AKENTEN APPIAH- MENKA UNIERSITY OF SKILLS TRAINING AND ENTREPRENEURIAL DEVELOPMENT

ANALYSIS OF THE VIABILITY OF HYBRID WIND–SOLAR ENERGY AS AN ALTERNATIVE ELECTRICITY SOURCE IN THE ASHANTI REGION

BY

JIBRIL TAHIRU

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This Thesis Is Submitted to the Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development in Partial

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Electrical and Electronic Engineering Degree

NOVEMBER, 2024

DECLARATION

Candidate's Declaration

I hereby declare that this project work is the result of my original research and that no part of this has been presented for another degree in the university and elsewhere.

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JIBRIL TAHIRU DATE

Candidate's Declaration

I hereby declare that the presentation of this long essay was supervised in accordance with the guidelines on the supervision of long essays laid down by the Akenten Appiah-Menka University of Skill Training and Entrepreneurial Development

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DR. P. N. AYAMBIRE DATE

DEDICATION

I dedicated this research work to my mother Habiba Mumin for her immense emotional support throughout the work by always encouraging me that I would succeed in the end. Also, to my brother Alilu Tahiru for his support and my wife Huzaima Saeed and children Tahiru Jibril and Abdul Mumin Jibril whose sight gives me a sense of encouragement to push hard for success and motivates me to keep going forward in life.

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ABSTRACT

This research investigates the viability of hybrid wind–solar energy as an alternative electricity source in the Ashanti region. Though the energy transmission in Ghana is fairly better now, there is the need to take advantage of modern renewable energy technology which cost efficient over time and more environmentally friendly. Therefore, incorporating this technology in the Ashanti region and its environs will go along way to impact lives and the environment positively.

In this study, primary data such as load profiles of both domestic and commercial activities was obtained through surveys and energy audits. Also, relevant secondary data such as wind speed, air temperature, and solar radiation was collected from the Ghana Meteorological Agency. The system was modelled comprehensively with simulation results that discover the feasibility of the system. All these data were simulated and analyzed using the HOMER Pro software.

The findings of the study after the simulation indicated that Ashanti region is technically feasible with an average wind power density of 254 W/m^2, coupled with this power density is the daily solar irradiation levels ranges from 4 to 6kWh/m^2 and the annual sunshine length spans from 1800 to 3000 hours.The financial and economic feasibility analysis conducted also indicated that with a present worth of $4,776,072 and annual worth of $369,450 for the project, the return on investment and internal rate of return are 18.9% and 23.7% respectively. The simple payback and the discounted payback are also 3.84 and 4.64 years respectively. This shows that the project is financially feasible and cost effective. The sensitivity analysis performed at different cost of diesel fuel at $1.0, $1.2, $1.50 resulted in the at prices of $0.458, $0.458 and $0.466 respectively with is fairly cot effective as well compared with the costs for using the grid.

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Abbreviation	Meaning
A G L	Above Ground Level
AC	Alternating Current
AM	Air mass
AV	Aventa
AWP	Available Wind Power
B.T.U	British Thermal Unit
COE	Cost of Energy
CSP	Concentrated Solar Power
DC	Direct Current
DNI	Direct Normal Irradiation
ECG	Electricity Company of Ghana
EPA	Environmental Protection Agency
EWP	Extractible Wind Power
GDP	Gross Domestic Product
GH₵	Ghana Cedis
GHG	Green House Gas
GHI	Global Horizonatal Irradiation
GMA	Ghana Meteorological Agency
Gmet	Ghana Meteorological Agency
$GtCO_2$	Gigatonne of Carbon Dioxide
GW	Gigawatt

GWh	Gigawatt hour
HAWT	Horizontal Axis Wind Turbine
HAWT	Horizontal Axis Wind Turbine
H_O	Extraterrestrial Radiation
HOMER	Hybrid Optimization of Multiple Energy Resources
IEA	International Energy Agency
IPCC	International Panel on Climate Change
K	Kelvin
kW	Kilowatt
kWh	Kilowatt hour
LCOE	Levelized Cost of Energy
MJ	MegaJoule
MW	MegaWatt
NPC	Net Present Cost
NPV	Net present Value
^{O}C	Degree Celsius
OECD	Organisation for Economic Co-operation and Development
PV	Photovoltaic
PV/WT	Photovoltaic/Wind Turbine
RETD	Renewable Energy Technology Deployment
RETScreen	Renewable Energy Project Analysis
SDG	SustainableDevelopment Goals
SPP	Simple Payback Period

SPV	Solar Photovoltaic
SWERA	Solar Wind Energy Resource Assessment
TCP	Technology Collaboration Programme
UN	United Nations
US$	United States Dollars
UV	Ultra Violet
VAWT	Vertical Axis Wind Turbine
WECS	Wind Energy Conversion System

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Energy access is a critical driver for the socio-economic and sustainable development of every country. It plays a pivotal role in performing daily human activities such as cooking, lighting, heating, and transportation. According to the United Nations (UN) Sustainable Development Goals (SDG's), achieving universal access to clean energy will transform the energy system as well as assist and contribute tremendously towards meeting other SDG's such as poverty alleviation, good health, water supply, sustainable cities, and mitigating climate change (IEA., 2017; IRENA., 2015).

About 840 million of the global population are still living without electricity. The Sub-Saharan Africa region alone has about 573 million people without electricity access (IEA I. U., 2019). A few African countries, including Ghana, have better electricity access. Ghana's electrification access rate in urban and rural areas was about 94% and 67%, respectively, in 2018 (World Bank, 2023)

Over the decades, fossil fuel combustion, including coal, oil, and natural gas, has significantly contributed to the world energy sector. Many scientific studies and research conducted worldwide depict fossil fuels as a significant contributor to greenhouse gas (GHG) emissions, which cause drastic changes to the climate, thus creating havoc for the environment.

Anthropogenic emissions of greenhouse gases (GHGs), in particular CO_2, CH_4, and N_2O, have significantly increased their atmospheric concentrations since the industrial revolution, causing a progressive global climate change that is provoking widespread harmful impacts across the world (Connors et al., 2021)

Since 1880, the average global temperature has increased by a little more than 1 ^{0}C. Almost two-thirds of the warming has happened since 1975, by about 0.15–0.2 ^{0}C per decade (IEA I. U., 2019). Almost half of global GHG (and CO_2) emissions (1850–2020) were emitted since 1990 (GCP, 2021; Gütschow, Günther, & Pflüger, 2021), mounting the mitigation challenge (Peters, et al., 2020). Since the Paris Agreement, emissions have increased annually, with a temporary drop in 2020 caused by the COVID-19 pandemic crisis (le Quéré, et al., 2020; Becker, Bouzdine-Chameeva, & Jaegler, 2020), the largest annual reduction ever observed (le Quéré, et al., 2021). However, no significant structural changes in the global energy system have been recorded, and global fossil CO_2 emissions have rebounded by 6% to 36 $GtCO_2$ in 2021 (IEA, IEA. Global Energy Review 2021; IEA: Paris, France, 2021., 2021).

Thus, a rapid decrease in anthropogenic GHG (45%) by 2030 is urgently required to stay on a 1.5 ^{0}C pathway (IEA., 2017; IPCC, . IPCC. Global Warming of 1.5 ◦C. An IPCC Special Report on the Impacts of Global Warming of 1.5 ◦C above Pre-Industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the Context of Strengthening the Global Response to the Threat of Clima, 2018). Since the establishment of the Intergovernmental Panel on Climate Change (IPCC), the world has not significantly changed pathways, continuing being on a middle-of-the-road pathway (Pedersen, et al., 2021), as fossil-fueled energy consumption has continuously increased, and the share of fossil fuel primary energy supply has remained almost unchanged at around 81% (IEA, 2021).

Although electric power generation from renewable energies reached 27% in 2019 and is fast increasing, there is no evidence yet of a sustained global energy transition from fossil to renewable sources (IEA, 2022). A renewable transition is needed before 2050, implying global annual emissions cuts of 1–2 $GtCO_2$ annually in the coming decade (le Quéré, et al., 2021).

Furthermore, studies assert that fossil fuels will deplete in due time. Even though these conventional energy sources negatively impact the world, they are still today's primary energy source for power generation and transportation in most developed and developing countries, including Ghana.

Therefore, there is the great need to integrate power generation from renewable energy technologies into our businesses and homes to lessen the impact of fossil-generated electricity on our environment among others.

Power generation on commercial properties is the technique of producing electricity on-site at commercial buildings in order to meet the property's electrical needs (Sharma et al., 2019). This can be accomplished using a variety of techniques, such as solar energy, wind generators, backup generators, or coal and gas generators. Commercial properties can opt to produce their own power for a variety of reasons. One of the most common reasons is to reduce reliance on the grid and ensure a consistent supply of electricity in the event of power outages or interruption (Elkholy, 2018). Furthermore, generating electricity on-site can assist commercial properties in lowering their energy costs and, in some cases, earning income from supplying excess energy to the national grid.

This research aim is to ascertain if it is viable to use hybrid wind-solar energy as an alternative source of electricity for businesses and household use in the Ashanti Region. Secondary data such as wind speed, solar radiation was obtained from the Ghana Meteorological Agency. Primary data such as fuel consumption of electricity generators, cost of electricity for businesses and households was also collected. This data would be analyzed to determine which electricity source will be most cost-effective, cleaner and relatively cheaper.

1.2 Statement of the Problem

Ghana has faced unstable power supply over the past years, which was marked by frequent outages and voltage fluctuations that impair economic activity and the standard of living for its people. Though this situation has improved fairly, there are still ocassional occurances that needs precautionary measures. This volatility impedes the nation's general development, restricts access to dependable electricity, and undercuts industrial expansion. The integration of hybrid wind-solar energy systems offers a potential remedy for these problems.

Based on the above-mentioned shortcomings, the main focus of this research is to ascertain how viable and feasible it can be to set up a hybrid wind-solar PV power system to augment the National Grid or serve as a standalone power source for domestic and business consumption. This in turn will keep many businesses in operation when the national grid electricity goes offline which will protect a lot of equipment that uses electricity which will ultimately boost the national economy.

1.3 Aim and Objectives of the Research

The main aim is to ascertain the viability of Wind-Solar Power Generation in the Ashanti region of Ghana. The specific objectives include:

1. To model and perform technical analysis of a hybrid wind-solar power system
2. To conduct a thorough techno-economic analysis of hybrid wind-solar systems in order to assess their viability, affordability, and potential for wide-scale adoption.
3. To perform sensitivity analysis to determine the performance of the hybrid wind-solar systems due variations of wind speeds, solar radiations, and prices of diesel.

1.4 Significance of The Research

Hybrid wind-solar systems represent a significant approach to sustainable energy production. By harnessing both the nature of wind and solar resources, this study contributes to the advancement of renewable energy technologies, emphasizing the potential for reduced greenhouse gas emissions and a gradual shift away from fossil fuel dependence.

Hybrid wind-solar system also addresses the issue of energy intermittency. This means that the system can provide a more consistent and reliable energy supply by combining the strengths of both wind and solar energy sources. The research also highlights that these systems can contribute to grid stability by providing a more consistent energy supply, which is especially important in areas with high penetration of renewable energy sources. Finally, hybrid wind-solar systems are a clean and sustainable way to generate electricity, making them a key part of efforts to combat climate change.

1.5 Scope of the Research

The thesis focuses on the analysis of the viability of hybrid wind-solar energy as an alternative electricity source in the Ashanti Region. It explores the use of both wind and solar energy as hybrid energy system and another opportunity to provide electricity for both households and businesses within the Ashanti Region. The average load profiles of households and commercial businesses was recorded to determine the relevant hybrid components for the research. Wind speeds, solar radiation and air temperature for the Ashanti Region was analyzed and modelled in order to ascertain the power output for the households and the businesses. The power outputs of the solar PV, wind turbine, the battery and the hybrid system were all determined.

Other analyses performed includes technical feasibility, economic and financial, emission reduction and sensitivity analyses to determine whether the hybrid system will be viable.

1.6 Limitations of the Research

The limitations pertaining to this research includes the inability of the research to conduct the energy survey to cover the whole households and businesses in the Ashanti Region.

Also, the research took into consideration the wind speeds at the height of 10m. Higher heights such as 50 m and above have more potential which leaves opportunity for further research.

1.7 Structure of the Research

The structure of the project is made up of five (5) chapters with chapter one consisting of the background of research, statement of the problem, aim and objective of the research, significance of the research, scope of research, limitations of research and structure of research.

Chapter two consist of the literature review which comprises history and background of wind energy, wind energy in Ghana, solar energy potential in Ghana, hybrid wind-solar energy system.

Chapter three comprises the research methodology, description of the research area, data collection, analysis of data collected, modelling of the hybrid wind-solar energy system, methodology of the hybrid wind-solar system, and average load profile Ashanti Region, households and businesses.

Chapter four covers the results and discussions. Here, the wind speeds data, the solar radiation and the air temperature was used to model and design the hybrid system using optimization and design software HOMER to come out with the expected results.

Chapter five is the conclusion and the recommendations. This chapter summarizes the results obtained from the research. It gives appropriate recommendations to the parametric results that was determined throughout the research.

CHAPTER TWO

LITERATURE REVIEW

2.1 History and Background of Wind Energy

Wind energy made its first steps centuries ago with vertical axis wind turbines found in Persian-Afghan borders around 200 BC and horizontal axis wind turbines in Netherlands and Mediterranean much later (Möllerström, 2019). In the USA during the 19^{th} century, 6 million small wind turbines were used to pump water. James Blyth built the first electricity-generating wind turbine in Scotland in 1887 (Gipe, 2018). The first large wind turbine to generate electricity was installed in Cleveland, Ohio, in 1888 (Zafirakis, 2011). During the end stage of World war, I, 25-kW wind turbines were widespread throughout Denmark (Zafirakis, 2011).

Meanwhile, active research on large-scale wind turbines was gaining speed in Europe. The governments of the US, Canada, Sweden, Germany, and many other countries focused on funding large-scale prototypes that, in the end, did not develop into commercial turbines (Möllerström, 2019). In contrast, in Denmark, the government supported the market for small wind turbines, so that Danish farmers bought Danish-built turbines (10-30 kW).

Thus, the Danish wind turbine market started growing and gained widespread attention. This resulted in several Danish manufacturers ready to export wind turbines to California when a market started there around 1980 due to combined federal and state subsidies. These Danish turbines evolved into today’s commercial products (Gipe, 2018).

Denmark took the leadership role in wind power development and took a path different from the USA. Unlike American wind turbines in the hands of the aerospace industry, Danish technology grew up in the hands of the agricultural sector. During the late stages of world war-I, more than one-fourth of rural power stations used wind power, with the widespread use of 25 kW machines throughout Denmark. In Germany, Ulrich Hütter later became famous for designing slender and fast-rotating two-bladed downwind turbines and experimented with different designs, including those that drove an asynchronous generator directly to a couple to an electric utility network. (Pasqualetti, 2004).

2.2 Wind Energy in Ghana

Energy is an indispensable driver for socio-economic growth and development. However, due to climate change, the fuel sources used for electricity generation are a global concern. The rise in electricity consumption, the depletion of fossil fuels, and greenhouse gas (GHG) emissions have sparked investments in renewable energy technologies for electricity generation (Odoi-Yorke, 2021). Renewable energy is a promising solution for mitigating global GHG emissions and climate change (IRENA, 2017).

Wind energy is emerging as one of the world's most promising renewable energy sources due to its ability to satisfy growing electricity demand at much lower costs than other renewables (Kumar et al., 2022). Global wind resources surpass demand, and the installed capacity of wind turbines expanded by more than 20% annually from 2000 to 2019 and is expected to grow by 50% by 2023 (Pryor et al., 2020).

Wind power generated about 273 TWh of electricity in 2021, which is 45% more than what was produced in 2020 (IEA, 2022). Also, the global wind power capacity has reached 837 GW, saving nearly 1.2 billion tonnes of carbon dioxide (CO_2) emissions annually (GWEC, 2022). Onshore wind is a mature technology, existing in 115 nations globally, whereas offshore wind is in its earliest stages of development, with capacity available in only 19 countries. As more nations develop or intend to develop their first offshore wind farms, offshore wind is projected to rise in the next few years (GWEC, 2022).

The growth of wind power has been driven by declining costs, improved technology, and supportive government policies. The average cost of wind power has fallen dramatically over the past decade, making it increasingly competitive with traditional energy sources such as fossil fuels (IEA, 2020). In addition, advances in wind turbine technology have improved the efficiency and reliability of wind power systems, increasing their appeal to investors and consumers alike (IEA, 2020).

Approximately 66.4% of Ghana's installed electricity capacity stems from fossil fuels (mainly oil and gas) and 33.9% from large hydropower. Only 0.7% is produced from solar photovoltaics and biogas (Odoi-Yorke & John., 2022). The thermal plants' surge in electricity generation could contribute to fuel price growth, fuel supply risks, and carbon emissions.

This has subjected Ghana's economy and electricity users to exorbitant and volatile oil-linked electricity prices (CSIR, 2016). Due to limited oil and gas supplies, uncertain water flow, and the need to stabilize economic activities, it is vital to diversify the energy mix. The demand for electricity in Ghana is rapidly increasing due to the growing population and the country's industrialization drive. However, most of Ghana's population still lacks access to reliable and affordable electricity, with about 13% lacking access to electricity (Energy Commission, 2022). This situation has led to exploring renewable energy sources to augment the country's power generation capacity. Wind energy is one of Ghana's most promising and abundant renewable energy resources (Energy Commission, 2011).

