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Submitted in partial fulfillment of the requirements for the Master degree in ENERGY ENGINEERING

Presented by

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MODELING AN ARTIFCIAL INTELLIGENCE- BASED ENERGY MANAGEMENT FOR HOUSEHOLD/MINI-GRID IN SUB-SAHARAN AFRICA: A CASE STUDY OF NIGERIA

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PAN AFRICAN UNIVERSITY

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A thesis submitted to the Pan African University Institute of Water and Energy Sciences (including Climate Change) in partial fulfillment of the requirements for the degree of Master of Science in Energy (Engineering option).

By

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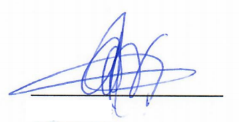
Dr. Erick Tambo		30/09/2020
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Dedication

I dedicate this work to God Almighty without whom none of my success would be possible.

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Biographical sketch

Rabiat Abdulaziz Ohunene is from Nigeria. She has a background in physics from the University of Ilorin, Nigeria and holds a master's degree in mathematical sciences from the African Institute for mathematical sciences (AIMS-Cameroon). She further pursues a second master's degree in Energy Engineering at the Pan African University for Water and Energy Sciences in Algeria. Her research interest span over Energy management, machine learning, and optimization. She look forward to a PhD opportunity in the field of energy management with AI.

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Abbreviations

AI	Artificial Intelligence
AMI	Advance Metering Infrastructure
ANN	Artificial Neural Network
DES	Distributed Energy System
DRE	Distributed Renewable Energy
DSM	Demand Side Management
EAC	East African Community
FIS	Fuzzy Inference System
GA	Genetic Algorithm
HEM	Home Energy Management
HEMS	Home Energy Management System
ICT	Information and Communications Technology
IEA	International Energy Agency
IoT	Internet of Things
IRENA	International Renewable Energy Agency
MYTO	Multi-Year-Tariff-order
NESI	National Electricity Supply Industry
NERC	Nigerian Electricity RegulationCommission
NREL	National Renewable Energy Lab
PLC	Power Line Communication
PV	Photovoltaic

SG	Smart Grid
SHEMS	Smart Home Energy Management System
SSA	Sub Saharan Africa
SSM	Supply side management

Abstract

It is no longer a news up to 600 million people living in the Sub-Saharan Africa (SSA) do not have access to electricity and 80% of them are located in the rural areas of the continent. The need for energy conservation especially electricity is of crucial importance as it is an economic solution to the problem of energy shortage and atmospheric carbon reduction. Buildings has been identified among the top largest world energy consumption accounting for up to 40% and in order to maximize energy conservation, there is need to put in place an effective energy management strategy.

The role of Artificial technology has also been displayed by researchers in the promotion of energy management. Most of past literatures in the line of energy management strategies proposed various energy management model based on smart grid and smart meter technology, demand side management, home energy management schemes and management based on Artificial Intelligence. However, majority of these proposed models are focused on the Urban regions mostly in developed countries. There are very few literatures focusing on energy management model strategy based on Artificial intelligence. Hence there is a knowledge gap.

The aim of this work is to model an Artificial intelligence-based energy management for households and mini-grid in SSA, specifically Nigeria. Genetic algorithm was used on smart meter-like data to optimize the energy consumption of households (i.e. low, middle and high income earners) for 24 hours in both weekday and weekend. To achieve this aim, we determine the typical load profile of a mini-grid setting (for household and commercial load profile), develop a simulation of smart meter-like data and develop an energy management system to optimize electricity consumption during a week day and weekend in a household.

Based on experimental results; the energy (and consumption) saved during week day for high, middle- and low-income earners are 16.74%, 9.9% and 32.55%, respectively. Similarly, the corresponding cost and consumption saved during weekends for high, middle- and low-income earners are 6.11%, 19.39% and 32.20%, respectively. The smart system algorithm will not only help the consumer to reduce electricity cost by reducing consumption but also help to reduce demand at the grid level.

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1. Introduction

1.1 Background of Study

Among the major concerns and pressing issues in the world today is the is the issue of energy security and access, energy efficiency as well as energy conservation. The demand for energy is on a constant increase as the world population and consumption is growing rapidly [59]. Energy has been an essential commodity right before the period when mankind work with stones and sticks to this modern era of rapid industrialization. The last decade of the 20th century to the beginning of the 21st century (1990 - 2014) marks a period of rapid increase in the world energy consumption at a rate of 151% [19, 62]. The population growth of Africa stands among the fastest and youngest in the world. In fact, according to the International Energy Agency (IEA) [43], one out of two people increase in the world population between today and 2040 are more likely to be from African. It is a well-known fact access to reliable energy system is very crucial to sustainable development of a nation [25, 55]. Energy is required for the development of many other sectors such as the Agricultural, Health, Transportation, Housing and soon. Access to reliable and sustainable energy can improve the economy of a country while also providing job opportunities for the citizens. However, in Africa, despite the rapid increase in population and demand for energy, there is still huge deficit of energy access especially in Sub-Saharan region of the continent. The continent is plague with persisting low access to electricity and clean cooking fuel which has a negative effect on development. According to IEA 2019 [43] report on Africa energy outlook, up to 600 million people have no access to electricity and 900 million people lacking access to clean cooking fuel but unfortunately, the efforts being put in place to combat this energy deficit is still outpaced by the population growth. Attentions are majorly focus on the urban region because of remoteness and thus cost of extending electricity to the rural settlements. Consequently, only about 1% of rural population in some Sub-Saharan African (SSA) countries (for example South Sudan, D. R. of the Congo, Chad, Central African Republic, Guinea, Niger, Mauritania, Burkina Faso) have access to electricity [36]. It is estimated that by 2030, about 530million people will still lack access to electricity with nearly a billion-lacking access to clean cooking oil in Africa [43]. The heat of Africa's energy setback is more pronounced in the Sub-Saharan Africa where electrification rate grows at a slower pace compare to the rest of the world. Africa is a home to overwhelming amount of energy resources both the conventional (fossil fuel) and the renewable energy sources (Solar, Wind, Biomass, Geothermal and Hydro). Fossil fuels which are the major source of energy supply is characterized with two major problems. First is the adverse effect these energy sources have on the environment which is the release of carbon dioxide gases into the atmosphere thereby causing global warming [11]. The second problem is the depletion of these energy resources with time due to their non-renewability within a human life-time frame. The consequences of this is an increase in the cost of energy with time which will result in a gradual increase in the energy cost allocation in the residential and commercial building budget [11]. Hence there is need for increase in investment in the area of renewable energy to complement the supply from the conventional sources. Furthermore, it is essential to upgrade the power sector by investing more on project such as grid extension, grid densification, mini-grids and standalone system in order to meet the exploding increase in electricity demand with time. The conventional grid systems in SSA faces a major setback like unreliability, high electrical tariff, poor support for incorporation of renewable energy sources, frequent blackout and brownout due to grid overload and high cost of reaching rural settlements in remote areas. To reach out and meet the electricity needs of these areas, the best solution is the decentralized energy technology [16], such as Mini-grids, Micro-grids and Standalone energy system. Mini-grids system a potential solution of electricity access for settlements cut out from the reach of the central grid system. The mini-grid system has the ability to be powered by hybrid energy sources such as renewable energy sources with the diesel engine as standby power supply. With the decreasing cost of Solar PV technology and storage system, the adoption of mini-grid system for rural has started gaining momentum although the cost is still high [16]. For example, Nigeria since 2010 has worked towards scaling up her mini-grids energy system and currently having up to 10 established commercial mini-grid located across the country with more still under construction [61]. Tanzania is the leading SSA country in terms of Mini-grid projects development with 109 already installed mini-grids serving up to 184,000 customers and a net capacity of 157.7MW [54]. According to a report [14], as at 2015 Kenya already have 15 established Mini-grid system with more on-going projects coming up. The penetration of Mini-grid electricity system is expected to penetrate more across various rural and urban regions in Africa as the mini-grid have the potential to power households as well as productive use of energy such as agriculture, schools, streetlight, milling and so on [16]. A potential way by which the existing mini-grids system and subsequent ones to be established in Africa can be upgraded and manage is with the integration of digital technology. Many authors [36, 16, 25] have agreed that digitalization of power sectors in Africa will be a key driver to the transformation of the power sector in SSA. The advancement of digital concepts such as, Artificial Intelligence (AI), Machine Learning, Internet of things (IoT), Big data, Smart grid system and smart metering technology has brought about a turning point in various application including the power sector. Digitalization in power sectors helps to enhance the connectivity among the power producer, the grid operators and the end users by allowing real time operational information flow between equipment at any point in the energy system [22]. Furthermore, inefficiency in the energy sector is reduced, improve in reliability and reduced cost of energy, decrease in frequent black outs and brown outs as there will be balance improved demand and supply. In essence, digital technology application in the power sector can help to improve grid stability and reliability, demand and supply forecast, efficient demand side management, optimize energy storage operations as well as other applications [23]. The smart grid system is a concept that involves the combined use of communication network and automation devices to enable control strategies and optimization of the electric network with real - time data processing [34]. Technology such as smart metering system, sensors and digital network management devices allows for bi-directional flow of data and information between the grid and end-user in a smart grid setting. The convergence of these technological devices (Smart meters, sensors and IoT) generates a large flow of data creating a good setting for the application of Artificial Intelligence. Artificial intelligence algorithms such as advance statistical tools (example Artificial Neural Network, Regression model) can be used to convert the large volume of data into useful information that allows for the automatic control and management of electricity consumption as well as load forecasting and control. It is not just enough to implement mini grid system to meet the electrical need of the people in the sub Saharan part of Africa, it is also important to provide a platform where energy demand and supply balance can be achieved. It is interesting to know that; mini grid system does not only allow the potential for the incorporation of renewable energy but also provide a potential for digitalization. For the fact that most mini-grids system make use of intermittent energy source requires digital technology and smart systems to ensure better balance between electricity demand and supply as well as ensuring more efficient operation of the system. In conclusion, the power sector in Africa needs an immediate and drastic intervention in order to improve electricity access in the continent especially in the rural Sub-Saharan region where majority have no access to electricity. The penetration of Mini-grid in these regions to meet remote communities who are not connected to the central grid system as well as the advancement of digital technology in the energy sector pave a great opportunity for transformation of electricity sector for Africans. There is great potential in making the existing and subsequent mini grid system a smart grid that allows for control and management of electricity supply and consumption which will in turn help in bursting the energy system efficiency at all point.

The need for energy conservation especially electricity is of crucial importance as it is an economic solution to the problem of energy shortage and atmospheric carbon reduction. Buildings has been identified among the top largest world energy consumption accounting for up to 40% [30] and in order to maximize energy conservation, there is need to put in place an effective energy management strategy. World electricity production highly depends on burning fossil fuel which releases a lot of greenhouse gases which are harmful to the atmosphere. In 2014, 67% of world electricity production source was from fossil fuel [48]. It is acceptable when we use limited amount of electricity to fulfill our convenience, however, excess consumption and wastage of electricity becomes a major issue. People usually find themselves in a situation such as being in hurry to leave the house and forget to turn off the lights, fan or other appliances. Other cases may be forgetting to put off appliances or putting them on standby when going to bed or just being indifferent about the status of appliances be it on when not in use or not. These actions may seem harmless but they are major source of electricity wastage in the average households 51. It is important to know that, be it being in hurry, forgetfulness or indifferent, these actions will weigh heavily on one's wallet. Figures (1.1[21][39]) shows a cellphone charger which is not disconnected from the wall and television on standby mode. Figure (1.2[17]) shows a light bulb which was not turned off during the day time.

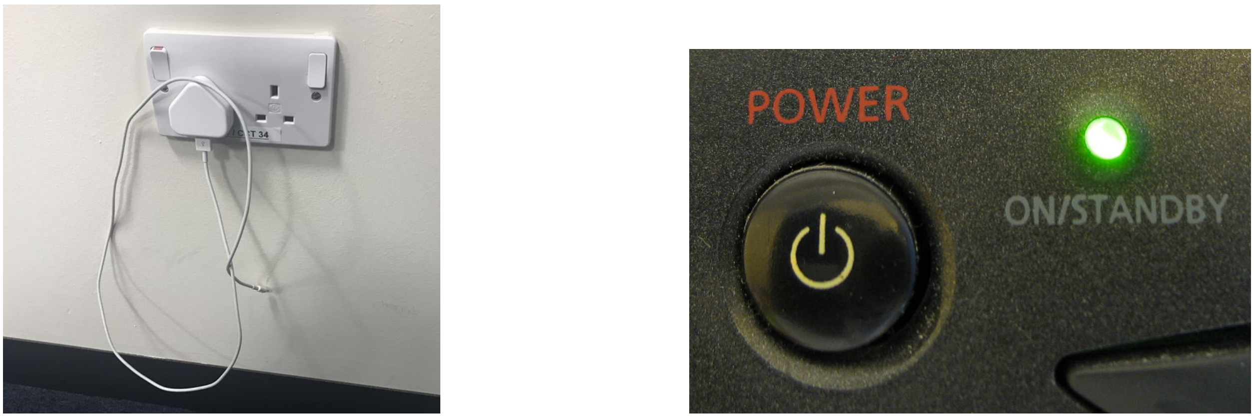


Figure 1.1: Some appliances on standby

Figure 1.2: An electric bulb "ON" during the day

1.2 Statement of Problem

It is no longer a news up to 600 million people living in the SSA do not have access to electricity and 80% of them are located in the rural area [36, 16, 25]. The central grid system majorly provides for Urban settlers leaving out the rural habitats whose remote location makes it unfavorable to extend the grid system to enable them have access to electricity. Other challenges associated with the central grid system is the problem of poor operation and maintenance as well as the use of outdated and old equipment in the system. Consequently, the grid is plagued with frequent power outage which is usually due to overloading of the system. Many SSA countries has taken the initiative of investing in the deployment of Mini-grid systems especially in the remote rural communities. It is estimated that by 2040, between 100,000 to 200,000 mini-grid projects will be deployed to serve up to 140 million rural inhabitants [16]. However, a major challenge identified in implementing mini-grid systems in Africa is the ability to ensure that throughout the life-time of the project, there is enough capacity to meet the dynamic pattern of electricity demand within the grid. The problem of increasing demand for electricity is inevitable in any grid system and with time the energy provider is burden with the difficult challenge of ensuring demand and supply balance. More often than not, the resulting consequences is power outages when the demand is highly more than the supply which cause loss to the energy producer and discomfort to the consumer. A way to address this challenge is through energy management strategy. Effective energy management strategy can be put in place through the integration of digital technology and communication network in the energy system. Many literature have address the use of Artificial intelligent-based optimization model for energy managements at household levels [29, 24, 62, 19] and demand side management at the grid level [15, 34, 38] in Saudi Arabia, Europe and Asia. Previous research [36, 16, 25, 41] in Africa has also identify potentials for of integration of digital technologies into electrical grid systems in SSA. Motivated work of [36, 16, 25, 34, 29, 24, 62, 19, 15, 41, 38], our work is aimed at modeling an AI- based energy management system for the household and mini-grid level in SSA.

1.3 Research question

How can an artificial intelligence based system be adopted at the household and mini-grid systems in rural Sub-Saharan African specifically Nigeria, in order to reduce electricity cost for consumers and peak demand management at peak hours for the mini-grid using already existing data and consumer behavioral data?

1.4 General objective

To model an automated system working with the principle of Artificial intelligence that can reduce power consumption cost household level as well as household peak demand.

1.5 Specific objective

In order to achieve the main objective mentioned above, we will follow the following objectives:

- Obtain typical load profile of a mini-grid setting (household and commercial load profile)
- To develop a simulation of smart meter like data

- Propose an energy management system to optimize electricity consumption during a week day and weekend in a household.

1.6 Significance of Study

The findings of this study will play an important role in accelerating energy management development in the household sectors thereby ensuring energy demand and supply balance in SSA regions. The increasing demand for energy justifies the need for efficient an efficient demand side energy management to support the stability and reliability of the mini grid system. This model will not only allow the customers to manage their energy consumption rate but also help them to reduce their electricity bill. As the proposed project will focused on a country in the Sub Saharan region of Africa, the result is strongly recommended in the deployment of mini grids in African countries.

1.7 Structure of the Thesis

Chapter 1: This section explain the background overview, problem statement, research question, objectives and significance of study.

chapter 2: present the concepts and definitions in mini-grid and state of electricity in SSA.

Chapter 3 give the literature review of previous related works based on the following; smart grid and smart metering technology, internet of things, demand side management, and identification of knowledge gap.

Chapter 4: captures the model methodology, its architecture and working principle, data, the mathematical formulation of the proposed system and its flowchart.

chapter 5: presents the results based on the itemized objectives.

The appendix is captured in section A.

2. Concepts and definitions

This chapter focus on the literature basis of the Thesis. It consists of definition of terms, review of concepts, state of the art and a review on existing literature and contributions to the topic study.

2.1 State of Electricity in Sub-Saharan Africa

Electricity and the socio-economic development have always been seen as interrelated. In fact, many has argued that electricity plays a crucial prerequisite for the socio-economic development [41]. However, access to energy is one of the greatest banes to social and economic development in Africa [18], especially in the Sub-Saharan part of the continent. The energy sector in the Sub-Saharan Africa (SSA) is plagued with challenges such as low energy access rate, high cost of electricity, insufficient generation capacity to meet the growing demand thereby causing a supply and demand mismatch and also the problem of unstable and unreliable supply [10]. Several literature have been published on the state of energy and electricity in the Sub-Saharan Africa as well as Challenges and possible solutions. Among these is the report of [6] where the state of power in Sub-Saharan Africa was analyzed, the challenges as well as power expansion opportunity paths were discussed. Having redefined the electricity gap in SSA as integral problem involving supply-demand mismatch, inequality and electricity access decisions, they suggested that in order to achieve full access to electricity in SSA, there is need to focus on multiple pathways and strategies such as synergies between centralized and distributed systems, bolstered financial support and investment, and improved institutional capacity and management. Philipps et al [41] worked made a systematic review on planning and implementation of electricity in SSA, after reviewing 306 scientific articles all related to electricity planning and implementation with SSA as case study the authors were able to identify several glaring gaps in this topic area that required to be filled. The further explained that there is need for more high-quality research on the need for energy provision in SSA.

2.2 Concept of Mini-grid System

The problem of extending electricity access to communities located significantly far away from the central grid system necessitate the need for mini-grid system. The mini-grid system which is also known as micro-grid system as represented in some literature can be described as mini-version of a central grid system which can be connected to the central grid or isolated as the case may be. The mini-grid system has been defined in the work of several scientific literature and organizations [13, 20, 8]. A mini-grid according to energypedia is a set of electricity generators and possibly energy storage systems interconnected to a distribution network that supplies electricity to a localized group of customers [13]. It is also defined as a cluster of loads, distributed generation, and energy storage systems [8]. While based on capacity, mini-grid is defined as the grid system with capacity range between 5kW to 1MW [8]. A mini-grid system can be powered by Renewable energy source (solar), fossil fuel energy source (diesel generator) or hybrid system combining both the renewable energy source and fossil fuel [7]. Mini-grid implementation has a great positive impact on the social sector especially as it allows for the involvement of the community, they serve in energy related decision making. The adoption of mini-grid energy system in the Sub-Saharan Africa is becoming more and more intensive as it the system is being recognized to have a good potential of solving the rural electrification problem in this region of the continent. Many literature and reports have been published recently on the potentials of mini-grid in different countries in the SSA. Abubakar et al. investigated the experience of designing, deploying, and operating rural community mini-grids in Kenya and Uganda under differing contexts. The study observed two key challenges to the deployment of mini-grid in the study region as the affordability when compared to the subsidized main grid cost and also the unfavorable political landscape. However, they highlighted that electrification promoted business creation and development. A similar study was carried out by Hobson but on the existing clean energy mini-grid system in West Africa. His study also identified unfavorable policy as the key challenges to clean energy mini-grid system as noted by

2.3 Energy Management

Energy management deals with the planning and control of energy supply and demand with the aim of conserving resources, reducing energy cost and wastage, environmental impact as well as enabling energy consumers have constant access to energy there by promoting energy security. Energy management strategy can be basically carried out in two forms which are the demand side management (DSM) and the supply side management (SSM). The demand side management involves the reduction of energy wastage by monitoring and controlling the consumption behavior of the consumer side of the unit to ensure more efficient system operation, lowering the electricity bill at the consumer side and reduction of peak demand all day through. The supply side management on the other hand deals with management and control at the energy supply side of the unit which involves construction of new generating units and putting in place new energy conservation policies to control demand [16].

