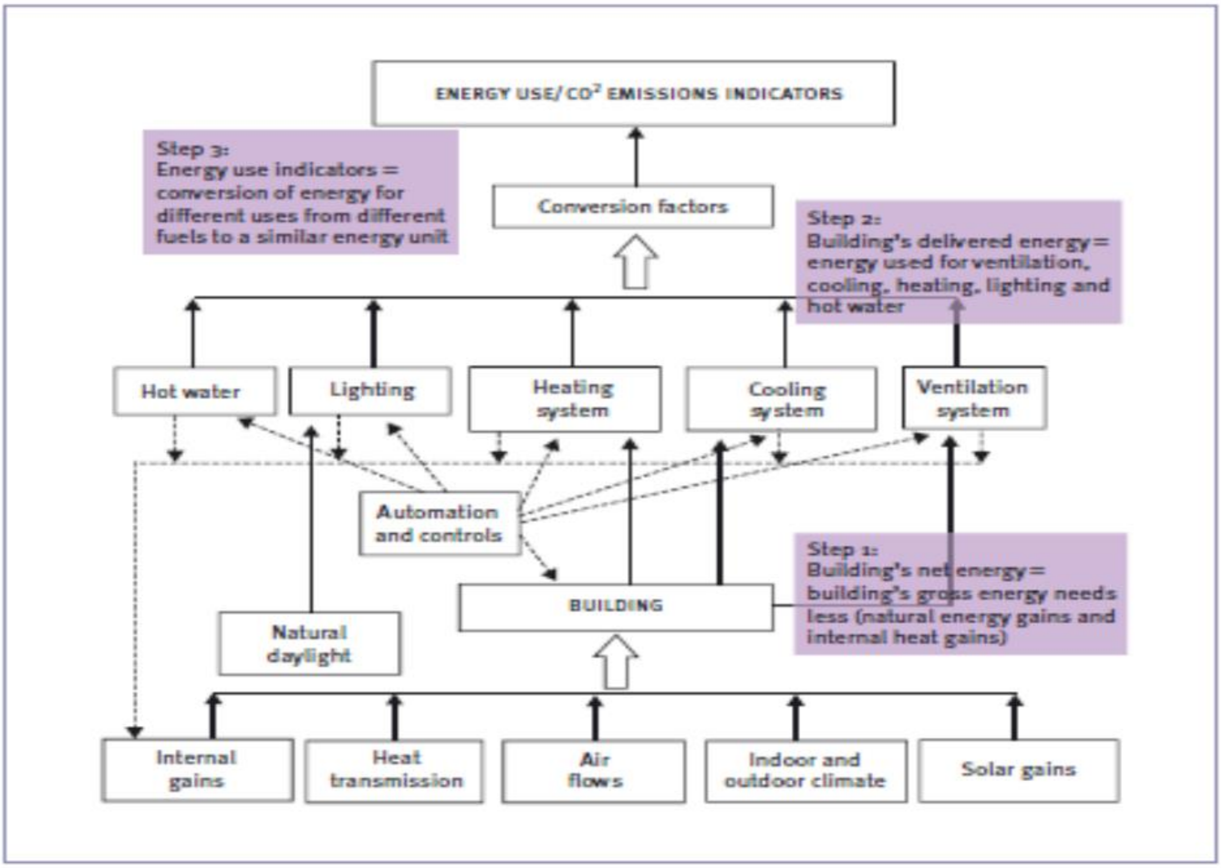
The table above show a description of various appliances, equipment, and lighting in the case study building. From the analysis above, it is evident which products have the greatest energy consumption per day. The top consumers are, in order of most to least, studio ceiling fans, and studio lights. This is because the studios and class rooms are always occupied 24 hours per day and 30 days per month by the students. Fridge, and studio laptop are next in that order. By identifying the highest energy consumers, the causes for the high consumption can be investigated and possible solutions can be formulated in order to reduce the overall consumption and associated costs.

4.8 Simulated baseline energy consumption

4.8.1 Prelude to determining energy baseline consumption

The energy performance of a building is based on the building information which is a factor of intrinsic energy performance which is the delivered energy needed to run the building equipment or appliances and regulate the indoor environment (Hootman 2013). For the case study building, the building energy performance was based on the energy used over a period of one year, obtained from energy audits, electricity bills and the cost of operating the case study building on diesel generator for a period of one year. In the general perspective, the amount of energy a building will need to attain the required indoor climate depends on the properties of the building i.e. how efficiently the delivered energy is used to meet the buildings net energy demand, how efficiently energy is used by the occupants in the building and the percentage of the building's energy requirement that is supplied by renewable energy (Hootman, 2013). The calculation of energy use in a building is based on the characteristics of the building and its installed equipment. It is structured in three stages as illustrated in figure 9 below and the calculation is performed from the bottom up (Hootman, 2013).

Figure 9: Calculation process of energy use indicators for buildings (Sustainable Energy Regulation and Policy making Training Manual, undated: 19.12).



Step one: Building's net energy

This is the calculation of the building's net energy requirements (amount of energy required to provide indoor climate requirements as specified by the building code). The calculation is used to determine the net energy required based on the outdoor climate and indoor climate requirements without neglecting the contributions from internal gains, solar gains, natural lighting and losses due to building properties, for example, heat transmission and airflows (air infiltration and exfiltration). As a result an intrinsic energy performance of the building is obtained.

Step two: Building's delivered energy

At this stage, there is the determination of the building's delivered energy (energy performance of the building in actual use). This includes the amount of energy used for heating, cooling, hot water, lighting, ventilation systems, inclusive of controls and building automation, among many others used. Furthermore, the energy used for different purposes and by different fuels is recorded as well.

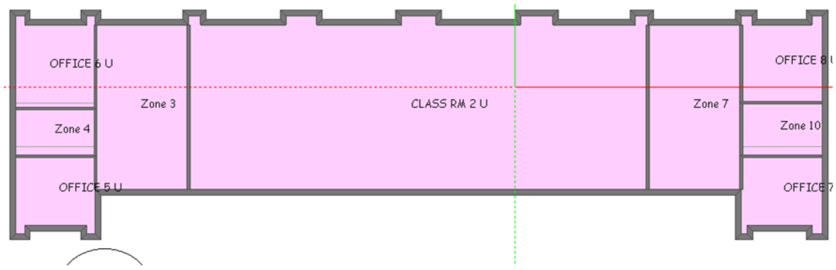
Step three: Energy use indicator

This stage combines the results from Step two for different purposes and from different fuels to obtain the overall energy use and associated performance indicators. A building might use more than one fuel (gas/electricity). Hence, different energy sources should be converted and combined in terms of primary energy in order to provide the optional end result of the calculation of energy performance. The most commonly used energy indicators for buildings are kWh/m_2 that is energy consumption in kilowatt hours per metre square of floor area or CO_2 emissions. To add on, energy performance calculations can also be started at the design stage for new buildings and refurbished buildings to simulate their energy performance. In most instances, software has been developed to aid these calculations.

Prior to the actual simulation of the DAOB, it was imperative to collect modelling input data, which involved gathering information needed for characterizing the building from construction documents (architectural and engineering drawings), narratives (user analysis) and survey data. Next was to perform input data calculations. This required data collected from various sources to be converted to a form used by the simulation program, Table B4, B5, and B6 in Appendix B is an input data calculation for the DAOB carried out based on the building load calculation procedure and mechanical system basics.

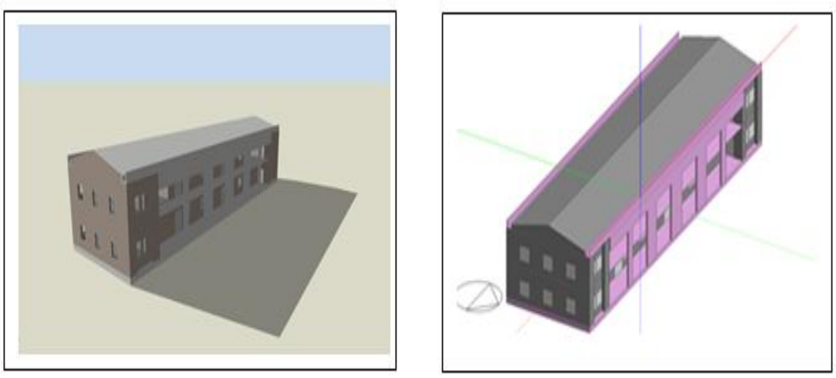
The next stage was the development of the DAOB geometry and zoning. This was done by first importing AutoCAD files containing the DAOB architectural drawings and manipulation as needed to incorporate into modelling software, then developed zoning based on thermal block concept. At this stage, it is advised that the zones of similar activities should be grouped together as one for easy simulation. Hence, the two classrooms on the ground floor has been zoned together as ‘CLASS RM1’, while the two classrooms on the upper floor have also been grouped together as ‘CLASS RM 2U’. (See figure below).

Figure 10: Model of typical ground and upper floor



A finished model of the DAOB is shown below, figure 4 shows the model in a rendered view as well finished model in edit view.

Figure 11: Finished model in rendered and edit view



Thereafter, the building input file was created using software wizard. This was done by using the modelling software graphical user interface to complete the basic building model based on the imported building design, project input data and the software default values. Furthermore, this previous stage was carried out bearing in mind the building envelope, lighting, and electrical system.

The software follows a 'model data hierarchy' in the following manner; site level, building level, block level, zone level, surface level and opening level respectively. Design Builder further uses 'data inheritance' through categories allowing you to automatically populate subcategories. This way information is passed automatically from higher category levels to lower category level making data input faster and more reliable. Default data is inherited from the level above in the hierarchy. So block data is inherited from building level, zone data is inherited from block data and surface data from zone data. When you change a setting for a category, this change is 'inherited' by all lower levels within the category. This arrangement allows you to either make settings at the building or block level. A selection for a wall type at the building level will affect all walls within the building whereas a selection at the block level will only affect the walls within that particular block.

Furthermore, Construction and window-to-wall-ratios default values are inherited down to the surface level where the data is actually used in the calculations. For example, it is the external wall construction model data at the surface level that defines the construction used for that external wall. The external wall model data set at zone, block and building level has no effect on model(other than providing a default values for lower lying levels), Most data at the building level is "user data" as buildings do not inherit their data from the site level. All openings inherit their data from the surface level.

From the data gathered on the DAOB, the Light Power Density (LPD) in watt/m^2, occupancy (person/m^2), computer and equipment in watt/m^2 for all the spaces were evaluated and fed into the software for simulation. The LPD was estimated at 5.68 W/m^2 at the building level, 4.9W/m^2 at the floor level, 4.7W/m^2 at the offices level, and 4.6W/m^2 at the classroom level. Table B4 in Appendix B shows a detailed calculation of the LPD.

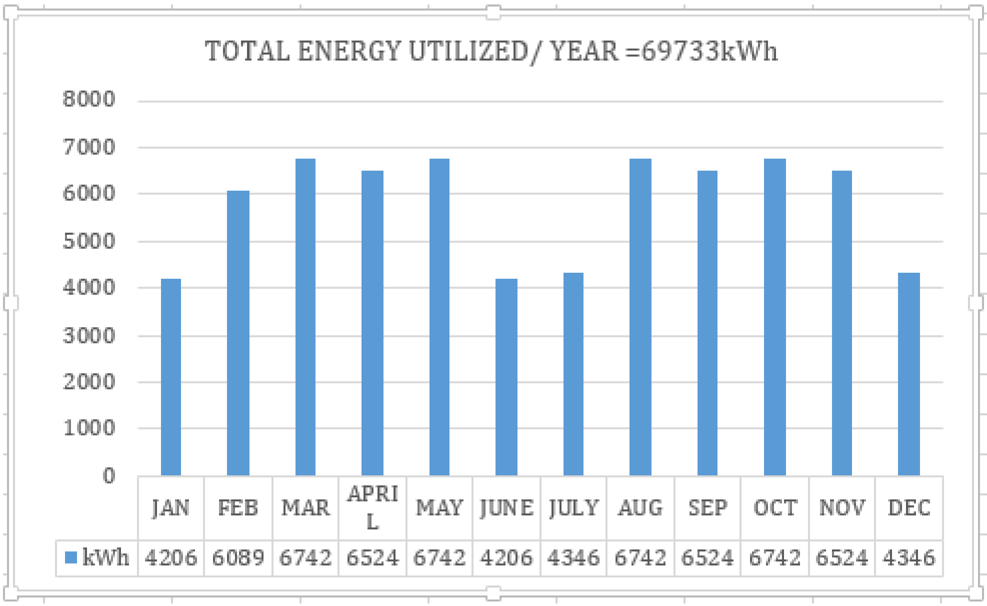
Computers was calculated at 5.56W/m^2 at building and floor levels, 40W/m^2 at offices 1,2,7 and 8, while it was estimated at 13.2W/m^2 at offices 3,4,5,6. It was valued further at 7.18W/m^2 at classrooms level. Equipment was calculated at 4.8W/m^2 at building level, 5.4W/m^2 at floor level, 45.5W/m^2 at offices 1,2,7,8 level, 4.5W/m^2 at offices 3,4,5,6, level and 6.5W/m^2 at the classroom level. Finally, occupancy was 0.142 at building, and floor levels, 0.17 at office level and 0.29 at the classroom level. See Appendix B, Table B4 to B6 for detailed calculation presented in table.

Series of simulations were done based on the procedure outlined above. The sequence of simulations were done following the building (DAOB) operation pattern. The first simulation was to determine the total annual baseline consumption of the DAOB, however, given the operation pattern of DAOB explained in section 4.5, different simulations were required for different occupancy period for the offices and classrooms.

The result (graph) of the first simulation for the period of 4 months (February to May), which is the period the polytechnic commences and ends first semester in the Appendix C. This implies the whole building is in operation throughout this period. For the purpose of this study, the schedule for the modelled building has adopted the actual schedule of the case study building (DAOB), which put the operating hours of the offices at 8 hours daily (8am to 4pm) excluding weekends, and the operating hours of the studios at 15 hours daily including weekends.

A further simulation was done for a period of 2 months (June and July) the students are usually on break. Only the offices are in operation within these periods and the daily occupied period of the offices is 8 hours (8am to 4pm) excluding weekends. To do this, design builder software gives an option to exclude or switch-off zones that are not occupied (CLASS RM 1 and CLASS RM 2U) from the ‘’include zone’’ option box. The results are presented in the appendix/figure. Next was to simulate for another 4 months (August to November) which is a period of second semester and hence, similar in operation to first semester. The last simulation was for the months of December and January and it excluded the classroom zones. All simulation graphs for the baseline consumption of the DAOB are presented in the appendix 14 to 20, however, the graph below was generated to present the overall annual energy consumption of the building.

Figure 12: Annual energy consumption of the DAOB based on simulation



A further analysis from the outcome of the simulation revealed that the room electricity which is a combination of all the plug loads, are the highest contributor to the energy consumed in the building followed by lighting. Furthermore, the result of the simulation revealed that the internal gains within the building are from solar gains through the exterior windows, computers, general lighting and occupancy respectively from highest to the lowest contributor. The highest internal gain from solar is coming through the south/east façades. The corresponding carbon produced over the period of 12 months as a result of the utilised energy was 42,044 kg.

By simulating for a real life operation pattern of the building using design builder software, the expected electricity consumption of the building in a year was 69,733 kWh/annum (68kWh/m^2/annum) at ₦1,673,592 (one million, six hundred and seventy three thousand, five hundred and ninety two naira) at ₦24/kW tariff rate (twenty four naira per kilowatt) the current electricity charge by the AEDC as shown below;

Table 12: Simulated baseline electricity and cost for a year.

Description	unit	Quantity	Rate (₦)	Rate ($)	Amount (₦)	Amount ($)
Annual baseline consumption	kWh	69,733	24	0.08	1,673,592	5,579

A comparison was made between the actual status-quo consumption and the simulated baseline consumption as shown in the table below;

Table 13: Comparison between the status-quo and the annual baseline simulation.

Description	Unit	Quantity	Rate (₦)	Rate ($)	Amount (₦)	Amount ($)
Electricity from the grid (AEDC) based on two hours electricity supply	kWh	12,407	24	0.08	297,762	944.16
Electricity from the grid (AEDC) assuming a scenario of 8 hours electricity supply	kWh	49,628	24	0.08	1,191,048	3,777
Electricity from stand-alone diesel generator	kWh	N/A	N/A	N/A	2,688,000	8,523
Annual baseline from simulation	kWh	69,733	24	0.08	1,673,592	5,579

From the table above, we assumed an 8 hours electricity supply from the grid based on data gathered for the 2 hours daily electricity supply to the building, this assumption put the assumed annual electricity supply for 8 hours and its cost at 49,628kWh, and ₦1,191,048 ($3,777) respectively, while the outcome of the simulation shows the annual electricity consumed by the building and the related cost to be 69,733kWh and ₦1,673,592 ($5,579) respectively. The 20,105kWh difference in electricity utilized is due to the extra 7 hours that the studio is in operation at night. A further analysis from the table shows that the total cost of operating the building in status-quo is (₦297,762+₦2,688,000) =₦2,985,762 ($9,467), this exclude the initial cost of purchasing the stand-alone diesel generator, while the outcome of the simulation put the annual running cost at ₦1,673,592 ($5,579) this implies that, an extra cost of ₦1,312,170 ($4,161) was incurred annually for operating the building on a stand-alone diesel generator excluding the initial cost of purchasing the generator set.

To answer the research question ‘’what is the current energy baseline consumption patterns and levels as well as related cost for the DAOB?’’ the response was based on two scenarios, the first scenario was based on the outcome of the simulation, which put the annual baseline consumption of the DAOB at 69,733 kWh with a corresponding cost of ₦1,673,592 ($5,579) while the second scenario considers both the cost of electricity from the grid and the cost of operating the building on diesel generator. Annual kWh from electricity bills is 12,407kWh at ₦297,762. Although the annual kWh from diesel generator is unknown due to lack of available data, however, the cost of operating DAOB from diesel generator is ₦2,688,000, based on this, the status-quo cost is (₦297,762+₦2,688,000) =₦2,985,762 ($9,467).