In light of this, Ghana passed the Renewable Energy Act, 2011 (Act 832), to promote enabling conditions and accelerate the development and utilization of renewable resources for generating heat and power (Energy Commission, 2011). Also, the law requires utilities and bulk consumers to purchase electricity from renewable resources. Moreover, in its recently drafted Renewable

Energy Masterplan, Ghana has targeted generating about 275 MW and 325 MW of electricity from utility-scale wind power plants by 2025 and 2030, respectively (Energy Commission, 2019). Several studies have shown the viability of wind energy in the country, with some areas experiencing high wind speeds suitable for wind power generation. A survey by Ghana Premium Consultant revealed that grid-connected large wind farms with stand-alone wind turbines are excellent for Ghana's coastal regions (Ghana Premium Consultant, 2016). The wind available in Ghana is classified under class 4–6 wind resources, mainly along the border with Togo and the highest ridges north-west of Accra (Asante et al., 2022).

The mountains along the Ghana/Togo border have a wind power density of 600–800 W/m^2 and a wind energy potential of 800 GWh (Asante et al., 2022). A recent study by Asare-Addo indicates that Ghana can generate 300 TWh of wind energy annually. In coastal areas, wind speeds between 6 m/s and 7.1 m/s can be harnessed at 50 m above the ground (Asare-Addo, 2021). Despite this potential, the country has no utility-scale wind power plants in the national electricity generation mix.

2.3 Solar Energy Potential in Ghana

Global electricity demand could be met with available solar energy potential due to its abundant, inexhaustible nature (Smith, 2017). The Global Horizontal Irradiation and Direct Normal Irradiation maps of Ghana in Figures 2.1 and 2.2 show the overall solar potential for thermal and photovoltaic applications. Ghana receives some of the highest amounts of radiation, globally, which makes it suitable for various solar energy applications particularly towards the northern part of the country (Asumadu-Sarkodie & Asantewaa, 2016).

Daily solar insolation levels range from 4 kWh/m^2 to 6 kWh/m^2 with an annual sunshine duration range between 1800 and 3000 h per annum which offers a high potential for solar electricity generation (Kemausuor & Obeng, 2011). This data is further confirmed in the Solar Wind Energy Resource Assessment (SWERA) report on Ghana (Schillings, 2004).

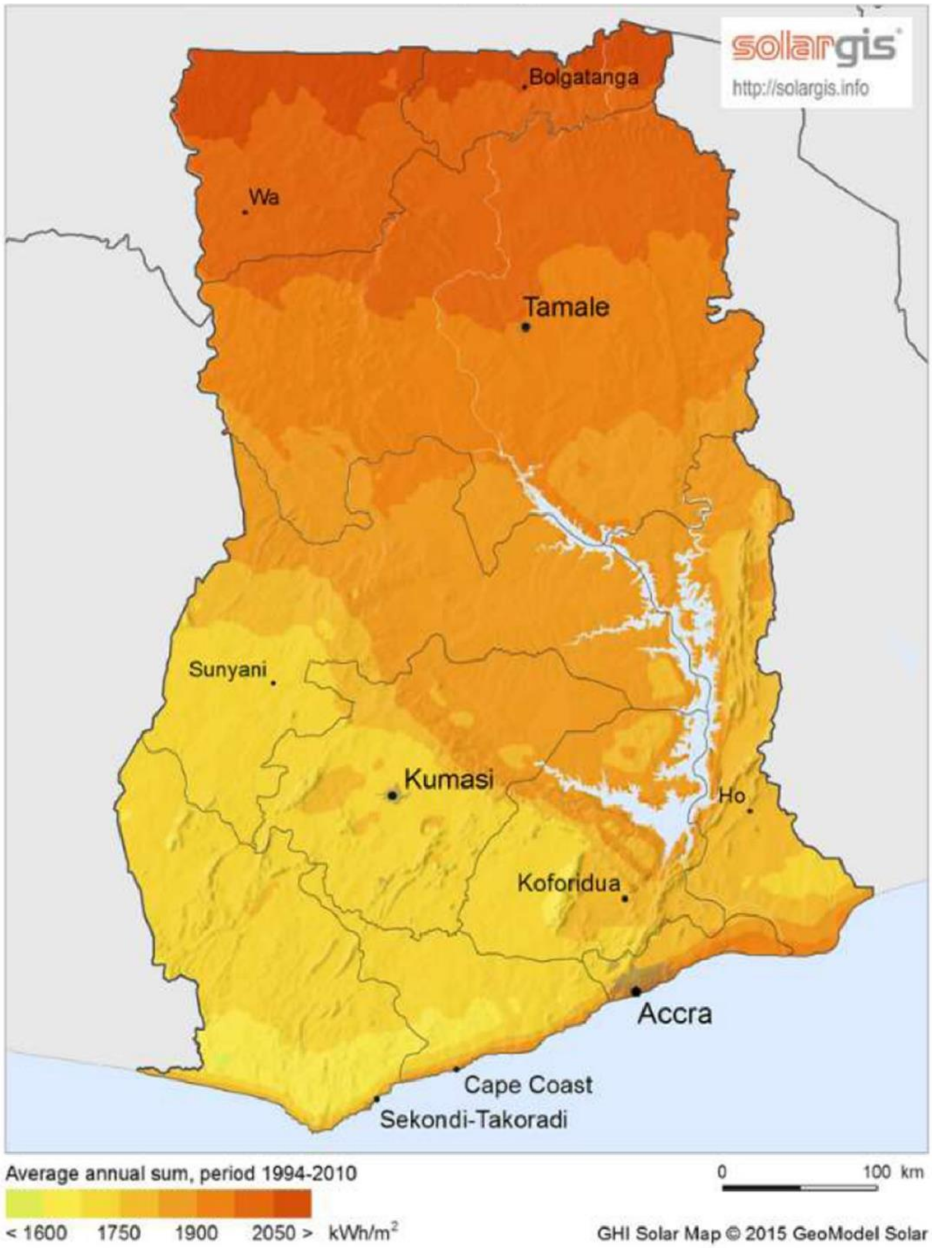

Figure 2.1 Global Horizontal Irradiation (GHI) of Ghana

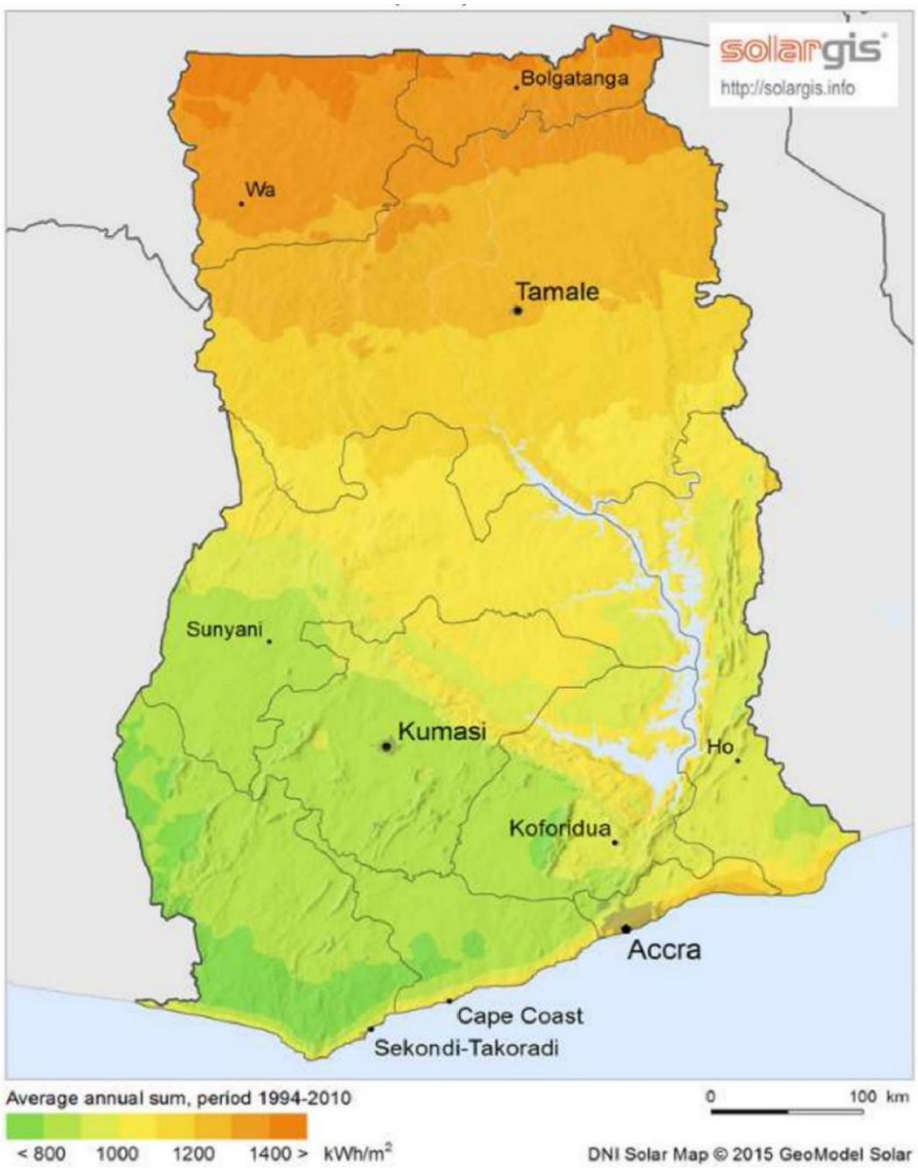

Figure 2.2 Direct Normal Irradiation (DNI) of Ghana

Despite this potential, challenges such as political will, technical expertise, availability of components, financing, availability of land, and others have hindered the growth of the sector over the years (Punia & Nehra, 2022). Recent advances in research have, however, reduced the cost of electricity from solar energy (Pillai, 2015). In Ghana, solar energy installations contribute 90% of all renewable energy installations according to a study by Gyamfi et al. Gyamfi & Modjinou, 2015).

2.4 Hybrid Wind-Solar Energy System

Renewable energy requirements have been focused on in developed countries as the global economy is developing rapidly. The major types of renewable energy sources include biomass, hydropower, geothermal, wind, and solar generation. In addition, fossil fuels are finite and possess negative impacts that lead to changes that are not desirable, while using renewable energy results in a slowdown of global warming. Renewable energies are essential sources of energy and can be considered as alternative options because of environmental protection; therefore, they have the potential to replace fossil fuel resources (Vine, 2007).

Nowadays, many countries in the world use renewable energy, and it is expected that the growing renewable energy markets will continue and improve powerfully in the future (Nematian, 2022). Solar energy and its technologies, as an essential source of renewable energy, have huge longer-term benefits, which enhance sustainability and reduce pollution (Pérez-Lópezet al., 2017).

Ghana, as a country, possesses the potential to use renewable energies; furthermore, solar energy has been known as a sound source of renewable energy in Ghana.

As for solar energy, hot water could be generated by solar energy using solar photovoltaic (PV), in which the systems are operated well, and their efficiency has been approved across the world over the last few years (Ellabban, 2014), in this regard, a PV system is used to convert solar energy into electricity (Lund et al., 2015) and a Concentrated solar power *(*CSP) technology is applied to generate electricity and also is conducted to be applied in a downstream process to generate electricity (Ellabban, 2014).

Furthermore, solar thermal heating and cooling provide thermal energy from sunrise and are applied in commercial applications (Sawin, 2013). Regarding solar energy, solar panels are strongly dependent on weather, which means the produced energy by the PV is dependent on sunlight. So, to be able to gather solar energy effectively, rainy and cloudy days may have an obvious consequence on the power of the system (Bahadori, 2013).

Furthermore, Wind turbine, as a technology of wind energy, is used to generate electricity and is popular as a sustainable renewable energy source, which has a much smaller negative impact on the environment than fossil fuels (Ghobadian, 2009). Consequently, it would be reliable to establish wind farms to generate power and electricity (Fazelpour, 2014).

Conversely, there are lots of disadvantages to using wind energy; for example, wind power is still used for pumping water and grinding food grains in addition to the generation of electricity (Wagner, 2018). Moreover, weather data such as wind speed (Yang, 2003) and load requirements for a specific site are essential, and it is one of the difficulties of using wind energy; also, in order to measure the performance of a current system, suitable weather data is necessary (Bahrami, 2013).

The main weakness of using solo renewable energy is that those energies cannot continuously supply energy because the systems depend on the weather. Therefore, a hybrid of these two sources is recommended to improve the overall energy output. Hence, to find the optimum system in terms of the number of PV and wind turbines, an appropriate optimization system is necessary to be applied (Kumar, 2021). Additionally, as another advantage of the hybrid system, the hybrid of PV and wind turbine results in reducing the battery bank and diesel requirements (Guo, 2018). Using hybrid renewable energies has benefited economically as well, in which many scholars have addressed hybrid renewable energy systems (Buonomano, 2018; Guino et al, 2014).

Therefore, the renewable counterpart, hybrid renewable energy, is the optimal solution for reducing energy demands. Hybrid renewable energy systems usually contain more than two types of renewable energy used together to increase system efficiency as well as maintain an outstanding balance in energy supply (Eisapour, 2021).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Introduction

This chapter discusses the methodology employed during the research. This study was designed to analyse the viability of wind-solar energy systems as an alternative energy source in the Ashanti Region due to the constant outages of power in the country. Wind and solar energy systems were taken as the alternative electricity power sources while the batteries and generators were used to compensate for the production-consumption inequalities.

The research data collected is made up of both secondary such as wind data, solar radiation data and air temperature which was collected from the Ghana Meteorological Agency, Accra, for Ashanti Region, and also primary data which was obtained through energy audit, interviews and observations at various businesses around Kumasi in the Ashanti Region.

The wind data is a ten-year period of data which was collected from 2012 to 2022 and the solar radiation data of Kumasi span from January 2022 through to December. The wind speeds were measured at the Ghana Meteorological Agency using the cup anemometer.

It consists of a horizontal shaft with four cups fixed on it. The shaft and cups both rotate in response to wind. The number of rotations per minute is then used to calculate the wind speed at the height of 10 meter. The maximum and the minimum air temperature of the day was recorded using Six's Maximum-Minimum thermometer. The Six's thermometer uses a U-shaped bent tube which uses two different fluids to measure temperature, that is mercury and alcohol. Mercury is used to record the temperature and the alcohol is to push it based on the temperature.

The mercury is maintained in its position by the alcohol contracting and forcing it to the lowest temperature ever recorded during the day. In this manner, the thermomete's two readings in its two bulbs provide readings for the day’s maximum and minimum temperatures. After the readings are recorded and the thermometer is prepared for further use, this bulb is reset to its default setting by using a magnet.

The solar radiation was recorded with a device called a pyranometer which consists of dome-shaped glass or plastic that works by first absorbing solar energy and a thermopile sensor that converts the energy into a numerical value for measurement.

3.2 Description of The Project Area (Ashanti Region)

The Ashanti Region is located in the southern part of Ghana and it is the third largest of 16 administrative regions, occupying a total land surface of 24,389 km^2 (9,417 sq mi) or 10.2 percent of the total land area of Ghana. In terms of population, however, it is the most populated region with a population of 5,440,463 according to the 2021 census, accounting for 17.64% of Ghana's total population. The Ashanti Region is known for its major gold bar and cocoa production. The largest city and regional capital is Kumasi.

The Ashanti Region is centrally located in the middle belt of Ghana. It lies between longitudes 0.15 W and 2.25 W, and latitudes 5.50 N and 7.46 N. The region shares boundaries with six of the sixteen political regions, Bono, Bono East and Ahafo Regions in the north, Eastern region in the east, Central region in the south and Western region in the Southwest.

Figure 3.1 Geographic location of Ashanti Region in the map of Ghana

3.3 Modelling of the Hybrid Wind-Solar Energy System Using Home Pro Software

The HOMER Pro software was used to model the PVs, wind turbines, converter, storage battery, and standby generator that make up the hybrid wind-solar energy system.

HOMER, which stands for Hybrid Optimization of Multiple Energy Resources is a software tool used for analyzing and designing renewable energy systems for various applications, such as off-grid and grid-connected power systems, microgrids, and distributed generation.

The software allows users to input data such as energy resource availability, load profiles and cost information for different components.

It then uses optimization algorithms to determine the optimal combination of energy sources, system sizing, and dispatch strategies that maximize the system's performance, depending on the user's objectives.

In order to meet the stable energy needs of the Ashanti Region as an alternative energy source of electricity, a hybrid energy system consisting of solar PV which provides energy during the day and wind turbine which works continuously throughout the day. The batteries store the electrical energy for future use or at moments where energy output of the system is low. Attached to the system is also bidirectional inverter whose purpose is to convert the DC produced from the solar PV DC bus to the AC bus which would then be transmitted to the connected loads. The generator is also connected to generate power in times of maintenance or emergencies.

The figure 3.2 below shows the schematics and technical components that form the wind-solar hybrid system.