2.4 Smart Grid and Smart Meter Concept

Smart grid is an advanced or digitalized electric grid system equipped with components such as smart meter, smart appliances and intelligent grid management system. The smart grid system makes use of digital technology to monitor and control grid activities from generation of energy, through transmission distribution and finally consumption. Unlike the conventional grid system that was designed to supply electricity to consumers and billing them monthly, the smart grid system is fashioned to allow for two-way transmission of energy and information between the grid and consumers. Other conventional grid drawback addressed by the smart grid system are problem of efficiency, energy management and peak demand. The smart grid system also allows for incorporation of renewable energy technology and electric vehicles in to the grid system. In essence, smart grid system makes use of network involving communication, controls, digital technologies, automation devices, sensors and computers to drastically improve the grid functions making it more efficient, reliable, secured and sustainable. The smart grid architecture is as illustrated in figure (2.1[53])

Key Features of Smart Grid System as an Improvement to the limitation of Conventional Grid. The existence of the conventional electrical grid system dated back to the 19th century (1886) when the first transmission of electricity to a remote load was demonstrated successfully in the united states [49]. The purpose of the electrical grid system as earlier stated was to supply consumer with electricity and bill them once every month. However, as the demand for electricity rises due to factors like industrialization, increasing population and mankind quest to improve livelihood electrical grid system started to face

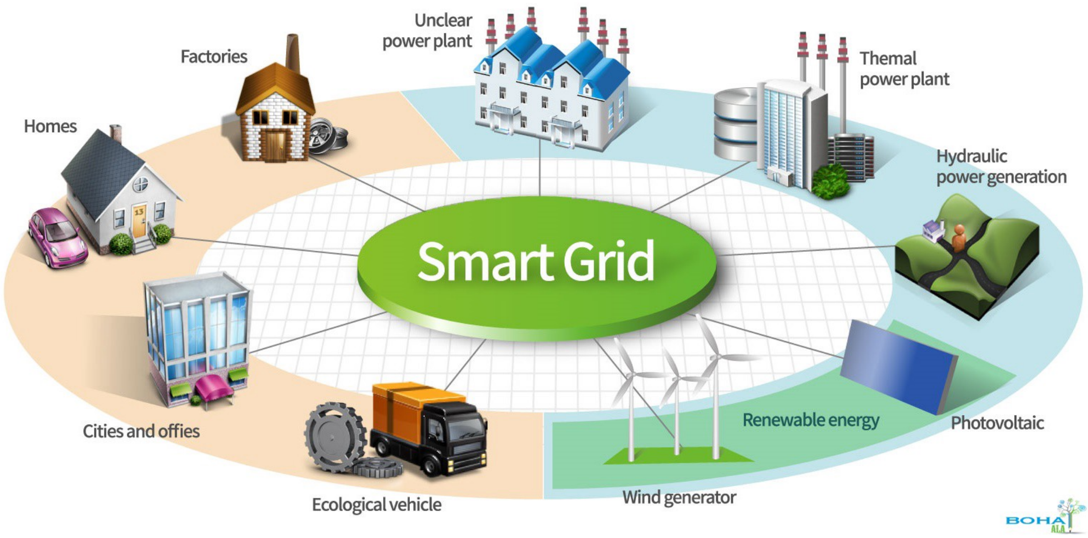


Figure 2.1: Smart grid System

challenges due to its limited features and capabilities. Problems such as brownouts and blackouts began to arise at times of peak electricity demand, also the incorporation of new technology system such as the renewable energy technology became limited in the conventional grid system which operates mainly on fossil fuel energy sources. In the race to address these limitations, Researchers began the idea of modernizing the grid system with by improving the features as will be discussed. Key features of the smart grid system as explained in [27] are listed as follows:

1. Two-way communication system
2. Renewable energy Integration
3. Advance Metering Infrastructure
4. Advance Energy storage technology
5. Data Management and Processing
6. Real time Operation and Control
7. Cyber and Physical Security System

2.5 Home Energy Management and Smart Home Energy Management

A home is not just described as a dwelling place but a place where one can feel relax, secured, cozy and happy. Advancement of technology has giving way for humanity to improve their home condition. Various home electricity appliances are being produced daily to make the home exciting, comfortable, secured and make life easy at home. The implication of these appliance is their heavy electric power consumption and the inevitable rapid increase in the demand for electricity supply which is currently out-numbering electricity generation itself. This problem has attracted the attention of scientific community which necessitate the need for Home energy management system or HEMS. Home Energy management system (HEMS) is defined by [35] a system that combines sensors within home devises through home area networks with the purpose of controlling power consumption, improving the smart grid performance, optimize demands, allows optimum electrical usage in the residential level. HEMS aims at improving energy management efficiency as wells as reducing consumption and electricity costs. The system can interact with household electrical devices and the utility unit paving way for possible schedules and adjustments of these devices with respects to dynamic conditions such as peak hour, grid prices and meteorological conditions [30]. HEMS is a concept developed in the year 1979 after it was revolutionized to for performance improvements up until the design of a HEM system by [56] which focused on home-based application and the introduction of home power-controlled system in Japan by the use of gateway in 2003 [35]. Artificial Intelligence-based HEM schemes were further introduced by [28] as cited in [35]. The HEM concept gained further advancement to improve the performance level of the system as Smart HEM was introduced which was integrated with controller based on event binary linear optimization which provide optimum electric energy at the residential sector [35]. Smart HEMS as defined in the work of [35] is a home that offers energy management services for efficient monitoring and management of electricity generation, power conservation and energy storage. Smart HEMS is equipped with five major functionalities which are the ability to monitor which facilitates real-time information on energy usage pattern, logging which involves collecting and saving data information related to electricity unit consumed per appliances, electricity generated as well as storage. Other functionalities are direct and remote control of electricity usage, Management ability and Alarming system in case of fault locations and fault type. HEMS is able to smartly manage and ensure efficient power consumption through the combination of smart meters, smart devices, appliances and smart plugs.

2.6 HEMS Architecture and Components

HEMS is typically design to control power consumption especially in the context of smart grid system, demand response and electrical appliance usage at the residence unit. Smart components such as smart meters, devices and plugs are integrated to enable the HEMS smartly monitor and adjusts power consumption. The architecture description and components of HEMS are presented as explained in the work of [35] and [30]. Figure (2.2[30]) Shows the architectural concept of a HEMS. The HEMS component are made up of the sensing devices, smart appliances, user interface and the energy management system/ central control platform.

1. Sensing devices: These devices detect the presence of a desired parameters and send the signal to a central unit. There different kinds of sensing devising depending on the parameter being monitored. We have the temperature sensor, current sensors, voltage sensor, humidity sensor motion sensor, sound sensor and so on. These devices are able to gather a generous amount of data which can be used to predict, control and manage energy consumption in the home.

2. Smart Meter: The smart meter device is used in the HEMS context to collect detail data on energy consumption at a given time interval as well as other human related information relevant to the promotion of energy management. The smart meter technology enables the bi-directional flow of information.

3. Smart Appliances: Smart appliances consists of domestic electrical appliances equipped with intelligence, computing and communication abilities. These system enables the users to have an idea of their energy consumption and energy efficiency measures to carry out.

4. Energy Management System/Control center unit: This unit deals with energy management and optimization. Using data from the smart meter device, the unit is able to adopt a scheduling technique based on optimization approach with an assumed performance index.

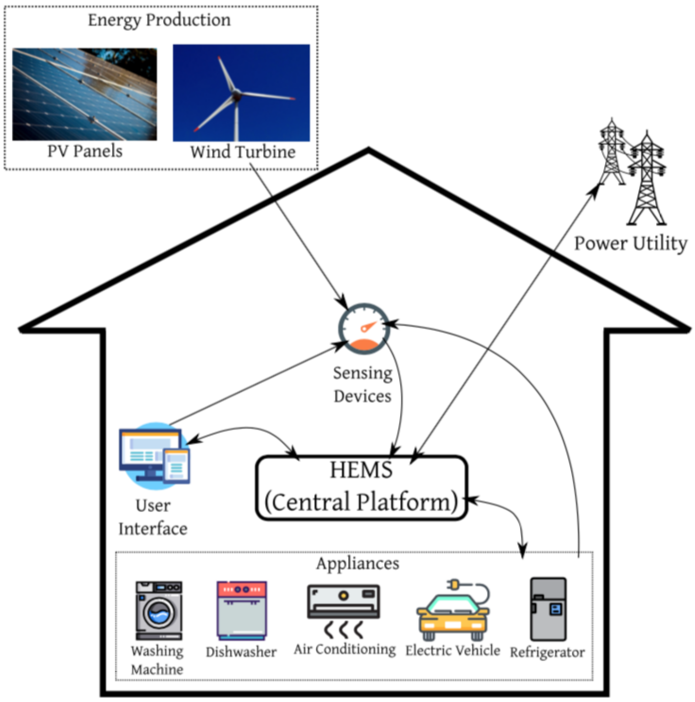


Figure 2.2: HEMS Architecture

3. Literature Review

The problem of extending electricity access to rural communities located significantly far away from the central grid system necessitate the need for mini-grid system in Sub-Saharan Africa. However, it is not just enough to establish mini-grid systems for these communities but also important to put in place, measures that will ensure sustainability and efficient managements of the mini-grid as well as affordability of the tariff by the consumers. Introducing into the Mini-grid context in SSA, the concept of Energy Management will improve significantly the state of electricity and mini-grid system in SSA.

Energy Management is one area in the energy sector that has and is still receiving much attention from the scientific community. This is due to the fact that many countries especially in Africa still depend on the conventional energy utility grid system which majorly work on fossil fuel. Aside the unsustainable nature of the fossil fuel, the environmental effects of burning fossil fuel for energy production and the ever increasing demand for energy compared to supply has raised a lot of concern.

3.1 Review on Energy Management Strategy

This section highlighted some of the previous literature on energy management strategy. Subsection 3.1.1 focused on some technology platforms for energy management which are the smart meter, smart grid,and the IoT platforms. Demand side management was reviewed in subsection 3.1.2 while subsection 3.1.3 reviewed some of the existing home energy management schemes. literature on Artificial intelligence based energy management were reviewed in subsection 3.1.4.

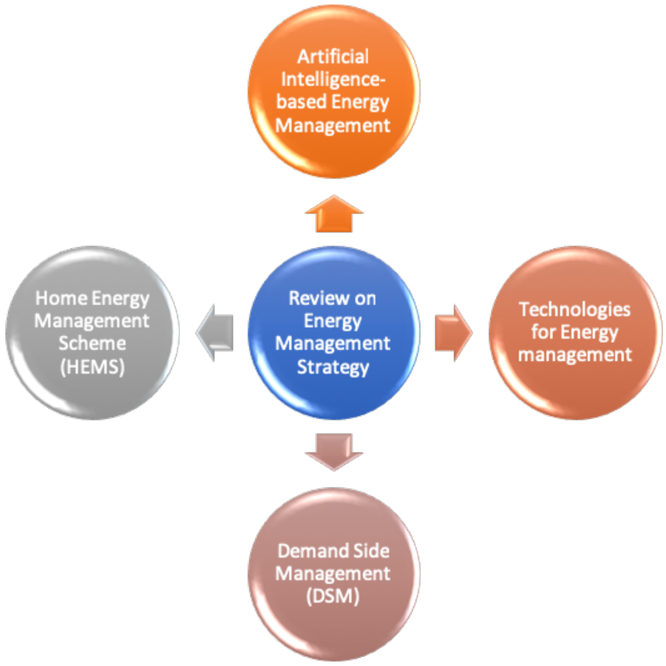


Figure 3.1: Review on Energy Management Strategy

3.1.1 Technologies for Energy management

Smart grid and Smart metering technology

The smart grid concept is vision of future power system incorporating sensing and intelligent system as well as creating opportunity for renewable energy source. The smart grid concept creates a more suitable platform for energy management and efficiency strategy among other functions compared to the traditional power grid system. For these reasons and more, many studies are being carried on the concept of smart grid system.

Smart metering technology which is sometimes refereed to as the Advance metering infrastructure (AMI) is considered as an essential component in smart grid system and an excellent tool in Energy management system. Smart meter is a key device in smart energy system that can give a real-time consumption data for both the utility and the consumer. Information such as consumption behavior of the consumer can be deduced from smart meter data. Furthermore, the power utility is able to carry out functions such as monitoring, customer billing, electricity theft among others with the help of smart meter technology.

Despite the fact that the developed countries have well-equipped and modernized energy grid system, they are also well engaged in the demonstration and deployment of smart grid and smart meter initiatives [2]. Deployment of smart metering system has already commenced in countries and data from installed smart meter have already and are still being used for research in countries like Ireland [58], England [62] , United States [44], Denmark [19] and other developed countries. In the case of Africa, the idea of smart grid and smart metering system is majorly at the conceptual stage.

Researchers has proposed various smart grid model simulation over time [37, 38, 44] . Ali Mekkaou et al. [37] presented a model simulation of smart grid integrated with solar/wind energy sources. The model demonstrates the change in active power at different load angle. The proposed model involves both types of solar and wind energy under normal operating conditions and explains the energy exchange between consumers and GEN. The advantage of the work was that analysis of active power gives the exact idea to know the range of maximum permissible loads that can be connected to their relevant bus bars. However, the electricity cost was not put into consideration in the work.

Mohamed and Ali [38] made a model simulation of a smart grid with integrated hybrid renewable energy systems. A novel smart grid application for optimal sizing of hybrid renewable energy systems was presented. The results show that the using of this smart grid concept will reduce the component size and the cost of generated energy compared to the case without dividing the loads. Smart optimization techniques like particle swarm optimization (PSO) and genetic algorithm (GA) was also used to optimally design the hybrid renewable energy system.

Smart meter data has been used for various energy management models and simulations. For example Krystian et al. [44] proposed a Meters to Models scheme to control energy use at home using smart meter data to predict and control home energy use. They proposed a simple model of an ensemble of houses from smart meter data, which may be used to anticipate peaking events. The research shows the strong benefit of modulating the thermostat set point in houses to lower peak demand, which can lead to diminished reliance on peaking plants and significant monetary savings in the future. However, The model is limited to off-line bin-Packing, on-line bin-Packing was not considered.

While Joga Rao et al. [47] made a model simulation of an automatic Meter Reading System for Smart Metering by using ASK/OOK Modulation in Rural Smart Micro-grids. ASK/OOK system which focuses on transmitting and receiving the measure data of multiple smart meters in smart micro-grid system by using power line communication (PLC) was simulated. Their finding showed that the present ASK/OOK modem is very simple, economical and has ability to control the data transmission for smart micro-grid. It can be an excellent, cost effective and also a reliable solution to mitigation the existing power crisis, power theft and power loss if properly implements this proposed model.

Smart grid concept simulation has also been carried out in context of Africa. Eunice et al. [41] examined the potential of a smart micro-grid for off-grid rural electrification in Nigeria. A combination of design thinking and model-based design methodology was employed to select a suitable micro-grid configuration and to develop a smart micro-grid model. A system consisting of a solar photovoltaic array, battery energy storage and a diesel generator is selected, and the model is developed in Simulink. The proposed smart micro-grid is found to be more suitable for off-grid rural electrification in Nigeria than diesel generators which are currently used for off-grid electrification in Nigeria.

Internet of Things (IoT)

Internet of Things (IoT) is an interconnection among computing devices like sensors and actuators for information sharing through platforms such as internet using a unified framework [57]. Examples are security systems, appliances in a household, vending machine and so on. The IoT design can be in physical form, virtual or a combination of both [57]. Application of IoT platform in energy management has been explored by different researchers. In [57], presented internet of things-based optimal method for home energy management system. The new method which is an improved version of butterfly optimization algorithm, is a multi-objective method with two purposes; energy consumption cost and user satisfaction. In other to determine the performance and effectiveness of the proposed method, the result was analyzed on a house and the results was compared with other consuming algorithms based on particle swam optimization and butterfly optimization algorithm. It was observed that the proposed method produced a better efficiency to the users. Hence, the method improved the system in both energy cost reduction and user satisfaction improvement.

Shafik et al. [52] studied past literature on and gave a comprehensive survey on internet of things-based energy management in smart cities. In their study, state of the art methods for effective energy management in smart cities were presented. [26] also carried out a comprehensive survey on previous research on smart grids and smart environment (such as cities, homes, metering and energy management system) and identified Energy Internet as one of the newly introduced concept. The author concluded by highlighting open issues and future research in direction of internet of things for energy internet infrastructure.

Amarnath and Sujatha [5] proposed a energy saving system using solar photovoltaic with wireless sensor network. Based on the result obtained, the proposed system demonstrated its superiority over other traditional methods. In [32], an Internet of things (IoT)-based energy management system which is based on edge computing framework with deep reinforcement learning was proposed. The energy scheduling scheme; deep reinforcement learning, was analyzed based on "with" or "without" energy servers. It was observed that the proposed method achieved low energy cost while causing lower delay.

3.1.2 Demand Side Management (DSM)

Various Energy management strategies have been device over the years in order to ensure more efficient means of energy generation and consumption. The two major approach to energy management is the Supply side management and the demand side management.

The demand side management involves the reduction of energy wastage by monitoring and controlling the consumption behavior of the consumer side of the unit to ensure more efficient system operation, lowering the electricity bill at the consumer side and reduction of peak demand all day through. Zare and Yazdankhah [63] has identify DSM scheme as the strategy to tackle the problem of demand and supply balance especially considering the fact that increasing demand is accompanied with limited fuel resources.

The six methods by which DSM scheme is achieved are as discussed below [34, 46]:

- **Peak Clipping**: The peak clipping method mainly involves the shedding-off load during peak hour. Implementation of peak clipping can help delay the need for grid expansion and this method of demand-side management can be executed by shedding-off consumer appliances directly from the grid control unit.

- **Valley Filling**: The valley filling method basically involves building up load in times of off-peak demand. The load involved are usually previously operated on fuels other than electricity. This method of demand-side management is mainly suitable in cases where the price of electricity is more than the cost of increasing electricity consumption in a long-run. Consumers are encouraged to practice off-peak consumption behavior. The result is an increase in electricity consumption without affecting the peak demand.

- **Load shifting**: This method involves rescheduling of electrical load from peak demand periods to off-peak demand. This process does not change the total consumption of the consumer while it helps to reduce peak-demand. This method takes into consideration schedulable and non-schedulable loads, uninterruptible and non-uninterruptible loads while shifting loads from peak periods to off-peak hour.

- **Load reduction or Strategic Conservation**: Involves conserving electrical power by practicing energy efficiency measures at the consumer end. This helps to reduce total energy consumption as well as peak demand.

- **Load building or strategic load growth**: The strategic load growth method employs strategic measures like intelligent system, efficient equipment and more competent energy sources to manage load increase in the grid system. Load increase can come as a result of new consumer connecting to the grid or old consumer increasing their electrical load to achieve more comfort.

- **Flexible Load shape**: In this method, the power utility and the consumer reaches an agreement that allows the utility control to interrupt the consumer load when necessary in order to manage peak demand hour.

The demand side management scheme as discussed by Sallam and Malik [50] is of two categories which are; the energy saving program which involves the customers changing their energy consumption behavior by replacing devices consuming more electricity with those designed to consume less but performs the same function. The second category is called the Demand Respond (DR) program which involves a set-up program usually based on tariff or direct load control with the goal of encouraging electricity consumers to adjust their usage pattern with respect to the varying electricity price. DR program can be price-based or incentive-based.

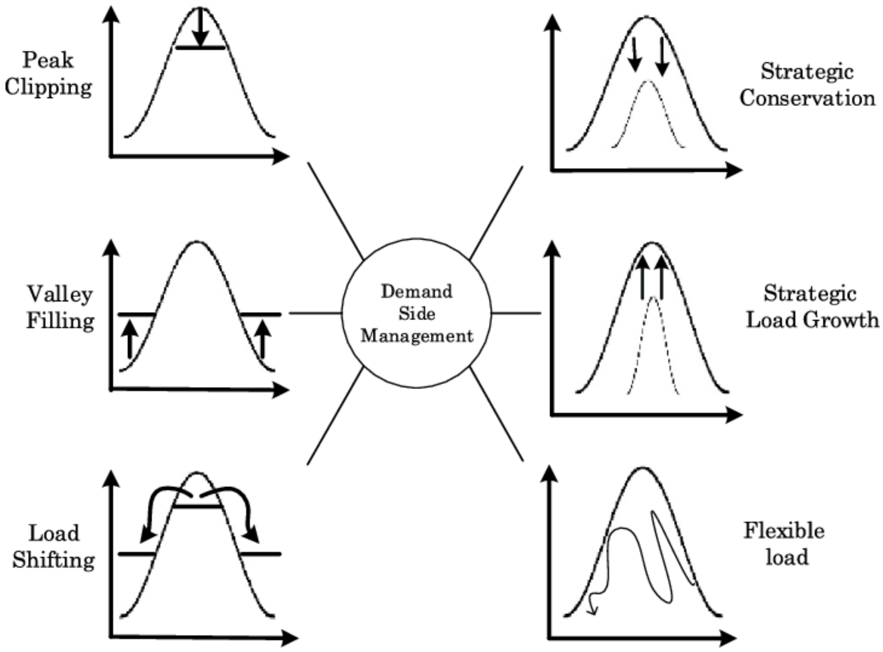


Figure 3.2: Demand-side management schemes [63]

The main objective or goal of DSM is to ensure efficient load management such that the efficiency of the grid is improved, pressure on the grid due to excess load is decrease and improve in the power system stability and sustainability [4]. This can be achieved by optimizing the power system capacity while the physical structures are not necessarily affected. Alwan and Abdelwahed [4] presented a review examination of several DSM technique and Algorithms, after which two DSM model were compared to show the performance based on cost minimization, voltage fluctuation and system power loss. Their results show the importance of balance between objectives such as electricity cost minimization, peak load occurrence, and voltage fluctuation evolution while simultaneously optimizing the cost.

Many researchers has adopted DSM system in devising schemes for efficient use of energy at the home level and grid level [34, 41, 24, 9, 45]. For example, Barbato et al. [9] worked on a distributed demand-side management framework for the smart grid where the DSM was designed to reduced peak demand by applying dynamic pricing system which is a function of the consumer total power demand. The appliances were controlled based on scheduling method. The proposed system was able to to decrease the capital expenditure (CAPEX) required to meet increasing demand on the grid system.