4.9 Intervention to optimize for electricity consumption

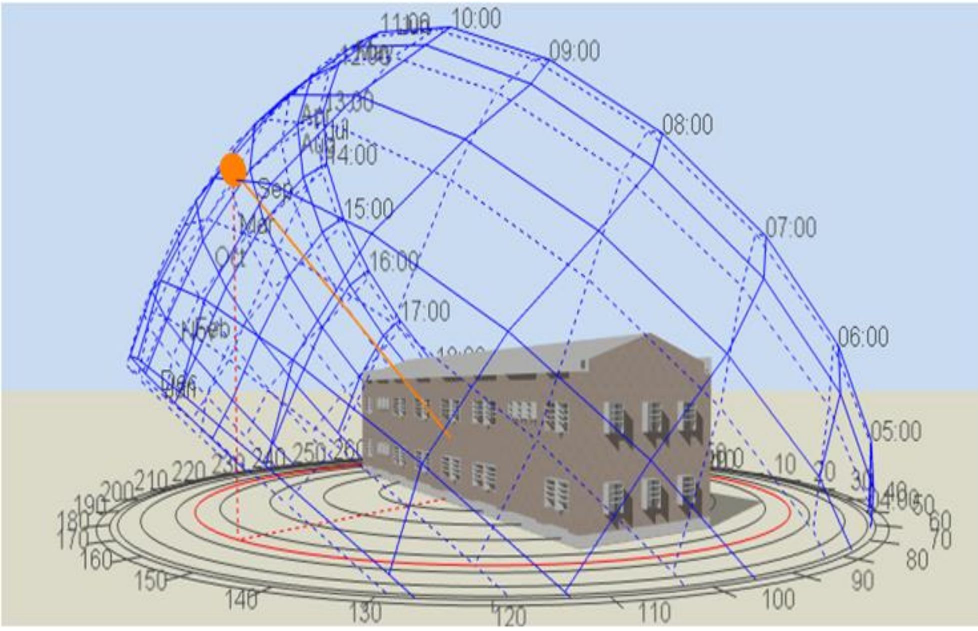
The analysis above presented quite a number of opportunities to optimize the DAOB for reduction in annual energy consumption of the building in form of passive and active interventions. Even though the design builder software is capable of optimising a building automatically to reduce energy consumption as well as size the required on site source of electricity generation like PV to suite the demand, however, the student version employed in this study is not licensed to perform this operations. A passive intervention maximises the use of natural sources of heating, cooling and ventilation to create a comfortable conditions inside the building. It harness environmental conditions such as solar radiation, natural ventilation, cool night air and air pressure differences to drive the internal environment. Passive measures do not involve mechanical or electrical systems.

As opposed to 'active' design which makes use of active building services systems to create comfortable conditions, such as boilers and chillers, mechanical ventilation, electric lighting and so on. Buildings will generally include both active and passive measures. Optimization for a reduced energy consumption as well as internal comfort was provided for in the building by prioritising for the following;

(a) One passive control intervention which is;

  (a) Provision of shading on the south/east external windows to reduce internal gains through solar radiation. (See figure below).

Figure 13: Showing shading on the external windows (south/east facade) of the DAOB.



(b) Three active control interventions which are;

  (a) Day lighting sensor and switching devices. This was achieved by placing daylight diming control in offices and classrooms where the amount of daylight entering the space controls the dimming ability of the lighting appliance.

  (b) Occupancy sensors. This was realised by installing sensors that turn lights on and off based on whether the monitored area is occupied or not. The device was placed in the following areas; offices, classrooms, washrooms and stores.

  (c) Increase the efficiency of appliances. This was done by replacing equipment and appliances to a more energy efficient type; photocopy machine, toilets and store lights, external light, office desktop appliances, external lights and printer. Energy star rated (6.0) appliances and equipment that consumes less energy are used so that the energy will be consumed at a rate that minimizes its usage (See table below).

Table 14: Equipment, Light and Computer (W/m^2)

S/N	Equipment/appliance/light	zone	Qty	Initial wattage	Proposed energy star rated wattage
1	Desktop	offices	4	450	130
2	Fridge	office	2	400	220
3	Printer	offices	2	100	35
4	Toilet & store light	Toilet & store	24	60	17
5	External light	External	10	80	40

The table above implies that by changing to a more efficient equipment, the total energy used by the equipment has been reduced from 4890 W to 4200 W

Table 15: Equipment (W/m^2)

Zones/ spaces	Total floor area (m^2)	Old total wattage (w) Rate x no	New total wattage (w) Rate x no	Old Equipment out put W/m^2	New equipment Out put W/m^2
Whole building level	1014.29	4890	4200	4.8	4.1

Table 16: Light Power Density (W/m^2)

Zones/ spaces	Total floor area (m^2)	Old total wattage (w) Rate x no	New total wattage (w) Rate x no	Old Light power density (LPD) W/m^2	New Light power density (LPD) W/m^2
Whole building level	1014.29	5760	4328	5.68	4.2

Table 17: Computer (W/m^2)

Zones/ spaces	Total floor area (m^2)	Old total wattage (w) Rate x no	New total wattage (w) Rate x no	Old computer W/m^2	New computer W/m^2
Whole building level	1014.29	5636	4356	5.55	4.2

For each intervention listed above, a separate simulation was performed for passive and then active measures for a period of 4months (February to May) to check and determine the resultant effect of each on the overall energy consumption of the building, and then a simulation was done for a combination of all active interventions separately, and all passive interventions separately for the same period of 4 months. Lastly, a combination of all passive interventions and all active intervention was done for a period of one year to determine the total energy reduction, internal gain reduction and reduction in the CO2 produced for a period of one year. Results for all these simulations are presented below.

4.9.1 Passive Design Intervention

The provision of external shading device on the south/east façade of the building helped in reducing the energy consumption from 26,098 kWh to 21551 kWh for a period of 4 months (February to May). A significant savings of 4,574 kWh was made, which translate to17% reduction in energy consumption of the building. This reduction was due mainly to the reduction in solar gain through the exterior windows from 18,662 kWh to 14,718 kWh.

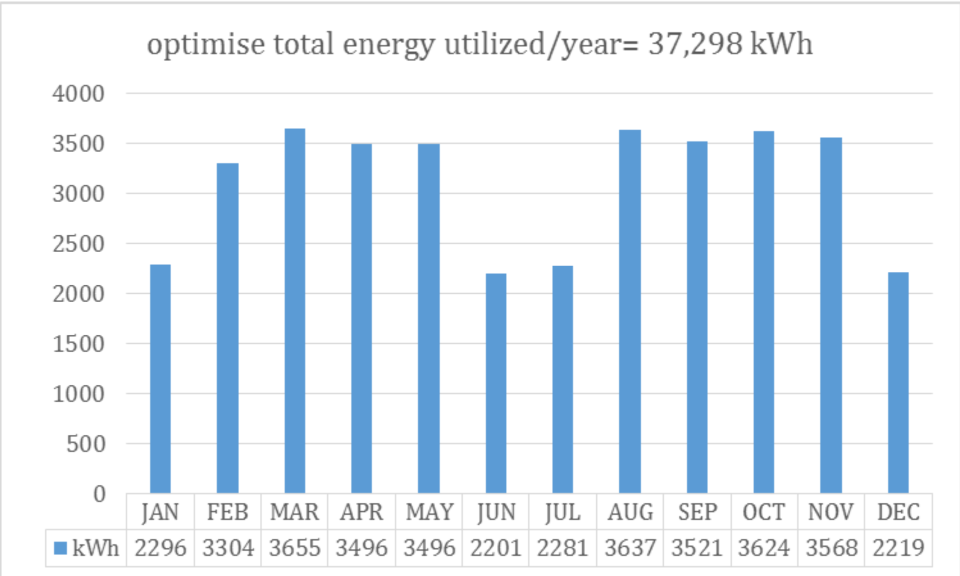
4.9.2 Active Design Interventions

Next was to simulate for the active interventions each and then combine all two interventions. The first active intervention was the installation of day lighting, and occupancy sensors in all the offices, classrooms, washrooms and store rooms. The outcome was a reduction in energy consumption from 26,098 kWh to 21,616 kWh, the 4,482 kWh savings made equal 17% reduction. The second simulation considered the effect of using a more energy efficient light, computers and equipment. The outcome of the simulation shows a reduction in energy utilised from 26,098 kWh to 21,098 kWh, the 5000 kWh saved is equivalent to 19% energy reduction. This reduction was due mainly to the reduction in general lighting and plug loads (computers and equipment) from 7,723 kWh to 4,408 kWh.

The next simulation performed combined the two proposed active interventions. The result shows a significant reduction in energy utilised by the building from 26,098 kWh to 16,884 kWh. The 9,214 kWh savings realised equals 35% reduction. The last simulation performed for testing these different initiatives combined the two proposed active interventions and one proposed passive intervention. The result shows a reduction in energy consumed from 26,098 kWh to 13,951 kWh which translate to 46% reduction or savings.

Since a 46% reduction in energy consumption is significant enough for the adoption of these initiatives, the next simulation combines all the initiatives for a one year period

Figure 14: Optimised total energy consumed in a year



4.9.3 Savings made through passive and active interventions.

Comparing the baseline energy consumption of the DAOB with the optimised energy consumption of the building, a significant saving was made by the passive and active interventions. From the annual baseline simulation, the total annual energy utilised by the DAOB was 69,733kWh, while the reduced energy through optimization was 37,298 kWh. This implies that a total savings of 32,453kWh was made, which translate to roughly 47% savings off the baseline consumption. Optimising the DAOB for a reduced energy consumption was accompanied by a significant reduction in the amount of carbon produced by the building as demonstrated in the table below.

Table 18: Comparison between annual baseline consumption and annual optimised energy consumption

Description	DAOB's status-quo based on simulation	Optimised DAOB based on simulation	Savings made through passive and active design intervention
Annual energy utilised	69,733 kWh	37,298 kWh	32,435 kWh
kWh/m^2/annum	69 kWh/m^2/annum	39 kWh/m^2/annum	32 kWh/m^2/annum
Cost (₦)	₦1,673,592	₦895,152	₦778,440
Cost ($)	$52,712	$2,835	$2,465
Annual CO_2	42,044 kg	22,488 kg	19,556 kg

Comparing the carbon produced annually as a result of the baseline energy utilized by the DAOB, a substantial reduction was made in the amount of carbon emission released after the improvements. To determine the savings made in terms of the overall electricity cost per year, firstly we established the cost of annual baseline consumption of the building by multiplying the annual baseline energy consumption of the DAOB by ₦24:00 (Twenty four naira) which is the current electricity tariff charged per kilowatt by the Abuja Electricity Distribution Company (AEDC). Next was to establish the cost of optimised energy in a year by multiplying the optimized energy by ₦24:00 (Twenty four naira). Then, subtracted cost of optimised energy for a year from the cost of annual baseline energy is summarised in the table above.

Based on the integrated savings performance of the interventions, the overall electricity cost savings per year is ₦778,440 ($2,465). To derive the Return On Investment and payback period for these initiatives, it was important to first establish the budget of retrofitting the building. The costs include the following;

- Cost of integrating shading devices in the external windows.

- Cost of integrating day lighting control sensors.
- Cost of integrating occupancy sensors and
- Cost of changing to more efficient.

The table shows an overall summary of the interventions and the relative cost implication of implementing each;

Table 19: Summary of the budget for interventions

Intervention type	Item description	Qty	Rate in Naira (₦)	Rate in dollar ($)	Cost (₦)	Cost ($)
Passive: provision of shading device	**1. shading device**					
	1.8m window	20	120,000	380.51	2,400,000	7,601
	1.2m window	5	100,000	317.09	500,000	1,584
	total				2,900,000	9184.
	labour 30%				870,000	2755.
	Total budget for shading				**3,770,000**	**11,939.**
Active: introduction of day lighting sensors	**2. Day lighting sensor**					
	Lighting sensor	24	7,500	23.78	180,000	571
	labour 30%				54,000	171
	Budget for lighting sensor				**234,000**	**742**
Active: Introduction of occupancy sensors	**3. Occupancy sensor**					
	Sensors	20	5000	15.85	100,000	317
	labour 30%				30,000	95
	Budget for lighting				**130,000**	**412**
Active: replacing equipment with more efficient types	**4. office equipment & lighting**					
	Acer B246 WL 25" LED LCD monitor	4	170000	539.05	680,000	2,156.
	Lexmark forms printer	2	194,834.99	617.80	389,669	1,236
	17 watts e26 bulb	20	2500	7.93	50,000	159
	watts e26 bulb	10	6000	19.03	60,000	190
	Budget for equipment & lighting				**1,179,669**	**3,736**
	Grand total budget for passive and active interventions				**4,949,669**	**15,676**

4.9.4 Financial analysis for energy efficiency intervention based on the proposed budget.

As discussed in chapter 2 of this report, the most simple and commonly used financial analysis method is the simple payback. Simple payback is defined as the time, in years, for a project's cumulative annual savings to equal its upfront cost. To calculate the simple payback for the energy efficiency retrofit on the DAOB based on the definition above, the following formula was adopted from Hootman (2013, 338);

SP=I/S.

Were;

I = budget for the initiative (investment)

S= cost of saved energy in a year

Therefore, the payback period for each initiative and their corresponding saving is presented in the table below;

Table 20: Different initiatives with their savings and payback.

S/N	Initiative	Energy saved	Cost of energy saved/year	Budget for the initiative	Payback period
1	Shading device	11,855kWh (17%)	₦284,520 ($901)	₦3,770,000 ($11,940)	13.2years
2	Occupancy and lighting sensors	11,856kWh (17%)	₦284,520 ($901)	₦364,000 ($1,153)	1.3years
3	Computers, equipment and lighting.	9,065kWh (13%)	₦217,560 ($690)	₦1,179,669 ($3,736)	5.4years
4	All the initiative combine	32,775kWh	₦786,600 ($2,491)	₦4,949,669 ($15,676)	6.3years

It is important to mention here that double glazing was one of the initiatives considered initially, however, comparing the saving made and the cost of installation to the other initiatives like those presented in table 19 above, double glazing intervention is not worthwhile.

Although, the payback period of 13 years and 2 months for the introduction of shading device as demonstrated in the table above is quite far, however, a payback period of 6 years and 3months when all the initiatives are combined as shown in the table is more realistic. Therefore, the simple payback (SP) = 6.3 Years

Return on investment for the energy efficiency

ROI = (1/SP) x100%

Where SP= 6.3 years

ROI= 15.9%

ROI of 16% means the investment gains compare favourably to investment cost which implies that the investment is good. Whereas simple payback does not take into account any benefits or costs that occur after the initial investment has been recouped. Net Present Value NPV offers a more rigorous analysis than simple payback by not only extending the analysis to include all cash flows over the useful life of the project, but also accounting for the time value of money. The project's cash flows include the first cost, energy cost savings (which may be assumed to increase with rising energy prices), and all other costs and benefits, such as O&M costs and any salvage value at the end of the analysis term. For this report, the following assumptions were made;

Assumed discount rate of 8% and assumed energy rise of 7% annually. The discount rate was applied using the equation for calculating present value. A table of present value factor for each year in the analysis period based on the net present equation was compiled; where S is 1, t is the year value (in this report, 1 through 25), and d is the discount rate (Hootman, 2013:338);

$PV=S_t/(1+d)^t$

Based on this assumption, a present value calculations for energy efficiency were made using excel based energy efficiency calculator. Table 26 below show the present value calculation in the form of spread sheets.

For a Net present value for energy efficiency, the following formula was adopted from Hootman (2013:342);

$NPV= PV-PV_o$

Where:

PV= ₦24,603,695-₦ 13,159747 =₦ 11,443,948 (sum of baseline energy cost in present value PV minus the sum of design energy cost in present value PV)

PV_O=4,949,669 (investment budget)

NPV = ₦11,443,948- ₦4,949,669

NPV=₦6,494,279 ($20,568)

Table 21: Present value calculation for interventions.

YEAR	PRESENT VALUE FACTOR (7%)	ELECRTIC ITY RATE (₦)	BASELINE ENERGY USE (kWh)	BASELINE ENERGY COST (₦)	BASELINE ENERGY COST (₦) PV	DESIGN ENERGY USE	DESIGN ENERGY COST(₦)	DESIGN ENERGY COST (₦) PV
1	0.9	24	69,733	1,673,592	1506232.8	37,298	895152	805636.8
2	0.81	25.68	69,733	1,790,743	1450502.186	37,298	957812.6	775828.2384
3	0.73	27.47	69,733	1,915,566	1398362.822	37,298	1024576	747940.5238
4	0.66	29.37	69,733	2,048,058	1351718.419	37,298	1095442	722991.8916
5	0.59	31.42	69,733	2,191,011	1292696.407	37,298	1171903	691422.8644
6	0.53	33.61	69,733	2,343,726	1242174.849	37,298	1253586	664400.4634
7	0.48	35.96	69,733	2,507,599	1203647.366	37,298	1341236	643793.3184
8	0.43	38.47	69,733	2,682,629	1153530.259	37,298	1434854	616987.2458
9	0.39	41.16	69,733	2,870,210	1119382.009	37,298	1535186	598722.4152
10	0.35	44.04	69,733	3,071,041	1074864.462	37,298	1642604	574911.372
11	0.31	47.12	69,733	3,285,819	1018603.878	37,298	1757482	544819.3456
12	0.28	50.41	69,733	3,515,241	984267.3484	37,298	1880192	526453.8104
13	0.25	53.93	69,733	3,760,701	940175.1725	37,298	2011481	502870.285
14	0.22	57.7	69,733	4,023,594	885190.702	37,298	2152095	473460.812
15	0.2	61.73	69,733	4,304,618	860923.618	37,298	2302406	460481.108
16	0.18	66.05	69,733	4,605,865	829055.637	37,298	2463533	443435.922
17	0.17	70.67	69,733	4,928,031	837765.2887	37,298	2635850	448094.4422
18	0.15	75.61	69,733	5,272,512	790876.8195	37,298	2820102	423015.267
19	0.14	80.9	69,733	5,641,400	789795.958	37,298	3017408	422437.148
20	0.12	86.56	69,733	6,036,088	724330.6176	37,298	3228515	387421.7856
21	0.11	92.61	69,733	6,457,973	710377.0443	37,298	3454168	379958.4558
22	0.09	99.09	69,733	6,909,843	621885.8673	37,298	3695859	332627.2938
23	0.08	106.02	69,733	7,393,093	591447.4128	37,298	3954334	316346.7168
24	0.079	113.44	69,733	7,910,512	624930.4101	37,298	4231085	334255.7245
25	0.071	121.38	69,733	8,464,192	600957.5993	37,298	4527231	321433.418
					24603694.95			13159746.67

A positive NPV indicates that the present value of the cash inflows is greater than the present value of the cash outflows over the analysis term. A negative NPV as demonstrated above indicates that the investment required is greater than the project's return.

