FEASIBILITY OF USING SOLAR PV AND LIGHT EMITTING DIODES (LEDs) FOR STREET-LIGHTS IN GHANA: A CASE STUDY OF WENCHI MUNICIPALITY

By

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A Thesis submitted to the Department of Mechanical Engineering, Kwame Nkrumah University of Science and Technology In partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

College of Engineering

JUNE 2014

DECLARATION

I hereby declare that this submission is my own work towards the Master's Degree in Renewable Energy Technologies and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the University, except where due acknowledgement has been made in the text.

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ABSTRACT

Most of the street lights in Ghana uses high pressure sodium vapor lamps and bulbs running from the national grid to light the street. The streetlight energy consumption in Ghana rose from 31 GWh in 2000 to 274 GWh in 2011 which translate to about $32,880,000 using an end user tariff of $0.12 /kWh. Even though there has been a steady and systematic increase in electricity rates over the years, the current street lighting levy of 0. 5% per unit electricity consumed by customer and government subsidy of 1.7% is not adequate to cover the payment of maintenance and the energy bills due to street lights. The main purpose of this research is to determine the technical possibilities and benefits of using Solar Energy through the combination of photovoltaic cells and Light Emitting Diode (LED) lights to power streetlights in Ghana. The cost involved in purchasing the equipment and maintaining a solar-powered/LED system are linked with the cost of using electricity to run grid connected street lights. The project concentrated on the feasibility of using solar energy to power the lights in the area surrounding Wenchi Municipal Assembly. The findings had to be consistent with merit of converting new areas to independent solar powered lighting and Light Emitting Diode (LED) systems. An economic analysis is also conducted to determine if the project is cost effective.

The project also considered the amount of savings in the form of energy, Greenhouse Gas emission reduction the technology would bring if found to be technically viable.

The research found out that though the initial cost of implementing the solar street light is higher than the traditional street lights, the final result in the long run makes the technology viable. The research considered 300 lamps and concluded that after 25 years of uses, solar street lights additionally makes savings at the end of the design life alongside the savings of energy for the national grid. The project pays for itself at the end of the seventh (7) year. It also saves the environment by preventing 2,312 tons of CO2 that would have been produced by the grid connected street lights.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

The main aim of this project is to determine the feasibility of replacing grid-powered street lights with a system that does not rely on the grid connection. The system adopted will be Solar PV and LED lights. The study was commenced to determine the capabilities of a Solar PV and LED lights and to determine if the long-term saving of electricity warrants the conversion of the grid powered street lights to solar powered street lights.

Lighting remains very important in our daily lives. Lighting has vast advantages ranging from visibility to security purposes. The total amounts of energy used by artificial lighting can substantially be reduced for the same level of output of lighting service if there were less energy excesses emanating from the use of inefficient lighting technologies, a lack of adequate controls, a failure to make better use of natural daylight and wide variations in recommended lighting levels.

The total Primary Energy Demand in the world increased from 5,536 GTOE in 1971 to 10,345 GTOE in 2002, representing an average annual increase of 2%. The average worldwide growth from 2001 to 2004 was 3.7% with the increase from 2003 to 2004 being 4.3% .It is expected to continue to grow over the next 50 years with significant differences (Energy commission, 2013). As the growth rate increases, it is estimated that the worldwide energy consumption may continue to increase at rates between 3% - 5%. The electrical energy sector in Ghana especially in rural areas with coverage of 60% is challenged with access to and reliability of adequate electricity supply. With the increase in economic growth, there is rapid increase in demand whereas the generating capacities do not meet the demand. Furthermore, individual consumers and industries have continually suffered heavily from load-shedding and power outages leading to over investment in backup electricity generators as an alternative supply by households and industries. The rising energy demand requires research into alternative ways of producing electrical energy. For that matter investment in sustainable and clean energy production using renewable technologies has become an important field of research. On the other hand, renewable energy could considerably improve the standard of living in rural areas (Del Rio and Burguillo, 2008).

Energy conservation is becoming a topic of great concern all over the world, especially in metropolitan areas. As cities continue to expand, people are searching for new ways to become more energy efficient and environmentally friendly (Ross, 2008). “Green” technology is rapidly growing in popularity and is being used more frequently in urban areas in order to benefit the environment by conserving energy. One way that some cities are trying to reduce energy consumption is by renovating their street lights.

Over the years, various governments of Ghana have recognized the need for street lights for the various cities and towns and have since commissioned various programs for the deployment of street lights in the country. One of the leading documents which will help this work is the policy framework for street lighting in Ghana. The policy framework states that private-public partnerships, community-based and other private initiatives have been deployed to provide street lighting throughout the country.

The Government of Ghana is therefore embarking on a program of systematic deployment of street lights, with the objective of ensuring adequate security and road safety at night particularly in the Regional, Metropolitan, Municipal and District capitals. The main goal of this framework is to achieve universal access to street lighting infrastructure that is developed, owned, operated and maintained on a sustainable basis and thus, attain public safety, security, beautification and to enhance socio-economic development of the citizenry. Some of the main challenges facing this policy are the Inadequacy of funds for the payment of energy consumed by street lights and for the maintenance of street lights. The existing street lighting levy is not adequate to fund operation and maintenance of street lights. The other challenges are the lack of efficient mechanism for the management of the street lighting fund (levy) and lack of a comprehensive regulatory manual, technical standards and specifications for street lighting (Ministry of Energy 2011). The policy also stated that the most efficient street lighting technology including low energy consuming and remote monitoring technologies shall be used as far as it will be practicable. It made also made it clear that as far as practicable renewable energy lighting technology shall be given high priority. The country has much renewable potential and so it is therefore important to utilize technologies that will make the government spend less on the use of street lights. Low energy consuming devices should be considered in the design of streetlights. Technologies which employ the usage of LED lights should be used so that more energy could be conserved in the energy sector. There are many reasons why the use of LED light is a viable option. LED lights are environmentally friendly because they consume so little energy. It is also free from hazardous chemicals such as mercury and lead. The bulbs are not made with filaments like regular ones but they are rather based with diodes which reduce the toxins released into the air and carbon footprints are reduced as well.