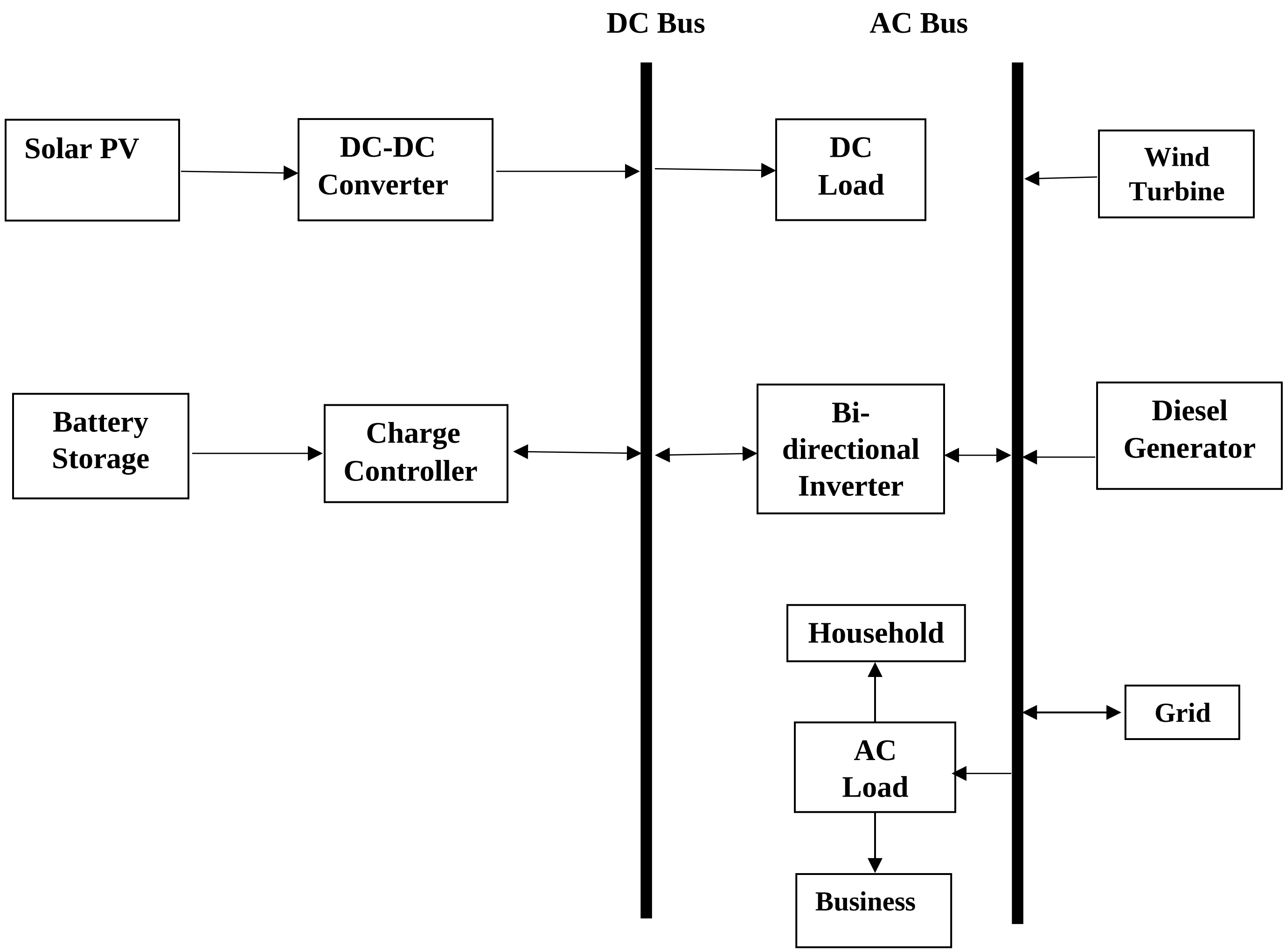

Figure 3.2 Schematicss of hybrid wind-solar system

Again, the HOMER optimization and design software was used to model the wind-solar hybrid system. Figure 3.3 shows the flowchart from modelling to the analysis of the hybrid system. To operate the software, the geographical location of the research is typed manually at the location search button. Also, the location can be searched by using the zooming feature.

Then, the electric load is selected and the type of load is also selected. The residential and commercial load was selected for this research. The annual average load of the location was loaded.

Add power resource button was used to select and size the genset to be used modelling. Its initial and replacement cost was added. With the add renewable resource button, solar PV and wind turbine were selected, their initial and replacement, operational and maintenance costs was entered as well as their lifetime in years.

Solar Global Horizontal Irradiance was downloaded from the NREL database. A bidirectional system converter was also added to convert the DC produced by solar system to the AC bus to be supplied to the loads. The initial and replacement costs of the converter was also entered. Lead-acid battery was used and the sizing and quantities to be used optimized by HOMER.

The software was ran and the following parameters was optimized as follows; Power output of PV, power output of wind turbine, power output of batteries, power output of Hybrid system.

Finally, the following analyses was also performed; Recommended components size, technical feasibility analysis, financial & Economic analysis, GHG emission reduction analysis and sensitivity analysis. The results to this modelling is presented in chapter four.

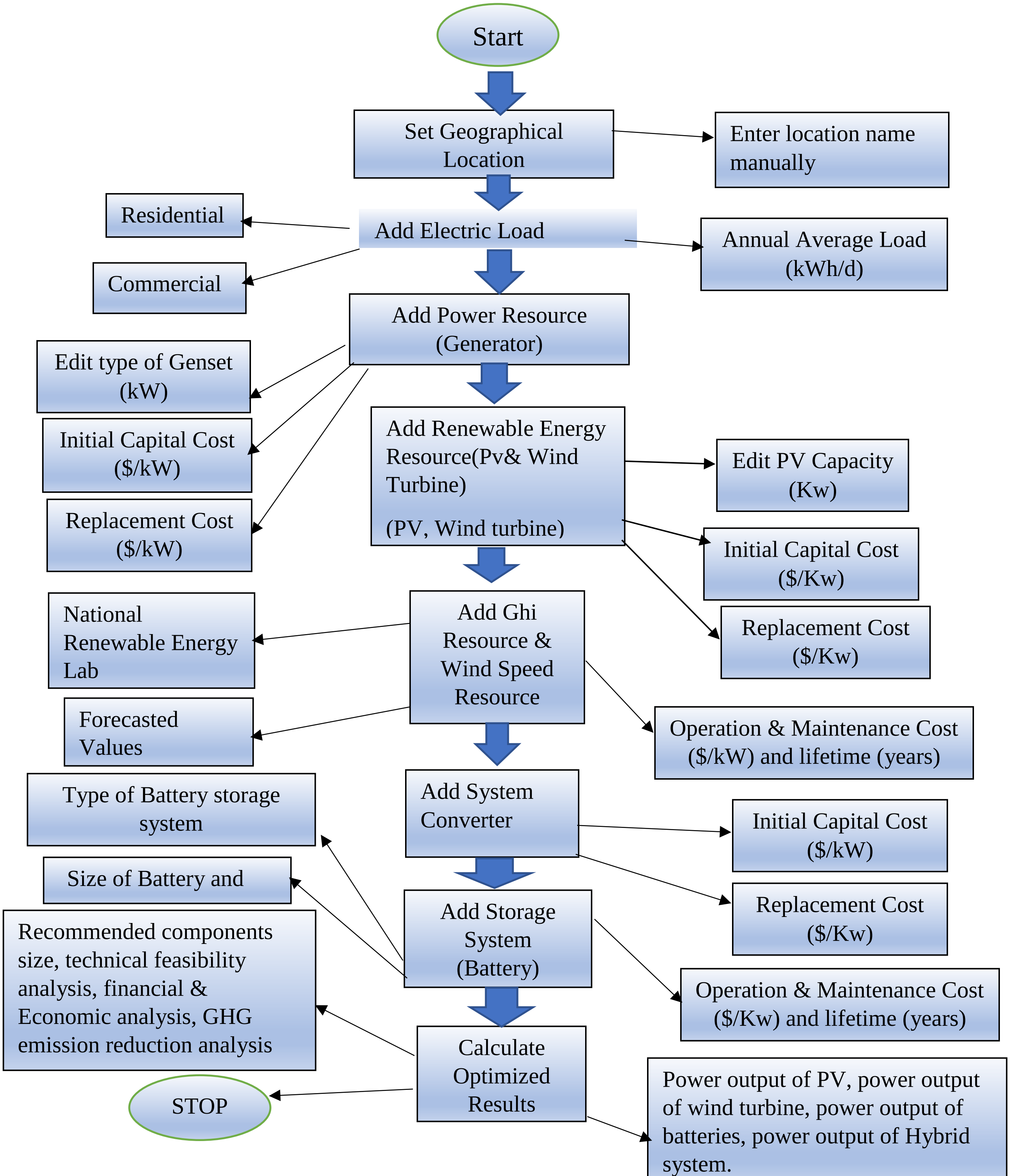

Figure 3.3 Flowchart of Methodology

3.4 Daily Average Load Profile of Community Households for Old Tafo in Ashanti Region

To determine a particular power system of a certain load profile for a specific location, the average load profile of the place must be known.

In this chapter, HOMER software was used to model the hybrid wind-solar energy systems for the community of Old Tafo Kumasi in the Ashanti Region which can be replicated in all parts of the Region. The average load profile data was obtained from the Electricity Company of Ghana (ECG), Kumasi and was fed into the software as displayed in the Table 3.1 below.

Table 3.1 Average daily load profile for Old Tafo Community obtained from ECG Kumasi in kilowatt (Kw)

Hour	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
1	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
2	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
3	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
4	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
5	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
6	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
7	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0
8	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
9	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
10	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
11	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
12	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
13	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
14	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
15	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
16	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
17	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
18	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0
19	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0
20	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0
21	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0
22	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
23	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0

The figure 3.4 shows the daily load profile of the Old Tafo community in the Ashanti Region. Hourly average load of the day is recorded for twenty-four (24) hour period to give a picture of how energy is consumed.

From the figure 3.4, it is seen that a low energy consumption of 2 kW was recorded for 0:00 hrs. to 4:00 hrs. which commensurate early morning as people are asleep of preparing for work and hence low usage of electrical gadgets. There is a slight increase of energy usage from the hours of 5:00, 6:00, and 7:00 which shows energy consumptions of 3 kW, 5 kW, and 7 Kw respectively and which means people are awoken and electrical gadgets are being used for heating purposes. At 9:00 hrs. through to 15:00 hrs, the energy consumption rose to 8 kW as thsese are the peaks hours for day since almost everyone is awake and various electrical gadgets are working. The energy consumptions continue to rise until at 21:00 hrs with 12 kW and then began to reduce down to 22:00 hrs. at 9 kW and finally 23:00 hrs. at 5 kW.

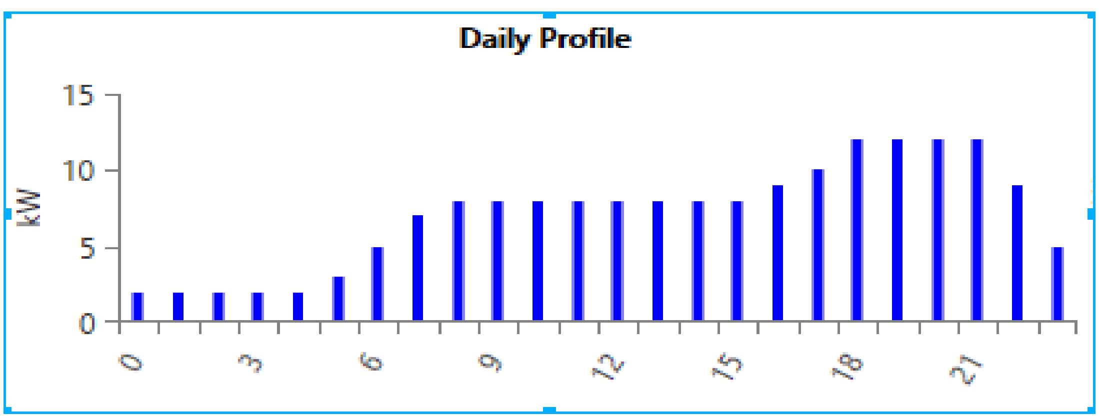

Figure 3.4 Daily load profile Old Tafo in Ashanti Region

Again, the commercial average load profile for the Old Tafo community was obtained from (ECG) and the data displayed in the Table 3.2 below.

3.5 Average Load Profile of Commercial Facilities from ECG Kumasi for Old Tafo in the Ashanti Region

Table 3.2 Average daily load profile for Old Tafo Commercial facilities obtained from ECG Kumasi in kilowatt (kW)

Hour	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0	30	30	30	30	30	30	30	30	30	30	30	30
1	30	30	30	30	30	30	30	30	30	30	30	30
2	30	30	30	30	30	30	30	30	30	30	30	30
3	30	30	30	30	30	30	30	30	30	30	30	30
4	30	30	30	30	30	30	30	30	30	30	30	30
5	30	30	30	30	30	30	30	30	30	30	30	30
6	30	30	30	30	30	30	30	30	30	30	30	30
7	100	100	100	100	100	100	100	100	100	100	100	100
8	200	200	200	200	200	200	200	200	200	200	200	200
9	200	200	200	200	200	200	200	200	200	200	200	200
10	200	200	200	200	200	200	200	200	200	200	200	200
11	200	200	200	200	200	200	200	200	200	200	200	200
12	200	200	200	200	200	200	200	200	200	200	200	200
13	200	200	200	200	200	200	200	200	200	200	200	200
14	200	200	200	200	200	200	200	200	200	200	200	200
15	200	200	200	200	200	200	200	200	200	200	200	200
16	200	200	200	200	200	200	200	200	200	200	200	200
17	160	160	160	160	160	160	160	160	160	160	160	160
18	130	130	130	130	130	130	130	130	130	130	130	130
19	100	100	100	100	100	100	100	100	100	100	100	100
20	30	30	30	30	30	30	30	30	30	30	30	30
21	30	30	30	30	30	30	30	30	30	30	30	30
22	30	30	30	30	30	30	30	30	30	30	30	30
23	30	30	30	30	30	30	30	30	30	30	30	30

The figure 3.5 below shows the daily load profile of the Old Tafo community in the Ashanti Region. Hourly average load of the day is recorded for twenty-four (24) hour period to give a glimpse of how energy is consumed.

As usual, from the plot the times of 0:00 hrs. to 6:00 hrs came with low energy consumptions of 30 kW. At 7:00 hrs, a consumption of 100 kW was recorded as various commercial facilities have started their electrical machines. The peak energy consumption of these facilities reached 200 Kw during the hours between 8:00 and 16:00.

Between the hours of 17:00, 18:00, and 19:00, the energy consumption had started to reduce to 160 kW, 130kW and 100 kW respectively as various companies have started to close.

Finally, the hours of 20:00, 21:00, 22:00, and 23:00 all recorded a constant energy consumption of 30 kW. During these periods, it is expected that almost all commercial companies have closed only lightnings are operating.

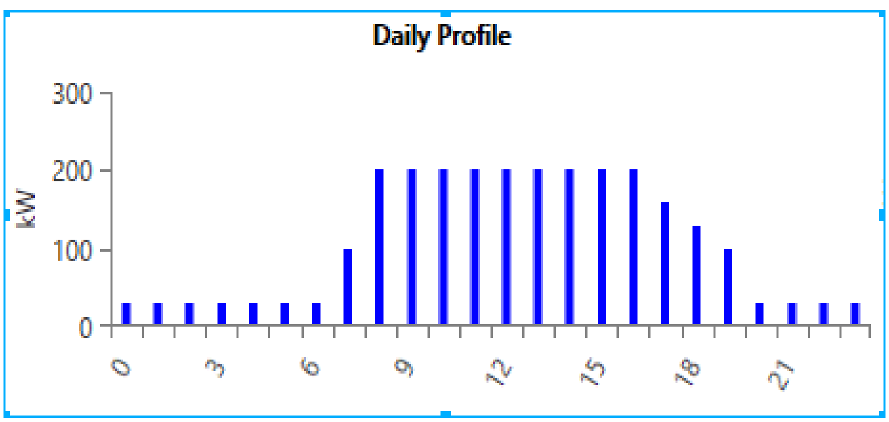

Figure 3.5 Daily load profile for commercial consumption in Old Tafo in Ashanti Region

3.6 Technical Specifications for both Wind Turbine and Solar Panel used for this Modelling

Table 3.3 and Table 3.4 shows the specification requirements of the wind turbine and solar PV to be used for this research.

Table 3.3 E-10 HAWT Wind Turbine Specifications E-10 HAWT Wind Turbine Specifications

Parameter	Details
Rated power	408 kW
Cut-in wind speed	2.0 m/s
Survival wind speed	7.0 m/s
Cut-out wind speed	30 m/s
Rotor Diameter	10.0 m
Number of blades	3
Weight	1,000kg
Configuration	Horizontal Axis
Life span	20 years

Table 3.4 Rosen Solar Module Parameter Specification

Parameter	**Details**
Material	Polycrystalline Silicon
Model number	RS65KW-OFF
Junction box	IP67 Waterproof
Connector	Mc4 Compatible Connector
Power output specification	695 W
Origin	China
Output Frequency	50/60 Hz
Application	Industrial/Domestic
Trademark	Rosen Solar
Warranty	25 Years
Efficiency	20.0 %

3.7 Power Output of the Solar PV Panels

The solar PV power output is a very important component in hybrid wind-solar energy system as its primary goal of a solar PV system is to generate as much energy as possible. By optimizing the system configuration, HOMER has identified the overall energy production in a year and other important parameters that are shown table in the table 3.12 below.

Table 3.5 Parameters of the Solar PV system power output

Quantity	Value	Units
Rated Capacity	695	kW
Mean Output	101	kW
Mean Output	2,413	kWh/d
Capacity Factor	14.5	%
Total Production	880,657	kWh/yr
Minimum Output	0	kW
Maximum Output	669	kW
PV Penetration	93.2	%
Hour of Operation	4,380	hrs/yr
Levelized cost	0.161	$/kWh

Table 3.5 above shows the power output and various parameter of the solar PV system of the wind-solar hybrid energy system. The rated capacity of the PV is 695 kW and its maximum power output is 669 kW. The mean output is 2,413 kWh/d with a total power production of 880,657 kWh/yr and a total operation yearly hour of 4,380 hrs/yr. the levelized cost of energy is 0.161 $kWh. Figure 4.3 shows PV power output Duration Curve commensurate with the power capacity and the total energy production duration.