4.9.5 Key findings.

- Since there is no cooling, the largest energy saving measures are achieved by replacing conventional lighting, computers and office equipment with high energy efficiency ones.
- A significant reduction in electricity for lighting, computers and office equipment is observed in the building when more efficient systems are introduced.

- Hours within the thermal comfort range (using the adaptive comfort approach) improves dramatically with passive measures, especially with the introduction of shading device

4.9.6 Conclusion.

The annual cost of operating the DAOB from the national grid was established from the monthly electricity bill. Although, the estimation only take into account the 2 hours electricity supply to the building as a result of the persistent power crises in the country, however, a different scenario of 8 hours was assumed and the energy performance checked based on the kWh/m^2/annum of the building, the outcome showed that the DAOB is a low energy consuming building. Furthermore, the annual cost of mitigating these erratic electricity supply to the building through a stand-alone diesel generator was estimated and the result showed a huge sum of money was been accrued annually, which implied that apart from the daily contribution to GHG emission and other forms of environmental pollution, self-generation through the use of fossil fuel based generator to mitigate power outage is expensive.

Based on the office equipment, computers, lighting, occupancy as well as the operation pattern of the DAOB, a simulation was done first to determine the status-quo baseline consumption of the building, which again shows that the DAOB is a low energy consuming building in terms of the kWh/m^2/annum of the building. Despite the low energy consumption of the building, opportunities for optimization to further reduce the energy utilised in the building were identified and implemented, and the outcome was a significant 47% reduction in annual energy consumption. The cost analysis associated with these energy efficiency retrofit revealed that it is a good business endeavour to venture into given the simple payback period of 6 years 3 months, ROI of 16% and a positive NPV of ₦6,494,279 ($20,568)

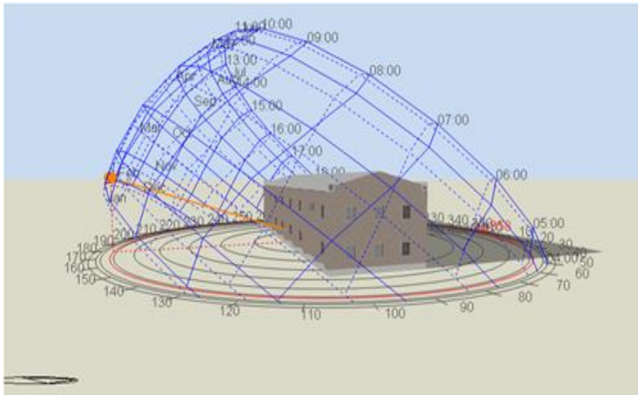
Chapter 5

Determining the available roof top area for solar PV installation on the DAOB

5.1 Available roof area for solar PV system installation.

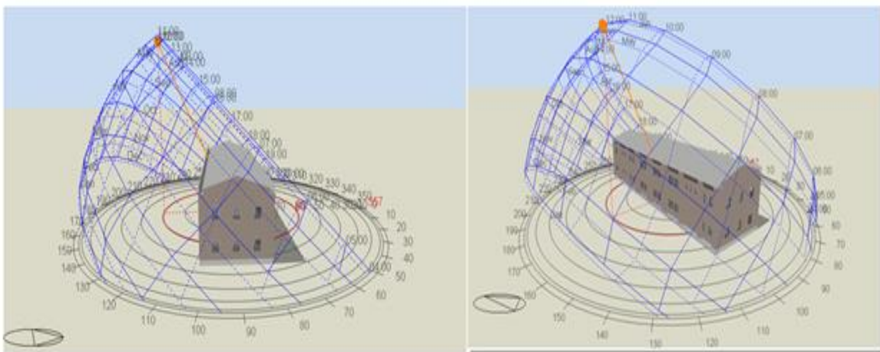
The total roof area of the DAOB was estimated at 505.75m^2. This estimate was done from the architectural drawing of the building. Additionally, a site survey was carried out to be sure that no part of the roof is shaded by any object. Although the available roof area was 505.75m2, the most suitable area of the roof for solar panel installation was the south facing area of the roof, this part of the roof which is 184.38m^2 in area, is most exposed to solar radiation at all times of the day and throughout the year. The lowest sun angle occurs between December and January at 20° to 18° as revealed by the Design Builder analysis.

Figure 15: showing the sun path and the lowest sun angle in January and December.



The highest sun angle occurs between June, July and August at as shown below.

Figure 16: showing the sun path and the highest sun angle in June, July and August



From the analysis above and the location of Nigeria as described in section 4.2, the sun trails towards the southern path (as it rises from the eastern part and sets at the western part daily) throughout the year. This makes the south facing portion of the roof most suitable for the solar panel installation.

Roof is not a constraining factor given the available roof area for PV installation on the DAOB. The available roof area allowed for an estimated number of 80 solar PV module to be installed. The PV type selected is 250W PV module poly crystalline solar panel based on high daily output, durability and resilience to all weather conditions. Each PV panel measured 1630mm in length, 983mm in breath and 47mm in thickness.

After establishing what direction the panels should face, to get the most sun reaching the panel throughout the day, it is vital to calculate an optimal tilt angle. This according to standard practice will depend on location (Guda and Aliyu, 2015). To determine the appropriate tilt angle the rule of thumb according to Guda and Aliyu, (2015) is to multiply the latitude of the building location by 0.87 provided the latitude is below 25° (Guda and Aliyu, 2015; Saleh, Haruna and Onuigbo, 2015).

Lokoja falls within latitude 7.8023° N, this is below 25° as recommended therefore, to determine the optimum fixed tilt angle for solar panel in Lokoja, we multiply the latitude 7.8023° by 0.87 to arrive at 6.788° as the ideal optimal tilt angle solar PV in Lokoja.

5.2 Solar PV system sizing.

The erratic nature of electricity supply from grid to the building warranted the use of diesel generator for mitigation. The objectives here are to first source for uninterrupted power supply to the building through a renewable source (solar PV), this was done by sizing a solar PV system based on DAOB's optimised electricity demand. The second objective (alternative option) was to size the PV system based on the available roof area of the DAOB.

However, due to grid unreliability, and non-availability of smart grid infrastructure in the country as yet, in addition to solar panel module and inverter, battery storage as well as solar charge controller were a necessity in both cases examined. In the first option, the battery and solar charger is required to get the building off the grid completely. Given, the similarity in the building sizes, electricity load, occupancy and the operation pattern of the nearby office building, (The Department of Urban and Regional Office Building DUROB) it was deemed fit to export excess electricity from the DAOB to the nearby DUROB in the form of mini-grid arrangement. The logistics involved in this kind of arrangement was not considered in this report. The second option (alternative option) utilises battery storage and charger due to existing grid unreliability.

5.2.1 Option 1: Solar PV system sizing based on DAOB's optimised electricity demand

The first step in going solar is not sizing the PV system, but reducing the electricity usage through conservation and efficiency measures (Haruna and Onuigbo, 2015). These measures were identified and implemented on the DAOB as shown in section 4. Once these measures have been implemented, next was to size a PV system to offset the remaining energy usage. The following steps were followed to size the required PV system for the DAOB.

(a) Determine the power consumption demands.

The first step in designing a solar PV system is to find out the total power and energy consumption of all loads that need to be supplied by the solar PV system as follows: First was to define the total energy consumed by the building. This was achieved by identifying the month that consume the highest electricity in a year and then divide the energy consumed by 30 days of the month based on the maximum occupancy density of the DAOB. The highest consuming month is March with 3,655 kWh consumption. By dividing 3,655 kWh by 30 days, we have 122kWh which is the energy utilised in a day by the building.

The next stage was to calculate the total kilo Watt-hours per day needed from the PV modules, to do this, we divide the out-put per day above by the total daily average sun hours. Although the total average sun hours for the case study area (Lokoja) are estimated at 12 hours per day all year round (Guda and Aliyu, 2015). However, there are cases of longer sun hours around June, July and August. For the purpose of this report, the 12 hours daily average sun hours was adopted. Dividing the 122kWh above by 12 daily sun hours gives 11 kWp. Next is to multiply the 11 kWp by 1.3 (the energy lost in the system) to get the total Watt-hours per day which must be provided by the panels as guided by (Guda and Aliyu, 2015; Saleh, Haruna and Onuigbo, 2015). The outcome of that is 14.3 kW/day which must be provided by the panels.

Different sizes of PV modules produce different amount of power (Guda and Aliyu, 2015). To find out the sizing of PV module and the total peak kilo watt required. The peak kilo watt (kWp) produced depends on the size of the PV module and climate of the site location (Guda and Aliyu, 2015; Saleh, Haruna and Onuigbo, 2015). Also, consideration was given to the Panel Generation Factor PGF, which is different from one site location to another (Guda and Aliyu, 2015; Saleh, Haruna and Onuigbo, 2015). Panel Generation factor (PGF) signifies the maximum watt peak needed to meet the requirement of electricity from solar panels (Guda and Aliyu, 2015). PGF varies from location and climate, this implies that different locations have different PGF depending upon the quality of solar insolation and irradiation falling on that place (Guda and Aliyu, 2015).

Although there are empirical relations to arrive at the PGF according to Guda and Aliyu (2015), for Nigeria, the panel generation factor is 3.41. hence to determine the sizing of PV modules for the DAOB, the calculation is as follows: (a) Calculate the total kilo Watt-peak rating needed for PV modules: to do this, we divide the total kilo Watt-hours per day needed from the PV modules (14.3 kWh) by 3.41 to arrive the total kiloWatt-peak rating of 4.2 kilo Watt-peak needed for the PV panels required to operate the DAOB.

(b) Calculate the number of PV panels for the system; divide the answer obtained in item (a) above (4.2 kW) by the rated output kilo Watt-peak of the PV modules available, the PV modules chosen in this case is the 250W (0.25 kW). So for the DAOB, we divided 4.2 kWp by 250 W (0.25 kW) to give 16.8 numbers of PV panels. It is advisable to increase any fractional part of this result to the next highest full number and that will be the number of PV modules required. In this case approximating 16.8 gives 17 numbers of PV panels required for the building.

Result of the calculation is the minimum number of PV panels. If more PV modules are installed, the system will perform better and battery life will be improved. If fewer PV modules are used, the system may not work at all during cloudy periods and battery life will be shortened (Saleh, Haruna and Onuigbo, 2015).

3. Inverter sizing.

Findings from solar PV experts interviewed revealed that inverters are used in the systems where AC power outputs are needed. The input rating of the inverter should never be lower than the total watt of appliances. The inverter must have the same nominal voltage as the battery (Guda and Aliyu, 2015; Saleh, Haruna and Onuigbo, 2015).

For stand-alone systems, the inverter must be large enough to handle the total amount of Watts required at a time (Guda and Aliyu, 2015; Saleh, Haruna and Onuigbo, 2015).

According to Guda and Aliyu (2015), the inverter size should be 25-30% bigger than total Watts of appliances. This implies that roughly 6kW inverter is required for the building. (Guda and Aliyu 2015).

4. Battery sizing.

The battery type recommended for solar PV system is deep cycle battery (Guda and Aliyu, 2015; Saleh, Haruna and Onuigbo, 2015). A deep-cycle battery is a lead-acid battery designed to be regularly deeply discharged using most of its capacity (Guda and Aliyu 2015). The battery should be large enough to store sufficient energy to operate the building at night and cloudy days. To find out the size of battery required for DAOB, the following considerations were made:

- Solar Panels deliver 14.3 kWh per day;
- Batteries need to be able to handle the 14.3 kWh charging and discharging per day and preferable not discharge more than 30% Depth of Discharge (30% DOD);
- On a 14.3 kWh solar system per day, with a 5 hour charging we can assume 4kW of Solar panel array;
- If we assume a 48V system, the peak charging current will be 5000W/48V = 125A;
- Thus the smallest battery bank permissible is thus 525A- and in order to prevent a recharging rate of higher than C/5 (Capacity /5) , thus if we have 125Ax5= 650A. This is the First test;
- 14.3kWh energy rotation, in battery bank, with maximum 30% DOD. Thus our battery bank need to have the ability of 14.3kW.h/0.3 = 48 kWh battery bank; and
- This means 48000Watt.hour/48V = 100A.h Battery bank.

For this, the following type of batteries are recommended; 21 x 180A.h Monobat VRLA deep cycle batteries , or 21 x 200A.h AGM deep cycle batteries;

Given the consideration, we could expect up to 5000 Cycles, which means an expected battery lifetime of 10-12 years.

5. Solar charge controller sizing

the solar charge controller is typically rated against Amperage and Voltage capacities. Select the solar charge controller to match the voltage of PV array and batteries and then identify which type of solar charge controller is right for your application. Make sure that solar charge controller has enough capacity to handle the current from PV array.

For the series charge controller type, the sizing of controller depends on the total PV input current which is delivered to the controller and also depends on PV panel configuration (series or parallel configuration).

According to standard practice, the sizing of solar charge controller is to take the short circuit current (Isc) of the PV array, and multiply it by 1.3

Solar charge controller rating = Total short circuit current of PV array x 1.3. For the DAOB, it was 17 multiply by 1.3 to arrive at 22 numbers of solar charger controller.

Table 22: Budget for the required PV components

S/NO	ITEM DESCRIPTION	RATE ($)	Rate (₦)	QUANTITY	COST ($)	COST (₦)
1	250W PV module poly crystalline solar panel	133	41,944	17	2,261	713,048
2	4000W Magnum energy inverter	2,239	706,111	2	4,478	1,412,222
3	200A.h AGM deep cycle batteries	99	31,221	21	2,079	655,641
4	Solar charge controller	27	8,515	22	594	187,308
5	Total cost of PV system component				9,412	2,968,219
5	Assumed 15% of the total cost of PV system (2,968,219) as the total cost of labour,				1,410	445,233

	installation and miscellaneous.					
6	Total cost				10,822	3,413,452
7	20% Maintenance				2,162	682,690
8	Grand total				12,973	4,096,142

In addition to the typical focus of thinking about up-front costs of a solar plant, determining a plan and budget for operations and maintenance (O & M) is essential in assessing the business case for a PV facility (Jake, 2010). As in the case of conventional generating plants, there are various types of maintenance strategies that can be used for a PV plant. For this study the 20% budget for O&M recommended by Hootman (2013:338) was adopted. To estimate for the total budget for the PV system, we calculated the 20% of the total budget of ₦3,413,452 to be ₦682,690 then add to the total budget as follows; ₦3,413,452 + ₦682,690=₦4,096,142 ($ 12,973 USD).

5.2.2 Option 2: Solar PV system sizing based on the available roof area.

The analysis in section 4.8.4 shows that the available roof area was capable of accommodating 80 numbers of solar PV panel for installation. Based on the system sizing procedure demonstrated above, the table below presents a summary of the solar PV component required to generate electricity from the available roof area of the DAOB. The calculations below are done as per the solar PV system investigation performed in the previous sections.

Table 23: Budget for the required PV components for option 2.

S/NO	ITEM DESCRIPTION	RATE ($)	Rate (₦)	QUANTITY	COST ($)	COST (₦)
1	250W PV module poly crystalline solar panel	133	41,944	80	10,640	3355524.
2	4000W Magnum energy inverter	2,239	706,111	8	17,912	5,648,887
3	200A.h AGM deep cycle batteries	99	31,222	88	8,712	2,747,491

4	Solar charge controller	27	8,515	200	5,400	1,702,992
5	Total cost of PV system component				42,664	13,454,898
5	30% of the total cost of PV system (21,332) as the total cost of labour, installation and miscellaneous.				12,799	4,036,469
6	Total cost				98,127	30,946,264
7	20% Maintenance				19,625	6,189,253
8	Grand total				117,752	37,135,517

Similar to simple payback for energy efficiency, a simple pay back for renewable energy is one of the simplest financial analysis that can be made on a project investment, decision. For the purpose of this study, a simple payback was calculated for the two scenario described above (optimised energy demand of the building, and electricity generation based on the available roof top for PV installation).

5.2.2.1 Financial analysis for option 1.

Using the same formula adopted from Hootman (2013) based on evaluation on savings from the outcome of simulation;

Simple payback SP=I/S

Where;

I = budget for investment = ₦4,096,142

S=cost for energy demand that could be saved by going solar= ₦895,152

Simple payback SP=4.6 years

Return On investment ROI= (1/SP) X100

Where;

SP=4.6years

ROI=21.7%

Analysing the investment based on savings made by going solar, and the cost of mitigating power outage through the use of diesel generator, the following consideration was made; (1) the cost of energy saved by going solar is ₦895,152 ($2,835), and (2) the cost of operating the building for a year on diesel generator is ₦2,688,000 ($8,513). Adding these together gives a total of ₦3,583,152.

Simple payback SP=I/S

Where;

I = budget for investment = ₦4,096,142

S=total saving by considering the actual status-quo= ₦3,583,152;

Simple payback SP=1 years, 2 months;

Return On investment ROI= (1/SP) X100

Where;

SP=1.2 years

ROI=88%

The investment make more sense when the actual cost of operating the building from the grid, and the cost of operating the building from diesel were factored in than when it was just based on savings made from the out-come of the simulation

Financial analysis based on Net Present Value (NPV) for option 1.

While ROI takes into account all of the financial benefits and costs of going solar, it doesn't take into account the future value of the money being invested. That is, it doesn't factor in inflation, risk, or the lost opportunity of investing in another type of investment, such as stocks and bonds. This is commonly referred to as the time value of money. NPV does account for the time value of money. Using a solar NPV formula, the table below shows how the 25 to 30 year lifetime cash flow of a solar project compares in today's Naira, factoring in for electricity escalation, interest, and other lost opportunity costs.