Although renewable energy technologies (RETs) have been in use in Ghana for many years, they have not seen much commercial success (Tse, 2000). Despite the fact that the country has much renewable energy potential, this project will focus on the use of solar as a renewable energy source to supplement the energy obtained from the grid in powering streetlights.

Solar energy is one of the renewable energy technologies which is gaining attention in recent years. PV technology has grown over the past decade at a remarkable rate – even during difficult economic times – and is on the way to becoming a major source of power generation for the world (IEA, 2013).

1.2 Problem Statement

Lighting uses more power globally than is generated by all nuclear- or hydro-power plants, (greater than 2200 TWh/year). Lighting accounts for ~17.5% of global electricity use with the largest share used in commercial and public buildings, followed by residential lighting, industrial sector lighting and outdoor/street lighting. This level of consumption could be substantially reduced for the same level of lighting that would be provided if less energy wastage occurring from the use of inefficient lighting technologies, a lack of adequate controls, a failure to make better use of natural daylight and wide variations in recommended lighting levels are addressed (IEA, undated).

It is estimated that 1.9 billion tons of CO_2 is produced every year. This is equivalent to the emissions from 70% of the world's passenger vehicles (The Climate Group, 2012).

Street lighting is a social facility which is a key indicator of the comparative socio-economic development position of a country. It contributes to improved road safety for pedestrians and drivers alike; it reduces criminal activities in the cities and towns. Streetlights also play an important role in improving the general business and living climate of urban and peri-urban areas.

Due to the lack of appropriate developmental, regulatory and operational framework on street lights in Ghana some streets are not properly lit and if there are, they are mostly off due to insufficient power supply. This has rendered most streets in the cities and towns unattainable of the benefits streetlights bring.

Ghana is looking for a way to diversify its energy system and supply. As part of this diversification, it would be appropriate to investigate if other forms of energy efficiency technology and source of energy (that does not rely on the national grid) can be employed to provide reliable street lighting. The investigations can consider industrial breakthrough in the lighting industries such as Light Emitting Diodes (LEDs) and the use of solar energy which is available in Ghana.

In Ghana lighting takes a lot of energy during the peaks. If streetlights are taken off the grid, power would be saved during the peak hours. If streetlights can be powered by Solar by using energy efficient technologies, it can be taken off the national Grid and provide the needed benefits streets lights provide.

Energy efficiency does not require a compromise in occupant comfort - not at all. Using higher efficiency makes it possible to increase comfort while reducing energy consumption

1.3 Justification

Solar Photovoltaic cells provide clean electrical energy because the solar energy is directly converted into electrical energy without emitting carbon dioxide. Solar energy is not limited, is free of charge and is distributed uniformly. It provides electricity with minimal infrastructural requirements and energy resources making it unique. Though they have high initial cost and long energy payback time, their merits of providing a more stable and sustainable energy as well as provision of clean energy amidst other advantages stimulates the desire for the RET's.

LEDs as light source have many advantages over conventional electric light sources; they have low power requirement, long lifetime, optical control, and operating characteristics (such as coming on and off without affecting the output of the lights).

Using Solar Energy to power streetlights would reduce the pressure on the current generating capacities however small the savings may be. This will limit the frequent load-shedding and its subsequent economic pressures on individual consumers and industries on the need to finding alternative source of energy, as well as reducing the cost incurred in the provision of street lights. Once they are taken off the national grid, it brings immense benefits to the country and the economy as a whole. It means that there will be more power for the other sectors of the economy.

1.4 Objectives

The main objective of this project is to investigate the feasibility of using Solar PV together with energy efficient technologies such as LED to power street lights in Ghana.

1.4.1 Specific objectives

The specific objectives of this project are to;

1. Identify the technical feasibility (power and light sources) of using LED lights in replacing the already existing conventional street lights in Ghana.
2. Identify the technical/financial feasibility of using solar PV together with LED technologies to replace the existing streetlights in Ghana.

1.5 Study Limitations

Even though the research reached its aims, there were some limitations that were unavoidable. Due to the time limit, the research was conducted using the technical parameters of the PV powered streetlights compared to that of the Conventional streetlights and the cost of operation and maintenance. No design was carried out to verify the technical parameters. To obtain a global results and applicability of the system, the research area should be increased and actual designs carried out to verify manufacturers' data.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Background

Energy is one of the basic elements required to alleviate poverty and promote socio-economic development of a country. This is because energy drives all sectors of the economy like food, health, water, environment etc. Equally worthy of notice is the fact that the consumption of the energy resources through anthropogenic activities releases greenhouse gases (GHGs). Carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride have been identified as GHGs released after consumption of energy (IPCC, 2007).

To foster economic growth as well as improve quality of life of families, the Government of Ghana (GoG) recognises the need to diversify the national energy mix to take account of renewables such as hydro, wind, solar PV (NDPC, 2005; Ministry of Energy, 2006; NDPC, 2008). The energy resource for solar energy is the sun. It is free and produces no GHG emission after installation. The energy resource once found must be technically transformed into a useful energy to the benefit of mankind. On the contrary, the solar energy is also affected by certain barrier which ranges from the resource availability, policies to promote it and make it economically attractive by a political will.

2.2 History of Solar Powered streetlights

Earlier studies conducted on solar powered streetlights delivered a high level of understanding of how solar energy is utilized around the world, and how this project fits with the application of solar powered street lighting. The awareness of using solar energy to power a street light started in the 1990’s as a way out to the high cost of operating street lights throughout the year. The design of the early systems incorporated lamps with loads lower than 50W, this was used primarily for lighting paths or walkways. Many of the systems at that time used lamps ranging from low pressure sodium lamp to fluorescent lamp. Notable areas around the world where case studies have been done on the viability of powering street lights with solar energy were carried out in countries/cities where solar insolation amounts were high. Some of the countries/cities include New Mexico, California, Thailand, and Spain.