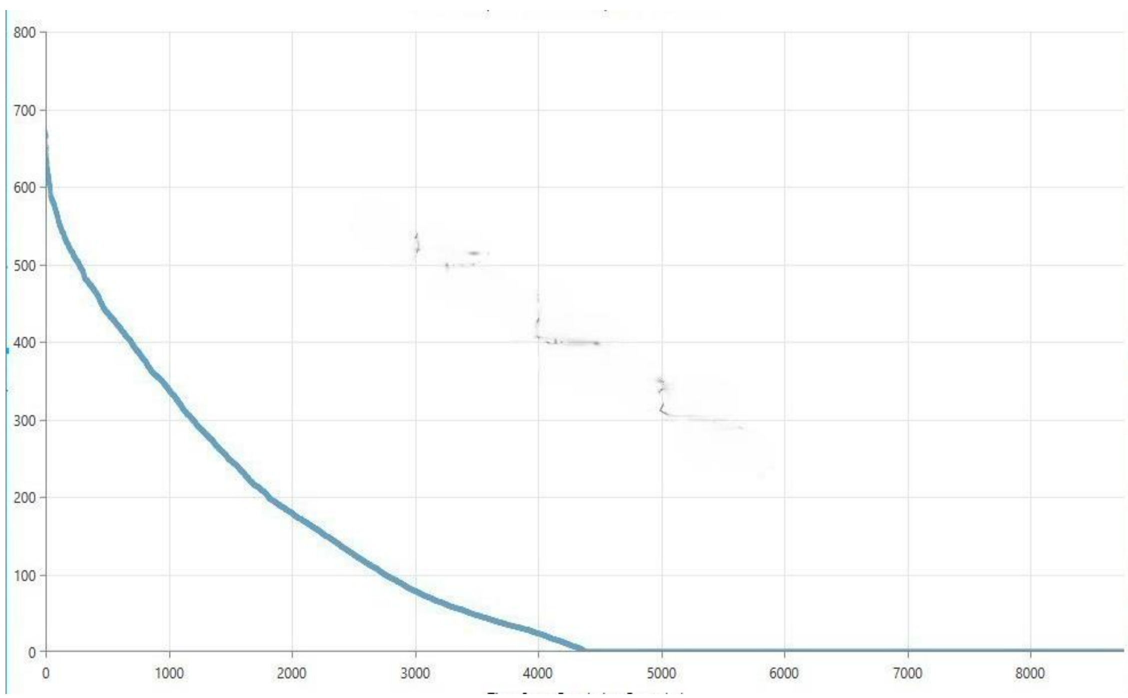

Figure 3.6 Generic flat plate PV Power output Duration Curve

3.8 Power Output of the Wind Turbines

Power output of the wind turbine is also a critically important parameter in designing a hybrid wind-solar energy system. The power output of wind turbine allows for the model of performance of a wind turbine based on various inputs, such as the wind speed data, turbine specifications, and system configuration. The HOMER software optimization after simulation provides the Table 3.13 below showing all the necessary parameters relating to the wind turbine power output.

Table 3.6 Parameters of the wind turbine system power output

Quantity	Value	Units
Total Rated Capacity	408	kW
Mean Output	53.0	kW
Capacity Factor	13.0	%
Total	464,594	kWh/yr
Minimum Output	0	kW
Maximum Output	397	kW
Hour of Operation	3,252	hrs/yr
Wind Penetration	49.2	%
Levelized cost	0.117	$/kWh

Table 3.6 above shows the power output and various parameter of the solar wind turbine system of the wind-solar hybrid energy system. The rated capacity of the wind turbine is 408 kW and its maximum power output is 397 kW. The total power production of 464,594 kWh/yr and a total operation yearly hour of 3,252 hrs/yr. the levelized cost of energy is 0.117 $kWh.

The power output of the hybrid system will therefore be the combine total power of both the solar PV system and the wind turbine system.

In total, the sum of the power output of both PV which is 695 kW and that of the wind turbine at 397 kW which equals 1,092 kW with a total annual production of the hybrid system for solar PV and wind turbine of 1,345,251 kWh/yr.

3.9 Power Output of the Batteries

The battery power output is a very important component in hybrid wind-solar energy system as it plays a vital role in ensuring the reliability and stability of the overall electricity supply.

During the optimization process of the HOMER software, it simulates every component and displays the feasible ones and their parameters in a table as can be seen in the table 3.7.

The table 3.7 displays the detail parameters of the batteries used for the system. The total number of batteries to be used is 1,663 pieces with a bus voltage of 12 V. the battery has a nominal capacity of 1,663 kWh and a lifetime throughput of 1,330,400 kWh. Each battery has an expected life of 4.86 years.

Table 3.7 Parameters of the batteries system power output

Quantity	Value	Unit
Batteries	1,663	qty.
String Size	1.00	batteries
Strings in Parallel	1,663	strings
Bus Voltage	12.0	V
Autonomy	9.25	hr
Storage Wear Cost	0.419	$/kWh
Nominal Capacity	1,664	kWh
Usable Nominal Capacity	999	kWh

Lifetime Throughput	1,330,400	KWh
Expected Life	4.86	yr
Average Energy Cost	0	$/kWh
Energu In	305,073	kWh/yr
Energy Out	244,631	kWh/yr
Storage Depletion	640	kWh/yr
Losses	61,082	kWh/yr
Annual Throughput	273,506	kWh/yr

Figure 3.7 below shows the charging state of the battery for the hybrid system throughout the year. Various colours represents the percentage charge at a particular point of the year. In the figure, high percentage of charging activities can be seen from colour yellow, brown and orange of percentages 76%, 88% and 100% signifying that there is high operation of the hybrid system which causes charging of the battery.

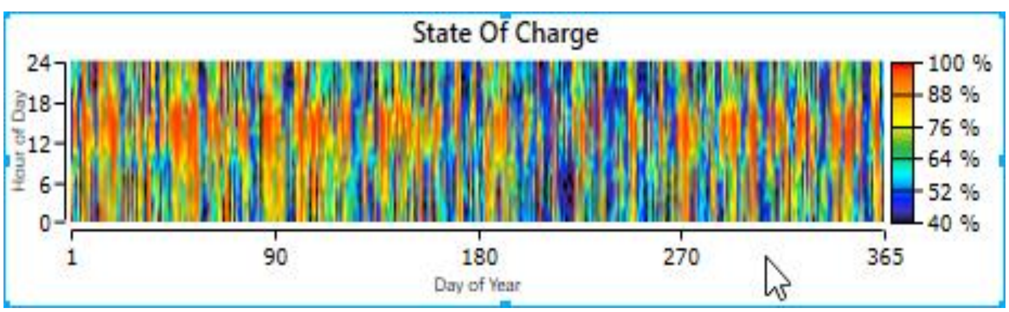

Figure 3.7 Plot showing the state of charging of the battery

3.10 Summary of the Chapter

This research seeks to perform analysis of the viability of hybrid wind–solar energy as an alternative electricity source in the Ashanti region. The development of renewable energy systems has been accelerated by the growing need for sustainable energy solutions and the urgency of reducing climate change. In particular, hybrid wind-solar systems have attracted a lot of interest because of their promise to increase energy output while lowering carbon emissions. In order to ensure the validity and dependability of the research findings, this passage summarizes the research methodology chapter for the study of hybrid wind solar systems with an emphasis on its essential elements.

Finding the research objectives is the first stage in developing a research methodology. The major goal of this research for hybrid wind-solar systems is to determine whether such a system is technically and financially feasible. This involves assessing the system's effectiveness and the costs associated with its implementation and deployment.

The collection of pertinent data is an essential component of any research process. Data gathered in this research of hybrid wind solar systems includes secondary data such as wind speed, solar radiation, ambient temperature, and average load profile of the Region, households and businesses were also obtained. Primary data was also obtained through energy audits and interviews of households and businesses to determine the cost of energy and fuel consumed at the end of the month.

Once all the necessary data was collected, analysis was performed to draw a meaningful conclusion in order to ascertain whether it is feasible to deploy hybrid wind-solar energy as an alternative energy source in the region.

Microsoft excel was used to provide graphical visualization of the wind speed, solar radiation and the ambient temperature. On the other hand, the National Renewable Energy Laboratory's (NREL) Hybrid Optimization Model for Electric Renewables (HOMER) software which uses hourly load and environmental data inputs to perform various simulations, was used for the modelling of the wind-solar energy systems. HOMER was also used to perform various analysis including the techno-economic analysis of the hybrid wind-solar systems.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter consists of the results and discussions of the research. The data obtained for this research was modelled in chapter three and fed into the HOMER software in order to be simulated. The research seeks to analyze the viability of hybrid wind-solar energy as an alternative electricity source in the Ashanti region. In this research, both primary and secondary data obtained were analyzed to ascertain the feasibility of the project's results. The wind velocities, solar radiations, air temperature, community households, and commercial average load profiles were obtained were modelled, and analyzed by the HOMER optimization software. The key results and findings of the data analyzed are presented in the following paragraphs.

4.2 Technical Feasibility Analysis

This hybrid wind-solar system is a combination of wind turbines and solar panels, which works hand in hand to produce electricity. The system is designed to make use of different weather conditions that affect wind and solar energy production.

The main merit of a hybrid wind-solar system is that it can generate electricity even when the weather conditions are unfavorable for one of the technologies.

Some of the technical considerations that need to be considered include the site of the project. Ashanti region has the potential for utility wind farm operation, with a mean wind power density of 254 W/m^2, of 10% of its windiest area. Asante region is one of the regions with a fair wind speed at almost 7 m/s. This indicates that the region is endowed with the potential for utility-scale wind speed. The Asante region has a fair to good wind speed. The summation of the spokes of the wind speed is 100%. And the direction of flow is around the west, south, south, and southwest. These areas experience strong wind speed and are suitable for wind farm siting (Government of Ghana, 2020).

On the other hand, according to the energy commission of Ghana, Ghana is endowed with vast solar energy resources which spread throughout the entire country. Daily solar irradiation level ranges from 4 kWh/m^2 to 6 kWh/m^2 with an annual sunshine duration ranging between 1800 to 3000 hours per annum which offers a high potential for grid connection (Energy Commission, 2011). The allocation of solar intensities in Ghana are as follows: the savannah zone which comprises; Upper East, Upper West, Northern, and upper parts of Brong-Ahafo and Volta Regions experiences 4.0–6.5 kWh/m^2/day of solar radiation; the middle forest zone which consists of, Ashanti, Eastern, Western and parts of Central, Brong-Ahafo, Volta Regions experiences 3.1–5.8 kWh/m^2/day of solar intensities whilst the coastal belt consisting of Greater Accra, coastal parts of Central and Volta Regions experiences 4.0–6.0 kWh/m^2/day of solar intensities (Kemausuor, 2011).

This clearly shows that the Ashanti region has a great prospect for the utilization of solar and wind energy and hence this was the prospect this research seeks to achieve as a case study in the region

4.3 Financial and Economic Feasibility Analysis

Economic and financial analysis of projects will support decision-making in the investment of resources. When one must decide to execute a big investment in some activity toward the future, which connotes risks of damage predictable or unpredictable, one must be scared of the possibility of losing own property. The financial and economic analysis will offer information on the most effective and efficient investment alternative by comparing cost and benefit in a certain manner and on the assumed risks being calculated.

After the input of all the required data such as the cost of equipment, fuel cost, maintenance and the others for simulation and by clicking the calculate button at the right top of HOMER's interface. After optimaization, the results displays the sizing and all the financials of the components involved by clicking on the compare economics button. The displayed Table 4.1 below shows the detailed financials of the equipment involved in the project.

Table 4.1 Components and Financials

Component	Capital ($)	Replacement ($)	O & M ($)	Fuel ($)	Salvage ($)	Total ($)
Autosize Genset	410,000.00	174,547.48	266,074.15	494,413.02	-32,084.78	1,312,949.86
Generic 1 Kwh Lead Acid Battery	510,900.00	1,049,972.03	220,155.61	0.00	-1,924.58	1,779,103.06
Generic Flat Plat PV	1,411,889.63	0.00	73,008.91	0.00	0.00	1,484,898.54
System Converter	166,096.37	70,470.34	42,944.27	0.00	-13,263.23	266,247.75
Wind Turbine (3 kW)	312,500.00	99,627.30	290,869.12	0.00	-56,146.37	646,850.05
System	2,811,386.00	1,394,617.15	893,052.05	494,413.02	- 103,418.97	5,490,049.26

The Table 4.4 above shows the various capitals, replacements, operation and maintenance (O & M), fuel cost and salvage for the components used in the hybrid systems modelled with HOMER. The figure 4.1 below gives the clear picture of how much to be spent on each component.

The highest capital to be spent was Generic Flat Plate PV with a sum of $1,411,889.63. Generic 1 Kwh Lead Acid Battery component came next with a capital of $510,900.00. the next component was the Autosize Genset generator with a sum capital of $410,000.00. components Wind Turbine (3 kW) and System Converter came next with capitals of $312,500.00 and $166,096.37 respectively.

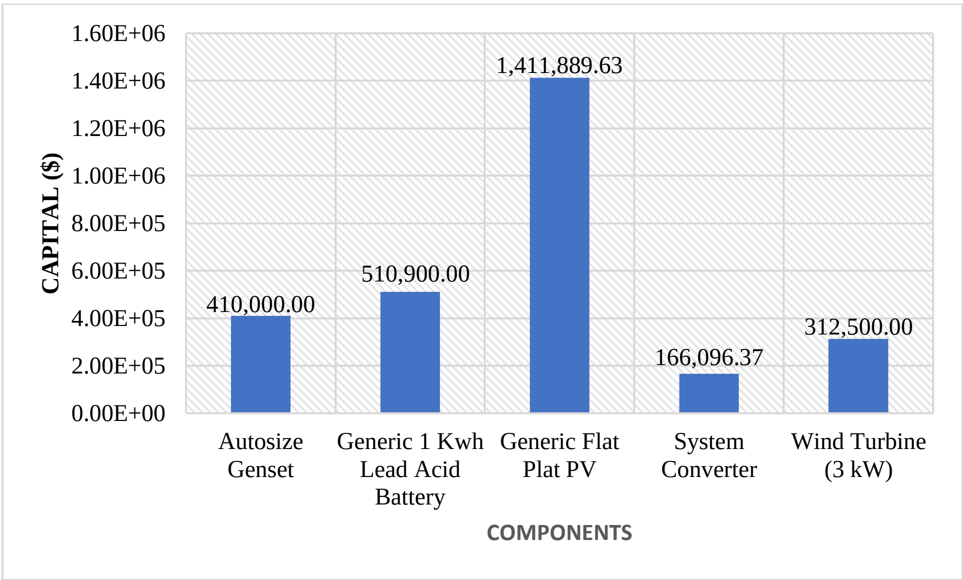

Figure4.1 Components and their respective capitals

Table 4.2 Economic Metrics

Metric	Value
Present worth ($)	$4,776,072
Annual worth ($/yr)	$369,450
Return on investment (%)	18.9
Internal rate of return (%)	23.7
Simple payback (yr)	3.84
Discounted payback (yr)	4.64

The Table 4.2 above shows the economic metrics obtained from HOMER after the optimization calculation which which is displayed after clicking on the economics button. are the measures used to assess and evaluate various aspects of a project economy's performance. These metrics provide quantitative data that can help policymakers, analysts, and researcher understand the overall health and trends of an economic metric.

The present worth of the project stands at $4,776,072 which refers to the stream of future cash flows, discounted to its equivalent value in the present time. The annual worth is $369,450 per year. The return on investment which is used to evaluate the profitability of the investment is 18.9 %. Again, the internal rate of return also is used to evaluate profitability and which is 23.7%. The simple payback period which is the number of years to recover the initial investment cost without considering the time value of the money stood at 3.84 years. The discounted payback which is the time it takes for an investment to generate enough discounted cash flows to recover the initial cost.

Table 4.3 Cost Summary

	Base Case	Lowest Cost System
NPC	$10.3M	$5.49M
Initial Capital	$410,000	$2.81M
O & M	$762,414/yr	$207,206/yr
LCOE	$0.840/kWh	$0.449/kWh

On the other hand, the cost summary of the investment in Table 4.6 includes the Net Present Cost (NPC) for the base case is $10.3M and the lowest cost system $5.49M. The initial capital of $410,000 for the base case and the lowest cost system $2.81M. Operation and maintenance (O&M) amounts to $762,414 per year and $207,206 per year for the lowest cost system. The levelized cost of energy for the base case is $0.840/kWh and $0.449/kWh for the lowest cost system.

4.4 Greenhouse Gas (Ghg) Emission Reduction Analysis

Emission reduction analysis is the process of evaluating the viability and efficacy of different technologies and strategies for reducing greenhouse gas emissions. It includes researching the causes of emissions, options for potential reduction, and the advantages and disadvantages of various strategies. Decision-makers can use the information from this analysis to make well-informed decisions on policies and actions aimed at reducing the effects of climate change.

The Table 4.4 shows the various emissions of the emergency generator if it were to be allowed to operate continuously for a year calculated in kilogram. The emergency generator was connected to the hybrid system in case there is total failure of the system which is unlikely. And even if there is likelihood of total failure if the system, it would be temporal as such the generator would not operate so long. This may cause only smaller emission to be released. The emissions table after optimization were obtained clicking on the architecture to show the emissions table is as shown below.

Table 4.4 Emissions when a Generator is used

Quantity	Value	Units
Carbon Dioxide	229,629	kg/yr
Carbon Monoxide	1,447	kg/yr
Unburned Hydrocarbons	63.2	kg/yr
Particulate Matter	8.77	kg/yr
Sulfur Dioxide	562	kg/yr
Nitrogen Oxides	1,360	kg/yr

On the other hand, based on the sensitivity cases, there would always be availability of suitable wind speed and solar radiation to power the system.