Table 24: NPV for option 1.

K	L	M	N	O	P	Q
YEAR	PRESENT VALUE FACTOR (7%)	ELECRTICITY RATE (₦)	RE GENERATION (kWh)	RE NET ENERGY USE (kWh)	COST OF SAVED ENERGY	COST OF ENERGY SAVED PV
1	0.9	24	155,347	37,298	895152	805636.8
2	0.81	25.68	155,347	37,298	957812.64	775828.24
3	0.73	27.47	155,347	37,298	1024576.1	747940.52
4	0.66	29.37	155,347	37,298	1095442.3	722991.89
5	0.59	31.42	155,347	37,298	1171903.2	691422.86
6	0.53	33.61	155,347	37,298	1253585.8	664400.46
7	0.48	35.96	155,347	37,298	1341236.1	643793.32
8	0.43	38.47	155,347	37,298	1434854.1	616987.25
9	0.39	41.16	155,347	37,298	1535185.7	598722.42
10	0.35	44.04	155,347	37,298	1642603.9	574911.37
11	0.31	47.12	155,347	37,298	1757481.8	544819.35
12	0.28	50.41	155,347	37,298	1880192.2	526453.81
13	0.25	53.93	155,347	37,298	2011481.1	502870.29
14	0.22	57.7	155,347	37,298	2152094.6	473460.81
15	0.2	61.73	155,347	37,298	2302405.5	460481.11
16	0.18	66.05	155,347	37,298	2463532.9	443435.92
17	0.17	70.67	155,347	37,298	2635849.7	448094.44
18	0.15	75.61	155,347	37,298	2820101.8	423015.27
19	0.14	80.9	155,347	37,298	3017408.2	422437.15
20	0.12	86.56	155,347	37,298	3228514.9	387421.79
21	0.11	92.61	155,347	37,298	3454167.8	379958.46
22	0.09	99.09	155,347	37,298	3695858.8	332627.29
23	0.08	106.02	155,347	37,298	3954334	316346.72
24	0.079	113.44	155,347	37,298	4231085.1	334255.72
25	0.071	121.38	155,347	37,298	4527231.2	321433.42
					56,484,091	13,159,747

From the table above, the discount rate was assumed to be 7%, electricity escalation was assumed to be 7% annually. The estimated cost of electricity saved over a period of 25 years by going solar was ₦56,484,091 ($178,889), but when the annual savings was discounted to the present day value of Naira, the savings over these periods was calculated at ₦13,159,747($41,678), therefore;

$NPV=PV-PV_O$

Where PV=₦13,159,747and

PV_O =₦4, 96,142 (Total budget for the solar system)

NPV=₦12,663,605 ($40,106)

A positive NPV shows that the investment is a good one and will add value for investor.

5.2.2.2 Financial analysis for option 2.

The second scenario evaluated in this study was based on the total generation resulting from the available rooftop area of the DAOB. By using the formula for calculating simple payback and ROI as demonstrated above, the second scenario was evaluated as follows;

I = budget for investment = ₦37,135,517 ($117,611)

S=cost for energy demand that could be saved by going solar= ₦895,152 ($2,835)

Simple payback SP=41.5years

Return On investment ROI= (1/SP) X100

Where;

SP=41.5years

ROI=2.4%.

A low ROI and long payback period shows that the investment is not a good one and will not add any value for the investor.

Financial analysis based on Net Present Value (NPV) for option 2.

By utilising the NPV to calculate for the renewable energy from the available rooftop, the table below assumed the discount to be 7%, electricity escalation was assumed to be 7% annually, and the renewable electricity tariff to be exported to the grid for revenue purpose was ₦ 12/kWh. The renewable tariff was assumed to be constant all through 25 years. From the earlier analysis, the available roof area generates 155,347.8kWh annually and only consumed an estimated amount of 37,298kWh/ year, which leaves a total of 118,049.8 to be exported to the grid for income generation.

Table 25: NPV for option 2.

YEAR	PRESENT VALUE FACTOR (7%)	ELECRTICITY RATE (₦)	RE GENERATION (kWh)	RE NET ENERGY USE (kWh)	COST OF SAVED ENERGY	COST OF ENERGY SAVED PV	RE ENERGY TO BE EXPORTED TO THE GRID	ASSUMED RE RATE	COST OF EXPORTED ENERGY	COST OF EXPORTED ENERGY PV
1	0.9	24	155,347	37,298	895152	805636.8	118,045	12	1416540	1274886
2	0.81	25.68	155,347	37,298	957812.64	775828.24	118,045	12	1416540	1147397.4
3	0.73	27.47	155,347	37,298	1024576.1	747940.52	118,045	12	1416540	1034074.2
4	0.66	29.37	155,347	37,298	1095442.3	722991.89	118,045	12	1416540	934916.4
5	0.59	31.42	155,347	37,298	1171903.2	691422.86	118,045	12	1416540	835758.6
6	0.53	33.61	155,347	37,298	1253585.8	664400.46	118,045	12	1416540	750766.2
7	0.48	35.96	155,347	37,298	1341236.1	643793.32	118,045	12	1416540	679939.2
8	0.43	38.47	155,347	37,298	1434854.1	616987.25	118,045	12	1416540	609112.2
9	0.39	41.16	155,347	37,298	1535185.7	598722.42	118,045	12	1416540	552450.6
10	0.35	44.04	155,347	37,298	1642603.9	574911.37	118,045	12	1416540	495789
11	0.31	47.12	155,347	37,298	1757481.8	544819.35	118,045	12	1416540	439127.4
12	0.28	50.41	155,347	37,298	1880192.2	526453.81	118,045	12	1416540	396631.2
13	0.25	53.93	155,347	37,298	2011481.1	502870.29	118,045	12	1416540	354135
14	0.22	57.7	155,347	37,298	2152094.6	473460.81	118,045	12	1416540	311638.8
15	0.2	61.73	155,347	37,298	2302405.5	460481.11	118,045	12	1416540	283308
16	0.18	66.05	155,347	37,298	2463532.9	443435.92	118,045	12	1416540	254977.2
17	0.17	70.67	155,347	37,298	2635849.7	448094.44	118,045	12	1416540	240811.8
18	0.15	75.61	155,347	37,298	2820101.8	423015.27	118,045	12	1416540	212481
19	0.14	80.9	155,347	37,298	3017408.2	422437.15	118,045	12	1416540	198315.6
20	0.12	86.56	155,347	37,298	3228514.9	387421.79	118,045	12	1416540	169984.8
21	0.11	92.61	155,347	37,298	3454167.8	379958.46	118,045	12	1416540	155819.4
22	0.09	99.09	155,347	37,298	3695858.8	332627.29	118,045	12	1416540	127488.6
23	0.08	106.02	155,347	37,298	3954334	316346.72	118,045	12	1416540	113323.2
24	0.079	113.44	155,347	37,298	4231085.1	334255.72	118,045	12	1416540	111906.66
25	0.071	121.38	155,347	37,298	4527231.2	321433.42	118,045	12	1416540	100574.34
					56,484,091	13,159,747			35,413,500	11,785,613

Further, considering the energy exported to the grid to be constant for the period of 25 years at the rate of ₦ 12/kWh, this implies that a total of ₦35,413,500 ($112,157) was realised over these periods, however, when discounted to the present value, a total of ₦11,785,613 ($37,326) was realised for the same period.

$NPV=PV-PV_O$

Where PV=₦11,785,613 + 13,159,747=24,945,360

PV_O =₦37,135,517 (Total budget for the solar system)

NPV=-₦12,190,157 (-$38,607)

A negative NPV as demonstrated by the second scenario indicates that the investment required is greater than the project's return. However, analysing the investment based on savings made by going solar, revenue made by exporting excess electricity to the grid and the cost of mitigating power outage through the use of diesel generator, the following consideration was made; (1) the cost of energy saved by going solar is ₦895,152 ($2,835), (2) the cost of exported energy to the grid is ₦1,416,540 ($4,486), and (3) the cost of operating the building for a year on diesel generator is ₦2,688,000 ($8,513). Adding these together gives a total of ₦4,999,692.

To calculate the simple payback based on the analysis above;

Simple payback SP=I/S

Where;

I = budget for investment = ₦37,135,517

S= ₦4,999,692

Simple payback SP= 7.5 years

Return On investment ROI= (1/SP) X100

Where;

SP=7.5 years

ROI=14%

A payback of 7 years and 4 months, ROI of 14% on solar PV system is a good investment for potential investors as well as for building owner. Table 25 below analyses the investment in the Net Present Value based on the consideration made above on status-quo cost of running the building.

When the status-quo cost of running the DAOB from the monthly electricity bills as well as the annual cost of running the building on diesel generator was considered for 25 years, with an assumed 7% annual electricity escalation on the bills and an assumed 5% annual increment on the cost of operating the building on diesel generator as presented in the table below, the total sum of the status-quo cost of running the building for 25years was estimated at ₦147,081,113 ($465,815), when discounted to present value, the cost was estimated at ₦37,444,484($118,589). To estimate for the actual savings made, the ₦11,785,613 ($37,326) cost realised in present value for excess electricity exported to the grid was added to the savings of ₦37,444,484 ($118,589) made over a period of 25 years for going solar, the outcome was ₦49,230,097 ($155,915) total savings in present value.

Table 26: Assumed cost of operating DAOB in status-quo for 25years

W	X	Y	Z	AA	AB	AC	AD
YEAR	PRESENT VALUE FACTOR (7%)	ELECRTICITY RATE (₦)	STATUS-QUO ENERGY FROM THE GRID	COST OF ENERGY SAVED	COST OF ENERGY SAVED PV	5% YEARLY ESCALATION IN THE COST OF RUNING DAOB ON DIESEL	5% YEARLY ESCALATION INCOST OF RUNING DAOB ON DIESEL PV
1	0.9	24	12,408	297792	268012.8	2,688,000	2419200
2	0.81	25.68	12,408	318637.44	258096.3264	2,822,400	2286144
3	0.73	27.47	12,408	340847.76	248818.8648	2,963,520	2163369.6
4	0.66	29.37	12,408	364422.96	240519.1536	3,111,696	2053719.36
5	0.59	31.42	12,408	389859.36	230017.0224	3,267,281	1927695.79
6	0.53	33.61	12,408	417032.88	221027.4264	3,430,645	1818241.85
7	0.48	35.96	12,408	446191.68	214172.0064	3,602,177	1729044.96
8	0.43	38.47	12,408	477335.76	205254.3768	3,782,286	1626382.98
9	0.39	41.16	12,408	510713.28	199178.1792	3,971,400	1548846
10	0.35	44.04	12,408	546448.32	191256.912	4,169,970	1459489.5
11	0.31	47.12	12,408	584664.96	181246.1376	4,378,469	1357325.39
12	0.28	50.41	12,408	625487.28	175136.4384	4,597,392	1287269.76
13	0.25	53.93	12,408	669163.44	167290.86	4,827,262	1206815.5
14	0.22	57.7	12,408	715941.6	157507.152	5,068,625	1115097.5
15	0.2	61.73	12,408	765945.84	153189.168	5,322,056	1064411.2
16	0.18	66.05	12,408	819548.4	147518.712	5,588,159	1005868.62
17	0.17	70.67	12,408	876873.36	149068.4712	5,867,567	997486.39
18	0.15	75.61	12,408	938168.88	140725.332	6,160,945	924141.75
19	0.14	80.9	12,408	1003807.2	140533.008	6,468,992	905658.88
20	0.12	86.56	12,408	1074036.48	128884.3776	6,792,442	815093.04
21	0.11	92.61	12,408	1149104.88	126401.5368	7,132,064	784527.04
22	0.09	99.09	12,408	1229508.72	110655.7848	7,488,667	673980.03
23	0.08	106.02	12,408	1315496.16	105239.6928	7,863,100	629048
24	0.079	113.44	12,408	1407563.52	111197.5181	8,256,255	652244.145
25	0.071	121.38	12,408	1506083.04	106931.8958	8,669,068	615503.828
				18790675.2	4377879.153	128,290,438	33,066,605

Thus $NPV=PV-PV_O$

Where PV=₦49,230,097

PV_O =₦37,135,517 (Total budget for the solar system)

NPV= ₦12,094,580 ($38,304)

By not only considering the cost of the status-quo base consumption from simulation but also the actual cost of operating the building from the grid as well as from diesel generator, a payback period of 7.5 years, ROI of 14% and a positive NPV of ₦12,094,580 ($38,304) was achieved. This shows that the investment will be a good one.

5.3 Key findings

Major areas that presented opportunity for energy efficiency optimised intervention to reduce the energy consumption of DAOB are provision of external shading at the south/east façade to prevent the solar irradiation there by reducing the solar gains via the external windows in this direction. Furthermore, occupancy and lighting sensor were introduced to maximize electricity consumption. Additionally, the conventional office equipment were replaced with more energy efficient ones to optimise consumption. Finally, solar PV integration in the roof is a well suited technology to offset non-renewable energy consumption in the DAOB. The inclusion of battery for the grid interactive solar sizing was due to the current infrastructure failure in the country. All these were necessary to answer the research question ‘’how can energy efficiency optimise intervention with integrated PV-based DG reduce the energy consumption of DAOB?’’

5.4 Conclusion

Roof is not a constraining factor in going solar on the DAOB. The outcome of the evaluation conducted on the available roof area for solar panel installation revealed that the available roof area on the case study building is capable of 80 numbers of solar panel installation, this is roughly times 4 of what the building required to supply its optimised annual energy demand. Based on this finding, solar system sizing was performed for two different scenarios, the first scenario was done based on the building’s optimised annual energy demand, while the second scenario envisages the potential for export of excess energy to the grid for revenue purposes based on the available roof area.

The financial analysis carried out for the two scenarios showed that both scenarios present good investment options given the simple payback period of 4 years, and 6 months, ROI of 21.7% and a positive NPV of ₦12,663,605 ($40,106) on the analysis performed based on savings from the outcome of simulation. When the evaluation was performed based on the actual status-quo cost of running the building, a better investment opportunity of 1.2 years and ROI of 88% was realised. However, the financial evaluation for the second scenario shows a simple payback of 41 years and 5 months, ROI of 2.4% and a negative of NPV=-₦12,190,157 (-$38,607) which is not too good an investment to consider. Nevertheless, when the savings based on revenue from export to the grid and the actual cost of operating the building from electricity monthly bills as well as the operating cost through diesel generator was factored in, a simple payback of 7 years 5months, ROI of 14% and a positive NPV of ₦12,094,580 ($38,304) was realised. This will be a very good investment to embark on by commercial developer. It will equally be a good venture for the building owner to look into, given the short payback period and high ROI. The table below compares the different options examined in the report.

Table 27: comparing option 1 and 2

Financial analysis	**First option** Based on savings made out of simulation result.	**First option** Based on the actual status-quo cost of running DAOB.	**Second option** Based on savings made out of simulation result & export to the grid.	**Second option** Based on the actual status-quo cost of running DAOB.
Simple payback	4.6 years	1.2 years	41.5 years	7.5 years
ROI	21.7%	88%	2.4%	14%
NPV	₦12,663,605 ($40,106)		-₦12,190,157 (-$38,607)	₦12,094,580 ($38,304)

To answer the research question ‘’how would the cost of retrofitting DAOB compare to the status-quo coping mechanism of the building in the short and long term?’’ based on the financial analysis above, it saves more to optimise and integrate PV technology in the DAOB than to choose to remain in status-quo for the following reasons; erratic nature of electricity supply from the grid, annual electricity tariff escalation, annual fluctuation/escalation in diesel price, and cost of maintaining the generating set. If the savings on electricity can payback the cost of PV in just 4 years and 6months (based on simulation), or if the savings made by not paying electricity bills and by not using diesel generator to power the building, then, its more beneficial both in the short and long term to retrofit and integrate solar PV system in place of the status-quo coping mechanism.

Chapter 6

Renewable energy business model for the DAOB

6.1 Introduction

This chapter starts off with some discussions around the existing renewable energy business model practises in Nigeria. The chapter conceptualised a business model specific to the DAOB by recalling the SPPA model discussed in Chapter 2 of this report. The business model proposed reviewed the financial analysis performed in Chapter 5 to ascertain its viability within the renewable energy vendors/ESCOs in the country. The chapter concludes by summarising the findings on grid parity and policy framework to open up a wider transformation towards distributed energy generation in the country.

6.2 Existing renewable energy business model in Nigeria

Findings revealed that apart from those government, NGOs and internationally sponsored pioneer projects discussed in chapter 2 of this report, common solar PV project finance practice in Nigeria are: self-sponsored model, where individuals, households, businesses, group of people or organisations interested in going solar bears the cost of purchase of the PV system, installation cost and the risk associated with purchase of substandard material and lack of proper maintenance. This is very similar to the circumstance surrounding the use of stand-alone, fossil-fuel based generator to mitigate power outage in the country.

A second model trending amongst the renewable energy vendors and Energy Service Companies (ESCOs) in Nigeria as revealed by a PV expert interviewed, requires the renewable energy vendors or ESCOs to perform an energy audit, investigate the financial capability of the potential client before designing and installing the solar PV system, with the energy company bearing the upfront cost of the PV system. A legal agreement (contract) is usually entered into on the methods and mode of paying back to the company.

A common practice among the ESCOs in the country is to evaluate the monthly income of such individual, company or organisation, and based on this evaluation, an agreement will be made on the monthly reimbursement to be paid into the company's account to enable it recoup its money back. An integral part of the contract is that the energy company bears the risk for system failure, and even though, the ownership of the PV system belongs to the client, the required maintenance for optimum performance remains the responsibility of the energy company, and all these will be clearly incorporated in the legal agreement. A penalty is usually agreed on by both party for breach of contract.

Another model specific to solar PV in Nigeria is the MTN Mobile Electricity, known as the Lumos smart solar system owned by the South African mobile telecommunication company MTN. The pack comprises of 80W panel, solar indoor unit with various DC sockets (12V max), mobile phone charger, 2 LED bulbs and an easy self-installation mounting kit and required cables. The complete system is sold and installed by the company's 3rd party installers at an estimated cost of ₦26,000 ($82), a monthly top up of ₦4,500 ($14) is required to stay connected.