The Parks and Recreation Department of Albuquerque, New Mexico One of the earliest studies was conducted by (Harrington etal, 1996). The results of the study showed the potential of using solar energy to power street lights. This studies built the groundwork for future designs. Studies conducted in Thailand used a basic photovoltaic system that worked seven hours a day and established how different types of lamps worked 7in the remote villages (Hiranvardom etal, 2003). The lifespan of the bulb, cost, light output in lumens, wattage, and color rendering were the categories that were instrumental in determining the type of light to use. Due to its lower cost and the adequacy of light production, the fluorescent lamp was selected.

2.3 Solar Powered Streetlights in the Future

Solar Street lighting applications in the future is determined by the improvements in equipment effectiveness and the advancement of new technologies. The studies conducted using light emitting diodes (LED) and HPS lamps shows the achievements made towards the application of solar energy to light highways. The newest form of street lighting that shows promise is the use of LEDs. Some research conducted in cities like California and San Diego analysed the application of LED lamps in comparison with the other forms of street lighting and the use of LEDs as a solution to the high cost of running the HPS lights.

With the advancements in equipment and design, the prospect of implementing solar powered street lighting is improving. The idea of cost and reliability of powering solar streetlights will influenced the switch from grid powered streetlights. When a design or system can pay for itself within a shorter period of time it becomes attractive.

2.4 The Solar Energy Resource

The sun is the source of the solar energy resource. The energy of all the other renewables is also obtained from the sun. It can be directly or indirectly converted into other forms of energy. Solar energy is very useful and can be adopted in many applications such as electricity, evaporation, utilization in plants for growth, heating of water and buildings.

The solar energy is harnessed by the utilisation of a solar photovoltaic device or solar concentrating thermal technologies. The former is used to convert the energy resource into electrical energy whiles the latter converts the resource into heat energy.

The general problems associated with solar energy are; the small thickness of energetic flow, huge oscillation of radiation intensity, large investments costs and the fact that solar energy can't be easily exploited in all areas. Solar energy is still a very tiny fraction on global world energy market due to the above reasons (Habjanec, 2008). Policies to ensure the reduction in the unit costs of solar PV have yielded solar energy's growth rates on the back of clean energy accepted by all and sundry. It is a well-known fact that once the solar PV device is installed, it has almost no variable costs. The fact that it is not exposed to market price fluctuations gives credence that there's no forward exchange rate risk. It is considered to be very reliable source of energy and thus, should play a more effective role in meeting the electricity needs of the world.

Solar energy could generate about 2.5% of the world's electricity by 2025 if properly harnessed (Asia, 2009). Asia (2009) argues that it has a very tremendous potential because for instance, the energy acquired from all of the world's reserves of coal, oil and natural gas can be matched by just 20 days' supply of continuous sunshine. From the current availability levels of the solar resource and favourable worldwide government policies such as the feed in tariff, it is expected to outgrow the other sources of energy. Feed-in tariffs allows individual owner of the solar PV module to sell excess electricity produced to the national grid for financial returns.

Ghana is endowed with the solar resource in abundance. All the available ten regions receive sunshine throughout the year. The regional map details the distribution of the energy resource in the ten jurisdictional regions of the country.

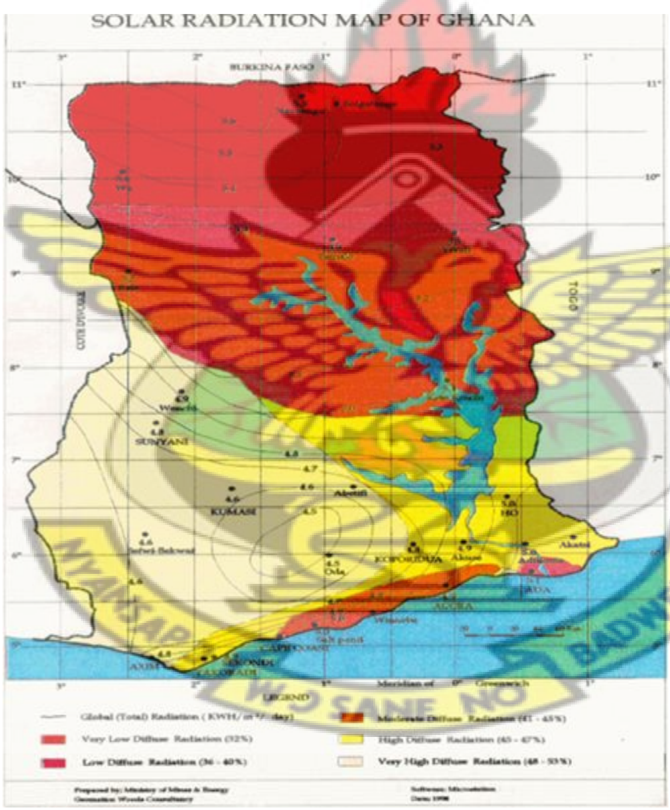


Figure 1: Solar Radiation Map of Ghana (Source; Energy Commission - Ghana, 2003)

With the available energy resource distribution, it remains imperative that this energy resource can be tapped to power lighting systems including street lights. The current available streetlights in Ghana are faced with so many challenges. Most of them have become white elephants because they do not function in dark hours due to the non-availability of electrical power to light them up when really needed The availability levels in the ten regions presents an opportunity to use the energy resource to power street lights in Ghana.

2.5 Harnessing Solar Energy Resource into final Energy

The Solar energy is harnessed into electric energy by the use of a PV module system The system consists of a PV module, battery, battery control unit/ charge controller, DC – AC inverter (where applicable) and a load (appliance). This is presented in Figure 2.