Therefore, if the use of the generator is ignored throughout the year, then no emission will be released throughout the year as table 4.5 shows below.

Table 4.5 Emissions without Generator

Quantity	Value	Units
Carbon Dioxide	0	kg/yr
Carbon Monoxide	0	kg/yr
Unburned Hydrocarbons	0	kg/yr
Particulate Matter	0	kg/yr
Sulphur Dioxide	0	kg/yr
Nitrogen Oxides	0	kg/yr

4.5 Sensitivity Analysis

Under specific input assumptions, HOMER determines the ideal system configuration. This section explains the sensitivity analysis procedure, which involves HOMER doing several optimizations with various input assumptions. A sensitivity analysis shows the sensitivity of the outputs to variations in the inputs.

The HOMER user inputs a range of values for a single input variable during a sensitivity analysis. A sensitivity variable is one for which the user has entered more than one value. A sensitivity variable in HOMER can be almost any numerical input variable that isn't a decision variable.

The sensitivity analysis for this research was carried out with varied parameters such as diesel prices, wind speeds, and solar radiations and their effects on all the components used for this hybrid wind-solar energy systems. These were selected as they are unstable and also their changes affects the overall performance of the hybrid system. The sensitivity analysis results table is obtained after running the optimization through the calculate button as it is shown in Table 4.9.

Table 4.6 Sensitivity Cases

Diesel Fuel Price ($/L)	Solar Scaled Average (kWh/m^2/day)	Wind Scaled Average (m/s)	PV (kW)	Wind Turbine	Generator	Battery	Converter (kW)	Cost Of energy ($)	Production (kWh)
1.00	4.31	2.50	555	121	410	1,650	316	0.458	155,996
1.20	4.40	2.40	584	132	410	1,712	321	0.458	121,371
1.50	4.40	2.40	624	145	410	1,930	338	0.468	91,585
1.50	4.31	2.32	588	152	410	2,127	330	0.466	86,078

Table 4.6 shows the sensitive cases on all the components of the hybrid wind-solar system, including the various variations of diesel fuel cost, energy cost, and energy production. Various values of wind speeds and solar radiations were considered. The variations of these parameters on the hybrid systems such as the PV, wind turbine, generator, battery, and converter were all collated in Table 4.6 above.

Variations of the parameters affect the cost of energy as well as energy production. At a diesel price of $1, average solar radiation of 4.31 kWh/m^2/day, and wind speed of 2.50 m/s, the cost of energy was recorded at $0.458, and production of 155,996 kWh. At a diesel price of $1.20, average solar radiation of 4.40 kWh/m^2/day, and wind speed of 2.40 m/s, the cost of energy was also recorded at $0.458 but the production was recorded at 121,371 kWh.

At a diesel price of $1.50, average solar radiation of 4.40 kWh/m^2/day and wind speed of 2.40 m/s, the cost of energy was also recorded at $0.468 but the production was recorded at 91,585 kWh.

Again, at a diesel price of $1.50, average solar radiation of 4.31 kWh/m^2/day and wind speed of 2.32 m/s, the cost of energy was also recorded at $0.468 but the production was recorded at 86,078 kWh.

Therefore, with these data of the changing values of diesel prices, wind speeds and average solar radiations, the project is still feasible as indicated by the various sensitivity cases.

The figure 4.2 below shows the plot the energy production against the various prices of diesel.

At a diesel price of $1, the production capacity stood at 155,996 kWh. At a diesel price of $1.2, the production capacity was at 121,371 kWh and at a diesel price of $1.5, the production capacity recorded is 91,585 kWh.

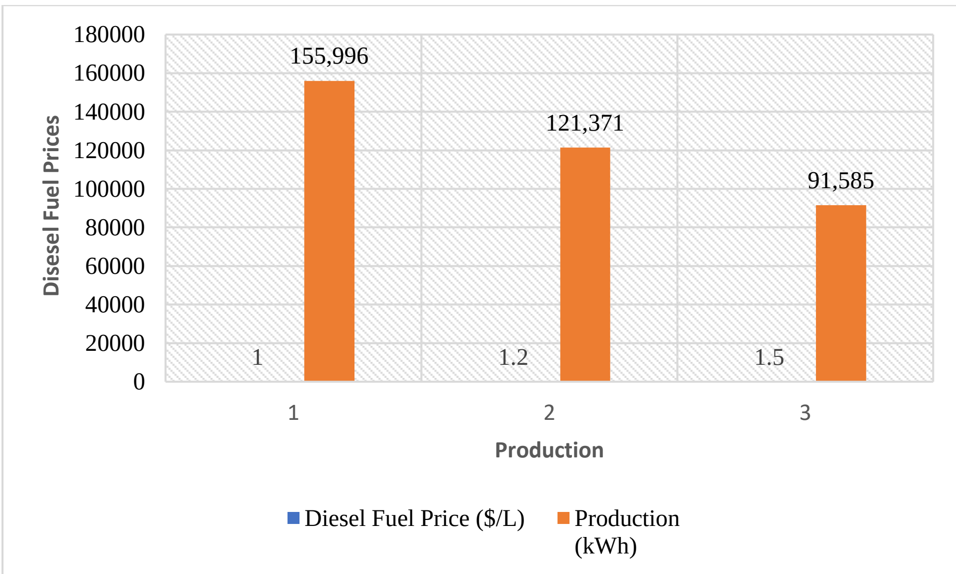

Figure 4.2 Components and their respective capitals at various fuel prices

CHAPTER FIVE

SUMMARY, RECOMMENDATIONS AND CONCLUSION

5.1 Summary of finding

This section summarizes the findings of the viability of hybrid wind-solar energy as an alternative electricity source in the Ashanti region. Ghana has been experiencing erratic electricity supply for a long period and as such, household and commercial entities have long suffered from its effects. Key analysis undertaken to determine the viability includes:

Technical Feasibility Analysis: The project's location is one of the technical factors that must be taken into account. With an average wind power density of 254 W/m^2, 10% of its windiest area, the Ashanti region offers the possibility to operate utility wind farms. Ashanti region is one of the regions with a fair wind speed at almost 7 m/s. This indicates that the region is endowed with the potential for utility-scale wind speed. The Ashanti region therefore has a fair to good wind speed.

On the other hand, Ghana's Energy Commission reported that the country has abundant solar energy resources spread out throughout its whole area. There is a great potential for grid connection since the daily solar irradiation levels ranges from 4 to 6kWh/m^2 and the annual sunshine length spans from 1800 to 3000 hours.

This demonstrates that the Ashanti region among other regions has good potential for solar and wind energy usage, which is the goal of this research's study in the area.

Financial and Economic Feasibility Analysis: Through specific cost-benefit comparisons and the calculation of expected risks, the financial and economic analysis will provide insight into the optimal investment option.

Once all necessary data has been entered into the HOMER Pro software, including equipment costs, fuel cost, maintenance cost, and other simulation-related data, the results simulated shows the sizing and all of the financial details of the associated components after optimization which are all cost effective as it is compiled in Table 4.1

With a present worth of $4,776,072 and annual worth of $369,450 for the project, the return on investment and internal rate of return are 18.9% and 23.7% respectively. The simple payback and the discounted payback are also 3.84 and 4.64 years respectively.

The cost summary of the investment of the research produced the Net Present Cost (NPC) for the base case of $10.3M and the lowest cost system of $5.49M. The initial capital of $410,000 for the base case and the lowest cost system $2.81M. Operation and maintenance (O&M) amounts to $762,414 per year and $207,206 per year for the lowest cost system. The levelized cost of energy for the base case is $0.840/kWh and $0.449/kWh for the lowest cost system.

The greenhouse gas emission generally shows very low values that can be managed with Carbon dioxide showing 229,629 kg/yr, Carbon monoxide of value 1,447 kg/yr, Unburned hydrocarbons 63.2 kg/yr and Particulate matter 8.77 kg/yr. However, during peak condition without the use generators, we record 0 kg/yr for all greenhouse gases.

Sensitivity Analysis: Sensitivity analysis was performed on all the components used for this research to ascertain the impact of different cost of diesel fuel at $1.0, $1.2, $1.50. The resulting cost of energy for these costs of diesel are $0.458, $0.458 and $0.466 respectively which is more cost effective for the households and commercial consumers. The overall data is presented in Table 4.6.

5.2 Conclusion

In conclusion, the adoption and implementation of the hybrid wind-solar energy system offers a revolutionary chance to improve energy security and sustainability, especially in areas like Ashanti region that have abundance of renewable resources. The conclusions and ramifications of this study are summarized in the following points:

5.2.1 Improved Energy Efficiency

By combining the advantages of wind and solar energy, the hybrid system lessens the sporadic nature of weach source. A more steady and dependable energy supply is ensured by thuis synergy, which is essential for both region and other communities.

5.2.2 Finacial Sustainability

The analysis shows that when compared to conventional fossil-based systems, hybrid systems dramatically lowers the overall cost of energy generation. For resolving Ghana's energy issues, hybrid systems are a viable option due to their economic advantages and falling technological prices.

5.2.3 Sustainability of the Environment

By switching to a hybrid wind-solar energy system, greenhouse gas emissions and the need for fossil fuels are significantly reduced. This strengthens Ghana resolve to fight climate change and is in line with international sustainability goals.

5.2.4 Prospective Routes for Research

To evaluate long-term performance, optimize hybrid system designs, and investigate cutting-edge technologies like energy storage options and smart grid integration, more research is essential.

Future research should take into account the socioeconomic effects on nearby populations as well as how hybrid systems can improve access to electricity.

5.3 Recommendations

The following are the recommendations that could play a role in embracing renewable energy systems research and applications as a whole in Ghana as obtained through this research:

5.3.1 Effective Wind Speed Measurements Research

There should be rigorous and effective wind data measurement research which goes beyond 10 m a.g.l to 120 m a.g.l to harness great wind speed for electricity generation in Ghana. Though, Ashanti Region has a potential high utility and therefore increasing turbine's height exploits more electrical energy.

5.3.2 Use of Modern Renewable Energy Resource Equipment

The Ghana Meteorological Agency must be supplied with ultra-modern equipment for efficient and accurate wind and solar energy measurement. The government of Ghana must invest in ultra-modern equipment in order to be at par with the current progress in renewable energy resource development.

5.3.3 Renewable Energy Publicity

There should be a planned publicity in the country and internationally in order to attract both internal and external investors so as to invest in the renewable energy resources in Ghana. This will in time limit the excessive use of the conventional energy and introduce rigorous renewable energy technologies in the country. It will also encourage many people and businesses to adopt renewable energy technologies to create more jobs in the country.

5.3.4 Solar and Wind Site

Government should introduce policies which stipulates the allocation of sites for renewable energy system installation around industrial and business areas. This will make sure that the business site draws its energy directly the wind-solar farm nearby to reduce cost of running the business.

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APPENDICES

APPENDIX A

Calculation for wind power density for Ashanti region

The maximum mean average wind speed for Kumasi from January 2012 to December 2022 is 2.70 m/s which occurred in May 2022 wind data. The variation wind speeds are attributed to weather conditions which include seasonal changes and time of the year. This is then used to calculate the wind power density for Kumasi.

$$\text{WPD} = \frac{1}{2} \times \rho \times v^3$$

Were

WPD = Wind power density

ρ = air density (*1.204 kg/m*^{3})

v = velocity/speed of wind

$$\text{WPD} = \frac{1}{2} \times 1.204 \times (2.7)^3$$

$$\text{WPD} = \frac{1}{2} \times 1.204 \times 19.683$$

WPD = 11.85 W/m^2

This is wind power density for the wind speed of 2.7 m/s minimum wind power density.

APPENDIX B

Calculation of power output for the solar panel

The ideal condition for solar panel to operate efficiently is 77 degrees Fahrenheit which equivalent to 25^0C. Another important parameter is the efficiency of the solar panel which is 19.58% and means that 20 % of the total sunlight striking its surface will be transformed into power.

Here's a simple formula for calculating your solar panel's power output.

Solar panel watts x average hours of sunlight x 75% = daily watt-hours

The 75% account for what is left of the solar radiation after variables like shades due to the position of the solar panel, the panel's angle and the sunlight that is reflected back to space.

Ghana's peak sun hours vary but it is mostly 6 hours.

So,

500 watts × 6 × 75% = 2,250 daily watt hours

This is the watt-hour value to be generated just by one solar panel.

APPENDIX C

Audit Conducted for Cold Rooms at Different Locations in Kumasi

Name of Business	Number Of Cold Room Machine Unit	Total Power Consu-mption of Cold-room Machines (Kilowatts)	Storage Material	Electricity Bill Per Month (GH₵)	Electricity Bill Per Year (GH₵)	Electricity Generator Fuel Consumption Per Hour in litres	Location
Foundation Gate Company	2	30.1	Chicken Products	5,000	60,000	8.6	Central Market
Racheal's Trading	1	50	Chicken Products	5,500	66,000	10.7	Central Market
Triton Aquaculture	2	90	Chicken/ Fish Products	6,000	72,000	21.4	Central Market
Halal Cold Products	2	84	Chicken Products	5,700	68,400	21.4	Central Market
NYC Limited	1	45.5	Chicken Products	5,300	63,600	10.7	Central Market
Joy Cold Store	2	125	Beef	7,000	84,000	32.1	Ahinsan
Agnes Cold Store	3	175	Beef and Mutton	8,800	105,600	42.8	Ahinsan
Empress Jamila Cold Store	2	150	Beef	8,250	99,000	32.1	Ahinsan
Fajas Cold Store	2	128	Mutton	7,500	90,000	32.1	Ahinsan
Ocean Fare Company	2	144	Mutton	9,500	114,000	32.1	Ahinsan
God's Grace Cold room	1	50	Beef	8,500	102,000	10.0	Old Tafo
Felibat Cold Store	1	51.2	Beef	5,700	68,400	10.5	Ahinsan

Mohammed Cold Store	2	75	Chicken	6,500	78,000	15.0	Santasi
Kuhnesi Cold Store	1	55	Chicken	6,800	81,600	15.5	Santasi
Parker food & Cold Store	1	60	Chicken	7,000	84,000	20.2	Santasi
Haya Cold Store	2	125	Chicken	9,200	110,400	30.5	Ahinsan
Rose Cold Store	1	46.5	Chicken	5,400	64,800	20.4	Central Market
Mahmud Colds Ltd.	3	160	Chicken & Beef	8,900	106,800	40.3	Central Market
Safo Nyame Cold Store	1	38	Chicken	4.800	57,600	15.2	Central Market
Dimaensa Cold Store	1	40	Chicken	4,900	58,800	16.5	Old Tafo
Nyame Beye Cold Store	1	35	Chicken	4,500	54,000	12.5	Old Tafo
Best Cold Store	1	30	Chicken & Beef	4,200	50,400	10.5	Pankrono
Cool Cold Store	1	45	Mutton	5,000	60,000	15.5	Old Tafo
Patience Cold Store	1	40	Beef &Mutton	4,700	56,400	17.5	Central Market
Greatness Cold Store	1	34	Chicken	4,000	48,000	14.5	Central Market
International Cold Products	2	120	Mutton	7,000	84,000	15.0	Central Market
Chicken Cold Ltd	2	95	Beef	6,100	73,200	13.5	Pankrono
Forever Cold Store	1	45	Chicken	4,250	51,000	14.2	Old Tafo
Adom Mbroso Cold Store	1	35	Mutton	4,600	55,200	13.3	Pankrono
C&G Fisheries Company Limited	2	85	Beef	6,800	81,600	19.5	Old Tafo
Perez Frozen Foods	2	110	Beef	7,800	93,600	21.5	Pankrono
Divine Foods Limited	1	36	Mutton	3,900	46,800	16.3	Meduma
Otuo Farms Limited	2	115	Chicken	7,900	94,800	22.6	Meduma

Atese Farms	1	41	Beef	4,500	54,000	18.3	Meduma
Inkunim Foods	1	40	Chicken	4,000	48,000	19.5	Meduma
Esbony Meat Packaging	2	90	Chicken	6,800	81,600	25.6	Meduma
Manurado Enterprise	1	33	Chicken	4,200	50,400	12.2	Suame
Foodies Health Court	1	25	Chicken	3,900	46,800	10.7	Suame
T. T International Limited	1	50	Chicken	5,000	60,000	21.7	Suame
							Suame
Master Meat Ghana Ltd	2	80	Chicken	7,000	84,000	29.5	Central Market
Laramart Cold Ltd	1	35	Chicken	4,000	48,000	11.6	Central Market
Faithful God Cold Store	1	45	Beef & Mutton	4,300	51,600	10.3	Central Market
Grace Abounds Cold Store	2	160	Chicken	7,500	90,000	29.6	Central Market
B.B Meat Shop	1	35	Chicken	3,700	44,400	10.9	Central Market
Asabee's Frozen Foods	1	28	Beef	2,500	30,000	8.9	Ahinsan
Izzy Meat Mart	1	32	Chicken	2,900	34,800	10.4	Ahinsan
Anointed Hand Cold Store	1	55	Chicken	5,400	64,800	15.6	Ahinsan
Nyametease Frozen Foods Ltd	1	45	Beef & Mutton	5,000	60,000	14.8	Ahinsan
Too Ice-Cold Stores	2	155	Chicken	7,900	94,800	30.2	Ahinsan
Mighty Cold Store	2	110	Beef & Mutton	7,500	90,000	25.7	Ahinsan

APPENDIX D

Cost Incurred When an Electricity Generator is Used for 12 hours (7 pm-7 am)