Puttamadappa and Parameshachari [45] proposed methodology which performed a DSM is in smart grids of households which has the energy storage (battery) and distributed solar photovoltaic generation storage. Non-residential load was considered in their work while their proposed model was able to reduce up to 11.2% of the energy cost.

3.1.3 Home Energy Management Scheme (HEMS)

In the light of Demand Respond strategy, researchers have over the time carried out studies to see how the consumers at the end-user unit can adjust their load level and consumption pattern in order to help improve factors such as addressing peak hour of demand, electricity cost and consequently reduction of greenhouse gas (GHG) emission while at the same time ensuring the comfortability of the consumer. Some of these studies comes in form of comparative study of various management scheme with respect to HEMS. The various energy management scheme as reviews by Mahapatra and Nayyar [35] are; Optimization based Residential energy Management (OREM), the In-home Energy Management (i-HEM), Home appliance coordination scheme for energy management, Optimal Load Management (OLM) Strategy and Decision Support Tool (DST). The author made a comparative analysis performance of the various scheme reviewed and his analysis showed that the OREM scheme shows a promising rate of reduction making it more suitable for electricity saving measures.

Lujano-Rojas et al. [33] proposed an optimal load management strategy for residential consumers which utilizes communication infrastructure of the future smart grid system. Their result showed that the proposed model give way to consumers to control their daily energy consumption as well as adjust their electricity bill according to their economic situation.

Zhou et al. [65] proposed a binary particle swarm optimization as an energy management technique in adjusting the appliance usage. In the work of Zhang et al. [64], a smart home energy management system with multi-layer structure which are the interface, control and load layer is designed. The author constructed an optimal scheduling model for the SHEM while a fusion of harmony search algorithm and the particle swarm algorithm is used to solve the model. The result showed an effective improvement in the load curve as well as a reduction in the electricity cost.

Furthermore, Hansen et al. [19] develop a home energy management system that utilized machine learning in order to reduce energy. The result showed an energy reduction potential but more data will be required to run a real test involving automated control of the devices.

Other researchers were able to propose HEMS scheme that put into consideration the comfort of the consumer while ensuring optimization of energy. For example, Ahmed at al. [3] proposed a HEM algorithm with demand response which schedules the operation of home appliances to save energy costs by considering customer convenience as well as characteristics of electric appliances. The algorithm was able to preserve the total electrical consumption below a given demand limit while considering the customers preference settings and load priority.

Iqbal et al. [46] proposed a Fuzzy Inference System (FIS) that uses humidity as an input parameter in order to maintain the thermostat set-point according to user comfort. Using simulation tool, they were able to show that the proposed techniques was able to reduce energy consumption by 28%.

3.1.4 Artificial Intelligence-based Energy Management

The recent advancement of smart grid system which involves two-way data and information flow and transition from the centralized energy generation system to distributed energy generation system which can use distributed energy resources such as renewable energy resources necessitate the automation system for grid control. One of the drawbacks of renewable energy resources such as solar and wind is the problem of intermittency and this has challenged researchers into finding solutions that will improve the efficiency of the grid system. Artificial Intelligence-based solutions have been shown by different literature to prevail in the automation, control and management of energy consumption from home to the grid level. Elkazaz et al. [12], proposed an automated control technique for optimizing the operational performance of the DG units within the residential applications. Having formulated the problem in a constrained-nonlinear optimization structure based on the economic system, the author applied a genetic algorithm to solve the problem and obtain the optimal setting of a distributed grid unit. His result showed significant decrease in the daily household consumption cost.

Jo and Yoon [24] proposed three intelligent models as IoT platform application services for a smart home. The three models are intelligence awareness target as a service (IAT), intelligence energy efficiency as a service (IE2S), and intelligence service TAS (IST). Having identify the challenges associated with managing smart home devices with separate IoT platform as network congestion and energy wastage, the proposed models were able to address these challenges as demonstrated in their work.

Deployment of smart grid system and smart homes involves connection of IoT and other intelligence devices such as sensors and smart meters that are capable of generating large flows of data. These data create a suitable platform for AI to predict load network, user consumption habit and drawing an accurate user consumption pattern for each energy user [23]. Many literature have demonstrated how AI predictive potential can be used as energy management strategy using data generated by smart meters and sensor devices. Reference [59] argues that energy prediction in building contributes significantly in global energy saving. The author gave a detailed review of AI based building energy prediction methods particularly, multiple linear regression, Artificial Neural Networks (ANN), and Support Vector Regression. The work showed that the Ensemble models improve prediction accuracy by integrating several prediction models.

3.2 Summary and Identification of Knowledge gap

The Aim of this chapter is to review the concept of energy management using already existing literature, present the knowledge gap and contribution of our study in the area of energy management. We have seen that Effective energy management strategy can be put in place through the integration of digital technology and communication network in the energy system. The role of Artificial technology has also been displayed by researchers in the promotion of energy management. Many literature have address the use of Artificial intelligent-based optimization model for energy managements at household levels [29, 24, 62, 19] and demand side management at the grid level [15, 34, 38] in Saudi Arabia, Europe and Asia. Previous research [36, 16, 25, 41] in Africa has also identify potentials for of integration of digital technologies into electrical grid systems in SSA.

Having reviewed past literature in the line of energy management strategies, we observed that many literature has proposed various energy management model based on smart grid and smart meter technology, demand side management, home energy management schemes and management based on Artificial Intelligence. However, majority of these proposed models are focused on the Urban regions mostly in developed countries. There are very few literature focusing on energy management model strategy based on Artificial intelligence. Hence there is a knowledge gap.

The aim of this work is to model an Artificial intelligence based energy management for households and mini-grid in SSA, specifically Nigeria.

4. Methodology

4.1 Data collection method and analysis

4.1.1 Data Collection

The collection of data process will go as follows:

1. Historical Data
   - Approach: To be collect from the case study mini-grid through the GVE limited company.
   - Data:

     - Electricity generation per hour from the case study mini-grid for the past one year.

     - Electricity consumption of the consumers connected to the case study mini-grid for the past one year.

     - The corresponding tariff system adopted by the mini-grid for the past one year.
2. Actual consumer consumption patterns/habit
   - Approach: questionnaire/interview-based building on the NREL excel load profile estimation template
   - Elements to be captured in the questionnaire are:

     - Research topic, goal, specific objectives and research questionnaires to be addressed

     - Socio-demographic information of the respondent such as Sex, Age, family size, income level, Education level

     - Appliances usage: the type of appliances and their frequencies shall be collected. Appliances such as TV, refrigerator, lightning and so on, and their period of usage.

     - Difficulty of energy savings behavior: Questions such as (i) Turning off appliances when leaving the house/not in use (ii) using energy efficient bulbs (iii) Turning off appliances on standby unplugging phone chargers when not in use, and many more.

     - Monthly electricity expenditure of the respondent.

- Definition of the different consumer groups to engage in the data collection process (households, hospitals, schools, etc.)

  - Household consumer: the data will be collected from sample of individual household connected to the mini-grid. - Commercial consumers: consumers in this category will include; Clinics, Schools, Street light, mini shops, Milling operations, Water pumping operations.

4.1.2 Data processing

Upon collection of the data, we shall carry out an exploratory analysis, their correlation and data cleaning.

- Generation of load profile using historical data and data collected from the consumer habit. The historical data will give a global load profile of the mini-grid over a year period.
- Definition of smart meter: This is a digital electricity metering device that measures electricity flow in and out of a consumer at a given time interval, and communicate this information to the utility service provider on daily basis.
- In proposed research, since smart meter data and smart meter system are not available in the proposed area of case study (i.e. Nigeria), we shall simulate the input smart meter-like data required for the model (i.e. Genetic algorithm). The smart meter-like data shall be simulated using the data from actual consumer consumption pattern and using the "NREL Rural Africa load profile tool".
- The proposed optimization model is the Genetic Algorithm to minimize the total energy consumption in each household in order to reduce cost. The Genetic Algorithm will be adopted as implemented in the framework of Python software.

4.1.3 Proposed Home Energy Management Based on Genetic Algorithm

A genetic algorithm is a search heuristic that reflects the process of natural selection where the fittest individuals are selected for reproduction in order to produce offspring of the next generation. This notion can be applied for a search problem. We consider a set of solutions for a problem and select the set of best ones out of them. Basic concepts in a genetic algorithm (GA).

- Chromosome: In GA, the problem to be solved is represented as a chromosome. The chromosome is a string of either real numbers or binary numbers.
- Encoding: Representing the problem as a chromosome is called Encoding, and it is a major challenge is GAs.
- Search Space: To solve a problem with genetic algorithm, some solutions are needed. The space of all feasible solutions is called search space. Each point in the search space represent one feasible solution.
- Fitness Function: a fitness function is a particular type of objective function that is used to determine how close a given design solution is to achieving the desired solution
- Selection: Chromosomes are ranked according to the fitness and there is higher probability for the chromosome of higher fitness to be picked for reproducing.
- Crossover: crossover is a genetic operator that combines two chromosomes, which are called parents, to produce a new chromosome which is called offspring.
- Mutation: Mutation is a genetic operator used to maintain genetic diversity from one generation to the next. It usually takes place after a crossover is performed.

4.1.4 Design of the Genetic algorithm

(i) Initialization: The initial population is randomly generated from the population size. Here, the population size is the number of appliances.

(ii) From the fitness function, compute the fitness value and score each member of the current population.

(iii) Perform selection using stochastic uniform selection.

(iv) Select some individuals from the current population that have more ability of energy cost saving as elite. These elite will be passed to the next population.

(v) Perform Crossover and mutation to produce offspring. Crossover function is set to be scattered and mutation function is set to be Gaussian.

(vi) Replace the current population with the children to form the next generation.

(vii) If stop criteria is not met, repeat the process from step (ii). Otherwise generate result.

In summary, Input of power price, input of the smart meter-like data and grid electricity generation are to be sent to genetic algorithm to generate output signal which controls the automated power cut-off system to shed-off loads based on priority in order to reduce cost and peak demand. The Output/expected results of the GA are; Original cost (system without optimization), genetic algorithm cost (system with optimization), and percentage of cost saved by the GA.

4.1.5 GA Decision making criteria

- Low priority load is to be shed-off at peak demand.
- Loads on standby are to be turned off as well.

4.2 Simulation of Smart System model

This section gives an insight on the simulated smart energy management system design proposed as a way of electricity cost reduction in mini-grid consumers specifically at the household level. The smart energy management model is designed to help the energy consumer manage and control their electrical appliance, fish out basic electrical energy wastage such as leaving appliances ON when they are not actually in use or putting appliances on standby. The system incorporates an hourly priority-based approach which is specified based on the customer's electrical usage behavioral pattern and the working mode of each appliances. The smart model offers a programmed operational intelligence for decision making during the cause of optimization. The following sections will discuss in details the working process of the Simulated Smart System Model.

4.3 Simulated Smart System Model Architecture

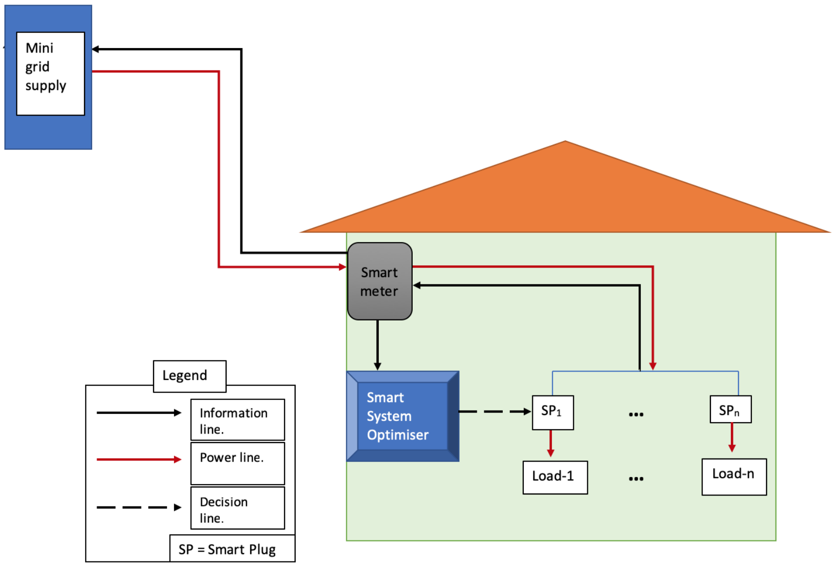


Figure 4.1: Model Architecture

The architectural presentation of the proposed Energy management system is as presented in the figure above. The working protocol of the proposed system is enabled by the presence of a smart meter (or prepaid smart meter), smart plugs, loads (in form of electrical appliances) and availability of power generation to the building from a mini-grid or any energy source. The systems combined system of smart things (smart meter, smart system optimizer and smart plugs) will interact and share information relevant for the optimization process via Internet of Things (IoT) protocol. Subsections below will give more insight on the functions of the components in the energy management system.

4.3.1 Mini-grid supply

The power supply to the building comes from a mini-grid energy utility system which can be based on 100% Renewable energy source or a hybrid system of both renewable and conventional energy source. The tariff system is majorly defined by the utility. The system assumes the grid system is also smart in the sense that, it enables a two-way communication flow via smart meter between the utility and the consumer. The utility uses information from the power consumption information from the smart meter to manage energy supply and demand at the grid level.

4.3.2 Smart meter

The smart meter device performs various functions in the system. Firstly, the electrical power entering the building is received at the smart meter end. For a prepaid smart, the consumer can purchase power unit which is inputted into the smart meter. The smart meter also serves as measuring device that obtain records the power consumption of each appliances on an hourly bases, and pass the information to the mini-grid utility and also the smart system optimizer. The smart meter device hence serves as a communication inter-phase between the appliances and the smart system optimizer.

4.3.3 Smart plugs

The smart plug is a smart device that can be controlled by an already pre-written program. This device enables the automated cutting off of an appliance. Each appliance or load are connected to a smart plug.

4.3.4 The Smart system optimizer

This smart system optimizer as we have named it is the brain-box of the energy management model. This system makes use of embedded algorithm to perform intelligent decision making to either turn of an appliance or let it run. It obtains information such as the power consumption of each appliance and the total consumption per hour from the smart meter, the appliances priority for that hour which has been predefined. The system uses this information to determine the demand limit for that hour and check if the demand limit is exceeded. The system communicate decision to the smart plug to either switch of a device or not.

4.4 Working Principle of the Smart System Optimizer

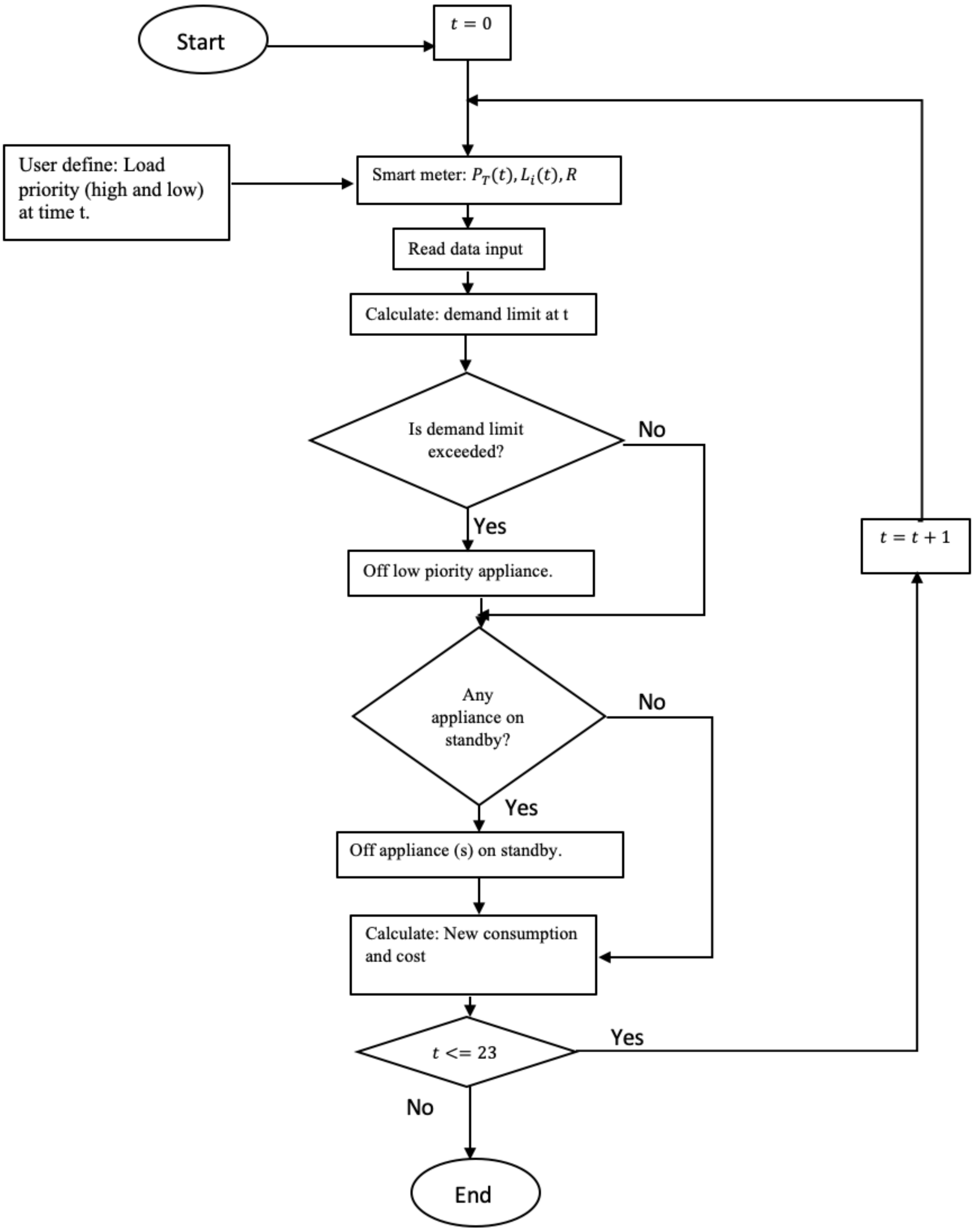


Figure 4.2: Flowchart of the smart system optimizer

4.4.1 Simulation process

This section explains all the steps involve in the simulating process. The simulation is a proposed energy management strategy aimed at reducing energy consumption and consequently cost of electricity by detecting and preventing electricity wastage in the households of rural communities in Nigeria. The proposed strategy work based on appliances priority and demand limits per hour.

4.4.2 Appliance Priority

The priority of the appliances is classified broadly into two. Based on the hour of the day, an appliance can be of high priority (H) or Low priority (L). We define a high priority appliance at a particular hour as an appliance that is highly necessary to stay actively working ("*on*" mode) when the user switch it on. For example, the light bulb is classified as high priority appliance in the night time while the user is still active but the priority will change at the hour when the user goes to sleep. Also, the refrigerator is classified as a high priority appliance throughout the day as it is necessary for it to stay on to preserve our food items all day long. On the other hand, is the low priority appliances which we define as appliances which must be put off if found actively working. These are appliances which the consumer is not necessarily using at that particular hour. For example, a light bulb at the day time is classified as a low priority appliance and must be put off if found in the "*on*" mode. The same applies to the television set in the mid night period when the user is asleep or periods when the consumer is away from home.

4.4.3 Demand Limit

The demand limit at a given hour is defined in this context as the allowable electricity power consumption limit at that hour. For any giving hour, the allowable consumption limit is the total consumption of all high priority appliance at that hour. If this limit is exceeded, it implies that a low priority appliance has been activated and in respond, the proposed energy management system adjusts the consumption level by turning off appliances of the low priority. Furthermore, the energy management system also ensures that all appliances on standby (both Low and high) is totally put on the "*off*" mode. It can be seen that the demand limit setting is directly link to the priority of the appliance.

4.5 Classification of household

One of the factors that affects electricity demand and appliance ownership is the economic level of the consumer [42]. Households with higher income acquires more appliances with higher ratings compared to their counterparts with lower income class [42]. Households were classified into three classes which is based on their income level. The three classes are; the high income, middle income and low-income level.

4.5.1 High class income:

This class as people in a rural settlement are those whose monthly income is above $\$600$. They are characterized with having the most electrical appliances compared to the middle and low-income classes and thus likely to consume more electricity. They can be working class people of a higher rank or owners of flourishing businesses in and outside the community.

4.5.2 Middle class income:

This class of people belong those whose monthly income is between $\$200$ and $\$600$ in a rural community. The electrical appliances are assumed to be less than that of the high class and more than the lower-class income. They can be working class people of middle rank, successive farmers, shop and milling machine owners within the community.

4.5.3 Low class income:

This class of people are those earning a monthly income below $\$200$. They make use of basic appliances necessary for daily activity. They can be working class people of lower ranking, subsistence farmers or petty traders.

4.6 Data simulation

The data input sample for the simulation process is as displayed in the tables 4.1 and ?? below. The first table displays the appliances power ratings in a fully working situation and in a standby status. The second table indicates the hourly priority of the appliance and the appliances working status. An appliance with low priority at a giving hour is indicated by "L", whole that with high priority is represented with "H". Furthermore, an actively working appliances is represented "n", when the appliance is off it is indicated with "o" while an appliance on standby is represented with "s". Therefore, an appliance represented with L/n implies that the appliance is of low priority and its actively working (i.e. ON mode). The simulation process was implemented in two stages. The first stage is designed to take in inputs of appliances rating from table (appliances power rating) and the appliances working status which can be either ON (n), OFF (o) or standby(s) from table (status) below. The algorithm uses this data to simulate the hourly consumption of each appliances, the working status of the appliance and the total hourly consumption. This stage serves as the smart meter data-like input for the simulation. The second stage of the simulation is embedded with algorithm that takes information output from the first stage simulation (hourly consumption of each appliances, the working status of the appliance and the total hourly consumption), calculates the demand limit at that hour and determine is the demand limit is exceeded. It uses table two to determine a working low priority load and loads on standby to execute the optimization (to put them on off mode).