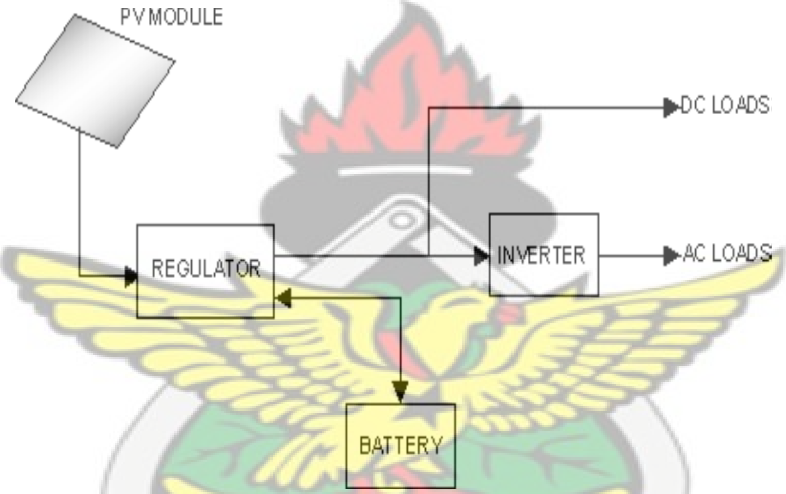


Figure 2: Typical Solar PV connections

2.6 Solar PV Design

A solar panel is made up of a semiconductor material that converts the light into energy through the use of a silicon composite pn junction. When light hits any material, the energy is reflected, transmitted, or absorbed. In designing or sizing of a solar PV system, the under listed are to be determined:

The System Voltage: to obtain the system voltage, you will have to determine all the appliances that will be powered by the system as well as the time usage. In the research, the streetlight will be on from 6pm to 6am. There are standards that determines the voltage of the

PV system based on the power consumption of the device and its efficiency. Table 1 below gives the recommended values.

Power installed (kW)	0 - 0.5	0.5 - 2	02-10	>10
Voltage recommended (V)	12	24	48	>48

Table 1: Power Installed vs Recommended Voltage

The Daily Energy Demand: to properly design the PV system the total energy demand of the system should be established. The energy demand is calculated by using the equation below

$$E_{tot}\ (Wh) = P(W) \times t(h)$$------ Equation 1

$$E_{tot} = total\ energy\ demand\ of\ the\ system$$

$$P(W) = Total\ power\ requirement$$

$$t(h) = Total\ time\ usage\ of\ appliance$$

The energy obtained is multiplied by an oversize coefficient of values from1.1 to 1.2. The coefficient corrects the errors that will be obtained during the energy estimation.

Battery Bank Sizing: the size of the battery bank to use depends on the determination of the under listed parameters:

- Daily energy consumption demand E_{tot} (Wh)
- Battery efficient B_{eff}: typically 75% to 95%
- Battery nominal voltage VBB (12V, 24V, 48V etc.)
- Depth of discharge (DOD): 20% to 30% for cars ‘batteries and 50% to 80% to solar batteries
- Number of days of autonomy Taut: 1 to 5 days depending on the system

After the above parameters are obtained, the size of the battery is evaluated with the formula below

$$Cbb = \frac{Etot \times Taut}{Vbb \times Beff \times DOD}$$ ---------- Equation 2

Solar Resource Estimation: The monthly average solar radiation (kWh/m²/day) in the horizontal plan and in the plan of the modules is determined from software and published data. In this case the worst month of solar radiation will be taken as a reference for the PV modules sizing.

Photovoltaic array sizing: this is the final stage of the design where the number of PV cell is determined. The equation below shows the sizing of PV arrays.

$$P_v = \frac{E_{tot}\ (\frac{Wh}{d})}{SPH\left(\frac{h}{d}\right) \times B_{eff} \times PV_{der}}$$ -------- Equation 3

Where:

- Etot: Daily total energy demand (Wh/d)
- SPH: Solar Peak Hour (h/d). We can also use H which is solar radiation (Wh/m²/d).
- Beff: Battery efficiency (%)
- PVder : PV Derating factor (%) which takes in account:
- Tolerances, temperature, or aging
- Module mismatches, dirt, shading
- Losses due to wiring, blocking diodes, connectors
- Efficiency of the charge controller
- Typical η = 80%.

2.7 Street Lighting

A streetlight is a raised source of light on the edge of roads designed to turn on at a certain time each night. A major task of street lighting is to increase safety for motorists and pedestrians, particularly at intersections where pedestrians may be. Lighting in the night provides psychological comfort for society's more vulnerable members. When designed properly, lighting can be an effective tool in promoting outdoor safety. The milestones for street lighting in general are presented hereafter:

Due to the immense role streetlights play in bringing security to drivers and pedestrians, the development of streetlights begun in the 9th Century with Kerosene lamps to High Pressure Sodium lights in the 20th Century to the more advanced and efficient technologies like the light emitting diodes.

Most street lights in the recent past are of the conventional nature. According to (Chang et al., 2010) "conventional streetlight usually adopts high-brightness and high-power light emitting elements to achieve high brightness, and the heat is dissipated by the casing of the streetlight. A conventional street light consists generally of a light bulb which is enclosed by a glass or plastic cover.

Conventional street lighting is estimated to account on a global scale for around 159 TWh of electricity use per year. A reduction of consumption by 50% would globally eliminate around 80 TWH of electricity consumption and avoid around 40 MtCO2 per year (CCI 2010). The share of street lights, of the electricity bills can vary between 5% to up to 60%, mainly depending on variables, such as the size of the city and its municipal services as well as the efficiency of its street lights (CCI 2010, REEP 2009). It is for this reason that the need to adopt the use of solar energy to power streetlights remains an attractive venture.

Solar Street Lights were initially used mainly in Third World countries, in remote areas or where electricity is not always available or supply is unreliable. Today's solar technology has evolved and solar projects are appearing in developed as well as developing countries. Solar panels have recently been developed to be installed on street lights of various sizes and wattages. Solar streetlights are photovoltaic powered panels generally mounted on the lighting structure that contribute to ensuring safety in the night. Most have light detectors which inform them of how bright it is outdoors so there is no need to worry about turning them on or off because they will turn on at dusk and off at dawn automatically (Solar home, 2010).

2.6Technical Parameters for Street lighting Technologies

Lighting is an essential requirement for all industrial use and residential use. Innovations and continuous improvement in the field of lighting, has given rise to tremendous energy saving opportunities in this area. Lighting systems are designed to minimize life-cycle cost at the same time meeting the intended lighting requirements (providing the least minimum illuminance requirements to ensure proper functioning and safety of users). To obtain an effective energy-efficient design, it is prudent to select the proper lamp and ballast combination that generates high lumens per watt and a fixture that meet design requirements and minimize glare, light trespass, and light pollution.