Name of Business	Cost of fuel used for 12 hours/GH₵	Projected Cost of fuel used for 12 hours in a year/GH₵	The cost difference of electricity bill per year and cost of fuel use per year/Loss
Foundation Gate Company	500	365,000	305,000
Racheal's Trading	550	401,500	335,500
Triton Aquaculture	600	438,000	366,000
Halal Cold Products	590	430,700	362,300
NYC Company Limited	550	401,500	337,900
Joy Cold Store	700	511,000	427,000
Agnes Cold Store	800	584,000	478,400
Empress Jamila Cold Store	870	635,000	536,000
Fajas Cold Store	750	547,000	457,000
Ocean Fare Company	900	657,000	543,000
God's Grace Cold room	490	357,700	255,700
Felibat Cold Store	500	365,000	296,600
Mohammed Cold Store	850	620,500	542,500
Kuhnesi Cold Store	550	401,500	319,900
Parker Food & Cold Store	490	357,700	349,300
Haya Cold Store	900	657,000	546,600

Rose Cold Store	500	365,000	300,200
Mahmud Colds Ltd.	480	350,400	243,600
Safo Nyame Cold Store	540	394,200	336,600
Dimaensa Cold Store	600	438,000	379,200
Nyame Beye Cold Store	650	474,500	420,500
Best Cold Store	570	416,100	365,700
Cool Cold Store	500	365,000	305,000
Patience Cold Store	485	354,050	297,650
Greatness Cold Store	580	423,400	375,400
International Cold Products	890	649,700	565,700
Chicken Cold Ltd	900	657,000	583,800
Forever Cold Store	640	647,200	599,620
Adom Mbroso Cold Store	560	408,800	353,600
C&G Fisheries Company Limited	800	584,000	502,400
Perez Frozen Foods	850	620,500	526,900
Divine Foods Limited	500	365,000	318,200
Otuo Farms Limited	900	657,000	562,200
Atese Farms	520	379,600	325,600
Inkunim Foods	580	423,400	375,400
Esbony Meat Packaging	480	350,400	268,800
Manurado Enterprise	560	408,800	358,400
Foodies Health Court	460	335,800	289,000
T. T International Limited	520	379,600	319,600

Master Meat Ghana Ltd	890	649,700	565,700
Laramart Cold Ltd	500	365,000	317,000
Faithful God Cold Store	500	365,000	313,400
Grace Abounds Cold Store	900	657,000	657,000
B.B Meat Shop	400	292,000	247,600
Asabee's Frozen Foods	510	372,300	342,300
Izzy Meat Mart	560	408,800	373,000
Anointed Hand Cold Store	490	357,700	292,900
Nyametease Frozen Foods Ltd	870	635,100	575,100
Too Ice-Cold Stores	950	693,500	598,700
Mighty Cold Store	860	627,800	537,800
TOTAL	**3,2085**	**23,601,450**	**20,252,270**

APPENDIX E

Energy Audit and Interview

NAME OF COMPANY: ……………………………………………………………….

LOCATION: ……………………………………………………………………….

HOW LONG IN BUSINESS: ………………………………………………………….

TYPE OF PRODUCT: ……………………………………………….…………

NUMBER OF COLDROOM MACHINE: ……………………………..………

ELECTRICITY BILL PAID MONTHLY FOR THE BUSINESS: …………….

ELECTRICITY BILL FOR THE HOUSEHOLD: ………………………………

ELECTRIC POWER OF ELECTRIC GENERATOR: …………………………

NUMBER OF LITERS CONSUMED: …………………………….………….

COST OF FUEL FOR 12 HOURS OF GENERATOR USED: …………………

HOUSE NUMBER: ………………………………………………………………..

DAILY ELECTRICITY CONSUMPTION: ………………………..…………

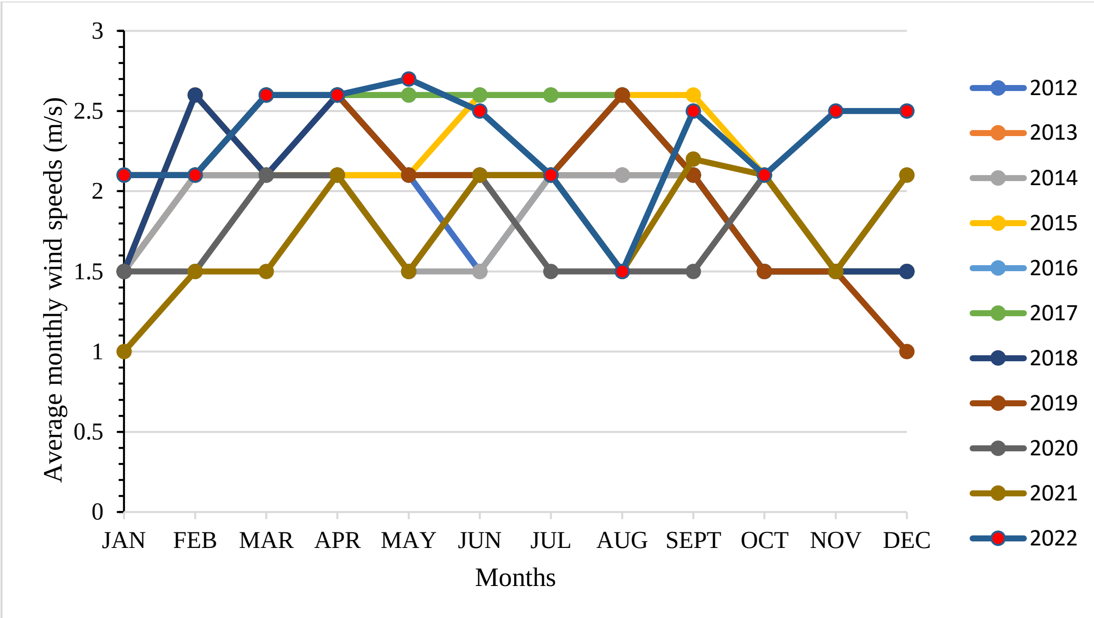
MONTHLY ELECTRICITY COST: ……………………………………………..

APPENDIX F

Data Collected Visualization and Intepretation

Month/Year	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
January	1.5	1.5	1.5	1.5	2.1	2.1	1.5	2.1	1.5	1.0	2.1
February	2.1	2.1	2.1	2.6	2.1	2.1	2.6	2.1	1.5	1.5	2.1
March	2.1	2.1	2.1	2.1	2.6	2.6	2.1	2.6	2.1	1.5	2.6
April	2.1	2.1	2.1	2.1	2.6	2.6	2.6	2.6	2.1	2.1	2.6
May	2.1	2.1	1.5	2.1	2.6	2.6	2.1	2.1	1.5	1.5	2.7
June	1.5	2.1	1.5	2.6	2.6	2.6	2.1	2.1	2.1	2.1	2.5
July	2.1	2.1	2.1	2.6	2.6	2.6	2.1	2.1	1.5	2.1	2.1
August	2.1	2.1	2.1	2.6	2.6	2.6	2.6	2.6	1.5	1.5	1.5
September	2.1	2.1	2.1	2.6	2.1	2.1	2.1	2.1	1.5	2.2	2.5
October	1.5	1.5	1.5	2.1	1.5	1.5	1.5	1.5	2.1	2.1	2.1
November	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	2.5
December	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.0	2.1	2.1	2.5
ANNUAL AVERAGE	1.85	1.90	1.80	2.16	2.20	2.20	2.03	2.03	1.75	1.77	2.32

Figure below shows the distribution of wind speeds over the course of 11 years from January 2012 to December 2022. It shows the average wind speed for each month and every year. The wind speeds range from a minimum value of 1.0 m/s to a maximum value of 2.7 m/s. Wind speeds of 1.5 m/s were mostly recorded in the year 2020. A wind speed range of values 2.1 m/s occurred in 2013 while most wind speeds of value 2.6 m/s were recorded in 2015, 2016, and 2017. However, a peak value of 2.7 m/s occurs in 2022.



Average monthly wind speeds (m/s) for the Ahanti Region from January 2012 to December 2022

APPENDIX G

Yearly average wind speeds for Ashanti Region (2012 to 2022)

Month/ Year	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	Average
Jan	1.5	1.5	1.5	1.5	2.1	2.1	1.5	2.1	1.5	1.0	2.1	1.7
Feb	2.1	2.1	2.1	2.6	2.1	2.1	2.6	2.1	1.5	1.5	2.1	2.1
Mar	2.1	2.1	2.1	2.1	2.6	2.6	2.1	2.6	2.1	1.5	2.6	2.2
Apr	2.1	2.1	2.1	2.1	2.6	2.6	2.6	2.6	2.1	2.1	2.6	2.3
May	2.1	2.1	1.5	2.1	2.6	2.6	2.1	2.1	1.5	1.5	2.7	2.1
Jun	1.5	2.1	1.5	2.6	2.6	2.6	2.1	2.1	2.1	2.1	2.5	2.2
Jul	2.1	2.1	2.1	2.6	2.6	2.6	2.1	2.1	1.5	2.1	2.1	2.2
Aug	2.1	2.1	2.1	2.6	2.6	2.6	2.6	2.6	1.5	1.5	1.5	2.2
Sept	2.1	2.1	2.1	2.6	2.1	2.1	2.1	2.1	1.5	2.2	2.5	2.1
Oct	1.5	1.5	1.5	2.1	1.5	1.5	1.5	1.5	2.1	2.1	2.1	1.7
Nov	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	2.5	1.6
Dec	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.0	2.1	2.1	2.5	1.7

APPENDIX H

Yearly average wind speeds (2012-2022) and air temperature for 2022

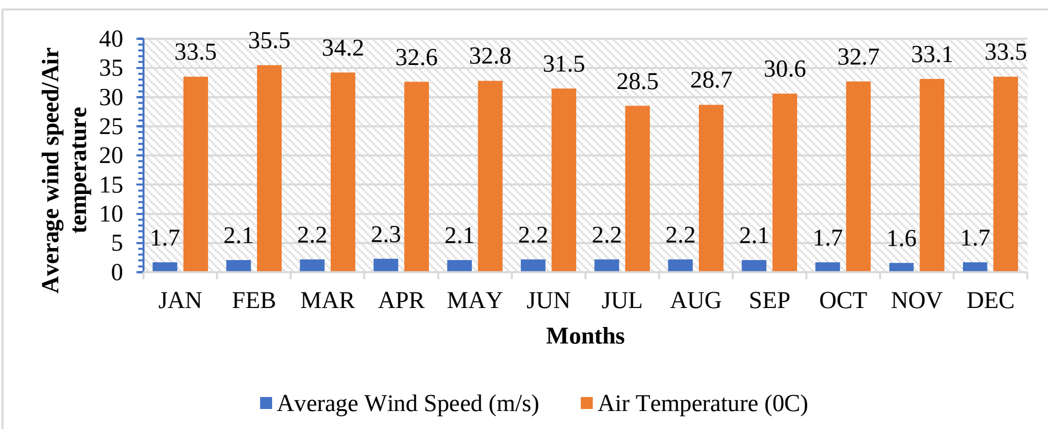
Month	Mean Wind Speed (m/s)	Air Temperature (^{0}C)
Jan	1.7	33.5
Feb	2.1	35.5
Mar	2.2	34.2
Apr	2.3	32.6
May	2.1	32.8
Jun	2.2	31.5
Jul	2.2	28.5
Aug	2.2	28.7
Sep	2.1	30.6
Oct	1.7	32.7
Nov	1.6	33.1
Dec	1.7	33.5

Figure below shows the result of the relationship between the average yearly wind speeds (2012-2022) and air temperatures for 2022. Temperature is the degree of heat in the atmosphere while the wind speed is the rate of motion of air. Temperature gradient occurs when two places are different temperatures which brings out air pressure differences between the two places. The atmosphere will then try to compensate the difference in pressure between these two regions hence formation of wind. Therefore, air temperature affects the wind speed at a particular location. Below plot shows the graphical relationship between the mean wind speeds (2012-2022) and the air temperatures in Ashanti region for the period of 2022.

It can be seen from the graph that as the air temperature increases, the mean wind speed also increases. In January, the mean wind speed recorded was 1.7 m/s at air temperature of 33.5 ^{0}C. In

February, the mean wind speed was 2.1 m/s and the corresponding air temperature stood at 35.5^{0}C. March recorded wind speed of 2.2 m/s and air temperature of 34.2 ^{0}C, April recorded mean wind speed value of 2.3 m/s with its respective air temperature of 32.6 ^{0}C. May recorded 2.1 m/s air temperature 32.8 ^{0}C. June, July and August recorded the same mean wind speed of 2.2 m/s and air temperatures of 31.5, 28.5 and 28.7 ^{0}C respectively. both had mean wind speeds of 2.1 and corresponding air temperatures of 32.8 ^{0}C and 31.5 ^{0}C respectively. July recorded a mean wind speed of 2.2m/s and air temperature of 28.5 ^{0}C. August recorded 2.3 m/s mean wind speed and air temperature 28.7 ^{0}C. September recorded a mean wind speed of 1.9m/s and air temperature of 30.6 ^{0}C. October, November and December all recorded the same mean wind speed of 1.6m/s and air temperatures of 32.7 ^{0}C, 33.1 ^{0}C and 33.5^{0}C respectively. The September month measured 2.1 m/s and its air temperature 30.6 ^{0}C. October recorded mean wind speed of 1.7 m/s and its corresponding air temperatures was 32.7 m/s. November mean wind speed was 1.6 m/s and its air temperature 33.1 ^{0}C. Though not all values were consistent, factors such as air pressure, humidity just to mention a few can introduce irregularities and the wind speed and air temperature relationships.

Month	Solar Radiation (MJ/m^2/day)
January	15.05
February	16.85
March	18.14
April	18.32
May	17.89
June	15.77
July	13.21
August	12.06
September	13.68
October	15.98
November	16.78
December	13.93

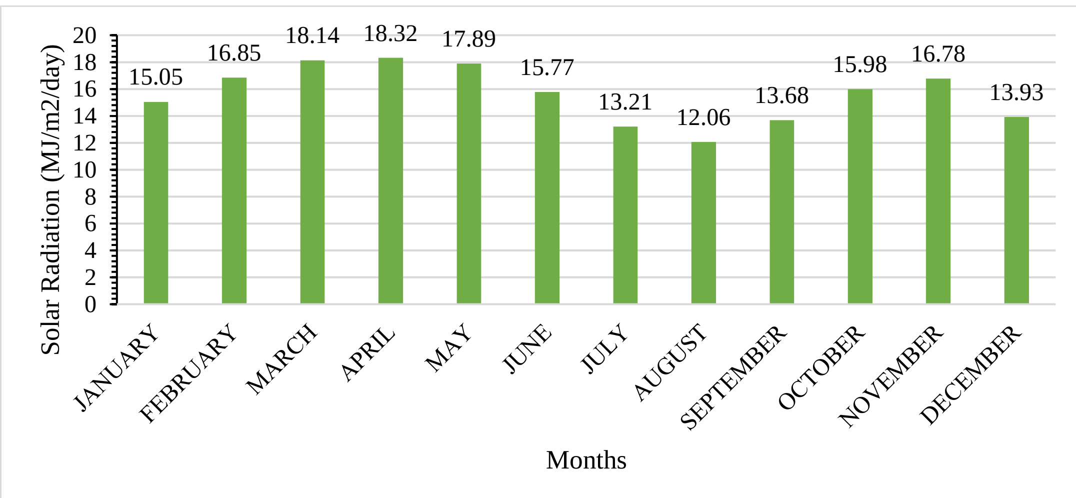


Plot of yearly average wind speeds (2012-2022) and air temperature for 2022

APPENDIX I

Mean Monthly Solar Radiation

The figure below shows the monthly mean solar radiation in the Ashanti region from January to December in 2022. As can be clearly seen in the figure, the highest mean solar radiation was recorded in the month of April indicating a value of 18.32 MJ/m^2/day. This was followed by a value of 18.14 MJ/m^2/day in March and the lowest recording took place in the month of August with a solar radiation value of 12.06 MJ/m^2/day.