Table 4.1: Appliances power ratings

	Appliances Power Ratings	
	[1]Appliance Wattage (W)	[2]Appliances Standby Power (W)
APPLIANCES		
Lighting System		
Incandescence bulb	100	0
Compact Florescence Bulb	29	0
Security light	50	0
Entertianment		
22 Inch LED TV	17	0.5
42 Inch LED TV	58	0.3
65 Inch LED TV	120	1
DVD Player	26	0.2
Radio	5	0.1
TV decoder	20	0.4
Thermal Comfort		
Fan	60	0
Air Conditioner	1000	1.5
Refrigerator	100	0
Electric Kettle	1200	0
Microwave	600	3
Other Appliances		
Phone Charging	4	0.2
Laptop Charging	50	2.5
Printer	20	0.1
Washing machine	500	1

Time	Compact Florescence Bulb	65" LED TV	Refrigerator	Security light	Radio	TV decoder	Laptop Charging	Phone Charging	42" LED TV
00:00	L / n	L / s	H / n	H / n	L / s	L / n	H / n	H / n	L / s
01:00	L / n	L / s	H / n	H / n	L / s	L / n	H / n	L / s	L / s
02:00	L / n	L / s	H / n	H / n	L / s	L / n	L / s	L / s	L / s
03:00	L / n	L / s	H / n	H / n	L / s	L / n	L / s	L / s	L / s
04:00	L / n	L / s	H / n	H / n	L / s	L / n	L / s	L / s	L / s
05:00	L / n	L / s	H / n	L / n	H / s	L / n	L / s	L / s	L / s
06:00	L / n	H / n	H / n	L / n	H / s	H / s	L / s	L / s	H / s
07:00	L / n	H / n	H / n	L / n	H / s	H / s	L / s	L / s	H / s
08:00	L / n	H / n	H / n	L / n	H / s	H / s	L / s	L / s	H / s
09:00	L / n	H / s	H / n	L / o	H / s	H / s	L / s	L / s	L / s
10:00	L / n	H / s	H / n	L / o	H / s	L / n	L / s	L / s	L / s
11:00	L / n	H / s	H / n	L / o	H / s	L / n	L / s	L / s	L / s
12:00	L / n	H / s	H / n	L / o	H / s	L / n	L / s	L / s	L / s
13:00	L / n	H / s	H / n	L / o	H / s	L / n	L / s	L / s	L / s
14:00	L / n	H / s	H / n	L / o	H / s	L / n	L / s	L / s	L / s
15:00	L / n	H / s	H / n	L / o	H / s	L / n	L / s	L / s	L / s
16:00	L / n	H / s	H / n	L / o	H / s	L / n	L / s	L / s	H / n
17:00	L / n	H / n	H / n	L / o	H / s	L / n	L / s	L / s	H / n
18:00	L / n	H / n	H / n	L / o	H / s	H / n	L / s	L / s	H / n
19:00	H / n	H / n	H / n	L / o	H / s	H / n	L / s	L / s	H / n
20:00	H / n	H / n	H / n	H / n	H / s	H / n	L / s	L / s	H / s
21:00	H / n	H / n	H / n	H / n	H / s	H / n	L / s	L / s	H / s
22:00	L / n	H / s	H / n	H / n	H / s	H / n	H / n	H / n	H / s
23:00	L / n	H / s	H / n	H / n	H / s	H / n	H / n	H / n	H / s

Table 4.2: Appliances priority and working mode per hour

^{L} Low, ^{H} High, ^{n} on, ^{s} standby and ^{O} off

4.7 Mathematical Formulation of the Proposed Energy Management Model

4.7.1 Notations

C_m: Represent the consumers connected to the mini-grid where $m = 1, 2, \dots, k$, is the number of consumer.

x_i: are the appliances in the home, where $i = 1, 2, \dots, J$

x_i^h and x_i^l: are the high priority and low priority appliances classification, respectively.

$P_{x_i}^r$: is the rated power of appliance x_i

$P_{x_i}^c$: is the power consumption of appliance x_i

t_{x_i}: is the number of working hours of appliance x_i

Z_{x_i}: is the working status of appliance x_i following the rule; $Z_{x_i} = \begin{cases} 1 & \text{iff } x_i \text{ is on} \\ 0 & otherwise \end{cases}$

P_t^c: is the power consumption at period t, where $P_t^c = \sum P_{x_i}^c$

$U_t^{C_m}$: is the upper power consumption threshold at period t set by consumer m.

$L_t^{c_m}$: is the lower power consumption threshold at period t set by consumer m.

E^m: is the total energy consumed by a consumer m connected to the mini-grid over a given period of time.

E_{cost}^m: is the total cost of energy used by consumer m over a given period of time.

U_{x_i}: is the Upper power consumption for appliance i.

L_{x_i}: is the lower power consumption for appliance i.

R: Unit price of electricity

The total energy consumption by each consumer is given by the equation below;

$$E^{c^m} = \sum_{i=1}^{J} P_{x_i}^c \cdot t_{x_i} \cdot Z_{x_i} \tag{4.7.1}$$

while the cost of energy is given by;

$$E_{cost}^{c^m} = \sum_{i=1}^{J} P_{x_i}^c \cdot t_{x_i} \cdot R \tag{4.7.2}$$

The condition for disconnection is given as follows:

For any time period t,

$$\sum P_{x_i}^{c} > U_t^{C_m} \quad \text{and} \quad Z_{x_l^l} = 1, \tag{4.7.3}$$

This implies that the power consumption has exceeded the given threshold and some lower priority load is working. The system automatically disconnects the lower priority load and the new power consumption is given by;

$$P_t^{c^1} = \sum P_{x_i}^{c} - \sum P_{x_i^l}^{c}, \tag{4.7.4}$$

While the new energy consumed over the next period will be given by;

$$E^{c^{m^1}} = \sum_{i=1}^{J} P_t^{c^1} \cdot t_{x_i} \cdot Z_{x_i} \tag{4.7.5}$$

with new cost given by;

$$E_{cost}^{c^{m^1}} = E^{c^{m^1}} \cdot R \tag{4.7.6}$$

Saved cost E_s will be;

$$E_s = E_{cost}^{c^m} - E_{cost}^{c^{m^1}} \tag{4.7.7}$$

The system further investigates and disconnect appliances on standby mode by checking if;

$$P_{x_i}^{c} < L_{x_i} \quad \text{and} \quad Z_{x_i} = 1, \tag{4.7.8}$$

This implies the appliance is consuming below its lower power consumption threshold, hence it's on a standby mode and thus disconnected.

4.7.2 Proposed Optimization Model

Starting with the objective function (4.7.9) which minimizes the total consumption cost of a consumer;

$$min \sum_{i=1}^{J} P^c_{x_i} \cdot t_{x_i} \cdot R \tag{4.7.9}$$

Subjected to:

$$U_t^{C_m} < P_t^a \tag{4.7.10}$$

Where (4.7.10) which shows that the upper power consumption threshold set by any consumer should be strictly less than the available power, must be satisfied at all time.

$$\sum P^c_{x_i} < U_t^{C_m} \quad \text{and} \quad Z_{x_i^l} = 0 \tag{4.7.11}$$

If (4.7.11) occurs, then no energy is loss at time period t.

$$P^c_{x_i} < L_{x_i} \quad \text{and} \quad Z_{x_i} = 0 \tag{4.7.12}$$

If (4.7.12) satisfied, then an appliance x_i is totally disconnected. On the other hand,

$$P^c_{x_i} < L_{x_i} \text{ and } Z_{x_i} = 1,$$

then the appliance is on standby mode, and should be automatically disconnected.

$$Z_{x_i} \in \{0, 1\} \tag{4.7.13}$$

and (4.7.13) shows that the integrality constraint.

5. Results and Discussion

In this section, we shall discuss the load profiles for households usage which will be classified into high, middle and low income earners. Similarly, we will discuss the load profiles for commercial usages and the total load profile for rural Africa.

Then we shall optimize these appliances based on each of the classes of households. And show their aggregate energy consumption and costs for each of these household classes.

5.1 Case study: Nigeria

5.1.1 Brief Introduction

Located in the western part of Africa, bounded to the north by Niger Republic, north-east by Chad, the south-east by Cameroon, the west by Benin and to the south by Gulf of Guinea lies the Federal Republic of Nigeria. Nigeria land area estimate is $910,770km^2$ which is equivalent to $351,650$sq.miles and water area estimate of $13,000$sq.miles earning her the 33rd largest mass area in the world. Nigeria is the most populous nation in Africa with a population of over 200 million inhabitants as at 2019 [60]. Nigeria electrification rate according to the International Energy Agency (IEA, 2014) was 50% with Urban access ratio is 83.6% and rural access ratio is 34.4%. Urban households make up 34% of the population, while rural households make up 66% [42].

5.1.2 Tariff System in Nigeria.

The Nigerian Electricity Regulation Commission (NERC) is the national body in charge of managing electricity supply activities including setting tariffs in Nigeria. The NERC uses the Multi-Year-Tariff -Order (MYTO) methodology. This rating system involves a flat tariff rate that cover the costs of electricity (energy & capacity), transmission use of system cost, regulatory and market administration charges, the Distribution companies (Discos') distribution charges and costs associated with metering, billing, marketing and revenue collection [40]. The National Electricity Supply Industry classifies all end-users of electricity into 5 broad tariff classes which is displayed in Table 5.1 (source [40])

Tariff Class	Description	
R	Residential	A customer who uses his premise exclusively as a residence i.e. house, flat, or multi-storied house
C	Commercial	A customer who uses his premise for any purpose other than exclusively as a residence or as a factory for manufacturing goods
I	Industrial	A customer who uses his premises for manufacturing goods including welding and ironmongery
A	Special	Customers such as agriculture and agro-allied industries, water boards, religious houses, government and teaching hospitals, government research institutes and educational establishments.
S	Street Lights	Street Lights

Table 5.1: End users of electricity tariff classification in Nigeria.

The Discos further classified the tariff classification into sub -levels as shown in the Table 5.2(source [40])

	TARIFF CODES	CUSTOMER'S DEMAND LEVEL
1.0	**RESIDENTIAL**	
	R1	<5kVA
	R2	>5kVA<15kVA
	R3	>15kVA<45kVA
	R4	>55kVA<500kVA
	R5	>500 <2MVA
2.0	COMMERCIAL	
	C1	>5kVA<15kVA
	C2	>15kVA<45kVA
	C3	>55kVA<500kVA
	C4	>500kVA<2MVA
3.0	INDUSTRIAL	
	D1	>5kVA<15kVA
	D2	>15kVA<45kVA
	D3	>55kVA<500kVA
	D4	>500kVA<2MVA
	D5	>2MVA
4.0	STREET LIGHT	
	S1	1-Ph, 3-Ph
5.0	SPECIAL TARIFF CLASS	
	A1	>15Kva <45kVA
	A2	>55kVA <500kVA
	A3	>500kVA < 2MVA

Table 5.2: Disco Sub-classification in Nigeria.

5.1.3 Mini-grid system in Nigeria

Mini-grid establishment in Nigeria is rapidly evolving from government and humanitarian-based contract to commercial mini-grid system [1] . One of the problems associated with mini-grid system in the high tariff price compared to the Discos and the central grid system tariff. The tariff price of mini-grids is typically near $N200/kWh$ (N= Nigerian naira) ($\$0.52/kWh$). Figure 5.1 (source [1])shows some of the already established mini-grid projects in Nigeria.

Figure 5.1: Some of the existing mini-grid in Nigeria.

5.2 Data

Due to the COVID-19 outbreak, the proposed area of study could not be visited for carrying this research. Hence, we resulted to using simulated data for our analysis [31]. The data simulations and assumptions were inspired by the National Renewable Energy Laboratory (NREL) Rural African Load Profile Tool [31].

We started by listing some appliances, classify the household usage into; low, middle- and high-income earners. Also, we classify the appliances into, high priority and low priority, and each of these could be on, standby or off.

5.3 Load profile for household

In this section, we explore the load profile of an household as given in figure 5.2.

We started by designing appliances count and hours of usage. This step helped us to understand the load profile for each of the three classes of households, the profile of commercial centers and the general or total load profile.

Table 5.3: Summary of Rural African Household load profiles (W)

	High Income Household	Medium Income Household	Low Income Household	All Households Assuming Varying % High, Medium, and Low Income
0:00	2460.6	459.6	27.6	400.5
1:00	2460.6	459.6	27.6	400.5
2:00	2460.6	459.6	27.6	400.5
3:00	2460.6	459.6	27.6	400.5
4:00	2315.6	402.8	27.6	369.0
5:00	2315.6	402.8	27.6	369.0
6:00	2483.9	477.0	47.2	419.8
7:00	2681.9	523.0	47.2	453.4
8:00	2333.9	427.0	47.2	389.8
9:00	152.0	32.0	0.0	24.8
10:00	152.0	32.0	0.0	24.8
11:00	152.0	32.0	0.0	24.8
12:00	152.0	32.0	0.0	24.8
13:00	152.0	32.0	0.0	24.8
14:00	152.0	32.0	0.0	24.8
15:00	152.0	32.0	0.0	24.8
16:00	2333.8	433.3	59.8	399.2
17:00	2977.8	454.8	59.8	470.1
18:00	3054.4	516.7	61.1	497.1
19:00	2611.1	528.7	65.4	458.9
20:00	2628.9	573.8	447.2	703.4
21:00	2628.9	573.8	447.2	703.4
22:00	844.6	359.0	448.5	461.2
23:00	918.9	375.3	447.2	472.8
Total Wh/day/household:	**41035.7**	**0.0**	**2343.3**	**7942.7**
Total kWh/year/household:	**14,978**	**0**	**855**	**2899**

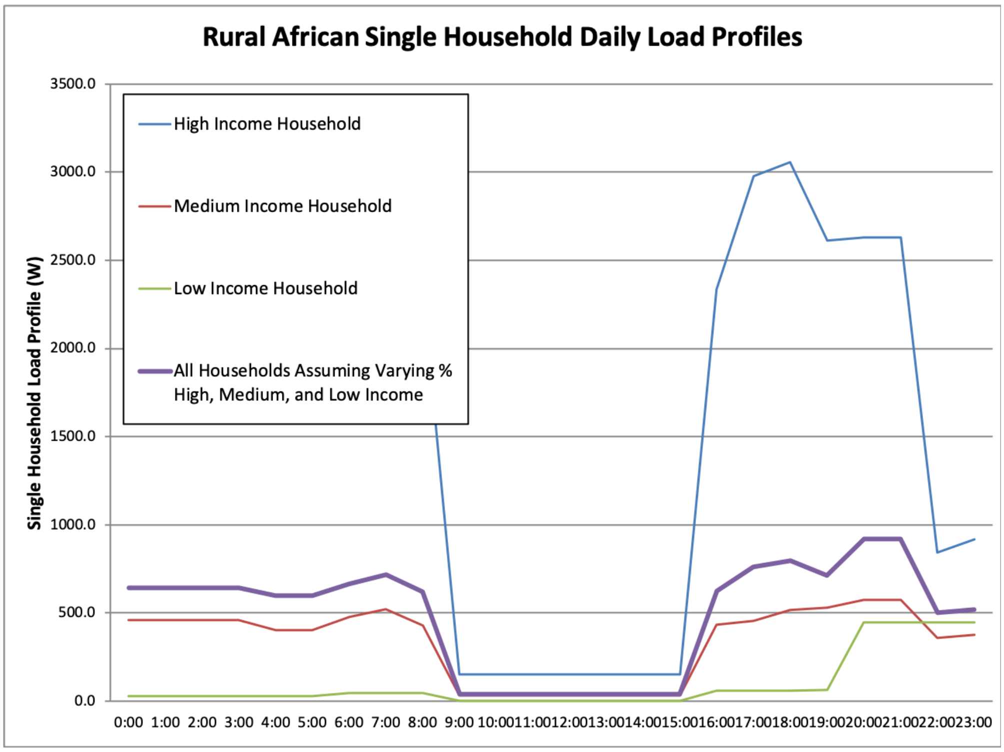


Figure 5.2: A single household load profile

Information from the household data collected allow us to subdivide electrical household consumers into three categories based on their income status. We have the high income households, medium income households and low income household. The graph in fig 5.2 shows the load profile of a single household for each categories of households. From the graph, it can be observed that consumption level depends on the income of the consumer. Low income household consumes the least while the high income household consume most among the household consumers.

Furthermore, we observe from the graph that the, consumption level at hour between 12:00am to 6:00am is very low. This is obviously the typical sleeping hour of households in this regions. This is a period of minimal activity and hence least consumption. The hours between 7:00am and 12:00 noon shows raise in activities involving electricity consumption for the medium and high income households but very minimal for the low income households. It was also noted that the consumption rate between this periods were stable. Lower consumption rate can also be observed between the periods 13:00 to 16:00. However, a sharp and peak demand were observed at from 17:00 up till 23:00. these periods shows times of maximum activities for the three categories of household consumers.

In summary, information deduced from fig 5.2 shows a good potential for energy management system based on the consumption pattern of a single household in a day.

5.4 Load profile for commercial users

In this section, we explore the load profile of an commercial as given in figure 5.3.

Similarly, we designed appliances count and hours of usage. This step helped us to understand the load profile for commercial users.

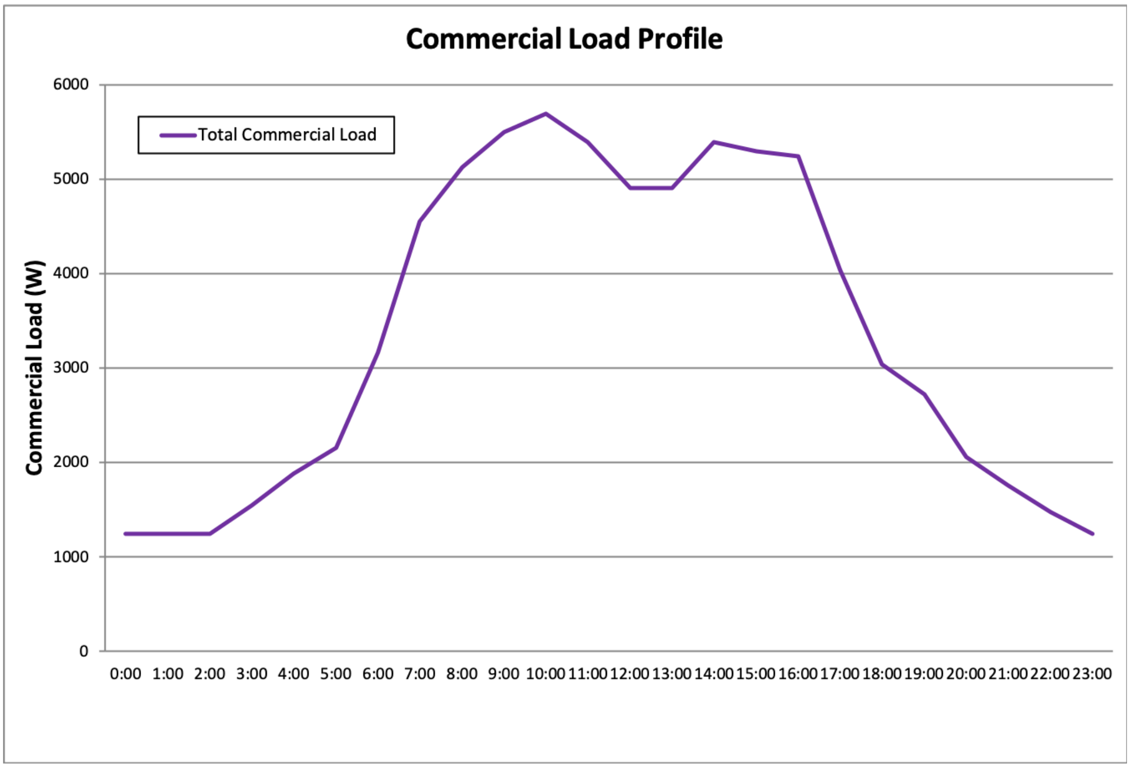


Figure 5.3: Commercial load profile

The typical period of maximum activity for a commercial consumers is usually during the day time. As can be observed from fig5.3, consumption level raised steadily from 5:00am and gained peak around 9:00am when workers have fully resumed and productivity is being carried out. However, between the periods of 12:00noon to 13:00, a sudden drop in consumption was observed which reflects the break period for the workers. Peak consumption was attained again at 15:00 after which consumption dropped steadily from 17:00 which is the usual closing hour for most commercial institute. Unlike the household consumption pattern, the commercial consumers experience their peak consumption hour between 9:00 to 17:00 hours during the day.

5.5 Global load profile at the mini-grid

Fig 5.4, shows the global load profile for all the mini-grid consumers. The load profile shows two major peak which occur in the day period between 8:00 and 12:00 noon and in the evening period between 19:00 and 22:00. However, from 12:00 to 5:00 shows periods of very low demand.