Components of lighting systems are basically grouped under:

- structural systems,
- electrical systems,
- optical systems

Lamp Technology

The source of light is the most important feature of an illumination system. The light source determines visual quality, cost, and energy efficiency aspects of an illumination system. An electric light source is a device that transforms electrical energy, or power (in watts), into visible electromagnetic radiation, or light (lumens). The rate of converting electrical energy into visible light is called "luminous efficacy" and is measured in lumens per watt.

Table 2: Properties of some Light sources

Type of Lamp	Luminous Efficacy (lm/W)	Color Rendering Properties	Lamp life in hrs	Remarks
High Pressure Mercury Vapor (MV)	35-65 lm/W	Fair	10,000-15,000	High energy use, poor lamp life
Metal Halide (MH)	70-130 lm/W	Excellent	8,000-12,000	High luminous efficacy, poor lamp life
High Pressure Sodium Vapor (HPSV)	50-150 lm/W	Fair	15,000-24,000	Energy-efficient, poor color rendering
Low Pressure Sodium Vapor	100-190 lm/W	Very Poor	18,000-24,000	Energy-efficient, very poor color rendering
Low Pressure Mercury Fluorescent Tubular Lamp (T12 &T8)	30-90 lm/W	Good	5,000-10,000	Poor lamp life, medium energy use, only available in low wattages
Energy-efficient Fluorescent Tubular Lamp (T5)	100-120 lm/W	Very Good	15,000-20,000	Energy-efficient, long lamp life, only available in low wattages
Light Emitting Diode (LED)	70-160 lm/W	Good	40,000-90,000	High energy savings, low maintenance, long life, no mercury. High investment cost, nascent technology

Source: Pacific Gas and Electric Company, 2008

Table 2 shows the properties of some light sources including LEDs. An LED lamp (or LED light bulb) is a solid-state lamp that uses light-emitting diodes (LEDs) as the source of light. LED lamps offer long service life and high energy efficiency, but initial costs are higher than those of fluorescent and incandescent lamps. Chemical decomposition of LED chips reduces luminous flux over life cycle as with conventional lamps (Wikipedia, LED Lamp). LEDs use less power (watts) per unit of light generated (lumens). LEDs differ from the traditional lamps in terms of thermal, optical power and control mechanism.

Authors like (Wu et. al, 2008) have recommended the use of solar PV systems with light emitting diode. They argue that the higher optical efficacies of LED and its energy saving potentials make it economically viable to combine the solar PVs and LED lambs. The Climate Group, 2012) outlined the benefits of LED lights as applied to outdoor use. They concluded that LED saves between 50%-70% energy when compared to conventional lights. The group also concluded that that the efficiency of LED lights has increased by a factor of 10 since 2000. The Climate Group also cited initial cost and awareness of the LED capabilities as the barriers to the use of LEDs.

In Solar LED Lighting, solar energy is used to charge a self-contained battery during daylight; at night, the battery powers the street lights. Solar LED street lighting is an especially cost-effective solution for parking lots, parks, residential streets, airports, and other applications where providing electricity is expensive or problematic. Two additional benefits of these types of LEDs is ease of installation - since the lamps rely on solar power, there is no need to dig trenches to lay underground cables - and immunity to power outages. (Silverman, Jacob 2009; Armand Hadife n.d.)

2.7 Streetlights in Ghana

Street light in Ghana serves the same purpose enumerated in earlier sections. The stakeholders in the road categorisation in Ghana (Ministry of Road and Transport) have grouped the available streets into ceremonial and residential road. The ceremonial road which consists of roads and truck roads serves as highways linking different cities and towns together. These roads receive a lot of traffic with high speeds. Such streets are lit with 400 Watts lamps. The converse of the ceremonial road is the residential roads which are also lit with a 250 Watts lights. The streetlights either adopt a single or a twin lamp. Single lamps are used for single carriage roads and the twin lamps are normally installed on dual carriage roads within the road medians.

Street lighting is a major preoccupation for most public authorities in the developing world because of its strategic importance to the economy and also to social stability. The heavy investments required of this sector are a major limiting force since the weak economies of developing nations cannot bear the burden of these investments. According to experts, over 30% of all energy used by cities is used in street lighting (Jones, 2010). Recent technologies can help cut public lighting costs by 30% to 60% while enhancing lighting quality and reducing environmental impacts (ibid).

The use of renewable energy (RE) and energy efficiency (EE) measures in Public Street lighting present opportunities to reduce energy demand, to gain possible financial savings from reduced electricity use and to reduce related GHG emissions. Many options exist for local governments to explore, such as:

- Energy conservation and efficiency (i.e., reducing operation hours, the number of lights and power);
- Stand-alone photovoltaic (PV) powered lighting;
- Grid-interactive PV-powered lighting; (IRENA, 2012).

The possibility of harnessing the solar radiation to power streetlight is very viable since most part of Ghana receive sunshine throughout the year. If solar streetlights are installed the amount of GHG emission estimated yearly in Ghana as a result of street lighting would be avoided.

2.8 Technical Requirements of Street lighting

Technical requirement for streetlights for this research was taken from British Standard (BS) 5489- 1(code of practice for the design of road lighting) published in 2003, BS EN 13201-1-4 published in 2003 and American Association of State Highway and Transportation

Organisation (AASHTO) GL- 6 Roadway Lighting Design Guide. These standard outlines the parameters to consider when design a lighting system for a road way taking into consideration vehicular and pedestrian requirements. The standards stipulates that in design a streetlight the under listed conditions will have to be met:

Visual Task: the lighting system will have to be design such that the driver of a vehicle will be able to view the road ahead and the surrounding.

Visual Guidance: the lighting system design should give guidance by revealing the road corridor particularly at T-junctions.

Lighting of surrounding and footpaths: the lighting system should be designed that objects in the carriageway or footpaths will be seen by the driver.