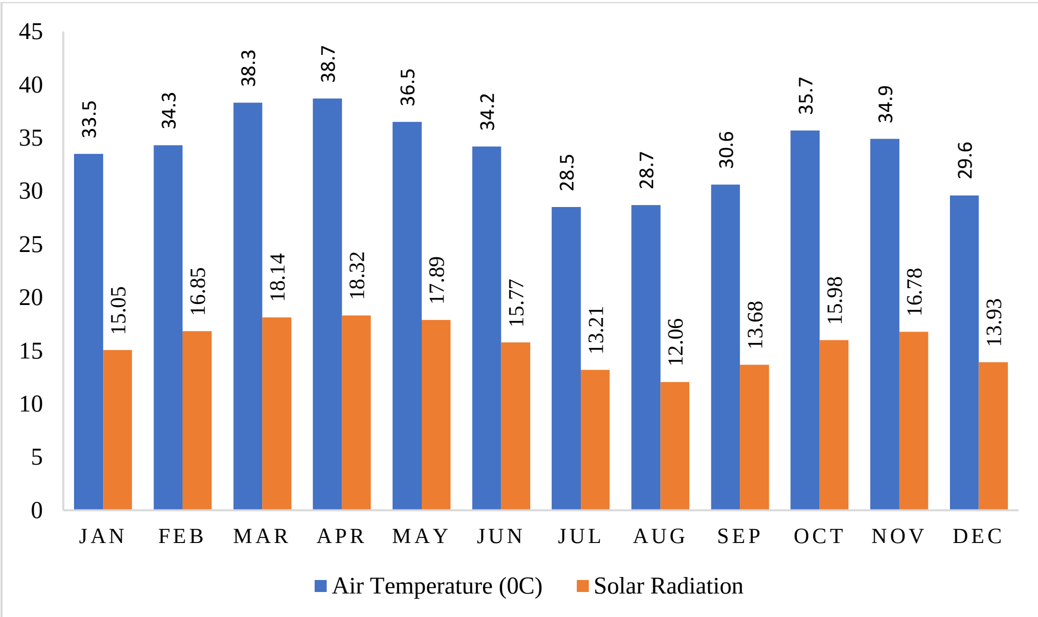
Plot showing the mean Solar Radiation for 2022 in Ashanti Region

APPENDIX J

The Relationship Between Air Temperature and The Solar Radiation

Month	Air Temperature (^{0}C)	Solar Radiation (MJ/m^2/day)
Jan	33.5	15.05
Feb	34.3	16.85
Mar	38.3	18.14
Apr	38.7	18.32
May	36.5	17.89
Jun	34.2	15.77
Jul	28.5	13.21
Aug	28.7	12.06
Sep	30.6	13.68
Oct	35.7	15.98
Nov	34.9	16.78
Dec	29.6	13.93

Air temperature relates directly to solar radiation as an increase in solar radiation results in an increase in air temperature. Such a relationship can be seen in the figure below. In January, solar radiation of 15.05 MJ/m^2/day gave rise to air temperature of 33.5 ^{0}C. In February, there was solar radiation of 16.85 MJ/m^2/day and the corresponding air temperature of 34.3 ^{0}C. in March, solar radiation of 18.14 MJ/m^2/day which produced air temperature of 38.3 ^{0}C. in April, solar radiation was 18.3 2 MJ/m^2/day and its corresponding air temperature of 38.7 ^{0}C. In May, the solar radiation was 17.89 MJ/m^2/day, and its corresponding air temperature of 36.5 ^{0}C. In June, the solar radiation recorded was 15.77 MJ/m^2/day, and its corresponding air temperature of 34.2 ^{0}C. In July, the solar radiation recorded was 13.21 MJ/m^2/day, and its corresponding air temperature of 28.5 ^{0}C. In August, the solar radiation recorded was 12.06 MJ/m^2/day, and its corresponding air temperature of 28.7 ^{0}C. In September, the solar radiation recorded was 13.68 MJ/m^2/day, and its corresponding air temperature of 30.6 ^{0}C. In October, the solar radiation recorded was 15.98 MJ/m^2/day, and its corresponding air temperature of 35.7 ^{0}C. And finally, in December, the solar radiation recorded was 13.93 MJ/m^{2}/day, and its corresponding air temperature of 29.6 ^{0}C.



Relationship between yearly average wind speeds (2012-2022) and air temperature for 2022.

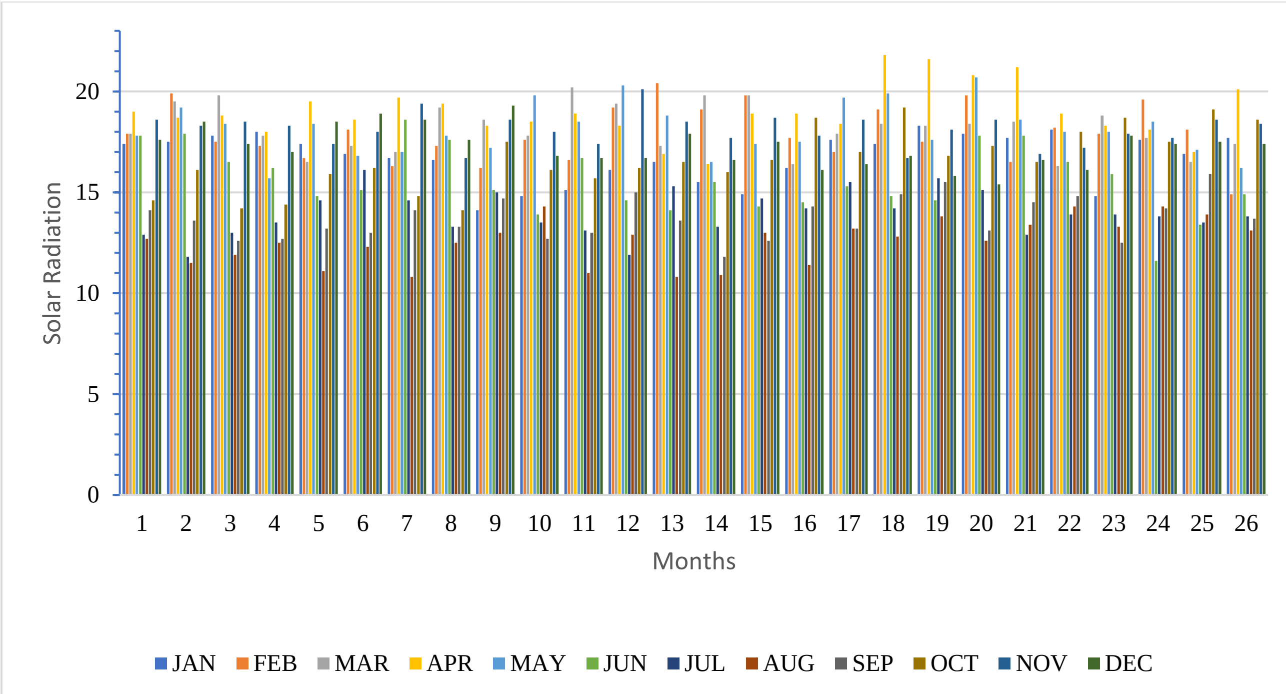
APPENDIX K

Solar Radiation Distribution for Ashanti Region 2022 Data

Day/ Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1	17.4	17.9	17.9	19.0	17.8	17.8	12.9	12.7	14.1	14.6	18.6	17.6
2	17.5	19.9	19.5	18.7	19.2	17.9	11.8	11.5	13.6	16.1	18.3	18.5
3	17.8	17.5	19.8	18.8	18.4	16.5	13.0	11.9	12.6	14.2	18.5	17.4
4	18.0	17.3	17.8	18.0	15.7	16.2	13.5	12.5	12.7	14.4	18.3	17.0
5	17.4	16.7	16.5	19.5	18.4	14.8	14.6	11.1	13.2	15.9	17.4	18.5
6	16.9	18.1	17.3	18.6	16.8	15.1	16.1	12.3	13.0	16.2	18.0	18.9
7	16.7	16.3	17.0	19.7	17.0	18.6	14.6	10.8	14.1	14.8	19.4	18.6
8	16.6	17.3	19.2	19.4	17.8	17.6	13.3	12.5	13.3	14.1	16.7	17.6
9	14.1	16.2	18.6	18.3	17.2	15.1	15.0	13.0	14.7	17.5	18.6	19.3
10	14.8	17.6	17.8	18.5	19.8	13.9	13.5	14.3	12.7	16.1	18.0	16.8
11	15.1	16.6	20.2	18.9	18.5	16.7	13.1	11.0	13.0	15.7	17.4	16.7
12	16.1	19.2	19.4	18.3	20.3	14.6	11.9	12.9	15.0	16.2	20.1	16.7
13	16.5	20.4	17.3	16.9	18.8	14.1	15.3	10.8	13.6	16.5	18.5	17.9
14	15.5	19.1	19.8	16.4	16.5	15.5	13.3	10.9	11.8	16.0	17.7	16.6
15	14.9	19.8	19.8	18.9	17.4	14.3	14.7	13.0	12.6	16.6	18.7	17.5
16	16.2	17.7	16.4	18.9	17.5	14.5	14.2	11.4	14.3	18.7	17.8	16.1
17	17.6	17.0	17.9	18.4	19.7	15.3	15.5	13.2	13.2	17.0	18.6	16.4
18	17.4	19.1	18.4	21.8	19.9	14.8	14.2	12.8	14.9	19.2	16.7	16.8

19	18.3	17.5	18.3	21.6	17.6	14.6	15.7	13.8	15.5	16.8	18.1	15.8
20	17.9	19.8	18.4	20.8	20.7	17.8	15.1	12.6	13.1	17.3	18.6	15.4
21	17.7	16.5	18.5	21.2	18.6	17.8	12.9	13.4	14.5	16.5	16.9	16.6
22	18.1	18.2	16.3	18.9	18.0	16.5	13.9	14.3	14.8	18.0	17.2	16.1
23	14.8	17.9	18.8	18.3	18.0	15.9	13.9	13.3	12.5	18.7	17.9	17.8
24	17.6	19.6	17.7	18.1	18.5	11.6	13.8	14.3	14.2	17.5	17.7	17.4
25	16.9	18.1	16.5	17.0	17.1	13.4	13.5	13.9	15.9	19.1	18.6	17.5
26	17.7	14.9	17.4	20.1	16.2	14.9	13.8	13.1	13.7	18.6	18.4	17.4
27	18.5	18.8	18.7	19.3	17.8	13.4	11.2	14.2	13.2	17.6	16.1	15.3

Figure below shows the distribution of solar radiation data from January to December in 2022. The data was recorded for 27 days in each month. This plot gives an overview of solar radiation and its distribution throughout the year. Each month has a total amount of solar radiation recorded. In ascending order, the highest amount of solar radiation occurred in April with a value of 512.3 MJ/m^2/day. The next highest month has a total solar radiation of 491.2 MJ/m^2/day which occurred in the month of March. The next month to follow was May with a total solar radiation of 489.2 MJ/m^2/day. The month of November followed with a total solar radiation of 486.8 MJ/m^2/day. February followed next with total solar radiation of 485.0 MJ/m^2/day. December followed next with a total solar radiation of 464.2 MJ/m^2/day. In the month of January, the total solar radiation was 454.0M J/m^2/day. October came next with 449.9 MJ/m^2/day. Followed by June with 419.2 MJ/m^2/day. The month of July came with 374.3 MJ/m^2/day. This was followed by September with a total solar radiation of 369.8 MJ/m^2/day. And finally, August recorded a total solar radiation of 341.5 MJ/m^2/day.



Solar radiation distribution in Ashanti Region for 2022

APPENDIX L

50 Household Electricity Consumption in Ashanti Region

House Number	Household Daily Consumption/kWh	Monthly Electricity Cost/GH₵
PLT 5 BLK 15	25.5	283.05
PLT 21 BLK 14	29.5	327.45
PLT 5 BLK 8	30.8	341.88
PLT 7 BLK 12	30.5	338.55
PLT 13 BLK 19	20.6	228.66
PLT 15 BLK 25	31.7	351.87
PLT 17 BLK 9	27.8	308.58
PLT 12 BLK 25	21.9	243.09
PLT 17 BLK 20	31.6	350.76
PLT 27 BLK 18	19.8	219.78
PLT 21 BLK 15	25.6	284.16
PLT 14 BLK 24	27.6	306.36
PLT 2 BLK B	28.9	320.79
PLT 23 BLK AA	31.5	349.65
PLT 16 BLK 9	32.4	359.64
PLT 14 BLK B	35.6	395.16
PLT 1 BLK 1	33.6	372.96
PLT 26 BLK 7	29.6	328.56
PLT 60 BLK F	23.5	260.85

PLT 12 BLK W	22.9	254.19
PLT 34 BLK A	30.2	335.22
PLT 21 BLK C	31.9	354.09
PLT 14 BLK 8	29.8	330.78
PLT 32 BLK J	25.7	285.27
PLT 25 BLK C	29.9	331.89
PLT 21 BLK E	25.8	286.38
PLT 17 BLK O	27.8	308.58
PLT 11 BLK 5	26.9	298.59
PLT 12 BLK XX	33.2	368.52
PLT 3 BLK 6	29.8	330.78
PLT 5 BLK 18	28.3	314.13
PLT 12 BLK H	29.5	327.45
PLT 15 BLK 6	31.2	346.32
PLT 54 BLK 11	28.9	320.79
PLT 17 BLK 14	27.5	305.25
PLT 32 BLK 8	31.5	349.65
PLT50 BLK XXI	29.6	328.56
PLT 6 BLK 2	24.9	276.39
PLT 21 BLK 32	28.7	318.57
PLT 18 BLK 25	26.9	298.59
PLT 44 BLK 18	25.8	286.38
PLT 7 BLK 23	28.8	319.68

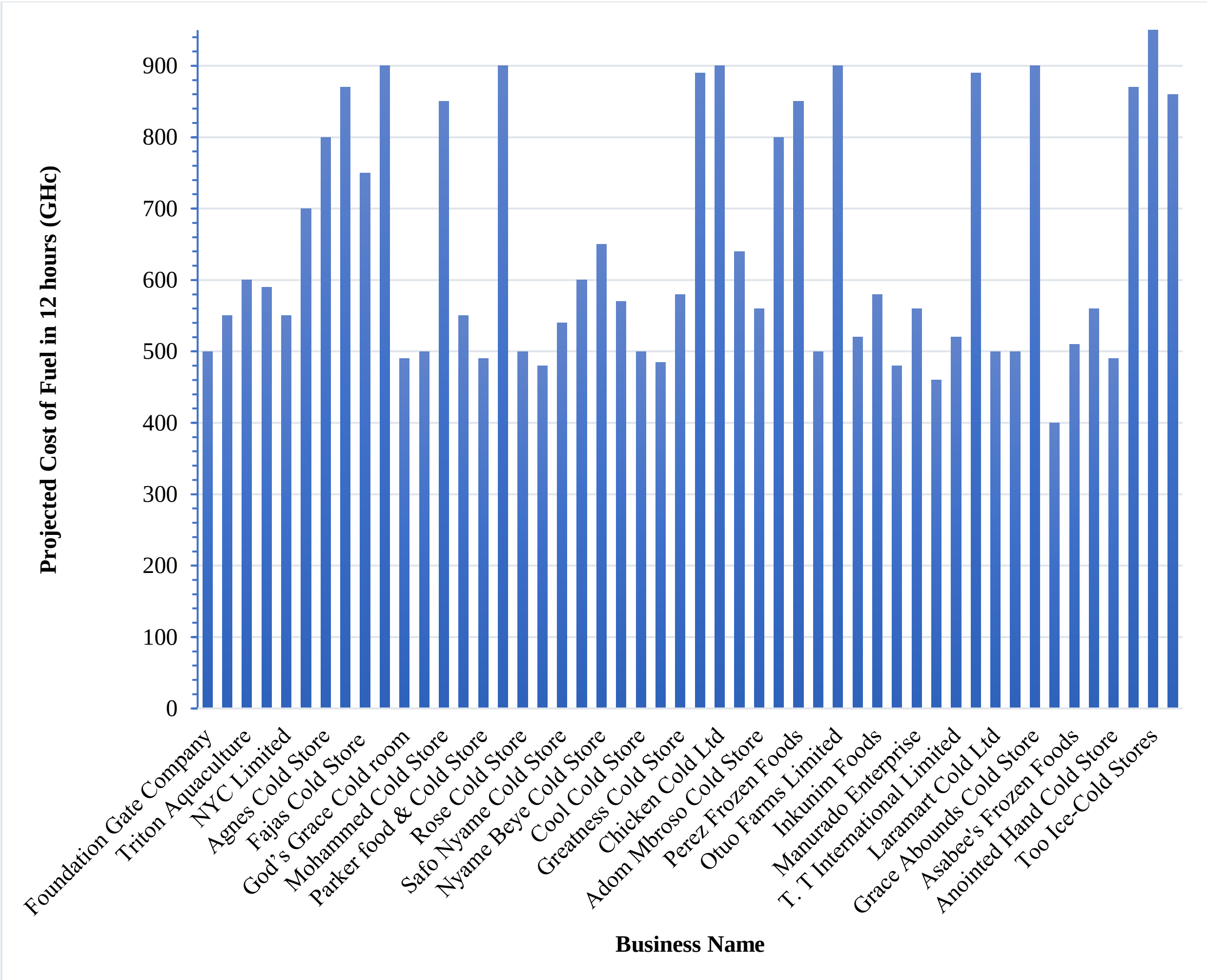
PLT 32 BLK F	28.7	318.57
PLT 33 BLK G	25.8	286.38
PLT 11 BLK Z	32.5	360.75
PLT 45 BLK 12	29.4	326.34
PLT 17 BLK 8	26.8	297.48
PLT 2 BLK 16	26.3	291.93
PLT 13 BLK XX	29.5	327.45
PLT 18 BLK 11	25.8	286.38
TOTAL	**1,418.3**	**18,992.1**

Table above shows the primary data obtained during the energy audit and interview conducted at various businesses around Kumasi in the Ashanti region. Fifty (50) companies were selected for this research. Most of these businesses were already operating as far back as 2010 and therefore have witnessed the effects of 2012 erratic power outages and even today in 2022 though there is great improvement compared with 2012. These businesses deal in beef, mutton, and chicken products. They contribute to the socioeconomic well-being of both the traders and consumers as well as contribute to the country's economic activities. The activities of the businesses are heavily dependent on electricity and therefore several factors come to play.

Below Figure is a plot showing the cost of fuel used for twelve (12) hours from 7 pm to 7 am. Normally, when there is a power outage, the cold room is turned on to operate by the use of an electricity generator throughout the night and switched off in the morning during business hours. Each of these companies has its various generator types and specifications. They have varying wattage of power they produced, the capacity of fuel they take, and the number of cold room machines they have. From the plot, it can be seen that the least cost of fuel use for GH₵ 460 during the 12-hour period. This is for the Foodies Health Court Company with one (1) cold room machines and electricity consumption of 25 kW.