The pay-as-you-go model requires the payment to be made via mobile airtime to activate and unlock the PV system for lighting. The monthly top-up of ₦4,500 ($14) usually last for 5 years after which the end user is no longer required to purchase any top-ups to access electricity. The company's representative interviewed revealed that there are plans to keep increasing the capacity of the solar system as time goes on, however, the respondent was unsure as to the question of the possibility of scaling it up to office or institution buildings like the DAOB.

6.2.1 Conceptualising business model specific to the DAOB

Given the circumstances around this existing solar PV business model as well as the slow uptake, in a capital constrained economy like Nigeria, where there are many competing demands for available scarce capital resources, the promoters of renewable energy technology face the problems of unsupportive climate for investments that has led to high transaction costs, restricted access to capital and poor business development skills by renewable energy system vendors.

To answer the research question ''what are the viable business model options for a PV retrofit of the DOAB?'' Solar PPA provide a means to avoid the upfront capital costs of installing a solar PV system as well as simplifying the process for the host customer. In some states, however, the PPA model faces regulatory and legislative challenges that would regulate developers as electric utilities. A solar lease is another form of third-party financing that is very similar to a PPA, but does not involve the sale of electric power. Instead, customers lease the system as they would on automobile. In both cases, the system is owned by a third party while the host customer receives the benefits of solar with little or no up-front costs. These third-party financing models have quickly become the most popular method for customers to realize the benefits of solar energy.

Business case for the DAOB

In order to establish the financial viability of putting PV on the DAOB, it is necessary to recall the financial analysis and purchasing options for the DAOB that was demonstrated in Chapter 5. A simple payback of 6 years 3 months, ROI of 16% and a positive NPV of ₦6,494,279 ($20,568) was realised on the Energy Efficiency (EE) optimization performed on the building. This implies that, in 6 years and 3 months, all expenses incurred on the DAOB for EE would be recovered. Additionally, a simple payback of 4 years 6 months, ROI of 22% and a positive NPV of ₦12,663,605 ($40,106) was also achieved on the solar PV system investment that was sized based on the optimised energy of the building. Hence it is financially viable to install PV on the building.

It was perceived that the most profitable investment on the DAOB could occur if there is an enabling environment for excess electricity to be exported to the grid for income generation for the DAOB. This assumption was based on the financial analysis performed for a solar PV system sizing based on the available rooftop area of the DAOB with the sole purpose of exporting to the grid for revenue. A simple payback of 7 years 5 months, ROI of 14% and a positive NPV of₦12,094,580 ($38,304) was achieved. The short payback as well as the high interest rate was possible because of the income generated from the grid.

Business model for the DAOB

The investments incurred on the DAOB can be undertaken by the renewable energy vendors/ESCOs in the country to assume most of the technical, financial, and performance risks under a PPA business model. Given that solar PV technology is still at its infancy in Nigeria, there seems to be no concrete business model for its proper deployment, however, as discussed in section 6.2, within the renewable energy vendor, there is a model that is similar to a Power Purchase Agreement. With this kind of model a developer arranges for the design, permitting, financing and installation of a solar energy system on the DAOB at little to no cost. The developer sells the power generated to the institution at a fixed rate that is typically lower than the local utility's retail rate of ₦24 ($0.8) per kWh.

This lower electricity price (say ₦12) serves to offset the customer's purchase of electricity from the grid while the developer receives the income from these sales of electricity as well as any tax credits and other incentives generated from the system. The agreement range from 10 to 25 years and the developer remains responsible for the operation and maintenance of the system for the duration of the agreement. At the end of the PPA contract term, a customer (the institution) may be able to extend the PPA, have the developer remove the system or choose to buy the solar energy system from the developer.

6.3 Summary of the findings on smart technology in Nigeria

6.3.1 Findings on smart grid technology

Key issue that came up on grid connection for the DAOB includes grid connection options discussed below; a net metering is intended for self-consumption as well as export of surplus to the grid. In this case, the prosumer (producers of electricity that also consume his product) receives compensation for electricity supplied to the grid. The distinctive feature in the design of this system is the bi-directional utility meter which records electricity imported and exported by the prosumer. The bi-directional meter can record electricity exported and imported on separate registers enabling the prosumer to restrict export to surplus electricity generated on site.

Smart technology like net metering is still lacking in Nigeria, even the prepaid meter that was rolled out some 15 years back is yet to be seen in most rural and semi-urban area of the country. Net metering is not really a solution for Nigeria, as businesses in the country are suffering from not getting any electricity. At the moment, it is technically not possible to feed back into the grid if the building is producing more than it is using.

6.3.2 Findings on Feed-in Tariffs

Findings further revealed that Feed-in tariffs (FiT) are designed to encourage the adoption and deployment of renewable energy technologies because they facilitate/guide electricity distributors on the purchase of electricity generated from qualifying generators at pre-determined tariffs. The FiT connection system is characterized by two meters that record electricity generated and consumed by the prosumer. The distinguishing feature of FiTs from the other mechanisms is the amount of tariff paid to the prosumer or the FiT level for electricity exported to the grid. FiT levels can be determined using different approaches depending on how effective the policy is intended to be towards improving solar PV uptake.

However, responses from one energy expert on the potential for export of excess electricity to the grid in Nigeria revealed that a couple of international organisations like the GIZ have come up with a model known as the integrated decentralised system. Some interested energy companies have been invited to register and become part of the new model, however, the process of registration is cumbersome and somewhat make it uninteresting as revealed by the energy expert.

The integrated decentralised model suggested by the GIZ is a type of model that is been used in California and in some areas close to Washington. In this model, individual households and organisations generate electricity and utilise the power to run their facilities and businesses in the day time, whatever excess electricity generated that are not consuming is exported to the grid. However, the generators are not allowed to use accumulators to store energy to be used at night, instead, they import back energy to be utilised at night from the grid.

In a situation where what was exported to the grid is higher than what was imported to be utilised at night, the utility pays for the leftover, also, in cases where the imported energy is more than the exported one, the prosumer pays for over consumption. Findings revealed further that the success of integrated decentralised model in Nigeria will depend largely on the introduction of smart grid technology, as well as on the fact that the grid must be stable and operational. If the grid is down, it cannot receive any electricity and in that case the system can only be used for its own use. Unless it is a large scale set up supplying the grid, but then it is not a roof application as per the case study building.

6.3.3 Findings on wide area monitoring and control

The outcome of the interview conducted following the enquiries on the possibility for smart grid technology in the country shows the various enhancements needed in order to fully integrate the smart grid network in the Nigerian electricity grid system. As revealed by the AEDC officer interviewed, if a wide area been monitored and controlled through the use of sensory equipment like Phasor Measurement Units (PMU), strain gauge, infrared sensors, magnetic sensors and accelerometers are integrated into the Nigerian grid system, they could ensure proper monitoring and enable the system to automatically adapt and respond to changing conditions. Also, distribution devices will become intelligent remote on communication networks providing data collected through sensors back to operations control centres.

According to the technical officer of the AEDC Lokoja branch office, current technology on the national grid does not monitor power flows throughout the distribution grid because measurements are usually only available at the distribution sub-stations. The sensors will also be able to collect information. Other types of wide area monitoring and control equipment that can also be mounted as mentioned by the interviewed officer include; advance system operator tools, wide area situation awareness (WASA), Wide Area Monitoring System (WAMS) and Wide Area Adaptive Protection, Control and Automation (WAAPCA).

The defunct Power Holding Company of Nigeria (PHCN) introduced Supervisory Control and Data Acquisition Systems (SCADA) to its power system to enable data monitoring and data collection of the generating stations. Other useful software includes GridLAB-D, Oracle Utilities Meter Data Management, Distribution Management System (DMS), and Visualizing Energy Resources Dynamically on Earth (VERDE)

Findings through secondary sources revealed that energy storage devices like hybrid air conditioning systems which come with lithium battery and inverter can convert electrical energy to thermal energy and store it. This is more economical than storing electricity in batteries. Such storage capabilities will be needed to grow the alternative energy sources, where unstable power flow from renewable energy plants such as rooftop solar PV can be stored and better controlled. It can also supply power to the grid when it goes into island mode.

6.3.4 Transmission and enhancement application

In Nigerian transmission power system, it will become important to fully utilize the existing transmission facilities instead of building new power plants and transmission lines that are costly to implement and involve long construction times. Flexible Alternating Current Transmission Systems (FACTS) controllers can be introduced in power systems. FACTS make it possible to control the voltage magnitude of a bus, active and reactive power flows through transmission line of a power system. Line sensors can also be introduced to monitor real time situations of the Network as revealed by the AEDC technical officer.

As discussed in Chapter 2 of this report Nigeria's electricity generating facilities are mainly thermal power plants and large centralized hydro plants scattered across the country. However, the AEDC officer interviewed argued that electricity must have to get to the users irrespective of where they reside. The integration of renewable energy into the national grid is one of the most important areas for infrastructure upgrades.

From findings, considering the high variability and unpredictability of generation from renewable energy sources, the power generated can be safely absorbed in the grid if the frequency is maintained in an appropriate range. Frequency Support Ancillary Service (FSAS) can be used to complement the daily changes in the renewable generation. In the future, based on the renewable forecast for the day, a dispatch schedule for FSAS can be prepared such that the variation in the renewable energy generation can be absorbed easily. In other words, the officer revealed that FSAS can be used as a mechanism to facilitate renewable energy integration by reducing the impact of variable generation.

6.3.5 Findings on Micro-grid

When asked to give his opinion on micro-grid, the officer stressed that micro-grids can be utilized as a framework of system that can reduce the negative effect of power fluctuation on existing power systems, simultaneously pursuing the coexistence of environmental and supply, and existing power system and distributed power generation. They can also be considered to be flexible load. It keeps the power demand and supply balanced by connecting to the external power system for maintenance of frequency and voltage. Micro-grid operators buy power through tie-line from the utility company when power in the micro-grids is deficient, and sell power when the power generated is in excess.

6.3.6 Findings on net metering

On metering infrastructure, the respondent revealed that in the past, electromechanical meters are used by consumers of the defunct Power Holding Company of Nigeria, they had mechanical parts that spin as electricity is consumed in the premises, and they show usage readout on small dials that a utility meter reader reads while on the property of your home. Presently in Nigeria, prepaid meters have been introduced in an effort to provide more efficient service for electricity consumers whereby the buy prepaid cards according to what they can afford. The prepaid meter disconnects from the national grid network once the available credit on the card runs out due to the customer home use. Despite the roll out of the prepaid meter roughly 15 years ago, the infrastructure is yet to be known or used in some part of the country.

Findings show that smart meters, otherwise referred to as Advanced Metering Infrastructure (AMI) or two-way meters are electric meters which utilize two-way communications between the meters and the utility company and enable two way power flows to consumers. This technology enables users to monitor their consumption patterns in real-time and enables features which include time stamping of meter data, outage reporting, communication into the customer premise and on-request reads. It also enables the consumer to supply power back to the grid from solar panels or other local renewable sources and enables load management by responding to fluctuations in demand.

As alleged by the respondent, with the introduction of smart grid technologies in Nigeria, customer-side system will also be introduced to aid in electricity management by residential, service and industrial customers, which will include; smart appliances, energy storage devices, energy management devices and energy applications for smart phones and tablets.

6.4 Summary of findings to open up a wider transformation towards distributed energy generation.

Finding revealed that there has been a lack of publicly available data and information on the clean energy potential like PV in Nigeria and potential new players in the sector lack the basic information upon which to make business decisions. The generation of reliable information and effective management of such information are paramount for good planning and implementation. Some of the renewable energy vendors interviewed state that adoption of decentralized electricity governance model would make for participatory, all-inclusive regime that makes it possible to integrate and engage the services or labour of trained local people closest to the projects.

Furthermore, there is no Power Purchase Agreements (PPA) plan currently for renewable energy generation to the national grid. A system of rational expectations between renewable electricity producers and the grid operators are imperative for the growth in grid-based renewables like rooftop solar PV.

According to some findings from commercial developer, the PPA set the terms by which power is marketed and/or exchanged. It determines the delivery location, power characteristics, price, quality, schedule, and terms of agreement and punishments for breach of contract. The respondent state that legally binding long-term PPA are a must since they provide comfort for the developers of renewable as well as lenders, and would also encourage the expansion of renewable electricity development through investments.

Some of the key issue that came up in the course of the discussion revealed that achieving adequate energy supply where renewables play a role necessitates the creation of appropriate policy framework of legal, fiscal and regulatory instruments that would attract domestic and international investments. This is in line with some issues discussed in chapter 2. Clear rules, legislation, roles and responsibilities of various stakeholders along every stage of the energy flow from supply to end-use are key elements of the overall policy framework needed to promote renewable energy technologies like solar PV. Such policy, legal and institutional frameworks are at their beginning stage in Nigeria and are being developed under the reform program revealed an officer from state ministry of works, housing and power.

6.4.1 Government incentives to promote RE

In order to achieve a successful subsidy and grant mechanism for solar PV development in Nigeria, a strong commitment is required from the government in not only the provision of funds, but also making them efficient enough through a cost recovery mechanism so as to ensure sustainability. The absence of a cost recovery system make the receiving entity vulnerable to financial critical situation and they may fail to maintain their operational efficiency.

On the issue of loans, the role of the Nigerian government is vital for a successful financial support on solar PV projects. The first step for the government in recovering loans like revolving funds may help encourage banks to finance RE projects and hence overcome the barrier of RE investment as revealed by one of the micro finance bank staff interviewed. The government can further support micro-finance banks by financing loans, providing soft loans and long loans for RE projects.

Furthermore, findings from secondary sources shows that, although FiT proved successful in some countries and unsuccessful in others, some measures that could be employed by policy makers in Nigeria include; provision of higher price to generators to stimulate increased supplies of solar PV as well as RE electricity, ensure a shorter payback period on investments, avoid market monopoly by removing market entry barriers of small investors. Others suggested by respondent from energy service provider are; the provision of a flexible FiT system based on technology type, market structure, and location. The government should ensure a secured return over years for investors so as to reduce the risk in RE projects. Finally and most importantly, the government should ensure that the FiT system is sustainable on the long run through an incremental cost recovery system.

6.5 Government instruments to promote RE

Three notable points on solar PV finance that came up during the course of the interview are: (1) the Renewable Portfolio Standard (RPS), (2) competitive bidding and (3) Fiscal support.

6.5.1 Renewable Portfolio Standard (RPS)

According to a respondent, RSP is considered as the least-cost option for RE development in many countries, RPS has a reputation for bringing down the cost of RE technologies and it creates a competitive market. RSP is a regulatory mandate to increase production of energy from renewable sources such as wind, solar, biomass and other alternatives to fossil and nuclear electric generation. It's also known as a renewable electricity standard. The RPS system has shown in many countries to be a sustainable policy to RE generators since the government will compensate them for their extra costs through subsidies. This option if considered by the

Nigerian government has the potential to create a RE market like solar PV in Nigeria that will be very competitive since Nigeria has the market and large RE resource potential. However, the Nigerian government should ensure the flexibility of targets and adjust it on the short-term bases. The respondent suggested that government should also take note of regional imbalance in pricing as some locations may have higher RE resource potential than others, while some may have the problems of electricity transmission and distribution.

6.5.2 Competitive Bidding

Competitive bidding mechanism is considered to be the most favourable policy for end users of electricity and the government in most countries, since it reduces the price of RE technologies through market-based pricing. The same respondent however warns that, the down-side of competitive bidding is that it may face the risk of price bids that are unsustainable on the long-run. Also extreme low price of energy/electricity may prevent investors and this should be taken into account by the Nigerian government if bidding system should be implemented.

6.5.3 Fiscal support

On fiscal support, it should be noted that tax incentives on investments can lead to reduction in operational efficiency. Findings from secondary sources made it clear that, this sometimes occur when the owners of the PV project receive the benefit of investment tax credit, after which the owner lose interest in maintenance and operation of the PV power plants. A more feasible approach will be production tax credit which motivates the RE owners to ensure an effective operation of the power plant. Another effective fiscal support pointed out by a respondent is the structural tax policy with strict enforcement mechanism followed by a good administrative system. In the Nigerian case, this will ensure that the incentives are efficiently utilized and the problems of tax payment and bad practices are avoided.

6.6 Insight for related intervention for commercial buildings in Nigeria

To answer the question ‘’what would be the related insights for scale-up of the related interventions for commercial building (new and existing) for Nigeria?’’ it was important to understand that the main factors driving energy efficiency are savings realised from a reduced need for investment in infrastructure (economy level) or savings on fuel expenses (individual entity level) as well as the mitigation of environmental effects and climate change (global level) by reduction of GHG emissions.

Any cost-related decision concerning energy efficiency, at the individual level, is based on a trade-off between an immediate cost and a future decrease in energy expenses expected from increased efficiency. The higher the energy price, observed or expected, the more attractive energy efficiency becomes.

Energy efficiency has three basic strategies to achieving minimized energy consumption in buildings (whole energy load reduction, efficiency of the systems, and on-site generation of electricity). But this is achievable depending on the scale of the facility and hours of operation, the use of advanced technology and mechanisms is more effective in enhancing energy efficiency during the buildings operational stage. The research work is built on the energy efficient principles which provided the essential tools needed to achieve low energy consumption in office building.

Inferring from various literatures and gathering information from the case studies indicated energy as a major problem and reducing its consumption is a paramount concern. Energy efficient buildings are beneficial in terms of economic growth, increased productivity, emission reduction and so on. It is expected that providing a large office building which is capable of reducing the amount of energy it consumes through provision of advanced technological means would act as an example of how the building industry can contribute to the economic growth of a country by saving money and using it elsewhere.

The general anticipation of this research is that, it will provide a model for the application of principles of energy efficiency not just in office buildings, but in any existing and every proposed building.