Table 5.4: Total load profiles (KW)

	Total Household Load	Total Commercial Load	Total Household + Commercial Load
0:00	10.69	1.25	11.94
1:00	10.30	1.25	11.55
2:00	10.08	1.25	11.33
3:00	9.94	1.54	11.48
4:00	9.51	1.89	11.40
5:00	9.40	2.16	11.56
6:00	9.81	3.16	12.97
7:00	9.71	4.56	14.26
8:00	7.72	5.13	12.84
9:00	2.99	5.50	8.48
10:00	1.58	5.69	7.28
11:00	1.16	5.40	6.56
12:00	1.10	4.91	6.01
13:00	1.18	4.91	6.09
14:00	1.66	5.40	7.06
15:00	3.18	5.30	8.48
16:00	8.26	5.24	13.50
17:00	10.72	4.04	14.77
18:00	11.84	3.04	14.88
19:00	12.55	2.73	15.27
20:00	15.39	2.06	17.45
21:00	15.42	1.76	17.18
22:00	12.65	1.48	14.13
23:00	11.75	1.25	13.00
Total kWh/day	199	81	**279**
Total kWh/year	72,477	29,524	**102,001**
Max kW/day	15.42	5.69	**17.45**
Min kW/day	1.10	1.25	**6.01**

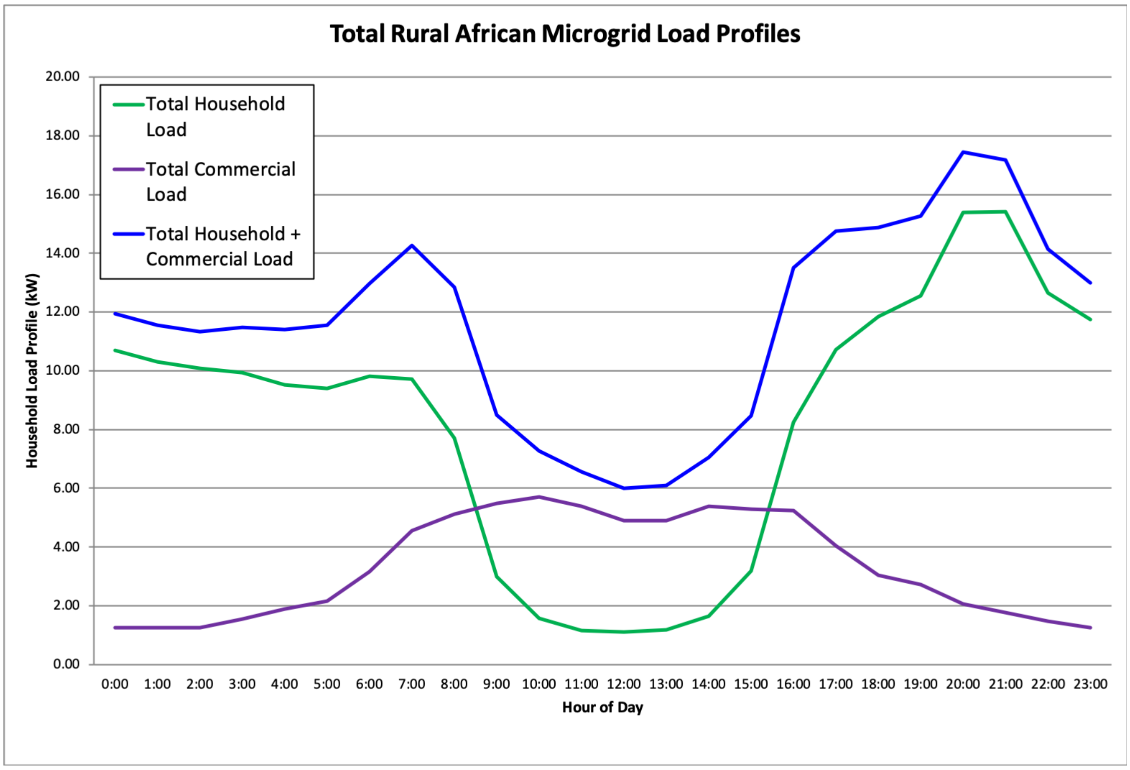


Figure 5.4: Global load profile

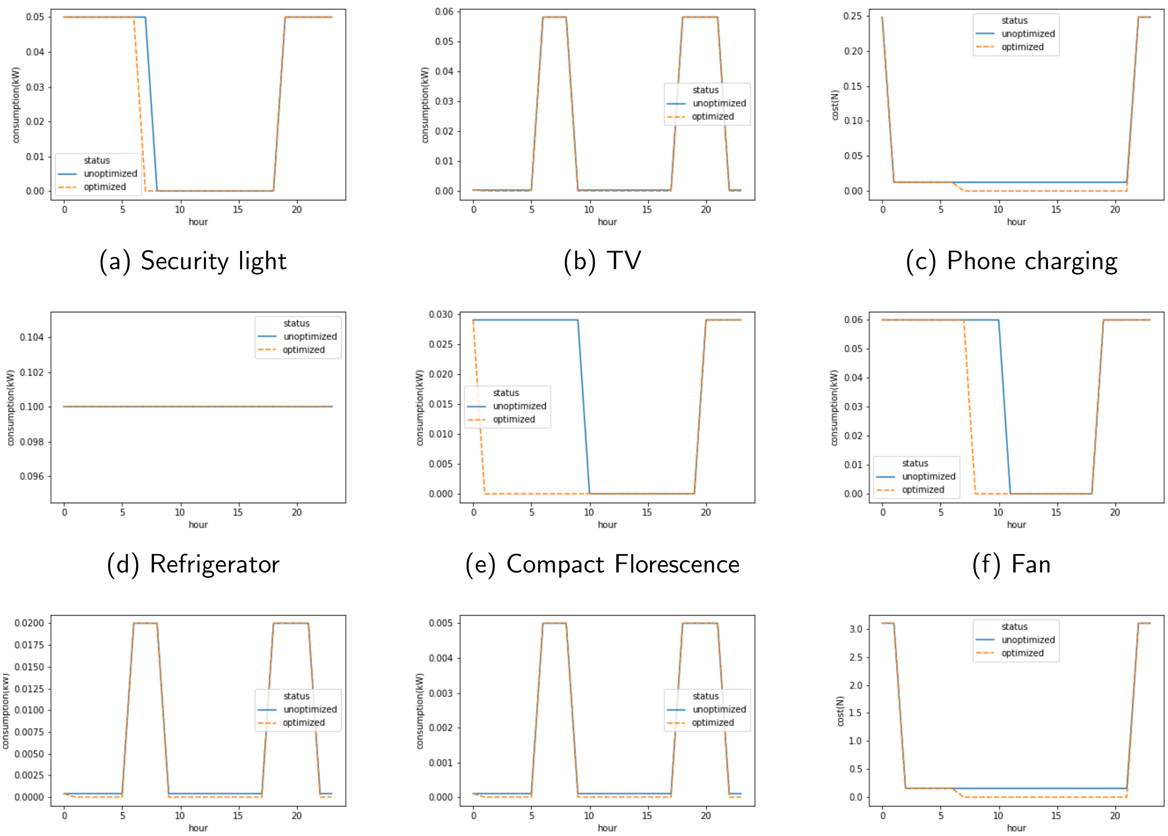
The mini-grid system may experience peak demand which might lead to grid overload and shut down at 19:00 to 22:00. The proposed Energy management system is used to manage the consumption rate at this period by shedding-off loads of households according to pre-determined priority. Furthermore, periods of 12:00 to 5:00 when there is least consumption gives the energy management system to conserve excess energy by storing it in energy storage unit. The stored energy can be uses to augment power supply in the peak hour periods.

5.6 PC used for simulation

In this thesis, All simulation processes were carried out in python 3 using the Jupyter notebook environment on MacBook Pro, 2.7GHz Intel core $i5$, 8 GB memory. Important libraries such as Pandas for storing reading and storing data, numpy for numeric computations, date, datetime, seaborn and matplot among others for various functions in the model.

5.7 Simulation to reduce consumption and cost for middle income

In order to optimize the total consumption for one day, we sum up the individual usage of each appliances. As shown in fig. In 5.5, the usage of nine (9) appliances and their hours of usage are plotted between the hours of $00:00-23:00$. The algorithm performed optimization on each of the appliances.



(a) Security light (b) TV (c) Phone charging

(d) Refrigerator (e) Compact Florescence (f) Fan

(g) TV decoder (h) Radio (i) Laptop charging

Figure 5.5: Optimization of appliances for middle income earners

The figure 5.5 shows the optimize and unoptimize state of each household appliance for a week day. The security light was on through the night until 9:00am in the morning in the unoptimize state. This is up to 3hrs due for it to be putt off, hence the security light consumed energy unnecessarily for 3 hours. However, in the optimize state, the model put off the security light immediately it became a low priority at 6:00am. In the case of the TV set, the un-optimize state shows the TV in a standby mode when it is not on while the optimize mode shows it in the off state when not in use. The refrigerator was left to run for 24hours both in the optimize and unoptimize mode. For the compact florescent light, the figure shows that it was put on all through the night there by consuming excess energy.In the optimize state, the model put it off at 1:00am in the morning. The TV decoder, Radio and Laptop charger was also optimize as shown in the figures.

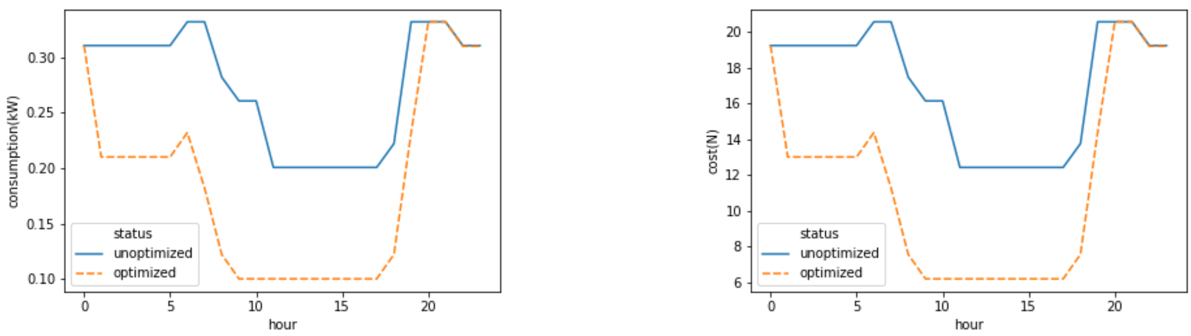


Figure 5.6: Aggregate consumption and cost for Low income

The aggregate optimization result for both cost and consumption as applied to low income, middle income and high income residential home is as display in figures (5.6),(5.7)and(5.8) respectively.

It was observed that in figure 5.6, the some appliances that is supposed to be turned off were left on thereby consuming more energy. Our algorithm turned these appliances off as seen in the graph. Similarly, figures 5.7 and 5.8 optimized the appliances usages in the morning hours. Between the hours of $00:00-7:00$, This could be due to some appliances that

It is interesting to note that, from the figures (5.6, 5.7 and 5.8), usage appears to be high between the hours of $17:00-23:00$. This could be because the household individuals have returned from work and high priority appliances are turned on.

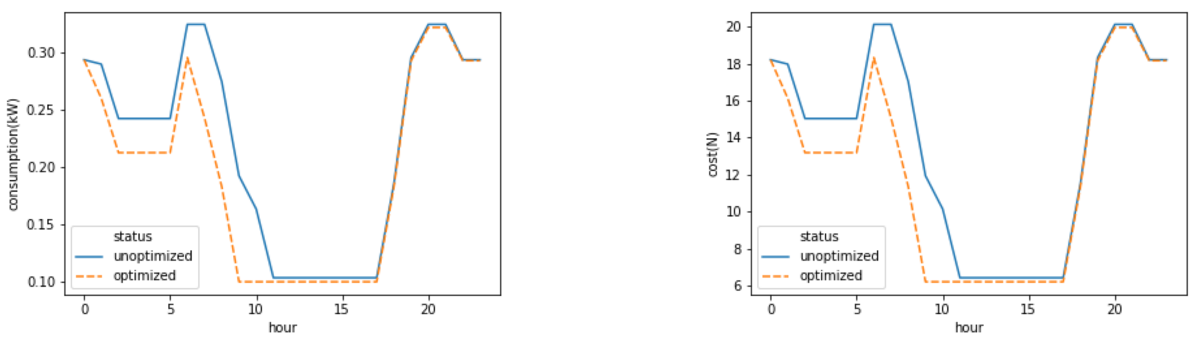


Figure 5.7: Aggregate consumption and cost for middle income

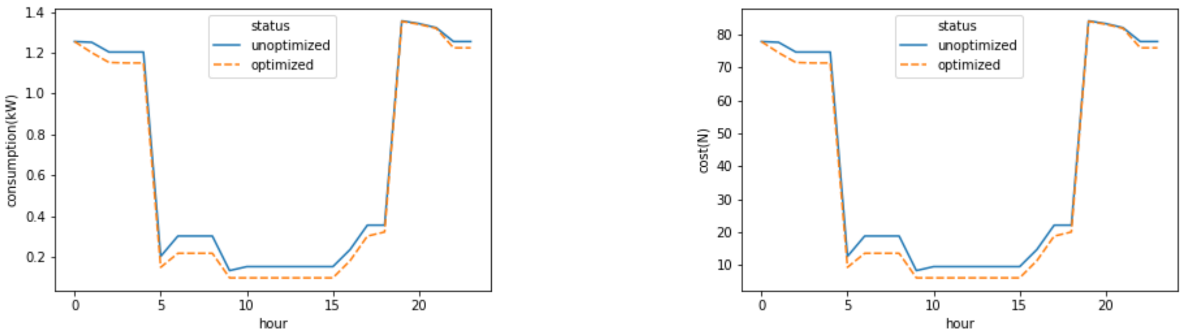


Figure 5.8: Aggregate consumption and cost for high income

Table 5.5 shows the aggregate of total energy consumed and its corresponding costs for a week day as presented for the low, middle and high income earners. The gap is computed using

$$\text{gap } \% = \frac{Unopti. - Opti.}{Unopti.} \times 100\% \tag{5.7.1}$$

where $Unopti.$ and $Opti.$ represents the value for unoptimized and optimized values, respectively.

Table 5.5: Summary of the result for week day

	High income			**Middle income**			**Low income**		
	Unopti.	Opti.	gap(%)	Unopti.	Opti.	gap (%)	Unopti.	Opti.	gap (%)
Consumption	21.01	17.49	16.74	354.81	319.68	9.9	6.57	4.43	32.55
Cost($Naira$)	1302.59	1080.55	16.74	5.72	5.16	9.9	407.60	274.95	32.55

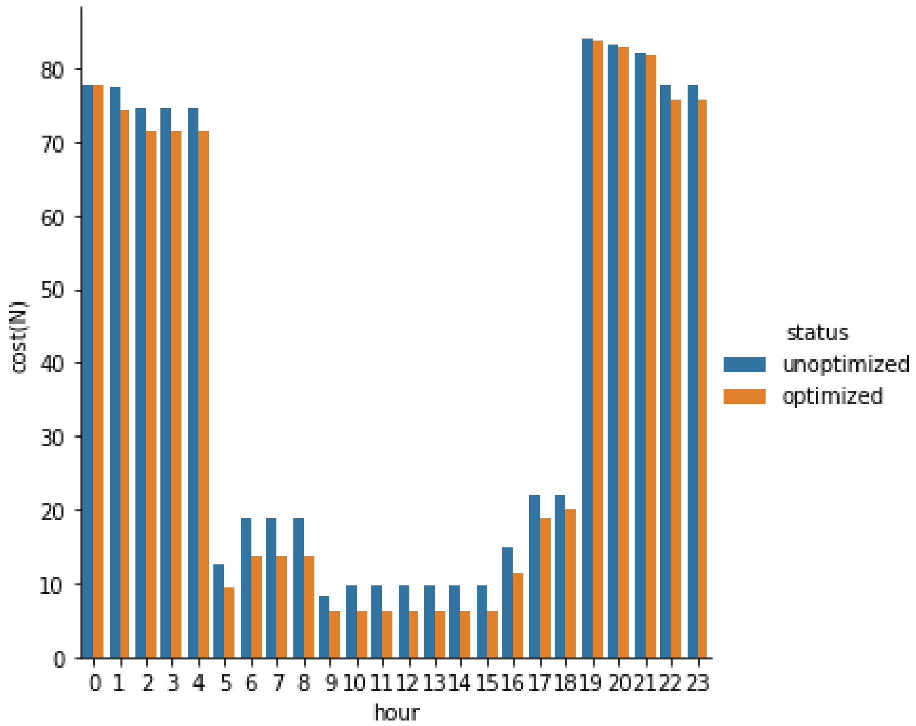


Figure 5.9: Plot showing cost per hour for high income week day

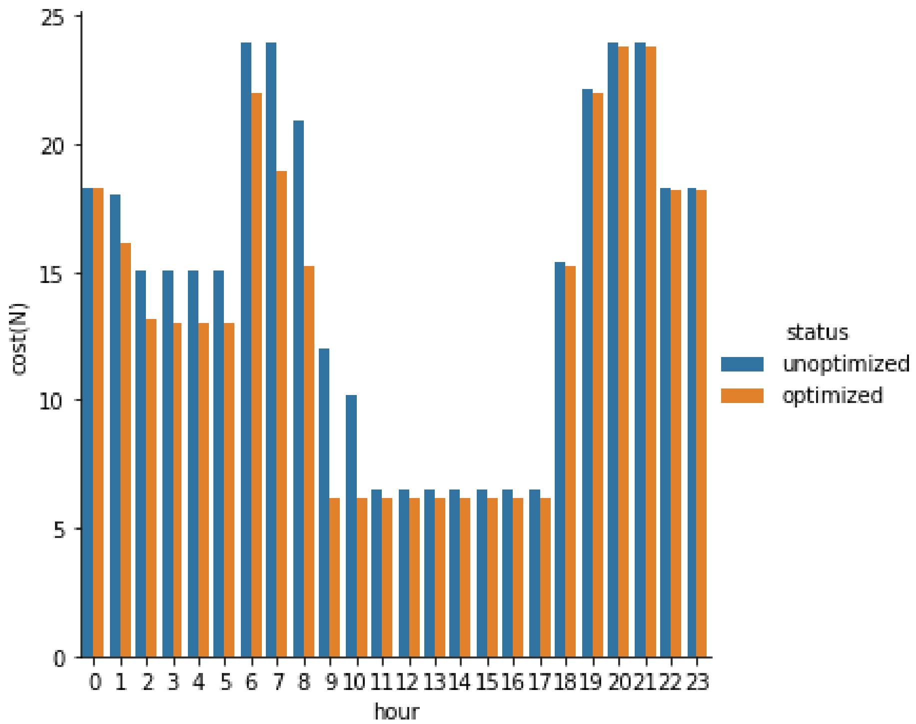


Figure 5.10: Plot showing cost per hour for middle income week day

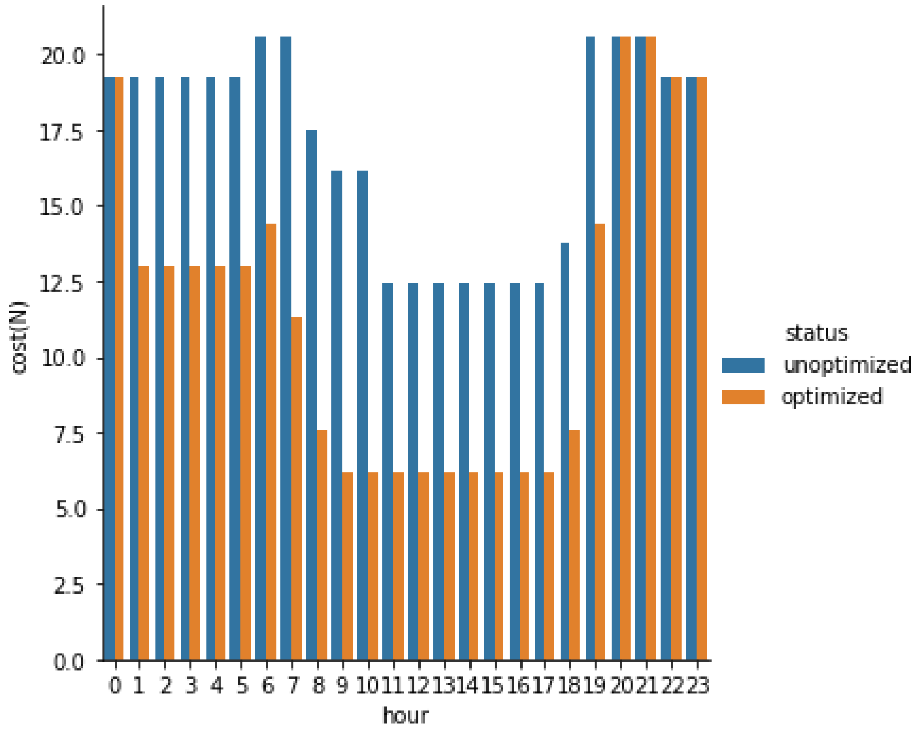


Figure 5.11: Plot showing cost per hour for low income week day

5.8 Simulation of appliances for Weekend usage

Just like we did simulation for week day, we also simulate for weekend as shown in figures 5.12, 5.13, and 5.14. It was observed that there was high usage of appliances during the day time, this could be because most people are indoor and using their appliances. Fig 5.12 shows a sharp increase between 09:00:00 and 10:00:00 because the individual make use of his washing machine withing the period. Also observed from these figures, some low-priority appliances during the day time (such as security light) were turned off and thereby optimizing the consumption and its corresponding cost.