Appearance, environmental aspect and hour of operation: the lighting system should be designed taking into consideration the environment effect such as buildings, trees etc. and the night operation. The most important factor under this requirement is the Colour Rendering Index (CRI) of the lamp and the correlated Colour Temperature (CCT). CRI is a quantitative measure of the ability of a light source to reproduce the colours of various objects faithfully in comparison with an ideal or natural light source. The colour rendering for urban and residential areas should be greater than 20. CCT is the temperature of the Planckian radiator whose perceived color most closely resembles that of a given stimulus at the same brightness and under specified viewing conditions.

Table 3: Lamp Colour appearance group

Colour appearance	Correlated Colour Temperature, T_{cp} (Kelvin)
Warm	>3,300
Intermediate	3,300 to 5,300
Cool	<5,300

Source BS 5489-1

Table 3 gives the recommended colour temperature with respect to the colour rendering index for urban roads. Any lighting fixture designed for a roadway should fall within the standard above.

2.9The use of LED in Street lighting

The benefits of LED compared to the other forms of light fixtures have been outlined in the text above. As was shown in the above standards the design of street lighting systems the colour rendering index and the correlated colour temperature of the fixture is paramount in determining its effectiveness for use in street lights.

The Department of Transportation in New Hemisphere United States in 2010 conducted test to determine the efficacies of LED light usages in their streets. The test compared measured illuminance data from the recent installation of LED outdoor luminaires at sites in which existing 70W HPS luminaires were replaced with new LED luminaires. The test considered the CRI and the correlated colour temperature. The Solid State street lighting consortium under the United States Department of Energy states that for an LED to be viable for use in a street light system, the CRI should be more than 60. The table below shows the results of their findings.

Table 4: Photometric Values of Outdoor Luminaires

	150WHPS	150W MH	LED
Luminaire system(Watt)	183W	167W	153W
CCT	2000K	3000K	6000K
CRI	22	80	75
Initial Rated Lamp Lumens	24000	11900	35000+

The results indicate that values obtained by the LED light fixtures meet the standards that was outlined in table 3. The test also revealed that LED's consume less power than the other source of lighting fixtures.

2.10 Feasibility of solar PV usage in Ghana

According to the Energy commission, Ghana (2009), "Over 4,500 solar systems have been installed in over 89 communities throughout Ghana. These systems include: Solar Home System for basic house lighting, radio and TV operation; Solar Hospital System for vaccine refrigeration and lighting; Solar School System for classroom lighting and television for Presidential Special Initiative on distance education; Solar Streetlight System for lighting general meeting points, such as markets, lorry stations, water supply points and important busy paths/roads requiring visibility; Solar Water Pumping System for the provision of water and irrigation; Solar Battery Charging System for charging automotive batteries for operating TV and radios in rural communities; Solar System for communication and centralized solar system for providing AC power into the grid. Three grid connected solar panels have been deployed at Energy Commission (4.25 kW), Ministry of Energy (50.0 kW) and Kwame Nkrumah University of Science and Technology (4.25kW). In all, the total installed capacity of solar PV is about 1.0 MW and generates approximately 1.8GWh of electricity per annum."

Table 4: Solar PV Installations in Ghana

SOLAR PV SYSTEMS	INSTALLED CAPACITY	GENERATION
Rural home system	450	0.70 – 0.90
Urban home system	20	0.05 – 0.06
School system	15	0.01 – 0,02
System for lighting health centres	6	0.01 - 0.10
Vaccine refrigeration	42	0.08 – 0,09
Water pumping	120	0,24 – 0.25
Telecommunication	100	0.10 – 0.20
Battery charging system	10	0.01 – 0.02
Grid connected system	60	0.10 – 0.12
Solar streetlights	10	0.04 – 0.06
TOTAL	853	1.34 – 1.82

Source: Energy Commission, 2013

2.11 Cost–benefit analysis PV systems

The three major components of the life-cycle cost of PV systems are capital investment cost, maintenance cost and decommissioning cost. The cost of decommissioning comprises of the net sum of dismantling and disposing the systems, and the potential worth of the recyclable aluminium frames. This is estimated to be 2% of the capital investment and can be safely neglected (Kannan et al., 2006). The cost of maintenance involves that of cleaning and other minor costs, which comprises 2% of the total life-cycle cost and can also be neglected according to (Ha Pham et al., 2008). The capital investment cost, which is the main cost of PV systems installation, is usually calculated as the sum of the cost of the PV modules and the Balance-of-System (BoS) cost that includes all other upfront costs such as the cost of the mounting structure, wiring, inverter and the cost of installation.

Lee et al. (2013) stated that, "in estimating the cost of PV systems, the annualised life-cycle cost which is the cost per year of owning and operating an asset over its entire lifespan provides a finer estimate of the actual cost than the simple payback calculation". The annualised cost of the investment (I_A)

$$I_A = \frac{I}{((1+r)^n - 1)/(r.(1+r)^n)} \text{ ------- Equation 4}$$

Where r is the real discount rate which is the rate adjusted to eliminate the effects of expected inflation and used to discount constant year benefits and costs, n the number of years of the life cycle based on the initial capital investment.

Lee et al. (2013) stated that, "the annual PV-related cost C is the sum of the annualised investment of PV systems and the net energy cost $\sum C_E$, which is the annual sum of the hourly cost of electricity minus any possible earnings from the feed-in tariff and any incentives (for own consumption scheme)."

$$C = I_A + \sum C_E \text{ ------- Equation 5}$$

Based on their observations, Lee et al. (2013) concluded that "an hour-by-hour energy performance simulation is necessary to provide the information to conduct the cost–benefit analysis for decision-makers to assess the economic viability of the deployment of PV systems

2.12 Performance of some solar street lighting projects

A survey was conducted by Ismail et al., 2012 to embark on performance assessments of installed Solar PV system in Oke-Agunla, Akure local government of Ondo State in Nigeria. There were visits to the village and the equipment on ground was examined while the people were interviewed. Both functional and non-functional facilities were traced to their manufacturers using the identification data on them and rated to ensure their efficiencies. Energy demands were also prorated, and observed the need to improve on the present energy supplied. Results of the assessments showed that PV facilities used were inadequate, trained technicians were not available giving room for quacks working on the facilities occasionally resulted in further complications and poor facilities maintenance. The assessment result showed that just 14.52% of the 4.5 kW installed solar PV was utilized due to significant malfunctioning and deterioration in performance. It was later concluded from this study that the installed solar PV systems were inefficient as a result of poor maintenance, lack of technical know-how and inability of the project contractors or managers to take these factors into consideration while embarking on the solar PV installations."