6.7 Conclusion

From finding, it became clear that securing financing for the upfront cost in Nigeria is difficult. The promoters of Renewable energy technology face the problems of high transaction costs and restricted access to capital. On the other hand the end users of renewable energy technology, especially the poor, face problems of access to credits. Lack of access to micro financing, high interest rates, poor business development skills by renewable energy system vendors and unsupportive climate for investments are some of the primary barriers to market growth at the moment.

Therefore, in order to support RE in Nigeria, funding requirements should be substantial. New investments are needed for research and exploitation activities. The required type of financing is long-term and should involve both foreign and domestic financing resources. Foreign investment capital will provide the greater proportion of needed funds. The Government should provide guarantees and financial frameworks aimed at stimulating the expansion of the renewable electricity market. Considering the risk element involved in financing renewable electricity projects. Government investments should enhance rates of return and shorten pay back periods in order to attract investors.

Additionally, the Federal Government should continuously improve the climate for enhanced funding of renewable electricity through equity, debt financing, grants and micro finance. Additionally, Government should be more committed to mobilizing resources through international cooperation, towards the development of renewable energy for sustainable development in Nigeria. Grant financing from agencies of government and independent foundations should also be promoted.

Owing to other competing needs, the Nigerian Government alone cannot continue to provide the major finance for developing the renewable energy sub-sector. Hence private sector participation is necessary and imperative. To attract foreign investments in the renewable energy sub-sector, the sub-sector will first need to be developed to a certain extent, via indigenous participation. To attract domestic banking sector participation, efforts should be made to sensitise them to renewable energy and to incentivise their investments in lending to renewable energy projects.

Exploration, production and conversion activities in the renewable energy sub-sector are characterized by large capital demands and often advanced technology. The capital formation capability of the country's private sector and the level of domestic technological development are still low, in relation to what are needed by the renewable energy sub-sector. Consequently, government and NGO’s had played a dominant role in investments in the sub-sector, while private sector presence, technological input and value added in energy sector activities have hitherto been overwhelmingly foreign, mainly from NGO’s.

If private sector participation in the renewable energy sub-sector is increased and government spending in the sector is optimised, the ability of the indigenous private sector, including ordinary Nigerian citizens, to participate and compete in the process should be encouraged, so as to allow for a secure and healthy development of the renewable energy sub-sector. The local content of value added in the renewable energy sub-sector activities should be raised to, and maintained at, a high level.

The integration of smart grid technology and renewables into the Nigerian electricity grid system will help the electricity crisis in the country. However, for smart grid technology to be realised in Nigeria, stable and operational grid as well as various technological integrations, enhancement and policy recommendation as discussed in section 6.5 that will support feed in tariff is required. The benefits of the smart grid technology will not only improve electricity production and efficiency in Nigeria, but will also enable electricity consumers to become producers of electricity and enhance Nigeria’s international competiveness.

Chapter 7

Conclusion and Recommendations

This report has identified the potential for energy efficiency and foresees the positive impact that implementing energy efficient lighting and systems performance could have on the energy demand and the environment in Nigeria.

7.1 Consolidation of findings and overall conclusions

This research's goal was to find the answer to the question: What is the potential of solar PV electricity generation through a retrofitting of the Department of Architectural Office Building (DAOB) as a case-study towards enhanced energy security, and what would be the responsive business model and policy framework to open up a wider transformation towards distributed energy generation with building integrated solar PV in Nigeria? To be able to answer the above question, the study employed the following research sub-questions.

- What is the current energy baseline consumption patterns and levels as well as related cost for the DAOB?
- How can energy efficiency optimised interventions with integrated PV-based DG reduce the energy consumption of DAOB?
- How would the cost of retrofitting DAOB compare to the status-quo coping mechanism of the building in the short and long term?
- What are the viable business model options for a PV retrofit of the DOAB building?
- What would be the related insights for scale-up of the related interventions for commercial building (new and existing) for Nigeria?

7.1.2 Research sub-question 1: What is the current energy baseline consumption patterns and levels as well as related cost for the DAOB?

The current baseline energy consumption pattern of the DAOB was determined from electricity bills as well as the outcome of the simulation performed. The bills and the outcome of the simulation show that the months of June, July, December and January are usually low in energy consumption due to the operation pattern of the building. The remaining months of the year consume energy more than these four months mentioned above due to the same reason.

As to the current baseline level of consumption, 12,408 kWh was estimated per annum from the bills. It was important to show the kWh/m^2/annum for the DAOB by dividing 12,408 by 1,014 (net area of the DAOB) to get 12.24 kWh/m^2/annum. This is extremely low when compared to what an average building consumed in Johannesburg (which is 200 kWh/m^2/annum). The low energy consumption of the building is due to the 2 hours daily electricity usage as well as the absence of HVAC in the building. Furthermore, from the result of the simulation, the annual consumption is 69,733 kWh/annum (68 kWh/m^2/annum). From this analysis, the DAOB is a low energy consuming building.

The current baseline consumption cost was established firstly from the monthly electricity bills charged to the building by the AEDC as well as the monthly cost of operating the building on stand-alone diesel generator. The annual cost of operating the building from the grid is ₦297,764 ($945) while the cost of operating the building annually from stand-alone diesel generator is ₦2,688,000 ($8,523). The current baseline consumption cost in a year from grid and diesel generator is ₦2,985,762 ($9,468)

7.1.3 Research sub-question 2: How can energy efficiency optimised interventions with integrated PV-based DG reduce the energy consumption of DAOB?

The study has provided an overview of how an energy efficiency retrofit (both passive and active) could reduce energy consumption in existing office building. The areas that provided opportunity for energy efficiency optimisations are: (1) provision of shading device on the south/east façade of the building with 17% savings made on the overall consumption, (2) provision of occupancy and lighting sensors with 17% savings achieved on the overall energy utilized annually and (3) replacement of office equipment, computer and lighting to more energy efficient ones with 13% saving made on the overall consumption. In all, a total of 47% was made on the overall consumption after optimisation.

The initiatives made some significant impact in the following extents: (a) reduction in the baseline energy consumption of the building from 69,733 kWh to 37,298 kWh, (b) reduction in kWh/m^2/annum of the building from 69 kWh/m^2/annum to 39 kWh/m^2/annum, (c) reduction in the annual CO^2 emission from 42,044 kg to 22,488 kg, and (d) reduction in the annual cost of operating the building from ₦1,673,592 ($52,712) to ₦895,152 ($2,835).

The study has also demonstrated the generation potential in the DAOB through a solar PV integration. Roof is not a constraining factor in going solar on the DAOB. The outcome of the evaluation conducted on the available roof area for solar panel installation revealed that the available roof area on the case study building is capable of 80 numbers of solar panel installation, this is roughly times 4 of what the building required to supply its optimised annual energy demand.

7.1.4 Research sub-question 3: How would the cost of retrofitting DAOB compare to the status-quo coping mechanism of the building in the short and long term?

Based on the financial analysis performed in section 5.2.2.2, it saves more to optimise and integrate PV technology in the DAOB than to choose to remain in status-quo for the following reasons; erratic nature of electricity supply from the grid, annual electricity tariff escalation, annual fluctuation/escalation in diesel price, and cost of maintaining the generating set. In a worst-case scenario, if the savings on electricity can payback the cost of PV in just 4 years and 6months (based on simulation), or the savings made by not paying electricity bills and by not using diesel generator to power the building (based on actual scenario), then, its more beneficial both in the short and long term to retrofit and integrate solar PV system in place of the status-quo coping mechanism.

7.1.5 Research sub-question 4: What are the viable business model options for a PV retrofit of the DOAB building?

Given that solar PV technology is still at its infancy in Nigeria, there seems to be no concrete business model for its proper deployment, however, as discussed in section 6.2, within the renewable energy vendor, there is a model that is similar to a Power Purchase Agreement. With this kind of model a developer arranges for the design, permitting, financing and installation of a solar energy system on the DAOB at little to no cost. The developer sells the power generated to the institution at a fixed rate that is typically lower than the local utility's retail rate of ₦24 ($0.8) per kWh. This lower electricity price (say ₦12) serves to offset the customer's purchase of electricity from the grid while the developer receives the income from these sales of electricity as well as any tax credits and other incentives generated from the system. The agreement range from 10 to 25 years and the developer remains responsible for the operation and maintenance of the system for the duration of the agreement. At the end of the PPA contract term, a customer may be able to extend the PPA, have the developer remove the system or choose to buy the solar energy system from the developer.

7.1.6 Research sub-question 5: What would be the related insights for scale-up of the related interventions for commercial building (new and existing) for Nigeria?

Insight from this study shows that the major drivers of energy efficiency are savings achieved from a reduced need for investment in infrastructure (economy level) or savings on fuel expenses (individual entity level) as well as the mitigation of environmental effects and climate change (global level) by reduction of GHG emissions.

Insight from this study also indicated energy as a major problem and reducing its consumption is a vital concern. It is evident from the study that energy efficient buildings are beneficial in terms of economic growth, increased productivity, emission reduction and so on.

Therefore, the reduction of the amount of energy utilised in office building through passive means as well as the provision of advanced technological means would act as an example of how the building industry can contribute to the economic growth of a country by saving money and using it elsewhere.

To achieve energy efficiency development in Nigeria, insight from the study revealed that the following barriers must be overcome: (1) lack of policy and legislation, (2) lack of trained energy efficiency professionals and research materials on energy efficiency, (3) importation of used machines, (4) inefficient metering system and low electricity pricing and (5) proliferation of inefficient equipment.

More so, adoption of decentralized electricity governance model would make for participatory, all-inclusive regime that makes it possible to integrate and engage the services or labour of trained local people closest to the projects.

There is no PPA or FiT plan for renewable energy generation to the national grid. A system of rational expectations between renewable electricity producers and the grid operators are imperative for the growth in grid-based renewables like rooftop solar PV. Legally binding long-term PPA or guaranteed FiT are a must since they provide comfort for the developers of renewable as well as lenders, and would also encourage the expansion of renewable electricity development through investments.

7.2 Recommendations

7.2.1 Recommendations on Energy Efficiency

Energy efficiency market is a start-up market. As part of the process, the government has started to draft mechanisms to encourage investments in energy efficiency through policies, strategies and support provisions. Up to now there is neither real experience, nor historical data available. At the same time, it is now well understood that energy efficiency is a source of energy.

The study's main recommendations are:

(1) To familiarise institutions with the concepts of energy efficiency and energy management, and to build capacities for policy development, implementation and monitoring;
(2) To finalise, approve and operationalize the National Energy Efficiency Policy (NEEP) including the mix of regulatory policy and public financing mechanisms in order to give a clear basis for decision making to investor;
(3) To develop financial and investment instruments adapted to each energy efficiency market segment (for example, industry/buildings: to offer incentives through savings from a better conversion rate and for the private household segment: microfinance schemes; non-bank financial institutions; bank consumer loans for appliances; leasing provisions; donor lending programmes);
(4) To create a greater government and public awareness in two areas: the use of efficient diesel generators and in the introduction of standards and labels;
(5) For industry to focus primarily on the establishment of an energy efficiency financing facility designed for small- and medium-sized enterprises (SMEs);
(6) For buildings (with a primary focus on public buildings) to develop and implement energy building codes;
(7) For household appliances to introduce energy efficiency standards as a first priority.

7.2.2 Recommendations on Grid Renewable Energy

The reasoning for on-grid renewables is strong. On the one hand, power plants overcome geographical grid challenges and on the other hand, renewable energies offer fast-delivery solutions and are cost-effective especially when replacing diesel generation capacity. At the same time, challenges are highlighted in what could be a key pioneering area.

The study's main recommendations are:

(1) To set-up a structured and reliable support mechanism such as a Bidding System for utility scale renewable energy and a feed-in tariff for small renewable energy projects

to focus efforts on development of solar photovoltaic (PV) farms and small hydropower plants (primary focus on quick wins);

(2) To align policies between governmental institutions, thus mitigating potential conflicts and to continue the support of the nation's current electricity delivery system;

(3) To strengthen key stakeholders capacity in order to ensure the achievement of the policy targets and to monitor and evaluate its results based on sound data and reliable statistical records;

(4) To develop financial and investment instruments including public-private partnerships (PPPs) and promote the contribution of private banks and International Financial Institutions (IFIs).

7.3 Further research recommendations

Further studies should be conducted to identify the optimal thermal performance requirements for the building envelope for all building typologies and construction systems in Nigeria in order to set cost optimal requirements in the future building code. This study has identified the large potential for energy efficiency and foresees the positive impact that implementing some key energy saving techniques in design and improving envelope, lighting and systems performance could have on the energy demand and the environment in Nigeria. Additionally, with the new energy efficiency regulations being developed for Nigeria, further studies should be conducted to determine how the energy saving mechanism would impact the energy consumption of existing buildings.

7.4 Contribution to Knowledge

The aim of this section is to draw out some important contribution to the body of knowledge captured in this report, below is an overview of contribution to knowledge identified in this study;

(1) The principles of energy efficiency can positively reduce energy consumption, as this research has enumerated the best way to achieve this is by installing low energy rated appliances and equipment and monitoring of its usage. The building materials are another important aspect.

(2) Energy conscious strategy in buildings reduces cost, improves the environment, and redefines architectural forms. This is because the project draws the designer's attention to how a building consumes energy throughout its life span so that designers will

understand the implication of every component he inserts into the design from inception to completion thereby making designers more environmental and energy conscious in their designs so that the building industry would make a positive impact in the nearest future. The designers will reduce cost either in the initial stages (using low embodied energy materials), or in the long run (through the building's operation).

(3) Achieving a conducive and comfortable working condition within a building is the primary reason why a lot of energy is consumed during the building's operation stage. This is because most electrical and mechanical devices within the building are usually used for adjusting interior conditions to suite the users.

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Appendix A

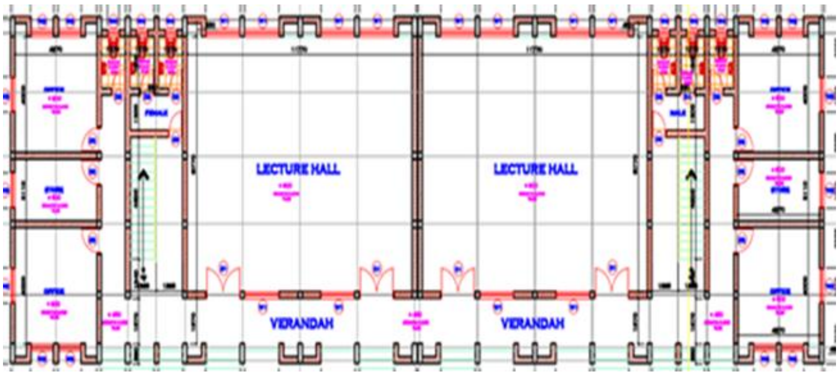

Figure A1: Typical ground and upper floor

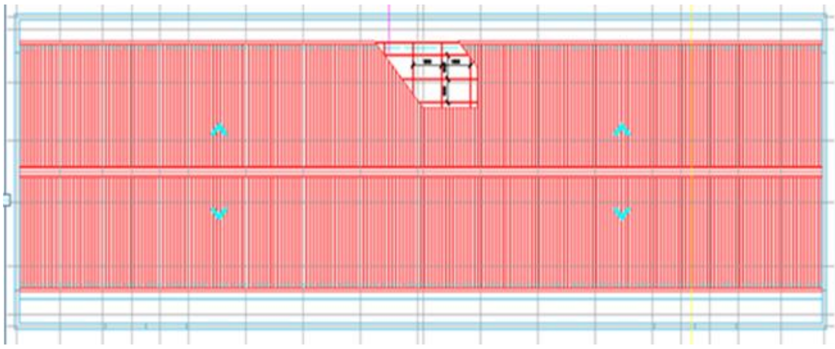

Figure A 2: Roof plan

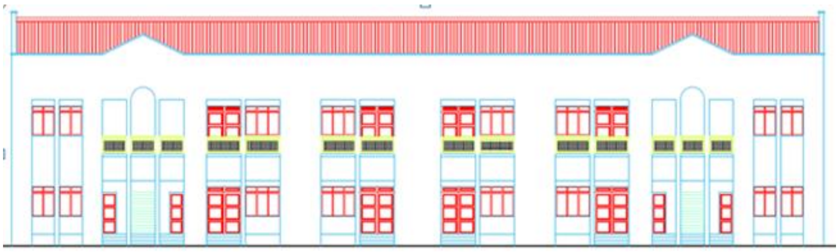

Figure A3: North facing façade

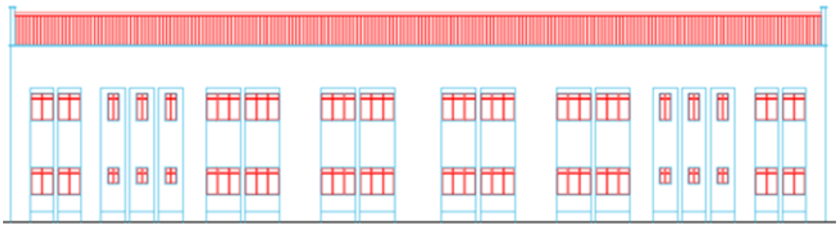

Figure A4: South facing facade

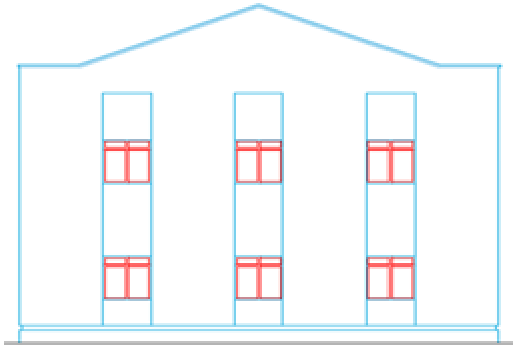

Figure A5: Typical west and east facade

Figure A6: Picture of the north façade

Figure: A7. Picture of offices showing some office equipment

Appendix B

S/N	DATE	NAME OF FEEDER	CAUSE OF INTERRUPTION	INTERRUPTION TIME				TOTAL DURATION
				START		END		
				DATE	TIME (HH:MM)	DATE	TIME (HH:MM)	
1	01/09/16	FELELE FDR III	LOAD MANAGEMENT	01/09/16	10:00 AM	02/09/16	6:00 AM	20 HOURS
2	02/09/16	FELELE FDR III	LOAD MANAGEMENT	02/09/16	10:00AM	03/09/16	6:00 AM	20 HOURS
3	03/09/16	FELELE FDR III	LOAD MANAGEMENT	03/09/16	10:00AM	04/09/16	6:00 AM	20 HOURS
4	04/09/16	FELELE FDR III	LOAD MANAGEMENT	04/09/16	10:00AM	05/09/16	6:00 AM	20 HOURS
5	05/09/16	FELELE FDR III	LOAD MANAGEMENT	05/09/16	10:00AM	06/09/16	6:00 AM	20 HOURS
6	06/09/16	FELELE FDR III	LOAD MANAGEMENT	06/09/16	10:00AM	07S/09/16	6:00 AM	20 HOURS
7	03/09/16	FELELE FDR III	LOAD MANAGEMENT	03/09/16	10:00AM	03/09/16	6:00 AM	20 HOURS
8	03/09/16	FELELE FDR III	LOAD MANAGEMENT	03/09/16	10:00AM	03/09/16	6:00 AM	20 HOURS
9	03/09/16	FELELE FDR III	LOAD MANAGEMENT	03/09/16	10:00AM	03/09/16	6:00 AM	20 HOURS
10	03/09/16	FELELE FDR III	LOAD MANAGEMENT	03/09/16	10:00AM	03/09/16	6:00 AM	20 HOURS
11	03/09/16	FELELE FDR III	LOAD MANAGEMENT	03/09/16	10:00AM	03/09/16	6:00 AM	20 HOURS
12	03/09/16	FELELE FDR III	LOAD MANAGEMENT	03/09/16	10:00AM	03/09/16	6:00 AM	20 HOURS
13	03/09/16	FELELE FDR III	LOAD MANAGEMENT	03/09/16	10:00AM	03/09/16	6:00 AM	20 HOURS
14	03/09/16	FELELE FDR III	LOAD MANAGEMENT	03/09/16	10:00AM	03/09/16	6:00 AM	20 HOURS