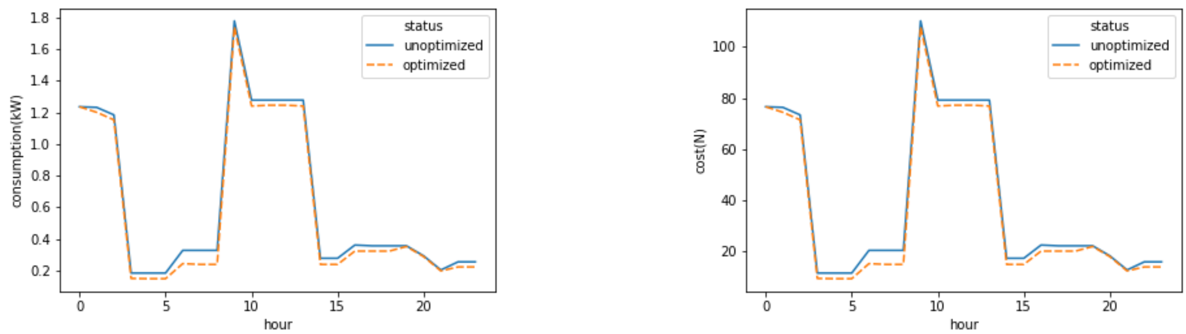


Figure 5.12: Aggregate consumption and cost for high income

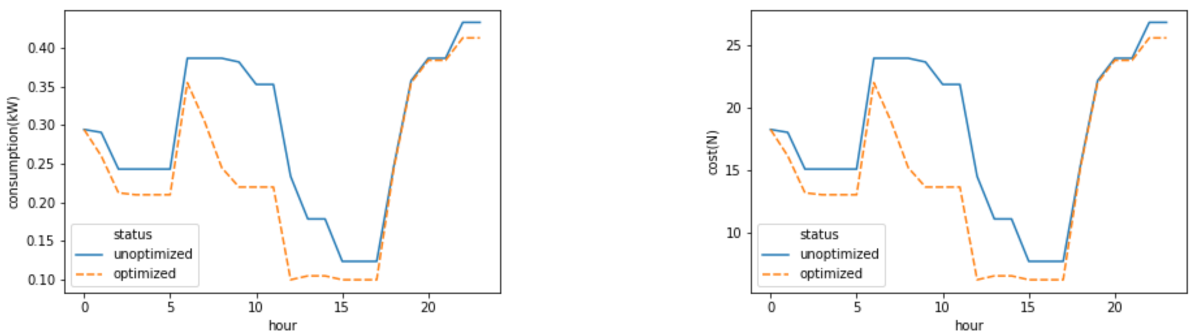


Figure 5.13: Aggregate consumption and cost for middle income

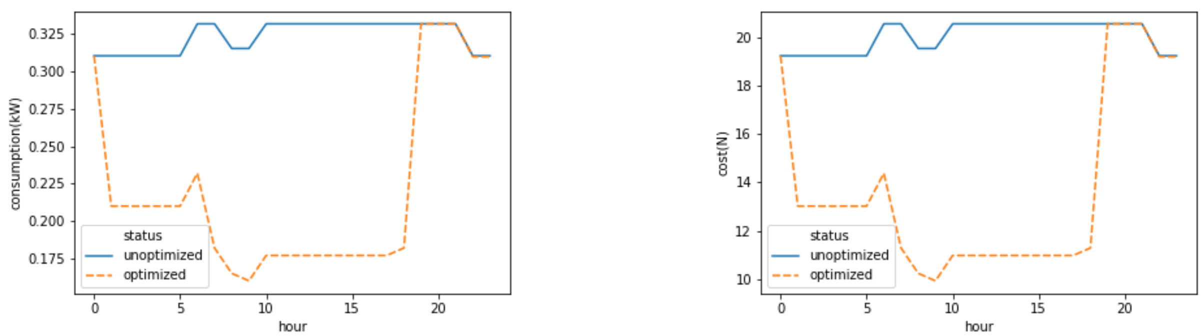


Figure 5.14: Aggregate consumption and cost for middle income

Table 5.6 shows the aggregate of the total energy consumed and its corresponding costs are presented for the low, middle and high income earners. The gap is computed using equation (5.7.1). For the high income earners, there was $\approx 6\%$ energy/cost saved. Similarly, the corresponding gap for middle and low income earners are $\approx 19\%$ and $\approx 32\%$, respectively.

It is worthy to note that table 5.6 is the total consumption and cost for 24 hours. The individual hourly consumption and costs are shown in figures 5.15, 5.16, and 5.17 for high, middle and low income earners, respectively. Each hourly costs presented are summarized in table 5.6.

Table 5.6: Summary of the result for weekend

	High income			**Middle income**			**Low income**		
	Unopti.	Opti.	gap(%)	Unopti.	Opti.	gap (%)	Unopti.	Opti.	gap (%)
Consumption	15.08	14.16	6.11	7.01	5.65	19.39	7.76	5.26	32.20
Cost($Naira$)	935.10	877.99	6.11	434.81	350.52	19.39	481.36	326.34	32.20

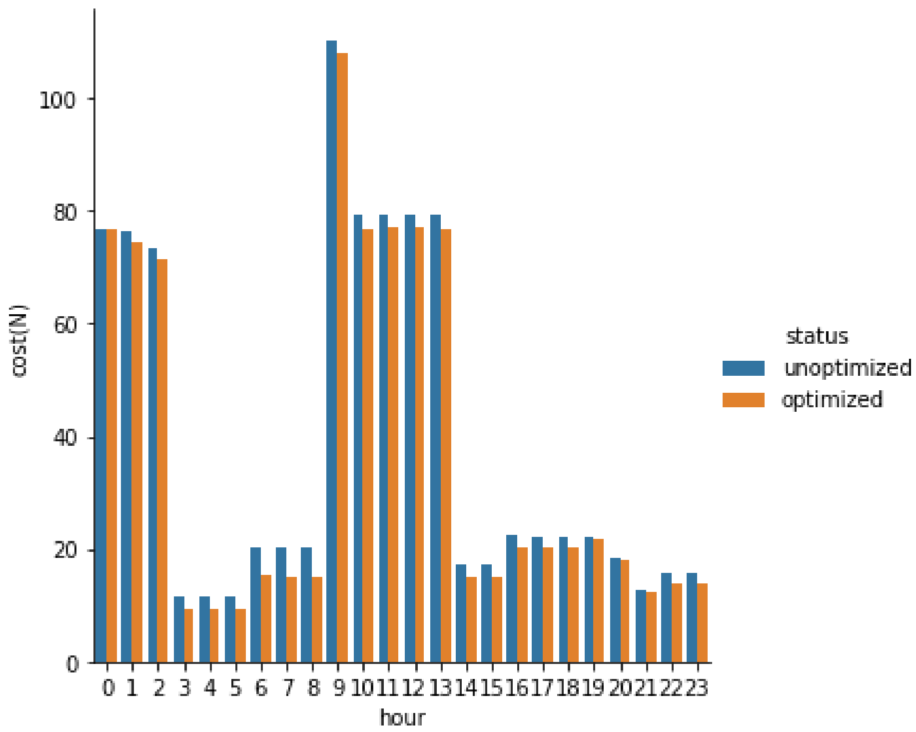


Figure 5.15: Plot showing cost per hour for high income weekend

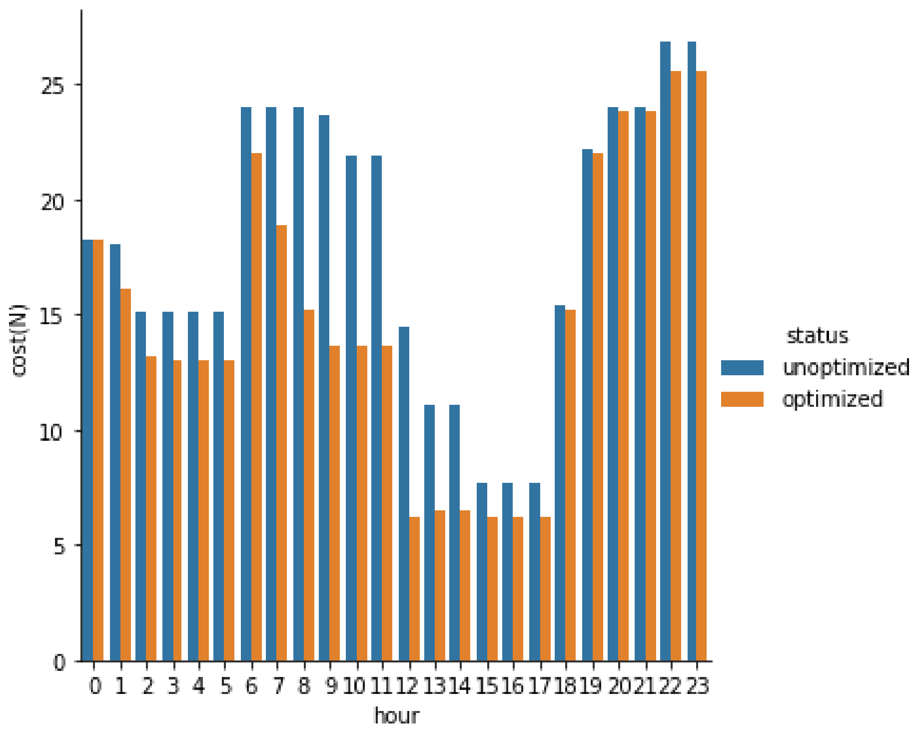


Figure 5.16: Plot showing cost per hour for middle income weekend

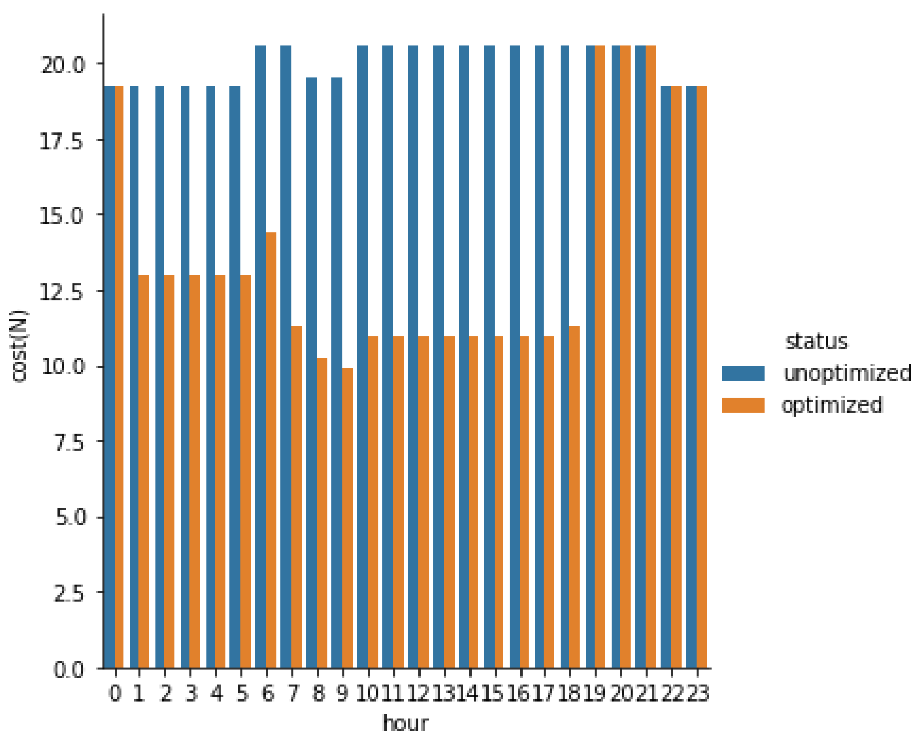


Figure 5.17: Plot showing cost per hour for low income weekend

5.9 Discussion

The analysis started by understanding the load profiles household, commercial centers and the general load profiles in Africa, as shown in figures 5.2, 5.3 and 5.4, respectively. Tables 5.3 and 5.4 summarized the total household load profiles and global load profiles. The appliance count used in given in appendix A.1.

Then for the optimizations of the simulated data, we optimize for high, middle and low income earners for weekdays as shown in figures 5.8, 5.7, and 5.6, respectively. And weekend as shown in figures 5.12, 5.13, and 5.14. The aggregate for 24 hours were also presented in tables 5.5 and 5.6.

Then the individual hourly consumption for high, middle and low are shown in figures 5.9, 5.10 5.11 for week days and 5.15, 5.16, 5.17 for weekend usage.

Having run the simulation for several test cases by varying the data in the excel input file, we observe that the proposed algorithm for the smart energy management performed effectively, by detecting and putting a working low priority load on the off-mode and standby load on the off mode.

- Low-income class During the weekday, it was observed that there was large amount of energy wastage between the hours of 03:00 to 16:00 hours as shown in Figure 5.6. These power wastages was mainly as a result of some low priority appliances (such as fan, security light, TV on standby and incandescence bulb) which were supposed to be put off were left on (see Figure A.1 in the appendix for details. The amount of energy used before optimization and after optimization in each hour were also shown in Figure 5.11 .
- Middle-income class During the weekday, energy was saved during the hours of 00:00 to 11:00. Some low-priority appliances were left either on or standby as shown in Figure A.2.
- High-income class Some low-priority appliances (as categorized based on the hour) such as bulb and radio were on instead of off.

The proposed algorithm will can serve as potential energy serving tool if implemented in households. The algorithm will assist electricity consumers in rural communities to effectively manage the electricity usage by avoiding wastage and the need to pay for energy wastage. At the grid level, the problem of peak demand can be managed with the presence of smart meter.

6. Conclusion and Outreach

6.1 Conclusion

Among the major concerns and pressing issues in the world today is the is the issue of energy security and access, energy efficiency as well as energy conservation.

The objective of this research is to develop an automated system working with the principle of Artificial intelligence that can reduce power consumption and cost at the household level using simulated data from already existing mini-grid systems and exploring the consumer 's electricity consumption behavior. The households were classified into three classes; High, Middle- and Low-income earners. The load profiles for each class of the household usage and the load profile for commercial centers (i.e. schools, hospitals, milling plant, water pump, and street lights examined. The simulated data was then simulated based on energy usage on week days and weekends. Based on experimental results; the energy (and consumption) saved during week day for high, middle- and low-income earners are 16.74%, 9.9% and 32.55%, respectively. Similarly, the corresponding cost and consumption saved during weekends for high, middle- and low-income earners are 6.11%, 19.39% and 32.20%, respectively.

It was observed that for low income earners, appliances such as incandescence bulb, security light, fan and television were left either on or standby, which consume energy and the smart system turned it off to save energy. For middle income earners, appliances such as security light and compact florescence bulb were left on, laptop and phone charger were left on standby, and these activities also consumed energy which the smart system was able to turn off. For high income, security, TV, compact florescence bulb was turned on, and some appliances such as laptop and phone charger were left on standby.

The proposed smart system algorithm has displayed a very good potential for energy management at the household level by cutting off electrical appliances which are not being used but fully consuming electricity as well as appliances on standby. The smart system algorithm will not only help the consumer to reduce electricity cost by reducing consumption but also help to reduce demand at the grid level.

6.2 Limitation of the research and Future work

This research intended to be carried out with 6 weeks internship with WASCAL, Burkina Faso (and later GVE ltd, Nigeria) with aim of getting historical data as well as primary data from one of the existing mini-grid in the intended country. Hence, we resulted to using simulated data.

In future works, real data will be used for simulations over six (6) months period. In addition, other AI techniques like Reinforcement learning will be used to enhance the operation of the automated system.

Further more, a modelling and simulation of smart meter using matlab/simulink will be carried out to obtained a smart meter data instead of simulating a smart meter-like data.

And finally, future work will focus on the application of the artificial intelligence based energy management at the minigrid level since the work here is concentrated at the household level.

References

[1] Abdulmumini Yakubu, E., Ayandele, J., Sherwood Olu, A., and Olu Sachiko, G. (2018). Minigrid investment report: Scaling the nigeria market.

[2] Agency, I. E. Technology roadmap, smart grid, 2011. www.iea.oeg. Accessed 4 July 2020.

[3] Ahmed, M. S., Mohamed, A., Homod, R. Z., and Shareef, H. (2017). A home energy management algorithm in demand response events for household peak load reduction. *PrzeglAd Elektrotechniczny*, 93(3):2017.

[4] Alwan, H. O. and Abdelwahed, S. (2019). Demand side management-literature review and performance comparison. In *2019 11th International Conference on Computational Intelligence and Communication Networks (CICN)*, pages 93–102. IEEE.

[5] Amarnath, D. and Sujatha, S. (2020). Internet-of-things-aided energy management in smart grid environment. *The Journal of Supercomputing*, 76(4):2302–2314.

[6] Avila, N., Carvallo, J. P., Shaw, B., and Kammen, D. M. (2017). The energy challenge in sub-saharan africa: A guide for advocates and policy makers. *Generating Energy for Sustainable and Equitable Development, Part*, 1:1–79.

[7] Azimoh, C. L., Klintenberg, P., Mbohwa, C., and Wallin, F. (2017). Replicability and scalability of mini-grid solution to rural electrification programs in sub-saharan africa. *Renewable Energy*, 106:222–231.

[8] Bahaj, A. S. and James, P. A. (2019). Electrical minigrids for development: Lessons from the field. *Proceedings of the IEEE*, 107(9):1967–1980.

[9] Barbato, A., Capone, A., Chen, L., Martignon, F., and Paris, S. (2015). A distributed demand-side management framework for the smart grid. *Computer Communications*, 57:13–24.

[10] Bazilian, M., Welsch, M., Divan, D., Elzinga, D., Strbac, G., Howells, M., Jones, L., Keane, A., Gielen, D., Balijepalli, V., et al. (2011). Smart and just grids: opportunities for sub-saharan africa.

[11] Bogolea, B. D., Boyle, P. J., and Shindyapin, A. V. (2007). Artificial-intelligence-based energy auditing, monitoring and control. US Patent App. 11/696,669.

[12] Elkazaz, M. H., Hoballah, A., and Azmy, A. M. (2016). Artificial intelligent-based optimization of automated home energy management systems. *International Transactions on Electrical Energy Systems*, 26(9):2038–2056.

[13] energypedia. Mini grids, 25 feburary 2019. https://energypedia.info/wiki/Mini_Grids#Challenges. Accessed 11 April 2020.

[14] ERC-IFC. Kenya mini-grids market assessment -final report. . 2015.

[15] Fontenot, H. and Dong, B. (2019). Modeling and control of building-integrated microgrids for optimal energy management–a review. *Applied Energy*, 254:113689.

[16] Fritzsche, K., Shuttleworth, L., Brand, B., and Blechinger, P. (2019). Exploring the nexus of mini-grids and digital technologies. potentials, challenges and options for sustainable energy access in sub-saharan africa.

[17] GHOSH, R. (2013). Electric bulb not switched off at day. waste of electricity. shot on morning hours.

[18] H. Manfred, T. S. and d. S. Lucia. Energy in africa: Chanallanges and opportunities. SpringerBriefsinEnergy. 2018.

[19] Hansen, H., Tewes, M. S., and Foldager, N. (2018). A home energy management system with focus on energy optimization.

[20] Hobson, E. L. Mappping and assessment of existing clean energy mini-grid experiences in west africa. 2016.

[21] HODGSON, S. and Hemmingham, C. (2017). Firefighters warn against leaving phone chargers plugged in after two fires.

[22] IEA. Digitalization & energy,.

[23] IRENA. Innovation landscape brief: Artificial intelligence and big data. InternationalRenewableEnergyAgency,AbuDhabi,. 2019.

[24] Jo, H. and Yoon, Y. I. (2018). Intelligent smart home energy efficiency model using artificial tensorflow engine. *Human-centric Computing and Information Sciences*, 8(1):1–18.

[25] John, T. M., Ucheaga, E. G., Olowo, O. O., Badejo, J. A., and Atayero, A. A. (2016). Towards building smart energy systems in sub-saharan africa: A conceptual analytics of electric power consumption. In *2016 Future Technologies Conference (FTC)*, pages 796–805. IEEE.

[26] Kabalci, Y., Kabalci, E., Padmanaban, S., Holm-Nielsen, J. B., and Blaabjerg, F. (2019). Internet of things applications as energy internet in smart grids and smart environments. *Electronics*, 8(9):972.

[27] Kim, S. C., Ray, P., and Reddy, S. S. (2019). Features of smart grid technologies: an overview. *ECTI Transactions on Electrical Engineering, Electronics, and Communications*, 17(2):169–180.

[28] Kushiro, N., Suzuki, S., Nakata, M., Takahara, H., and Inoue, M. (2003). Integrated residential gateway controller for home energy management system. *IEEE Transactions on Consumer Electronics*, 49(3):629–636.

[29] Lee, S., Jung, S., and Lee, J. (2019). Prediction model based on an artificial neural network for user-based building energy consumption in south korea. *Energies*, 12(4):608.

[30] Leitão, J., Gil, P., Ribeiro, B., and Cardoso, A. (2020). A survey on home energy management. *IEEE Access*, 8:5699–5722.

[31] Li, X., Salasovich, J., and Reber, T. (2018). Microgrid load and lcoe modelling results.

[32] Liu, Y., Yang, C., Jiang, L., Xie, S., and Zhang, Y. (2019). Intelligent edge computing for iot-based energy management in smart cities. *IEEE Network*, 33(2):111–117.

[33] Lujano-Rojas, J. M., Monteiro, C., Dufo-Lopez, R., and Bernal-Agustín, J. L. (2012). Optimum residential load management strategy for real time pricing (rtp) demand response programs. *Energy policy*, 45:671–679.