2.13 The role of LEDs in street lighting

Because of their advantages as compared to the other conventional light sources, majority of the off-grid lighting manufacturers are designing and producing their products with LED technology (van Eekhout, Undated). Some notable advantages of the LEDs are their energy efficiencies and their longer lifetime (Khan and Abas, 2011; Muller and Kamins, 2003).Most LEDs have efficiencies which ranges from 50 to 140 lumen/W (Gaur and Thakur, 2010). Some other good attributes of LED technologies are that they have better lighting at lower costs. LED lights also have an improved quality of life, income and health. They also have reduced Greenhouse emissions and reduced fire hazards.

All these advantages will be of an immense contribution to the reduction of electricity tariffs and the reduction in the health hazards associated with the use of the sources of lights. When this technology is fused into our lighting system, it will reduce the cost involved in the repair and maintenance of our street lights; hence it will make room for improved lighting system in the country. The reduction of greenhouse gases produced by these lights will help against climate change,

2.14 Some solar street lighting projects in Ghana.

Solar Streetlight System for lighting general meeting points, such as markets, lorry stations, water supply points and important busy paths/roads requiring visibility is important in the usage clean energy in the country. The Energy Commission in 2009 reported that "the Ministry of Energy financed the installation of 46 solar street lights to determine the feasibility of the replacement of the conventional street lights at the following places: (i) the University of Ghana, Legon, (ii) the University of Cape Coast, Cape Coast and (iii) the Army Recruit Training School, Shai Hills. It was realized that project established that in the short to medium terms the feasibility for the widespread deployment of solar street lights to replace conventional street lights on the country's roads is not favorable. It however concluded that some essential sectors such as military installations, police check points, custom's outposts where they could be installed for security considerations".

Figure 3: Solar Streets on Road from American House to UPS roundabout (Otinshi-Accra)

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Introduction

The main purpose of street lighting is to provide security for towns and cities and also provide an improvement in the visibility of driving vehicles. The investment involved in the provision of street lighting has become a huge drain for most districts the world over. The cost involved in energizing streetlights represents the single biggest component. The application of LED lamps reduces power usage without reducing the luminous efficacy and provided energy efficiency, thus reducing overall electricity consumption for street lighting and helping to lower power costs significantly. The combined utilization of LED lamps and solar PV for street lighting has and added advantage of reducing the annual costs in the provision of street lighting services. Solar PV implemented with LED lamps for street lighting increases electricity services as it makes available electricity consumption of grid connected street lights for other use.

The research will establish the technical feasibility of solar PV used together with LED lamps for street lighting in Ghana. This research will pave way as capacity building tool for the use of energy efficient lighting technology and renewable energies for street lighting services in Ghana.

The research carried out the energy saving analysis of street lighting systems using conventional sodium lamps and the high-power LED Street Lights. The economic feasibility of the solar-powered street lighting using high-power LED luminaires (80W) for 2.5 km highway was studied. Economic comparison of street lighting design of LED Solar Powered Street Lights, and conventional sodium lamps was carried out.

3.2 Case Study Area

The site for the study is Wenchi in the Wenchi Municipality of the Brong Ahafo Region of Ghana. This site was selected because of convenience and also for data availability. The Wenchi Municipality is located in the Western part of Brong Ahafo Region of Ghana. It is situated at the northeast of Sunyani (Regional Capital). It lies within latitudes 7º 30' south and 7º 15' North and longitudes 2º 17' West and 1º 55' East. In terms of land size, the Municipality covers 1,296.6 Square kilometres (Curtis, 2012). It is the largest of the 22 districts in the Brong Ahafo Region and with the support of the Ghana Statistical Services; the Municipal Assembly estimated a population of 102,175 people for the year 2010 and projects a population of 113,684 for 2013 (Wenchi Municipal Assembly, 2012).

Notable towns in the Municipality are; Wenchi (Capital), Awisa, Akrobi, Awoase, Tromeso and Amponsakrom, Nchiraa, Asuogya, Nsawkaw, Badu, Subinso and Subinso No. 2. Wenchi, the Municipal capital is about 29km from Techiman and 56km from Sunyani.

The temperature in Wenchi is generally high with an average mean of about 26.1ºC. Average maximum temperature is 30.9 ºC and the average minimum of 21.2 ºC (Agyei, 2006). February, March and April are the hottest months. Studies conducted by the Energy Commission (2003) revealed that, Wenchi has an average solar irradiance of about 5.017 kWh/m2- day. The electricity coverage is about 62.53% for Brong Ahafo Region (Ministry of Energy, 2010) thus; there are still some communities without electricity. Street lights in the Municipality are not at its optimum and the Municipality seeks to rehabilitate non-functioning street lights in the major towns and rural communities.

The Wenchi Municipal Assembly currently has about 320 streetlights made up of two different lamp types (Wenchi Municipal Assembly, 2013). The power consumptions of streetlights vary from 250W to 400W. The 400W lamps are used for the main (ceremonial streets) and the 250W for residential streets.

It costs the Municipal about GHS15, 000 quarterly for the maintenance (replacement of lamps, damaged poles and stolen cables) of streetlights (Wenchi Municipal Engineer, 2013). The costs due to the usage of electricity by streetlight were not readily available.

The study area, Wenchi Municipal Assembly currently has about three hundred and twenty (320) installed and functioning double lamp street lights using 858,480kWh/yr. of electricity (Municipal Engineer, Wenchi). There are more neighbourhoods in the municipality without streetlights than there are with streetlights and the number of potential solar street lighting opportunities is in the hundreds. Majority of these streetlights have been installed on the 2.5Km ceremonial road from the Wenchi Methodist Senior High to the defunct British Tobacco yard. About one hundred and twenty (120) double lamp streetlights have been installed on the stretch.