15	03/09/16	FELELE FDR III	LOAD MANAGEMENT	03/09/16	10:00AM	03/09/16	6:00 AM	20 HOURS
16	03/09/16	FELELE FDR III	LOAD MANAGEMENT	03/09/16	10:00AM	03/09/16	6:00 AM	20 HOURS
17	03/09/16	FELELE FDR III	LOAD MANAGEMENT	03/09/16	10:00AM	03/09/16	6:00 AM	20 HOURS
18	03/09/16	FELELE FDR III	LOAD MANAGEMENT	03/09/16	10:00AM	03/09/16	6:00 AM	20 HOURS
19	03/09/16	FELELE FDR III	LOAD MANAGEMENT	03/09/16	10:00AM	03/09/16	6:00 AM	20 HOURS
20	03/09/16	FELELE FDR III	LOAD MANAGEMENT	03/09/16	10:00AM	03/09/16	6:00 AM	20 HOURS
21	03/09/16	FELELE FDR III	LOAD MANAGEMENT	03/09/16	10:00AM	03/09/16	6:00 AM	20 HOURS
22	03/09/16	FELELE FDR III	LOAD MANAGEMENT	03/09/16	10:00AM	03/09/16	6:00 AM	20 HOURS
23	03/09/16	FELELE FDR III	LOAD MANAGEMENT	03/09/16	10:00AM	03/09/16	6:00 AM	20 HOURS
24	03/09/16	FELELE FDR III	LOAD MANAGEMENT	03/09/16	10:00AM	03/09/16	6:00 AM	20 HOURS
25	03/09/16	FELELE FDR III	LOAD MANAGEMENT	03/09/16	10:00AM	03/09/16	6:00 AM	20 HOURS
26	03/09/16	FELELE FDR III	LOAD MANAGEMENT	03/09/16	10:00AM	03/09/16	6:00 AM	20 HOURS
27	03/09/16	FELELE FDR III	LOAD MANAGEMENT	03/09/16	10:00AM	03/09/16	6:00 AM	20 HOURS
28	03/09/16	FELELE FDR III	LOAD MANAGEMENT	03/09/16	10:00AM	03/09/16	6:00 AM	20 HOURS
29	03/09/16	FELELE FDR III	LOAD MANAGEMENT	03/09/16	10:00AM	03/09/16	6:00 AM	20 HOURS
30	03/09/16	FELELE FDR III	LOAD MANAGEMENT	03/09/16	10:00AM	03/09/16	6:00 AM	20 HOURS

Table B1: Daily interruption table for Felele area of Lokoja

S/N	ITEMS	CAPACITY
1	Manufacturer	FG Wilson
1	Engine Make	Perkins.
2	Fuel Tank Capacity	180 Litres.
3	Fuel consumption (100% load)	15 litres (in about 5 hours)
4	Fuel consumption (50%)	30liters (in about 10 hours)

Table B2: Generator capacity

S/N	ZONES/ SPACES	TOTAL FLOOR AREA (m^2)	TOTAL WATTAGE (W) Rate x No	LIGHT POWER DENSITY (LPD) W/m^2	SCHEDULE OPERATION HOUR/DAY
1	Whole building level	1014.29	5760	5.68	15
2	Ground floor level	507.14	2480	4.9	15
3	Upper floor level	507.14	2480	4.9	15
4	Office 1	16.8	80	4.7	8
5	Office 2	16.8	80	4.7	8
6	Office 3	16.8	80	4.7	8
7	Office 4	16.8	80	4.7	8
8	Office 5	16.8	80	4.7	8
9	Office 6	16.8	80	4.7	8
10	Office 7	16.8	80	4.7	8
11	Office 8	16.8	80	4.7	8
12	Classroom 1	103	480	4.6	15
13	Classroom 2	103	480	4.6	15
14	Classroom 3	103	480	4.6	15
15	Classroom 4	103	480	4.6	15
16	Store 1	8.82	60	6.8	N/A
17	Store 2	8.82	60	6.8	N/A
18	Store 3	8.82	60	6.8	N/A
19	Store 4	8.82	60	6.8	N/A
20	Washroom 1	6.84	60	8.77	8
21	Washroom 2	6.84	60	8.77	8
22	Washroom 3	6.84	60	8.77	8
23	Washroom 4	6.84	60	8.77	8

Table B3: Light Power Density LPD

S/N	ZONES/ SPACES	TOTAL FLOOR AREA (m^2)	TOTAL WATTAGE (W) Rate x No	COMPUTER W/m^2	SCHEDULE OPERATION HOUR/DAY
1	Whole building level	1014.29	5636	5.56	8
2	Ground floor level	507.14	2818	5.56	8
3	Upper floor level	507.14	2818	5.56	8
4	Office 1	16.8	672	40	8
5	Office 2	16.8	672	40	8
6	Office 3	16.8	222	13.2	5
7	Office 4	16.8	222	13.2	5
8	Office 5	16.8	222	13.2	5
9	Office 6	16.8	222	13.2	5
10	Office 7	16.8	672	40	8
11	Office 8	16.8	672	40	8
12	Classroom 1	103	740	7.18	6
13	Classroom 2	103	740	7.18	6
14	Classroom 3	103	740	7.18	6
15	Classroom 4	103	740	7.18	15

Table B4: Computer

S/N	ZONES/ SPACES	TOTAL FLOOR AREA (m^2)	TOTAL NO OF PEOPLE IN A SPACE	OCCUPANCY No of people/m^2	SCHEDULE OPERATION HOUR/DAY
1	Whole building level	1014.29	144	0.142	15

2	Ground floor level	507.14	72	0.142	15
3	Upper floor level	507.14	72	0.142	15
4	Office 1	16.8	3	0.17	8
5	Office 2	16.8	3	0.17	8
6	Office 3	16.8	3	0.17	8
7	Office 4	16.8	3	0.17	8
8	Office 5	16.8	3	0.17	8
9	Office 6	16.8	3	0.17	8
10	Office 7	16.8	3	0.17	8
11	Office 8	16.8	3	0.17	8
12	Classroom 1	103	30	0.29	15
13	Classroom 2	103	30	0.29	15
14	Classroom 3	103	30	0.29	15
15	Classroom 4	103	30	0.29	15

Table B5: Occupancy (Person/m^2)

S/N	ZONES/ SPACES	TOTAL FLOOR AREA (m^2)	TOTAL WATTAGE (W) Rate x No	EQUIPMENT W/m^2	SCHEDULE OPERATION HOUR/DAY
1	Whole building level	1014.29	4890	4.8	15
2	Ground floor level	507.14	2720	5.4	15
3	Upper floor level	507.14	2720	5.4	15
4	Office 1	16.8	765	45.5	8
5	Office 2	16.8	765	45.5	8
6	Office 3	16.8	75	4.5	8
7	Office 4	16.8	75	4.5	8
8	Office 5	16.8	75	4.5	8

9	Office 6	16.8	75	4.5	8
10	Office 7	16.8	765	45.5	8
11	Office 8	16.8	765	45.5	8
12	Classroom 1	103	675	6.5	15
13	Classroom 2	103	675	6.5	15
14	Classroom 3	103	675	6.5	15
15	Classroom 4	103	675	6.5	15

Table B6: Equipment

Appendix C.