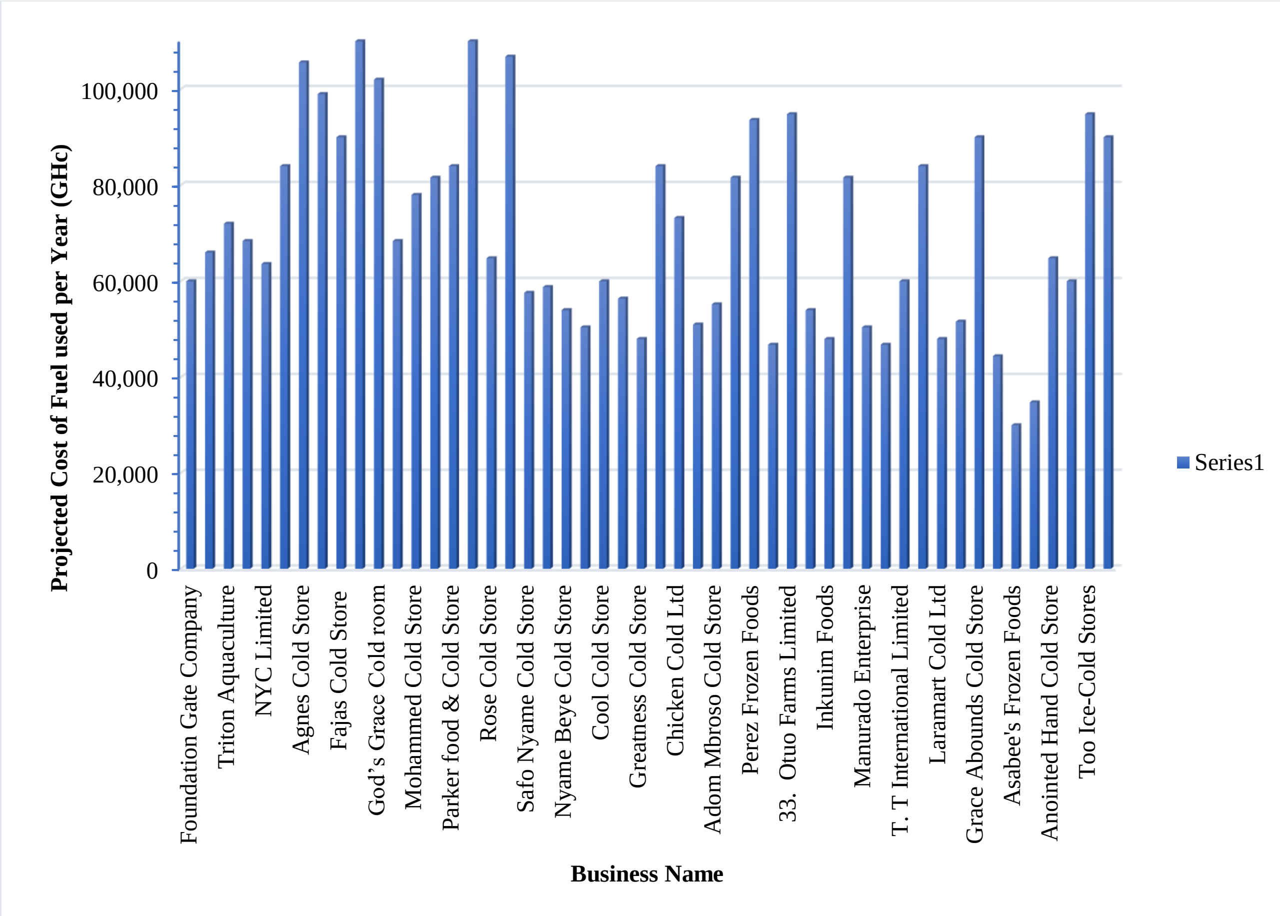
However, the highest cost spent on fuel came from Too Ice-Cold Stores at a sum of GH₵ 950 with two (2) cold room machines and electricity consumption of 15 kW. The next closed ones are Grace Abounds Cold Store which spent c on fuel alone has two (2) cold room machines and electricity consumption of 160 kW. Followed by Ocean Fare Company with fuel cost of GH₵ 900 and which has two (2) cold room machines and electricity consumption of 144 kW. The next company to follow is the Haya Cold Store with GH₵ 900 cost of fuel and has two (2) cold room machines and electricity consumption of 125 kW. Otuo Farms Limited followed next with fuel cost of GH₵ 900, two (2) cold room machines and electricity consumption of 115 kW. And lastly, Chicken Cold Limited came as the last company which spend GH₵ 900 as fuel cost, has two (2) cold room machines and electricity consumption of 95 kW.

The rest of the companies spent between the sum of GH₵ 400 - GH₵ 890 and mostly use one (1) cold room machine and electricity consumption between 35 kW – 80 kW.



Cost of Fuel Used in 12 hours (7pm – 7am)

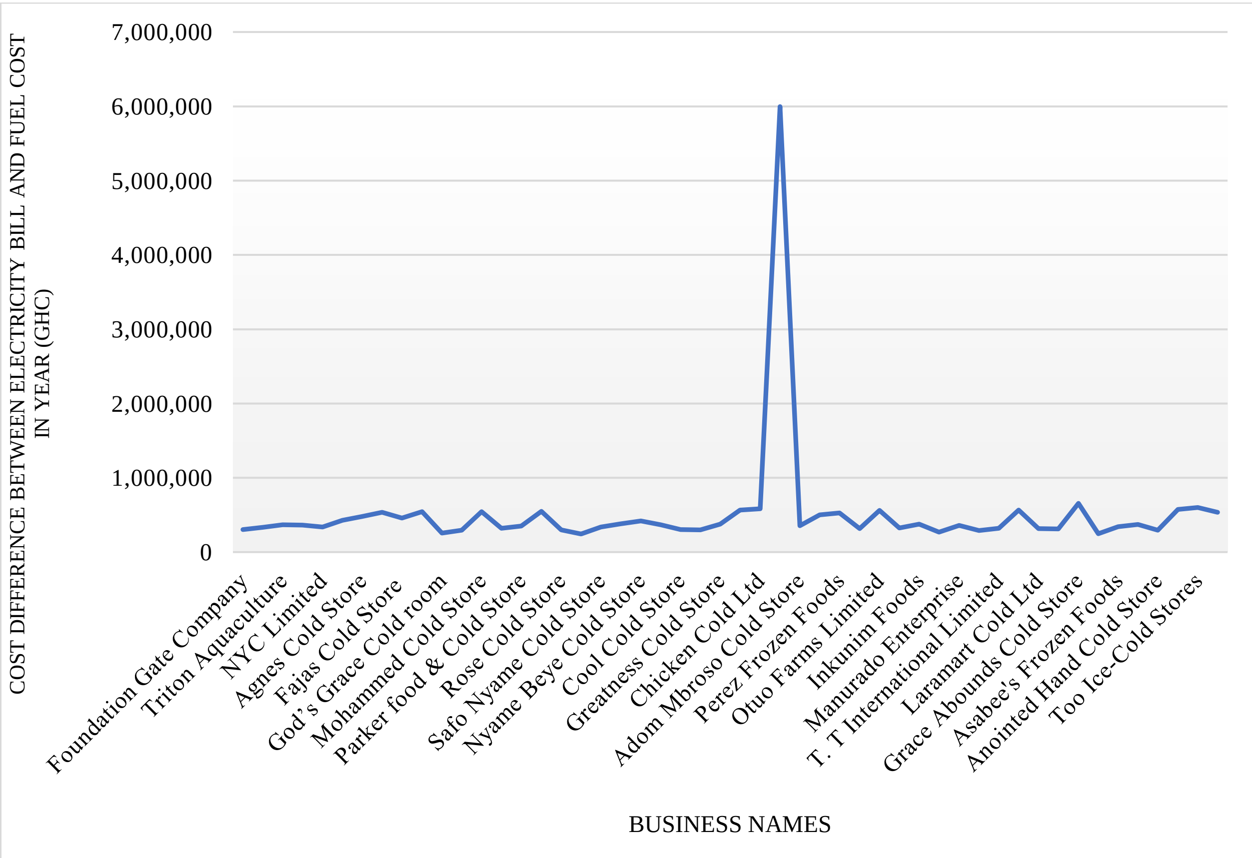
On the other hand, the figure below shows the projected cost of fuel for a year. This is the projected cost of the fuel for the usage of the electricity generator for twelve (12) hours in a year. It can be noticed that the highest projected fuel cost comes with the Too Ice-Cold Stores with a huge yearly cost of GH₵ 693,500. It was then followed by Ocean Fare Company with a fuel cost of GH₵ 543,000. Haya Cold Store follows with the cost of GH₵ 657,000. Otuo Farms Limited projected cost of fuel was recorded as GH₵ 657,000 in a year. Followed by Chicken Cold Limited which will spend GH₵ 657,000 in a year. The rest of the companies will spend between the sum of GH₵ 292,000 - GH₵ 649,700.



Projected cost of fuel for a year

The figure below shows the plot of the cost difference between electricity bill and fuel cost in a year. The results came out with a huge difference to show how expensive it is to run the businesses with only or partly electricity power generator. It is seen that the highest cost difference comes with the power consumption from the electricity power generator. The higher the fuel consumption, the higher the cost difference. Therefore, Grace Abounds Cold Store had a high cost of GH₵657,000 and followed by Forever Cold Store with a cost difference of GH₵599,620, Chicken Cold Ltd with a cost difference of GH₵583,800. The next company is Otuo Farms Limited with a cost difference of GH₵562,200. Haya Cold Store came with a cost difference of GH₵546,000. Ocean Fare Company with a cost difference of GH₵543,000.

It can be concluded that, running a business solely on the use of power generator is quite expensive compared with the use of the national grid. So, if businesses were to use renewable energy technologies in place of power generators and National grid, a huge chunk of this yearly fuel cost and electricity bill would come out as profits.



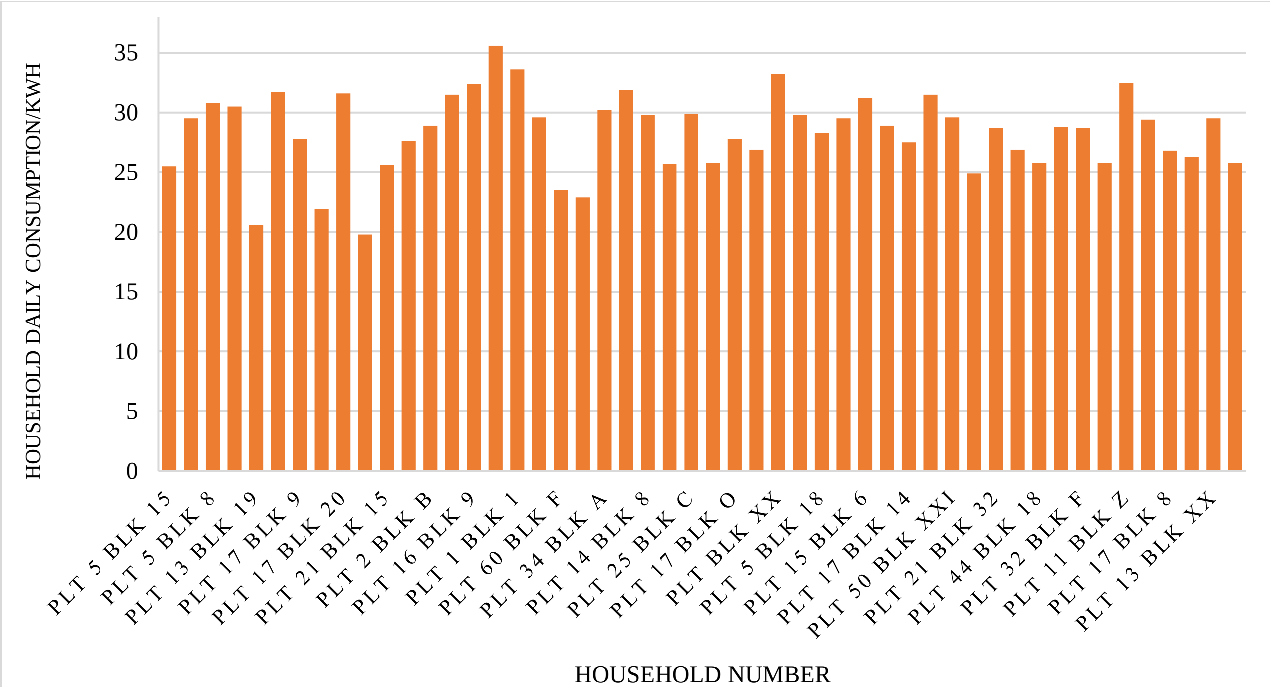
Cost Difference Between Electricity Bill and Fuel Cost in a Year

The current cost of electricity cost in Ghana stands at 0.37 cedis per kilowatt-hour for household use according to the Electricity Company of Ghana. Therefore, all calculation was carried out at this rate. The household energy audit was carried out on fifty (50) households to ascertain the electricity consumption in order to determine the quantity of energy used per day. This quantity is then multiplied by an average of thirty (30) days which makes a month to determine the total electricity cost in a month. Various households use varying electrical equipment and the number of hours used was also noted. This account for the difference in the amount of electricity consumption in the various households.

Figure below shows the daily electricity consumption rate of various households in Kumasi in the Ashanti Region. The energy audit was conducted at these fifty (50) households. Here, the electrical gadgets type, their electricity consumption and their use for a day was computed and their resulting values was recorded. In addition, the house numbers of these households were also recorded. The relationship between electricity consumption and the various households is as shown in the following figure.

The highest consumption was recorded for household PLT 14 BLK B at 35.6 kWh and this is followed by household PLT 1 BLK 1 with a consumption at 33.6 20kWh. Household PLT 12 BLK XX at 33.2 kWh, household PLT 11 BLK Z at 32.5 kWh. The least consumption took place at PLT 16 BLK 9 at 32.4 kWh and followed by consumption of 31.9 kWh which was recorded for the household number PLT 21 BLK C.

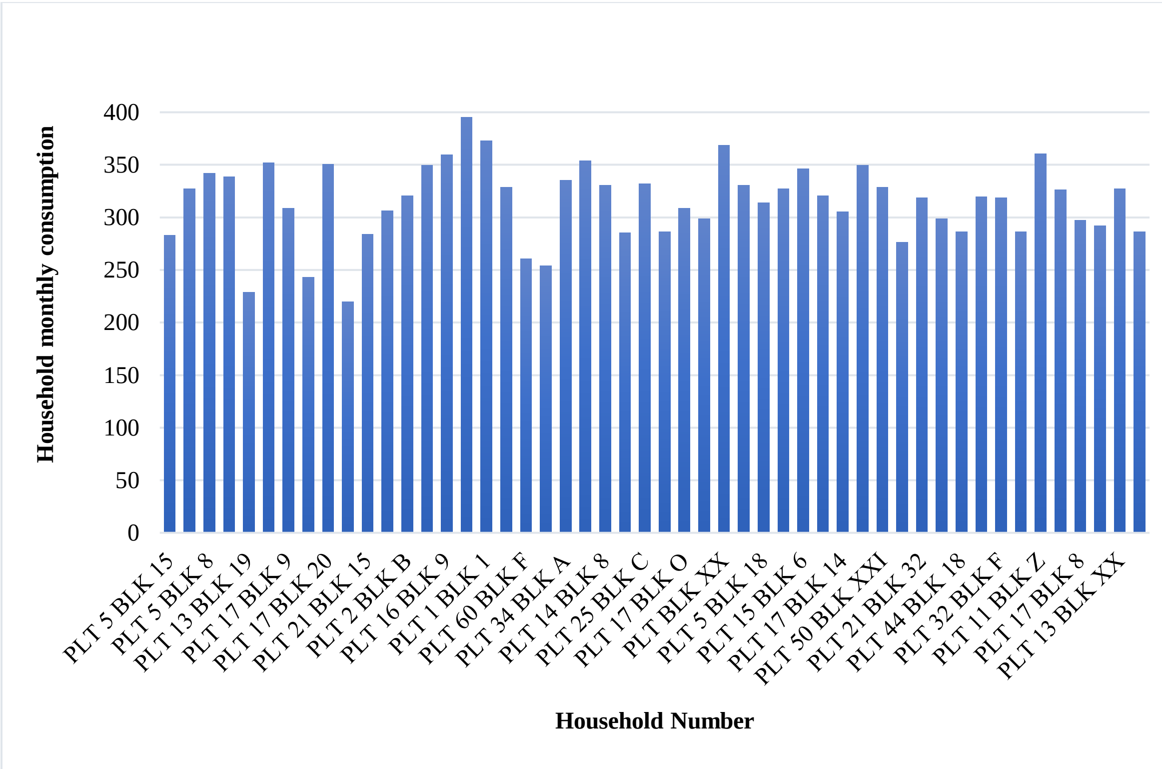
The rest of the household recorded daily consumption between 21.9 kWh to 31.7 kWh.



Daily Electricity Rate for the Households

Figure shows the plot of the monthly cost of electricity for the various households. As stated earlier, the daily electricity use was multiplied to the current cost of electricity which was published in June 2022 Electricity Company of Ghana and again multiplied by 30 to determine the average cost of electricity in a month. Below is the plot showing the house numbers against the monthly electricity cost of the various households. It can be seen that there is a correlation between the household electricity used and the monthly cost of electricity. The higher the electricity used per day, the higher the monthly electricity cost. It can clearly be seen in the plot that PLT 14 BLK B which has a daily consumption rate of 35.6kWh pays an electricity cost of GH₵ 395.16 at the end of the month. The next electricity cost is GH₵ 372.96 for the house of PLT 1 BLK 1. The next household of number PLT 12 BLK XX has GH₵ 368.52 as a monthly electricity cost. The next house to follow is PLT 16 BLK 9 had an electricity cost of GH₵ 360.75. household number PLT

21 BLK C had an electricity consumption cost of GH₵ 354.09. the rest of the households has electricity consumption cost between GH₵ 243.09 - GH₵ 351.87.



Monthly Electricity Cost for the Households