[34] Macedo, M. N., Galo, J. J., De Almeida, L., and Lima, A. d. C. (2015). Demand side management using artificial neural networks in a smart grid environment. *Renewable and Sustainable Energy Reviews*, 41:128–133.

[35] Mahapatra, B. and Nayyar, A. (2019). Home energy management system (hems): concept, architecture, infrastructure, challenges and energy management schemes. *Energy Systems*, pages 1–27.

[36] Mazzoni, D. (2019). Digitalization for energy access in sub-saharan africa: challenges, opportunities and potential business models.

[37] Mekkaoui, A., Laouer, M., and Mimoun, Y. (2017). Modeling and simulation for smart grid integration of solar/wind energy. *Leonardo Journal of Sciences*, 30:31–46.

[38] Mohamed, M. A. and Eltamaly, A. M. (2018). *Modeling and simulation of smart grid integrated with hybrid renewable energy systems*. Springer.

[39] MrReid.org (2013). Standby power.

[40] NERC (2019). Distribution/end user tariff.

[41] Nnaji, E. C., Adgidzi, D., Dioha, M. O., Ewim, D. R., and Huan, Z. (2019). Modelling and management of smart microgrid for rural electrification in sub-saharan africa: The case of nigeria. *The Electricity Journal*, 32(10):106672.

[42] Oluwole, O. (2018). *Weather-sensitive, spatially-disaggregated electricity demand model for Nigeria*. PhD thesis, University of Edinburgh.

[43] Outlook, A. E. Africa energy outlook 2019. https://www.iea.org/reports/africa-energy-outlook-2019. ccessed 4 April 2020.

[44] Perez, K., Cole, W., Baldea, M., and Edgar, T. (2014). Meters to models: Using smart meter data to predict and control home energy use. In *ACEEE 2014 Summer Study on Energy Efficiency in Buildings*.

[45] Puttamadappa, C. and Parameshachari, B. (2019). Demand side management of small scale loads in a smart grid using glow-worm swarm optimization technique. *Microprocessors and Microsystems*, 71:102886.

[46] Qurat-Ul-Ain, Iqbal, S. and Nadeem, J. (2018). *User Comfort Enhancement in Home Energy Management Systems using Fuzzy Logic*. PhD thesis, Department of Computing.

[47] Rao, G. J., Naresh, P., Venkatesh, G., and Ramireddy, P. Simulation of an automatic meter reading system for smart metering by using ask/ook modulation in rural smart micro-grids.

[48] Ritchie, H. (2019). Access to energy. *Our World in Data*.

[49] Safiuddin, M. History of the electric grid. 2016.

[50] Sallam, A. A. and Malik, O. P. (2019). Demand-side management and energy efficiency.

[51] Services, W. E. (2020). Electrical energy waste and misuse at home.

[52] Shafik, W., Matinkhah, S. M., and Ghasemzadeh, M. (2020). Internet of things-based energy management, challenges, and solutions in smart cities. *Journal of Communications Technology, Electronics and Computer Science*, 27:1–11.

[53] Thomas, J. (2019). Latest trends in smart grid technology in the utilities industry.

[54] Tisheva, P. Overview - africa's mini grid sector preparing to take off.

[55] Trotter, P. A., McManus, M. C., and Maconachie, R. (2017). Electricity planning and implementation in sub-saharan africa: A systematic review. *Renewable and Sustainable Energy Reviews*, 74:1189–1209.

[56] Wacks, K. P. (1991). Utility load management using home automation. *IEEE Transactions on Consumer Electronics*, 37(2):168–174.

[57] Wang, X., Mao, X., and Khodaei, H. (2020a). A multi-objective home energy management system based on internet of things and optimization algorithms. *Journal of Building Engineering*, page 101603.

[58] Wang, Y., Chen, Q., and Kang, C. (2020b). *Smart Meter Data Analytics: Electricity Consumer Behavior Modeling, Aggregation, and Forecasting*. Springer Nature.

[59] Wang, Z. and Srinivasan, R. S. (2015). A review of artificial intelligence based building energy prediction with a focus on ensemble prediction models. In *2015 Winter Simulation Conference (WSC)*, pages 3438–3448. IEEE.

[60] Worldbank (2019). Population-total, nigeria.

[61] Yakubu, A., Ayandele, E., Sherwood, J., Olu, O., and Graber, S. (2018). Minigrid investment report: Scaling the nigerian market. *The Nigerian Economic Summit Group*.

[62] Yang, C. (2012). *Development of intelligent energy management system using natural computing*. PhD thesis, University of Toledo.

[63] Zare Oskouei, M. and Yazdankhah, A. (2017). The role of coordinated load shifting and frequency-based pricing strategies in maximizing hybrid system profit. *Energy*, 135.

[64] Zhang, Z., Wang, J., Zhong, H., and Ma, H. (2020). Optimal scheduling model for smart home energy management system based on the fusion algorithm of harmony search algorithm and particle swarm optimization algorithm. *Science and Technology for the Built Environment*, 26(1):42–51.

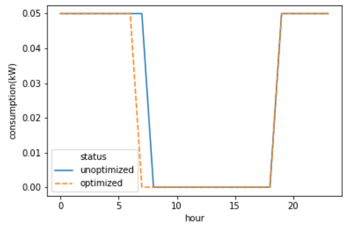
[65] Zhou, Y., Chen, Y., Xu, G., Zhang, Q., and Krundel, L. (2014). Home energy management with pso in smart grid. In *2014 IEEE 23rd International Symposium on Industrial Electronics (ISIE)*, pages 1666–1670. IEEE.

Appendix A. Some additional data

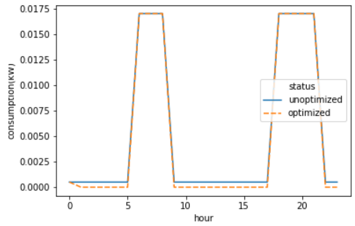
A.1 Additional tables and Figures

	Appliances Power Ratings		High Income Household	Medium Income Household	Low Income Household
	Appliance Wattage (W)	Appliances Standby Power (W)	Appliance Count	Appliance Count	Appliance Count
APPLIANCES					
Lighting System					
Incandescence bulb	100	0	0	2	4
Compact Florescence Bulb	29	0	5	2	0
Security light	50	0	3	1	0
Entertianment					
22 Inch LED TV	17	0.5	0	1	1
42 Inch LED TV	58	0.3	2	1	0
65 Inch LED TV	120	1	1	1	0
DVD Player	26	0.2	1	1	1
Radio	5	0.1	3	1	1
TV decoder	20	0.4	1	1	1
Thermal Comfort					
Fan	60	0	4	3	2
Air Conditioner	1000	1.5	2	1	0
Refrigerator	100	0	2	1	0
Electric Kettle	1200	0	1	1	0
Microwave	600	3	1	0	0
Other Appliances					
Phone Charging	4	0.2	4	2	1
Laptop Charging	50	2.5	2	1	0
Printer	20	0.1	1	0	0
Washing machine	500	1	1	0	0

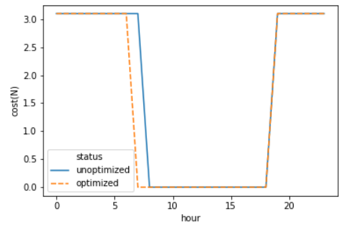
Table A.1: ASSUMED APPLIANCE WATTAGE & COUNT



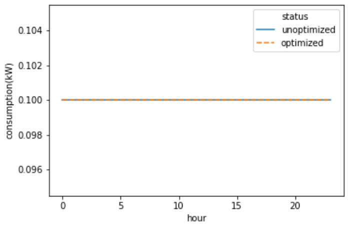
(a) Security light consumption



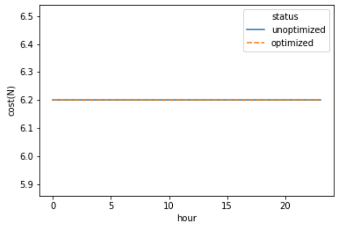
(b) TV consumption



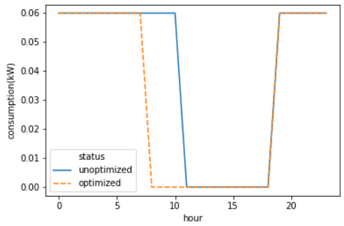
(c) Security ligh cost



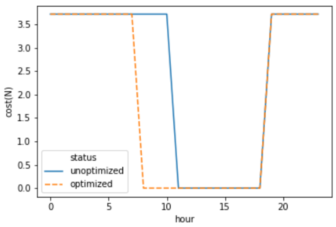
(d) Refrigerator consumption



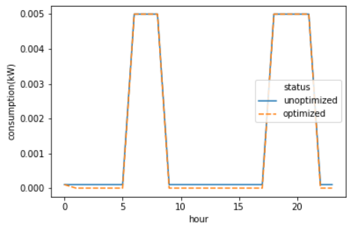
(e) Refrigerator cost



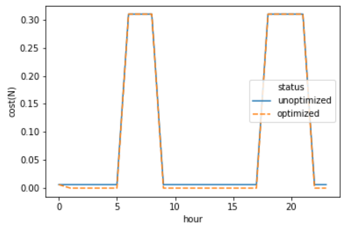
(f) Fan consumption



(g) Fan cost

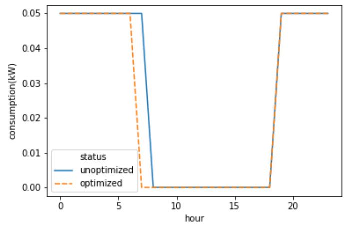


(h) Radio consumption

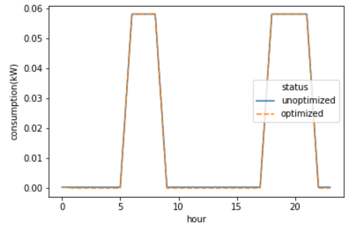


(i) Radio cost

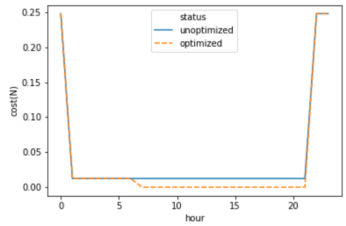
Figure A.1: appliances for low income earners



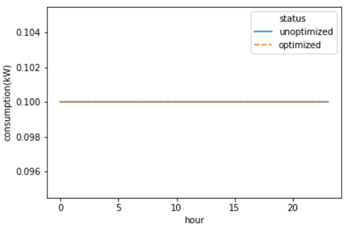
(a) Security light



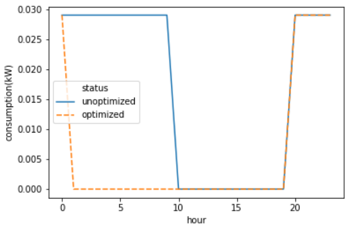
(b) TV



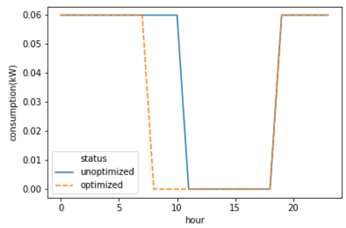
(c) Phone charging



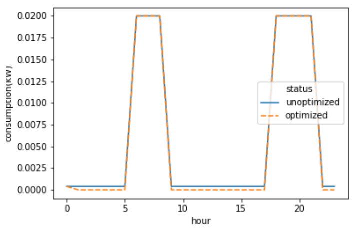
(d) Refrigerator



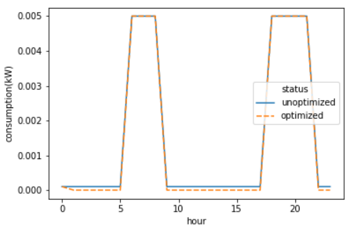
(e) Compact Florescence



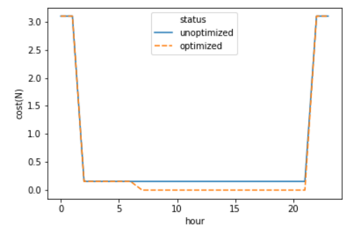
(f) Fan



(g) TV decoder

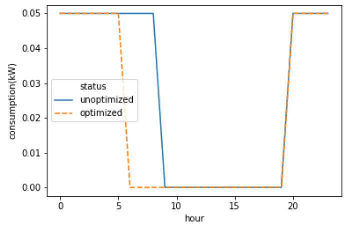


(h) Radio

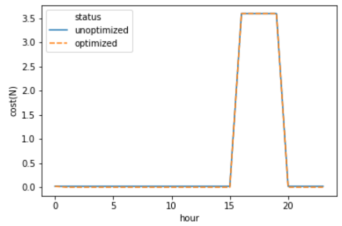


(i) Laptop charging

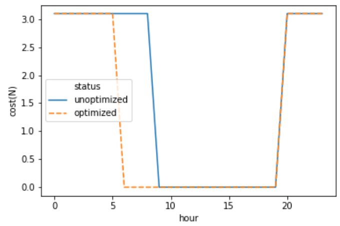
Figure A.2: Appliances for middle income earners



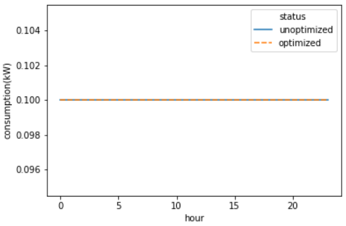
(a) Security light consumption



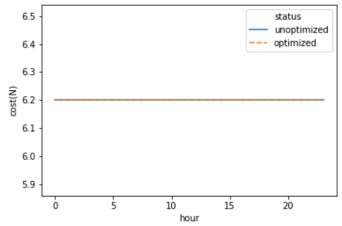
(b) TV cost



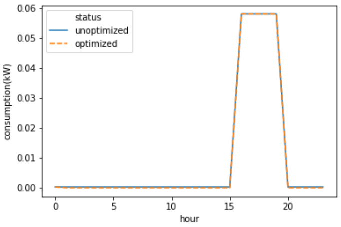
(c) Security ligh cost



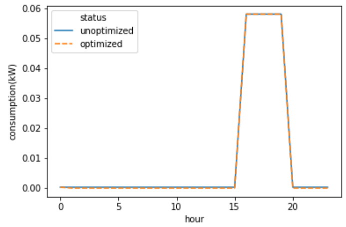
(d) Refrigerator consumption



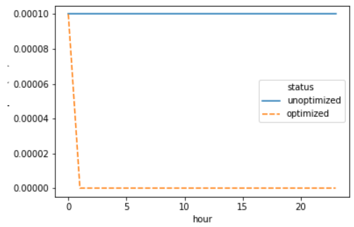
(e) Refrigerator cost



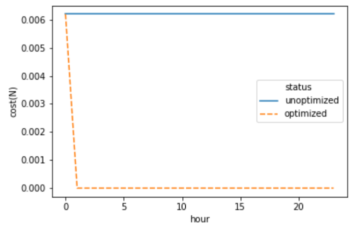
(f) 42" TV consumption



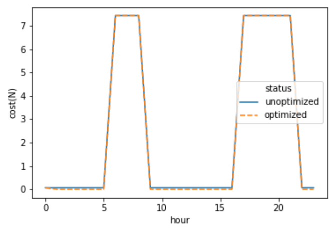
(g) 65" TV comsumption



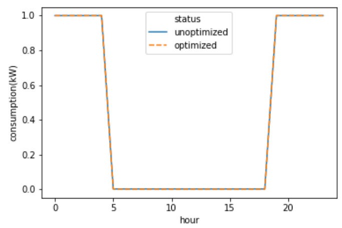
(h) Radio consumption



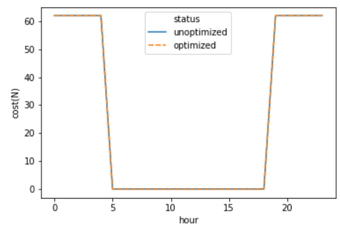
(i) Radio cost



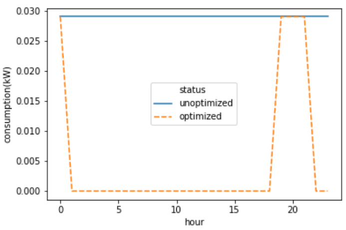
(j) 65" TV cost



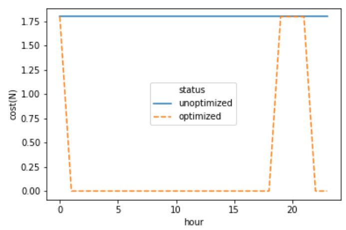
(k) AC consumption



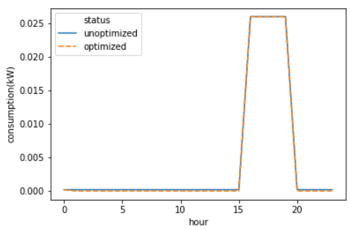
(l) AC cost



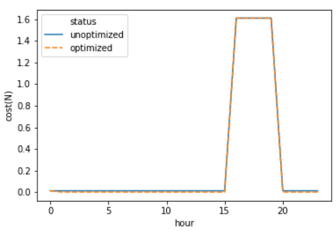
(m) C.F. Bulb consumption



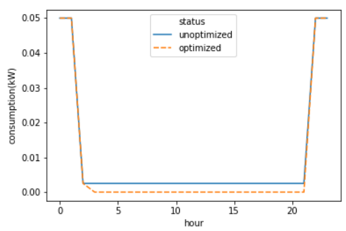
(n) C.F. Bulb cost



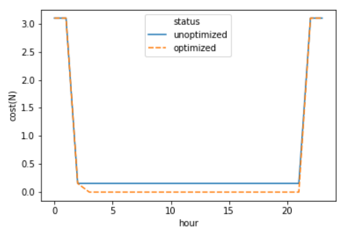
(o) DVD player consumption



(p) DVD Player cost



(q) Laptop charging consumption



(r) Laptop Charging cost

Figure A.3: appliances for High income earners

A.2 Analysis of hourly consumption

As shown in appendix A.1, A.2, and A.3:

- At 00:00:00, Compact Florescence Bulb had a consumption of $0.029kW$ and an optimized consumption of 0.029kW 65 Inch LED TV had a consumption of 0.001kW and an optimized consumption of 0.001kW Refrigerator had a consumption of 0.1kW and an optimized consumption of 0.1kW Security light had a consumption of 0.05kW and an optimized consumption of 0.05kW Air Conditioner had a consumption of 1.0kW and an optimized consumption of 1.0kW Radio had a consumption of 0.0001kW and an optimized consumption of 0.0001kW TV decoder had a consumption of 0.02kW and an optimized consumption of 0.02kW Laptop Charging had a consumption of 0.05kW and an optimized consumption of 0.05kW Phone Charging had a consumption of 0.004kW and an optimized consumption of 0.004kW Printer had a consumption of 0.0001kW and an optimized consumption of 0.0001kW DVD Player had a consumption of 0.0002kW and an optimized consumption of 0.0002kW 42 Inch LED TV had a consumption of 0.0003kW and an optimized consumption of 0.0003kW Washing machine had a consumption of 0kW and an optimized consumption of 0kW.

- At 01:00:00, Compact Florescence Bulb had a consumption of 0.029kW and an optimized consumption of 0kW 65 Inch LED TV had a consumption of 0.001kW and an optimized consumption of 0kW Refrigerator had a consumption of 0.1kW and an optimized consumption of 0.1kW Security light had a consumption of 0.05kW and an optimized consumption of 0.05kW Air Conditioner had a consumption of 1.0kW and an optimized consumption of 1.0kW Radio had a consumption of 0.0001kW and an optimized consumption of 0kW TV decoder had a consumption of 0.02kW and an optimized consumption of 0kW Laptop Charging had a consumption of 0.05kW and an optimized consumption of 0.05kW Phone Charging had a consumption of 0.0002kW and an optimized consumption of 0kW Printer had a consumption of 0.0001kW and an optimized consumption of 0kW DVD Player had a consumption of 0.0002kW and an optimized consumption of 0kW 42 Inch LED TV had a consumption of 0.0003kW and an optimized consumption of 0kW Washing machine had a consumption of 0kW and an optimized consumption of 0kW.

- At 02:00:00, Compact Florescence Bulb had a consumption of 0.029kW and an optimized consumption of 0kW 65 Inch LED TV had a consumption of 0.001kW and an optimized consumption of 0kW Refrigerator had a consumption of 0.1kW and an optimized consumption of 0.1kW Security light had a consumption of 0.05kW and an optimized consumption of 0.05kW Air Conditioner had a consumption of 1.0kW and an optimized consumption of 1.0kW Radio had a consumption of 0.0001kW and an optimized consumption of 0kW TV decoder had a consumption of 0.02kW and an optimized consumption of 0kW Laptop Charging had a consumption of 0.0025kW and an optimized consumption of 0kW Phone Charging had a consumption of 0.0002kW and an optimized consumption of 0kW Printer had a consumption of 0.0001kW and an optimized consumption of 0kW DVD Player had a consumption of 0.0002kW and an optimized consumption of 0kW 42 Inch LED TV had a consumption of 0.0003kW and an optimized consumption of 0kW Washing machine had a consumption of 0kW and an optimized consumption of 0kW.