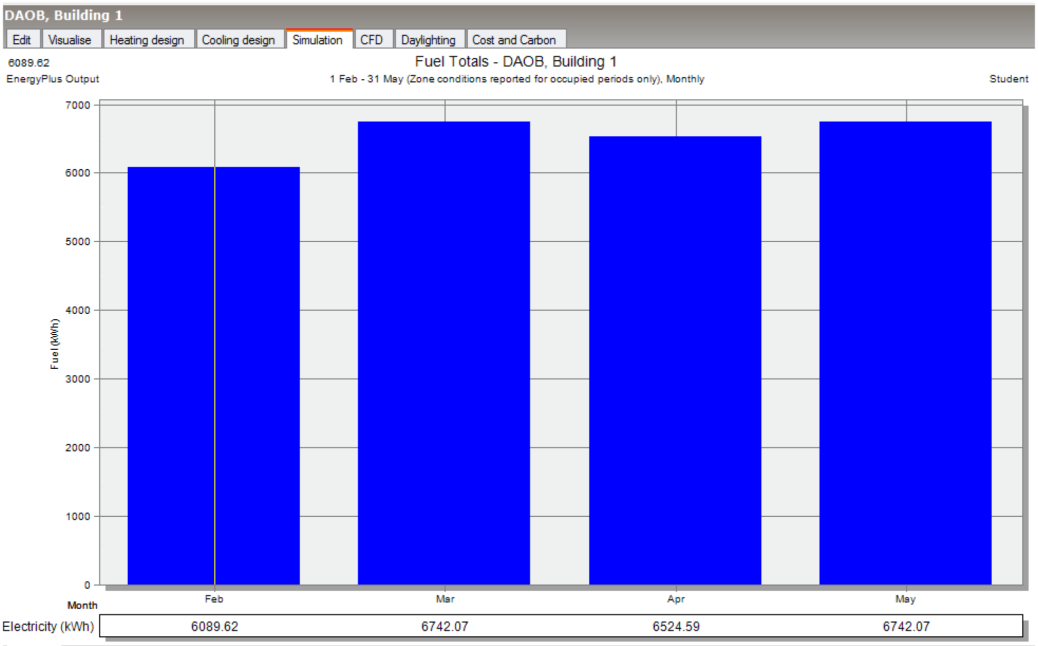

Figure C1: Monthly consumption of the DAOB from February to May

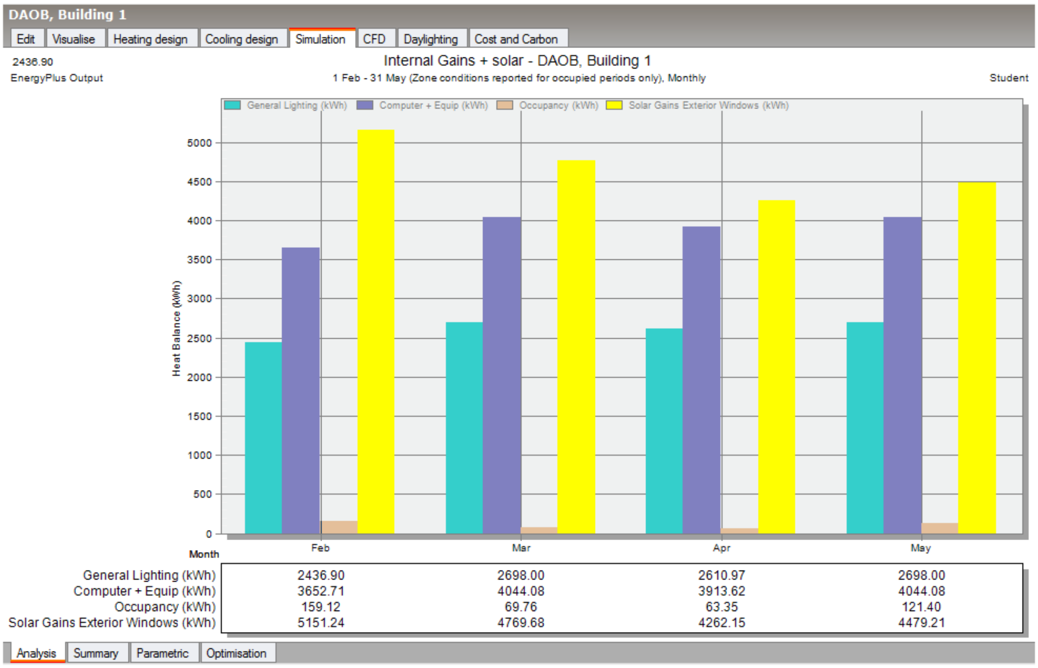

Figure C2: Internal gains for the months of February to May

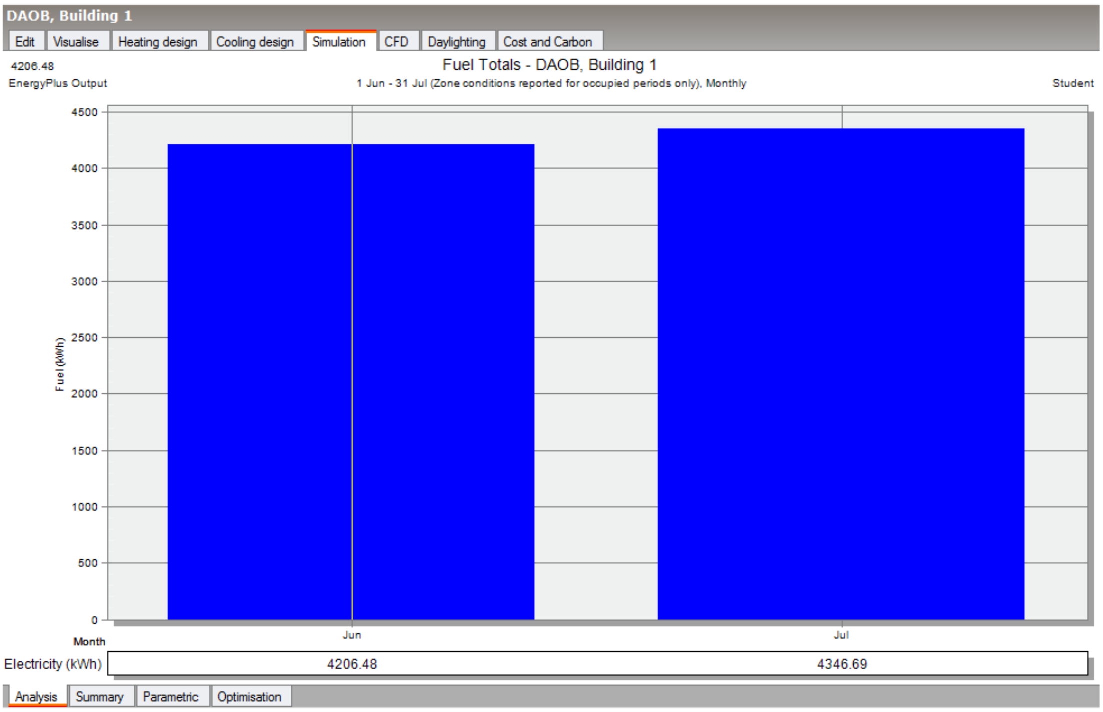

Figure C3: Monthly consumption for June and July

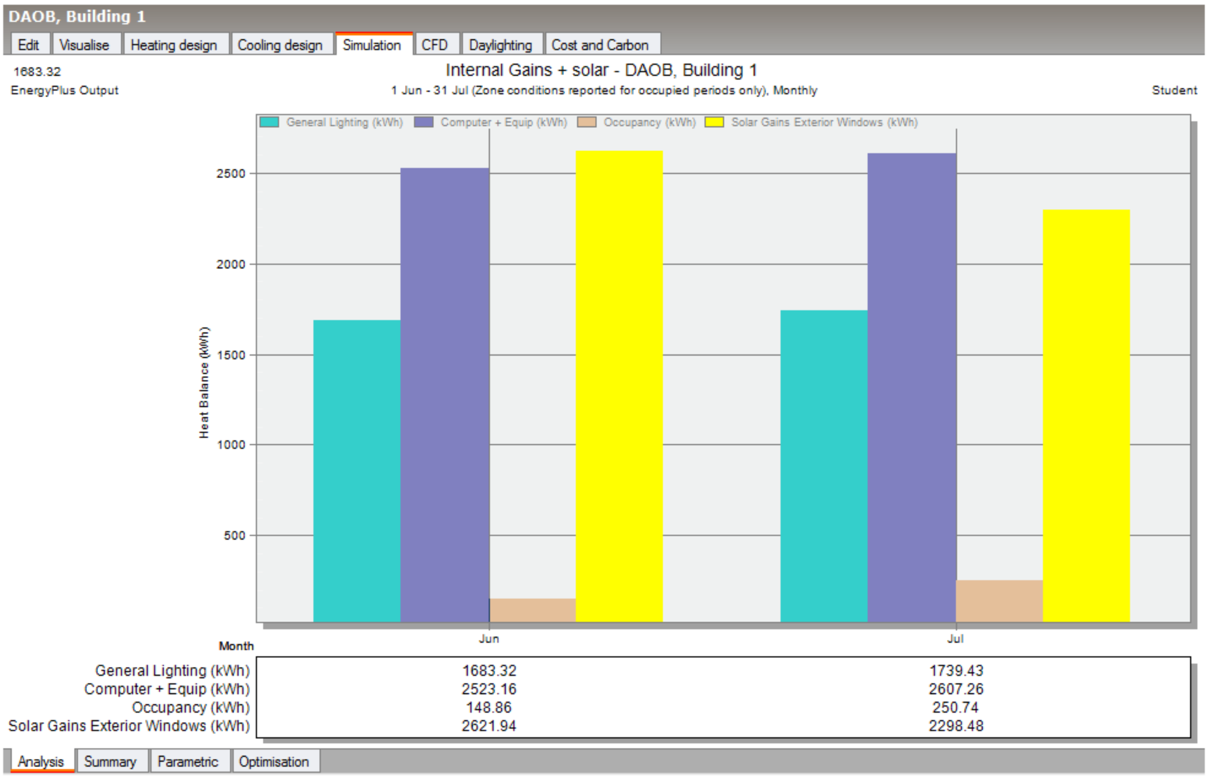

Figure C4: Internal gains for June and July

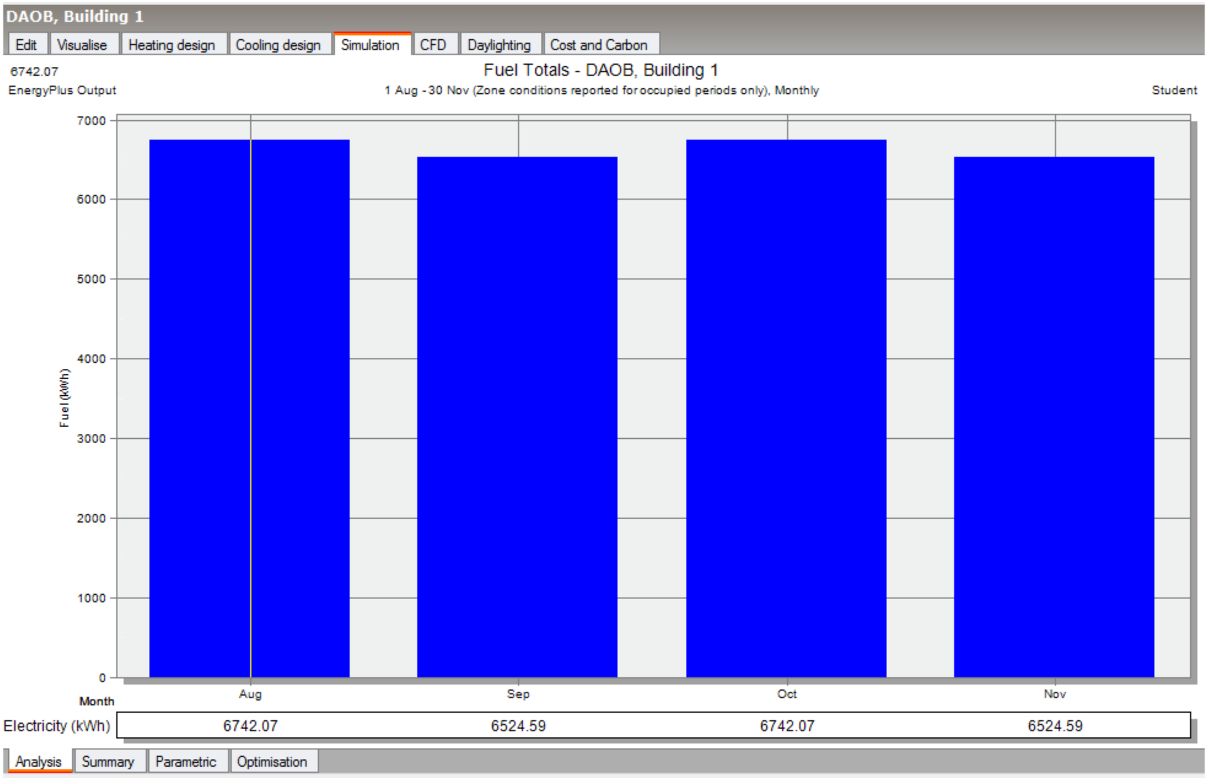

Figure C5: Monthly fuel consumption from August to November

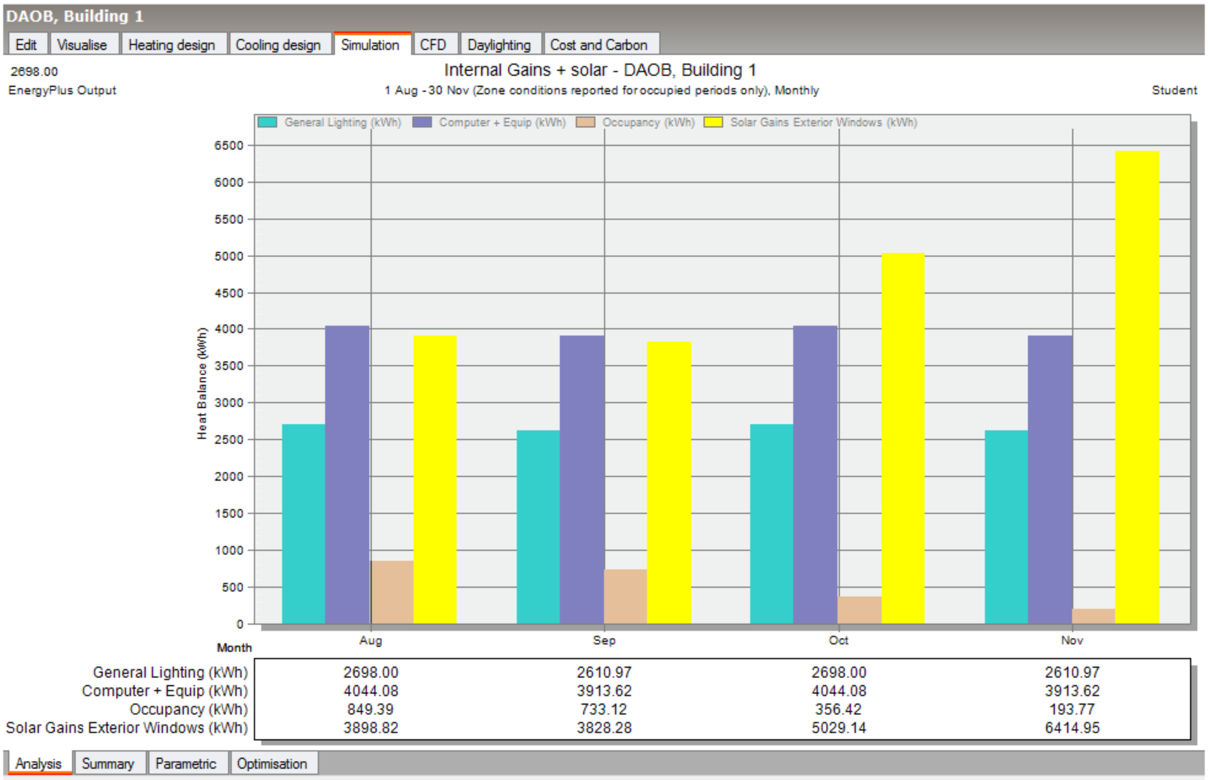

Figure C6: Internal gains from August to November

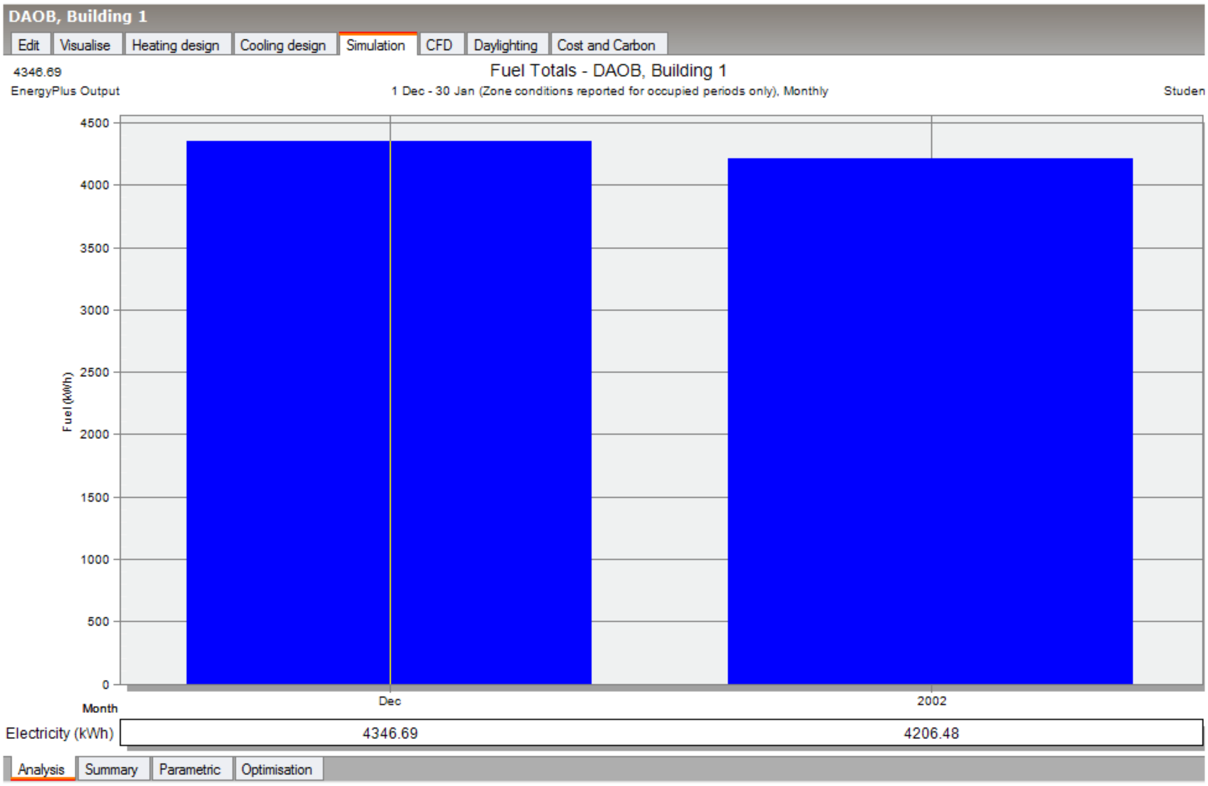

Figure C7: Monthly fuel for the Months of December and January

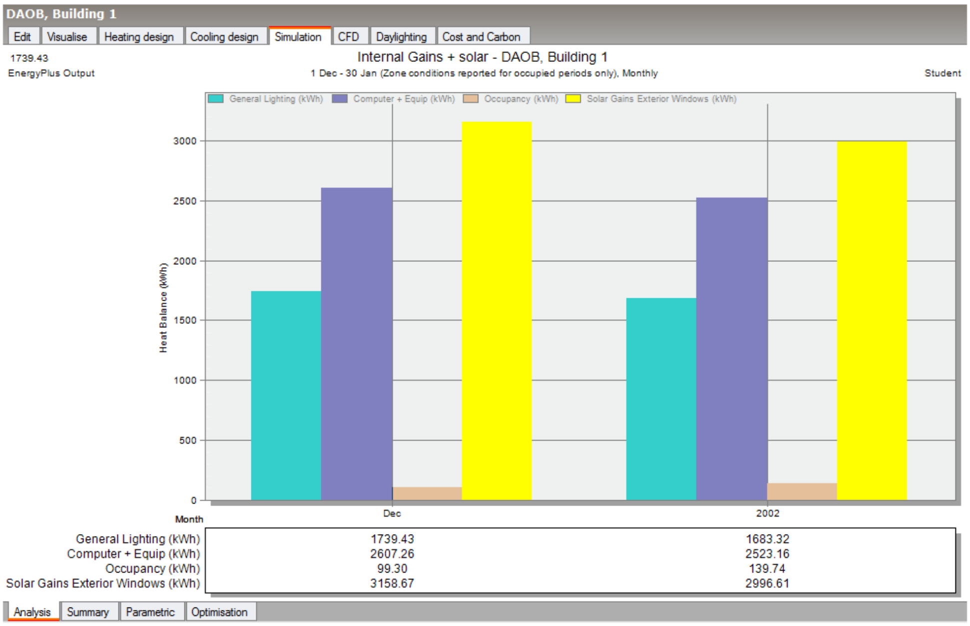

Figure C8: Internal gains for December and January

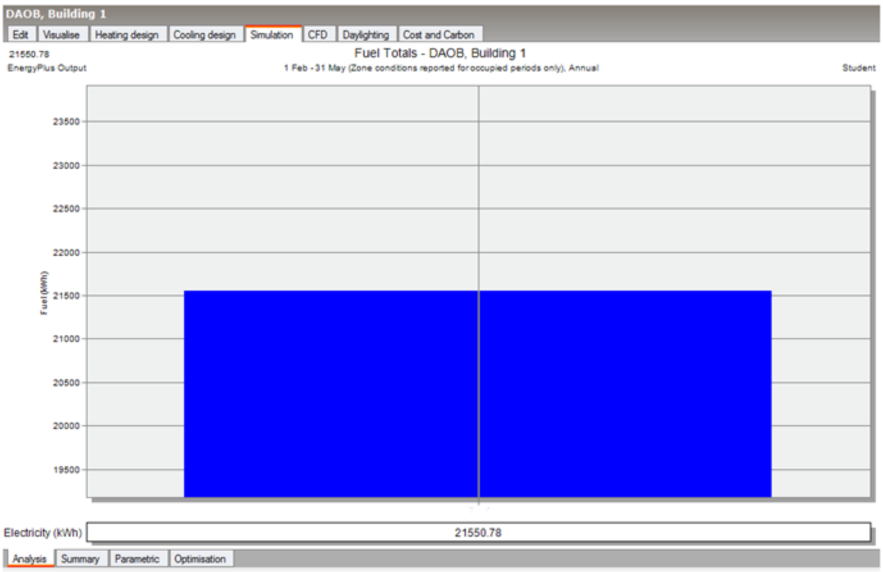

Figure C9: Optimised energy consumption after the installation of shading device.

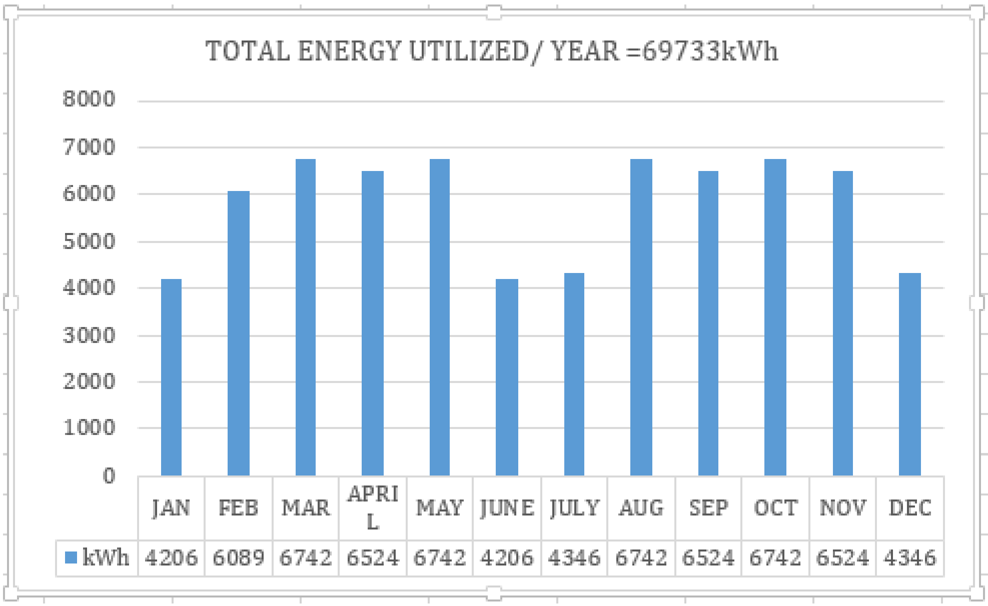

Figure C10: Total annual consumption of the DAOB

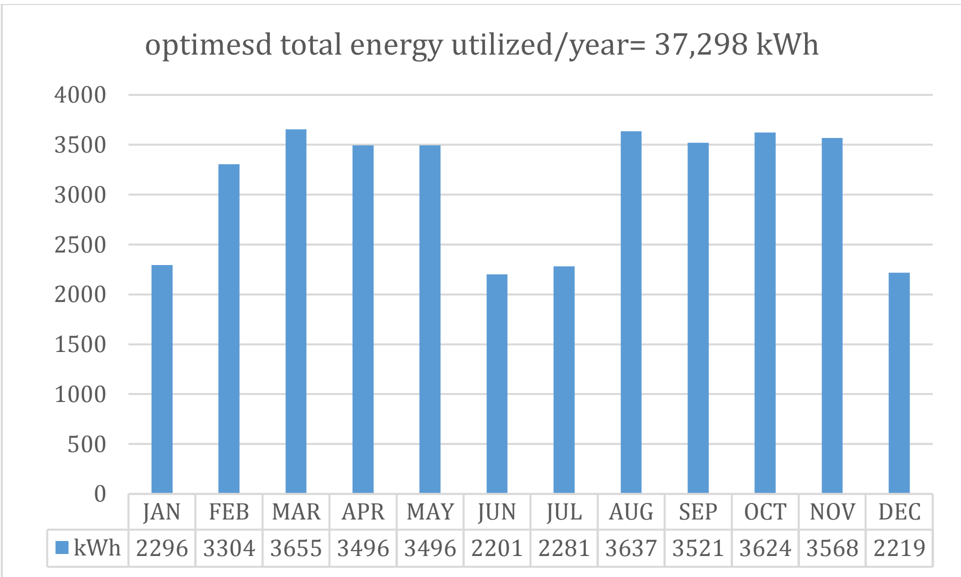

Figure C10: Optimised total annual consumption of the DAOB