- At 03:00:00, Compact Florescence Bulb had a consumption of 0.029kW and an optimized consumption of 0kW 65 Inch LED TV had a consumption of 0.001kW and an optimized consumption of 0kW Refrigerator had a consumption of 0.1kW and an optimized consumption of 0.1kW Security light had a consumption of 0.05kW and an optimized consumption of 0.05kW Air Conditioner had a consumption of 1.0kW and an optimized consumption of 1.0kW Radio had a consumption of 0.0001kW and an optimized consumption of 0kW TV decoder had a consumption of 0.02kW and an optimized consumption of 0kW Laptop Charging had a consumption of 0.0025kW and an optimized consumption of 0kW Phone Charging had a consumption of 0.0002kW and an optimized consumption of 0kW Printer had a consumption of 0.0001kW and an optimized consumption of 0kW DVD Player had a consumption of 0.0002kW and an optimized consumption of 0kW 42 Inch LED TV had a consumption of 0.0003kW and an optimized consumption of 0kW Washing machine had a consumption of 0kW and an optimized consumption of 0kW.

- At 04:00:00, Compact Florescence Bulb had a consumption of 0.029kW and an optimized consumption of 0kW 65 Inch LED TV had a consumption of 0.001kW and an optimized consumption of 0kW Refrigerator had a consumption of 0.1kW and an optimized consumption of 0.1kW Security light had a consumption of 0.05kW and an optimized consumption of 0.05kW Air Conditioner had a consumption of 1.0kW and an optimized consumption of 1.0kW Radio had a consumption of 0.0001kW and an optimized consumption of 0kW TV decoder had a consumption of 0.02kW and an optimized consumption of 0kW Laptop Charging had a consumption of 0.0025kW and an optimized consumption of 0kW Phone Charging had a consumption of 0.0002kW and an optimized consumption of 0kW Printer had a consumption of 0.0001kW and an optimized consumption of 0kW DVD Player had a consumption of 0.0002kW and an optimized consumption of 0kW 42 Inch LED TV had a consumption of 0.0003kW and an optimized consumption of 0kW Washing machine had a consumption of 0kW and an optimized consumption of 0kW.

- At 05:00:00, Compact Florescence Bulb had a consumption of 0.029kW and an optimized consumption of 0kW 65 Inch LED TV had a consumption of 0.001kW and an optimized consumption of 0kW Refrigerator had a consumption of 0.1kW and an optimized consumption of 0.1kW Security light had a consumption of 0.05kW and an optimized consumption of 0kW Air Conditioner had a consumption of 0.0015kW and an optimized consumption of 0kW Radio had a consumption of 0.0001kW and an optimized consumption of 0kW TV decoder had a consumption of 0.02kW and an optimized consumption of 0kW Laptop Charging had a consumption of 0.0025kW and an optimized consumption of 0kW Phone Charging had a consumption of 0.0002kW and an optimized consumption of 0kW Printer had a consumption of 0.0001kW and an optimized consumption of 0kW DVD Player had a consumption of 0.0002kW and an optimized consumption of 0kW 42 Inch LED TV had a consumption of 0.0003kW and an optimized consumption of 0kW Washing machine had a consumption of 0kW and an optimized consumption of 0kW.

- At 06:00:00, Compact Florescence Bulb had a consumption of 0.029kW and an optimized consumption of 0kW 65 Inch LED TV had a consumption of 0.12kW and an optimized consumption of 0.12kW Refrigerator had a consumption of 0.1kW and an optimized consumption of 0.1kW Security light had a consumption of 0.05kW and an optimized consumption of 0kW Air Conditioner had a consumption of 0.0015kW and an optimized consumption of 0kW Radio had a consumption of 0.0001kW and an optimized consumption of 0kW TV decoder had a consumption of 0.0004kW and an optimized consumption of 0kW Laptop Charging had a consumption of 0.0025kW and an optimized consumption of 0kW Phone Charging had a consumption of 0.0002kW and an optimized consumption of 0kW Printer had a consumption of 0.0001kW and an optimized consumption of 0kW DVD Player had a consumption of 0.0002kW and an optimized consumption of 0kW 42 Inch LED TV had a consumption of 0.0003kW and an optimized consumption of 0kW Washing machine had a consumption of 0kW and an optimized consumption of 0kW.

- At 07:00:00, Compact Florescence Bulb had a consumption of 0.029kW and an optimized consumption of 0kW 65 Inch LED TV had a consumption of 0.12kW and an optimized consumption of 0.12kW Refrigerator had a consumption of 0.1kW and an optimized consumption of 0.1kW Security light had a consumption of 0.05kW and an optimized consumption of 0kW Air Conditioner had a consumption of 0.0015kW and an optimized consumption of 0kW Radio had a consumption of 0.0001kW and an optimized consumption of 0kW TV decoder had a consumption of 0.0004kW and an optimized consumption of 0kW Laptop Charging had a consumption of 0.0025kW and an optimized consumption of 0kW Phone Charging had a consumption of 0.0002kW and an optimized consumption of 0kW Printer had a consumption of 0.0001kW and an optimized consumption of 0kW DVD Player had a consumption of 0.0002kW and an optimized consumption of 0kW 42 Inch LED TV had a consumption of 0.0003kW and an optimized consumption of 0kW Washing machine had a consumption of 0kW and an optimized consumption of 0kW.
- At 08:00:00, Compact Florescence Bulb had a consumption of 0.029kW and an optimized consumption of 0kW 65 Inch LED TV had a consumption of 0.12kW and an optimized consumption of 0.12kW Refrigerator had a consumption of 0.1kW and an optimized consumption of 0.1kW Security light had a consumption of 0.05kW and an optimized consumption of 0kW Air Conditioner had a consumption of 0.0015kW and an optimized consumption of 0kW Radio had a consumption of 0.0001kW and an optimized consumption of 0kW TV decoder had a consumption of 0.0004kW and an optimized consumption of 0kW Laptop Charging had a consumption of 0.0025kW and an optimized consumption of 0kW Phone Charging had a consumption of 0.0002kW and an optimized consumption of 0kW Printer had a consumption of 0.0001kW and an optimized consumption of 0kW DVD Player had a consumption of 0.0002kW and an optimized consumption of 0kW 42 Inch LED TV had a consumption of 0.0003kW and an optimized consumption of 0kW Washing machine had a consumption of 0kW and an optimized consumption of 0kW.
- At 09:00:00, Compact Florescence Bulb had a consumption of 0.029kW and an optimized consumption of 0kW 65 Inch LED TV had a consumption of 0.001kW and an optimized consumption of 0kW Refrigerator had a consumption of 0.1kW and an optimized consumption of 0.1kW Security light had a consumption of 0kW and an optimized consumption of 0kW Air Conditioner had

a consumption of 0.0015kW and an optimized consumption of 0kW Radio had a consumption of 0.0001kW and an optimized consumption of 0kW TV decoder had a consumption of 0.0004kW and an optimized consumption of 0kW Laptop Charging had a consumption of 0.0025kW and an optimized consumption of 0kW Phone Charging had a consumption of 0.0002kW and an optimized consumption of 0kW Printer had a consumption of 0.0001kW and an optimized consumption of 0kW DVD Player had a consumption of 0.0002kW and an optimized consumption of 0kW 42 Inch LED TV had a consumption of 0.0003kW and an optimized consumption of 0kW Washing machine had a consumption of 0kW and an optimized consumption of 0kW.

- At 10:00:00, Compact Florescence Bulb had a consumption of 0.029kW and an optimized consumption of 0kW 65 Inch LED TV had a consumption of 0.001kW and an optimized consumption of 0kW Refrigerator had a consumption of 0.1kW and an optimized consumption of 0.1kW Security light had a consumption of 0kW and an optimized consumption of 0kW Air Conditioner had a consumption of 0.0015kW and an optimized consumption of 0kW Radio had a consumption of 0.0001kW and an optimized consumption of 0kW TV decoder had a consumption of 0.02kW and an optimized consumption of 0kW Laptop Charging had a consumption of 0.0025kW and an optimized consumption of 0kW Phone Charging had a consumption of 0.0002kW and an optimized consumption of 0kW Printer had a consumption of 0.0001kW and an optimized consumption of 0kW DVD Player had a consumption of 0.0002kW and an optimized consumption of 0kW 42 Inch LED TV had a consumption of 0.0003kW and an optimized consumption of 0kW Washing machine had a consumption of 0kW and an optimized consumption of 0kW.
- At 11:00:00, Compact Florescence Bulb had a consumption of 0.029kW and an optimized consumption of 0kW 65 Inch LED TV had a consumption of 0.001kW and an optimized consumption of 0kW Refrigerator had a consumption of 0.1kW and an optimized consumption of 0.1kW Security light had a consumption of 0kW and an optimized consumption of 0kW Air Conditioner had a consumption of 0.0015kW and an optimized consumption of 0kW Radio had a consumption of 0.0001kW and an optimized consumption of 0kW TV decoder had a consumption of 0.02kW and an optimized consumption of 0kW Laptop Charging had a consumption of 0.0025kW and an optimized consumption of 0kW Phone Charging had a consumption of 0.0002kW and an optimized consumption of 0kW Printer had a consumption of 0.0001kW and an optimized consumption of

0kW DVD Player had a consumption of 0.0002kW and an optimized consumption of 0kW 42 Inch LED TV had a consumption of 0.0003kW and an optimized consumption of 0kW Washing machine had a consumption of 0kW and an optimized consumption of 0kW.

- At 12:00:00, Compact Florescence Bulb had a consumption of 0.029kW and an optimized consumption of 0kW 65 Inch LED TV had a consumption of 0.001kW and an optimized consumption of 0kW Refrigerator had a consumption of 0.1kW and an optimized consumption of 0.1kW Security light had a consumption of 0kW and an optimized consumption of 0kW Air Conditioner had a consumption of 0.0015kW and an optimized consumption of 0kW Radio had a consumption of 0.0001kW and an optimized consumption of 0kW TV decoder had a consumption of 0.02kW and an optimized consumption of 0kW Laptop Charging had a consumption of 0.0025kW and an optimized consumption of 0kW Phone Charging had a consumption of 0.0002kW and an optimized consumption of 0kW Printer had a consumption of 0.0001kW and an optimized consumption of 0kW DVD Player had a consumption of 0.0002kW and an optimized consumption of 0kW 42 Inch LED TV had a consumption of 0.0003kW and an optimized consumption of 0kW Washing machine had a consumption of 0kW and an optimized consumption of 0kW.

- At 13:00:00, Compact Florescence Bulb had a consumption of 0.029kW and an optimized consumption of 0kW 65 Inch LED TV had a consumption of 0.001kW and an optimized consumption of 0kW Refrigerator had a consumption of 0.1kW and an optimized consumption of 0.1kW Security light had a consumption of 0kW and an optimized consumption of 0kW Air Conditioner had a consumption of 0.0015kW and an optimized consumption of 0kW Radio had a consumption of 0.0001kW and an optimized consumption of 0kW TV decoder had a consumption of 0.02kW and an optimized consumption of 0kW Laptop Charging had a consumption of 0.0025kW and an optimized consumption of 0kW Phone Charging had a consumption of 0.0002kW and an optimized consumption of 0kW Printer had a consumption of 0.0001kW and an optimized consumption of 0kW DVD Player had a consumption of 0.0002kW and an optimized consumption of 0kW 42 Inch LED TV had a consumption of 0.0003kW and an optimized consumption of 0kW Washing machine had a consumption of 0kW and an optimized consumption of 0kW.

- At 14:00:00, Compact Florescence Bulb had a consumption of 0.029kW and an optimized consumption of 0kW 65 Inch LED TV had a consumption of 0.001kW and an optimized consumption of 0kW Refrigerator had a consumption of 0.1kW and an optimized consumption of 0.1kW Security light had a consumption of 0kW and an optimized consumption of 0kW Air Conditioner had a consumption of 0.0015kW and an optimized consumption of 0kW Radio had a consumption of 0.0001kW and an optimized consumption of 0kW TV decoder had a consumption of 0.02kW and an optimized consumption of 0kW Laptop Charging had a consumption of 0.0025kW and an optimized consumption of 0kW Phone Charging had a consumption of 0.0002kW and an optimized consumption of 0kW Printer had a consumption of 0.0001kW and an optimized consumption of 0kW DVD Player had a consumption of 0.0002kW and an optimized consumption of 0kW 42 Inch LED TV had a consumption of 0.0003kW and an optimized consumption of 0kW Washing machine had a consumption of 0kW and an optimized consumption of 0kW.

- At 15:00:00, Compact Florescence Bulb had a consumption of 0.029kW and an optimized consumption of 0kW 65 Inch LED TV had a consumption of 0.001kW and an optimized consumption of 0kW Refrigerator had a consumption of 0.1kW and an optimized consumption of 0.1kW Security light had a consumption of 0kW and an optimized consumption of 0kW Air Conditioner had a consumption of 0.0015kW and an optimized consumption of 0kW Radio had a consumption of 0.0001kW and an optimized consumption of 0kW TV decoder had a consumption of 0.02kW and an optimized consumption of 0kW Laptop Charging had a consumption of 0.0025kW and an optimized consumption of 0kW Phone Charging had a consumption of 0.0002kW and an optimized consumption of 0kW Printer had a consumption of 0.0001kW and an optimized consumption of 0kW DVD Player had a consumption of 0.0002kW and an optimized consumption of 0kW 42 Inch LED TV had a consumption of 0.0003kW and an optimized consumption of 0kW Washing machine had a consumption of 0kW and an optimized consumption of 0kW.

- At 16:00:00, Compact Florescence Bulb had a consumption of 0.029kW and an optimized consumption of 0kW 65 Inch LED TV had a consumption of 0.001kW and an optimized consumption of 0kW Refrigerator had a consumption of 0.1kW and an optimized consumption of 0.1kW Security light had a consumption of 0kW and an optimized consumption of 0kW Air Conditioner had a consumption of 0.0015kW and an optimized consumption of 0kW Radio had a consumption of 0.0001kW and an optimized consumption of 0kW TV decoder had a consumption of 0.02kW and an optimized consumption of 0kW Laptop Charging had a consumption of 0.0025kW and an optimized consumption of 0kW Phone Charging had a consumption of 0.0002kW and an optimized consumption of 0kW Printer had a consumption of 0.0001kW and an optimized consumption of 0kW DVD Player had a consumption of 0.026kW and an optimized consumption of 0.026kW 42 Inch LED TV had a consumption of 0.058kW and an optimized consumption of 0.058kW Washing machine had a consumption of 0kW and an optimized consumption of 0kW.

- At 17:00:00, Compact Florescence Bulb had a consumption of 0.029kW and an optimized consumption of 0kW 65 Inch LED TV had a consumption of 0.12kW and an optimized consumption of 0.12kW Refrigerator had a consumption of 0.1kW and an optimized consumption of 0.1kW Security light had a consumption of 0kW and an optimized consumption of 0kW Air Conditioner had a consumption of 0.0015kW and an optimized consumption of 0kW Radio had a consumption of 0.0001kW and an optimized consumption of 0kW TV decoder had a consumption of 0.02kW and an optimized consumption of 0kW Laptop Charging had a consumption of 0.0025kW and an optimized consumption of 0kW Phone Charging had a consumption of 0.0002kW and an optimized consumption of 0kW Printer had a consumption of 0.0001kW and an optimized consumption of 0kW DVD Player had a consumption of 0.026kW and an optimized consumption of 0.026kW 42 Inch LED TV had a consumption of 0.058kW and an optimized consumption of 0.058kW Washing machine had a consumption of 0kW and an optimized consumption of 0kW.

- At 18:00:00, Compact Florescence Bulb had a consumption of 0.029kW and an optimized consumption of 0kW 65 Inch LED TV had a consumption of 0.12kW and an optimized consumption of 0.12kW Refrigerator had a consumption of 0.1kW and an optimized consumption of 0.1kW Security light had a consumption of 0kW and an optimized consumption of 0kW Air Conditioner had a consumption of 0.0015kW and an optimized consumption of 0kW Radio had a consumption of 0.0001kW and an optimized consumption of 0kW TV decoder had a consumption of 0.02kW and an optimized consumption of 0.02kW Laptop Charging had a consumption of 0.0025kW and an optimized consumption of 0kW Phone Charging had a consumption of 0.0002kW and an optimized consumption of 0kW Printer had a consumption of 0.0001kW and an optimized consumption of 0kW DVD Player had a consumption of 0.026kW and an optimized consumption of 0.026kW 42 Inch LED TV had a consumption of 0.058kW and an optimized consumption of 0.058kW Washing machine had a consumption of 0kW and an optimized consumption of 0kW.

- At 19:00:00, Compact Florescence Bulb had a consumption of 0.029kW and an optimized consumption of 0.029kW 65 Inch LED TV had a consumption of 0.12kW and an optimized consumption of 0.12kW Refrigerator had a consumption of 0.1kW and an optimized consumption of 0.1kW Security light had a consumption of 0kW and an optimized consumption of 0kW Air Conditioner had a consumption of 1.0kW and an optimized consumption of 1.0kW Radio had a consumption of 0.0001kW and an optimized consumption of 0kW TV decoder had a consumption of 0.02kW and an optimized consumption of 0.02kW Laptop Charging had a consumption of 0.0025kW and an optimized consumption of 0kW Phone Charging had a consumption of 0.0002kW and an optimized consumption of 0kW Printer had a consumption of 0.0001kW and an optimized consumption of 0kW DVD Player had a consumption of 0.026kW and an optimized consumption of 0.026kW 42 Inch LED TV had a consumption of 0.058kW and an optimized consumption of 0.058kW Washing machine had a consumption of 0kW and an optimized consumption of 0kW.

- At 20:00:00, Compact Florescence Bulb had a consumption of 0.029kW and an optimized consumption of 0.029kW 65 Inch LED TV had a consumption of 0.12kW and an optimized consumption of 0.12kW Refrigerator had a consumption of 0.1kW and an optimized consumption of 0.1kW Security light had a consumption of 0.05kW and an optimized consumption of 0.05kW Air Conditioner had a consumption of 1.0kW and an optimized consumption of 1.0kW Radio had a consumption of 0.0001kW and an optimized consumption of 0kW TV decoder had a consumption of 0.02kW and an optimized consumption of 0.02kW Laptop Charging had a consumption of 0.0025kW and an optimized consumption of 0kW Phone Charging had a consumption of 0.0002kW and an optimized consumption of 0kW Printer had a consumption of 0.02kW and an optimized consumption of 0.02kW DVD Player had a consumption of 0.0002kW and an optimized consumption of 0kW 42 Inch LED TV had a consumption of 0.0003kW and an optimized consumption of 0kW Washing machine had a consumption of 0kW and an optimized consumption of 0kW.

- At 21:00:00, Compact Florescence Bulb had a consumption of 0.029kW and an optimized consumption of 0.029kW 65 Inch LED TV had a consumption of 0.12kW and an optimized consumption of 0.12kW Refrigerator had a consumption of 0.1kW and an optimized consumption of 0.1kW Security light had a consumption of 0.05kW and an optimized consumption of 0.05kW Air Conditioner had a consumption of 1.0kW and an optimized consumption of 1.0kW Radio had a consumption of 0.0001kW and an optimized consumption of 0kW TV decoder had a consumption of 0.02kW and an optimized consumption of 0.02kW Laptop Charging had a consumption of 0.0025kW and an optimized consumption of 0kW Phone Charging had a consumption of 0.0002kW and an optimized consumption of 0kW Printer had a consumption of 0.0001kW and an optimized consumption of 0kW DVD Player had a consumption of 0.0002kW and an optimized consumption of 0kW 42 Inch LED TV had a consumption of 0.0003kW and an optimized consumption of 0kW Washing machine had a consumption of 0kW and an optimized consumption of 0kW.

- At 22:00:00 Compact Florescence Bulb had a consumption of 0.029kW and an optimized consumption of 0kW 65 Inch LED TV had a consumption of 0.001kW and an optimized consumption of 0kW Refrigerator had a consumption of 0.1kW and an optimized consumption of 0.1kW Security light had a consumption of 0.05kW and an optimized consumption of 0.05kW Air Conditioner had a consumption of 1.0kW and an optimized consumption of 1.0kW Radio had a consumption of 0.0001kW and an optimized consumption of 0kW TV decoder had a consumption of 0.02kW and an optimized consumption of 0.02kW Laptop Charging had a consumption of 0.05kW and an optimized consumption of 0.05kW Phone Charging had a consumption of 0.004kW and an optimized consumption of 0.004kW Printer had a consumption of 0.0001kW and an optimized consumption of 0kW DVD Player had a consumption of 0.0002kW and an optimized consumption of 0kW 42 Inch LED TV had a consumption of 0.0003kW and an optimized consumption of 0kW Washing machine had a consumption of 0kW and an optimized consumption of 0kW.

- At 23:00:00, Compact Florescence Bulb had a consumption of 0.029kW and an optimized consumption of 0kW 65 Inch LED TV had a consumption of 0.001kW and an optimized consumption of 0kW Refrigerator had a consumption of 0.1kW and an optimized consumption of 0.1kW Security light had a consumption of 0.05kW and an optimized consumption of 0.05kW Air Conditioner had a consumption of 1.0kW and an optimized consumption of 1.0kW Radio had a consumption of 0.0001kW and an optimized consumption of 0kW TV decoder had a consumption of 0.02kW and an optimized consumption of 0.02kW Laptop Charging had a consumption of 0.05kW and an optimized consumption of 0.05kW Phone Charging had a consumption of 0.004kW and an optimized consumption of 0.004kW Printer had a consumption of 0.0001kW and an optimized consumption of 0kW DVD Player had a consumption of 0.0002kW and an optimized consumption of 0kW 42 Inch LED TV had a consumption of 0.0003kW and an optimized consumption of 0kW Washing machine had a consumption of 0kW and an optimized consumption of 0kW