Figure 4: A View of the Street in Wenchi

All the streetlights use High Pressure Sodium (HPS) lamps with wattages ranging between 250W- 400W. Since the ceremonial road contains the highest number of streetlights located on a straight stretch, the analysis will be carried out using this stretch of road. The analysis would be carried out to consist of the cost involved in installing, operating and maintaining a new conventional streetlight using HPS lamp and cost involved in the installation of solar powered streetlight.

A discussion with the Area Manager of NEDCo indicated that two roads that qualify for street lights are the Ceremonial and Residential Road. He defined the ceremonial roads as the main roads that lead to and from the Municipality and residential roads as roads that lead to the various neighbours of the Municipality. Ceremonial roads require 400 Watts illumination whiles a Residential road requires a 200 Watts illumination.

Observations from a reconnaissance survey of the municipality presented the Wenchi High Street as the possible stretch to meet the study sample stretch.

3.3Methodology

3.3.1 Technical Details and Components

The solar powered street lighting system consists of independent installations where the energy is produced on the spot. They are self-generating stations of energy which guarantees the supply of electric power that is independent from the power grid. The principal components are:

- Solar panel
- Light source: LED lamp.
- Battery Controller: with current limitation functions for saving more energy
- Pole: 8 to 15 meters high and 4 millimetre in diameter, composed of a galvanized steel frame with powder anti-corrosion coating.
- Accessories: all necessary cables, (cable joined) and screw bolts, packing

There are about 120 twin HPS lamps installed on the ceremonial roads of the selected case studies which are spaced at a distance of 20 meters. The lamp pole height is 8m.

3.4.2 PV and battery Sizing

- To size the solar PV panel and battery, the following is assumed
- Hours of operations per day: 12 hours from 6pm – 6am hours daily
- Assumed days of autonomy: 3 days
- Battery voltage level: 12 V
- Array inclination: 15 degrees

Using an 80-watt LED lamp powered by a solar PV will require an average daily energy 0.480 kWh.

3.4.3 Factors adopted in establishing the feasibility of street lighting systems.

A comparison of the conventional grid connected streetlight and solar power streetlight is carried out to draw most importantly the economic benefits as well as the social and environmental benefits. The analysis focuses on the basic components of the two systems for twenty (20) years of use. The main components of expenditure for the road lighting are:

- The cost of procuring products,
- The cost of installation of components like transformers and cables,
- The energy consumption cost
- Operating and Maintenance costs.

3.4.4 Conventional Street light investment cost

Table 5: Conventional Streetlight Investment Cost: source Bui Power Authority streetlight construction, 2013

Component	Quantity	Cost $	Total Cost $
400 Watts (W) High Pressure Sodium Lamps	240	200	48,000
Light Pole	120	200	24,000
Transformer	1	5000	5,000
Cable	3	3000	9,000
Labour cost	120	200	24,000
Installation Cost	120	200	24,000

Miscellaneous Cost	120	500	60,000
Initial Investment Cost			**194,000**

Electricity Consumption:

The total electricity consumption by a conventional street light is estimated by using the formula: $\boldsymbol{Econ = U \times v \times t}$ ----- Equation 6

E_{con} = amount of electricity consumed

U = number of units

v = lamp rated power and

t = total working hours

The lights operates between the hours of 6:00 p.m. to 6:00 a.m. giving a total number of hours run as 12hrs. Using the cost of electricity consumption in kWh as 0.12USD. Using 400w HPS lamps for the street lamp, the electricity consumption per pole per day will 9.6kWh and the cost of electricity will be USD 1.152 per day. The electricity consumption and cost for all the light poles will be 1,152kWh and USD 138.240 per day respectively. The total cost of electricity in one year (365 days) and for 25 years of exploitation will be of USD 50,457.60 and USD 1,261,440 respectively.

Maintenance Cost:

The highest cost of high pressure sodium lighting is the lamp replacement. Equipment purchasing fees and wages for workers adds up to the cost of maintenance. With no voltage fluctuation effects the average lifespan of street lamps is five year. Considering the above parameters a total maintenance cost for the conventional streetlight will be USD 50,000.

From the above analysis the total cost of the conventional street light including equipment purchasing, electricity consumption and maintenance give a total will be 1,508,440 for 25 years.

3.4.5 Solar Powered LED streetlight investment cost

Table 6: Solar Powered LED streetlight Investment cost

Component	Quantity	Cost $	Total Cost $
200Wp Solar PV panel	120	300	36,000
LED Lamp 80w	240	120	28,800
300Ah, 12volts	120	300	36,000
Charge Controller	120	120	14,400
Pole	120	200	24,000
Lamp bracket	120	50	6,000
Battery Box	120	20	2,400
Labour Cost	120	100	12,000
Installation Cost	120	250	30,000
Miscellaneous Cost	120	500	60,000
Initial Investment Cost			**249,600**

Battery Cost:

The cost related to battery replacement for the solar powered LED is assumed to be the cost of electricity consumption for the solar system with five year life span of the battery. The cost associated with battery replacement will be USD 36,000 for every five years and USD 900,000 for the life span of the system.

Maintenance Cost:

For estimating the maintenance cost of the solar powered LED streetlights the under listed is assumed:

- The lifespan of the solar panel is 25years;
- The Lifespan of LED lamps 50,000 hours, which means they can be used for more than 10 years without any replacement;
- The life span of controller is 10 years and
- The Life span of light pole 30 years

Therefore the cost of maintenance for the 25yr period will be USD 42,800 made up of the cost of LED lamp replacement and charge controller. From the above analysis the total cost of the solar powered LED streetlight including equipment purchasing, battery cost and maintenance will be USD 1,149,600 for 25 years.

Table 7: Capital Expenditure/ Operational Expenditure of current and proposed methods of street lighting

Type of Structure	Capital Expenditure	Operational Expenditure
Grid Powered Street lights	194,000	1,311,440
Solar Powered LED Streetlights	249,600	942,800

The operational expenditure of the grid powered street light as indicated in the table above includes the maintenance cost and the cost of electricity consumed. The capital expenditure for the solar powered LED Street light includes the cost of battery replacement, replacement of LED.

3.4.6 Economic viability of the Solar Powered LED Street lights.

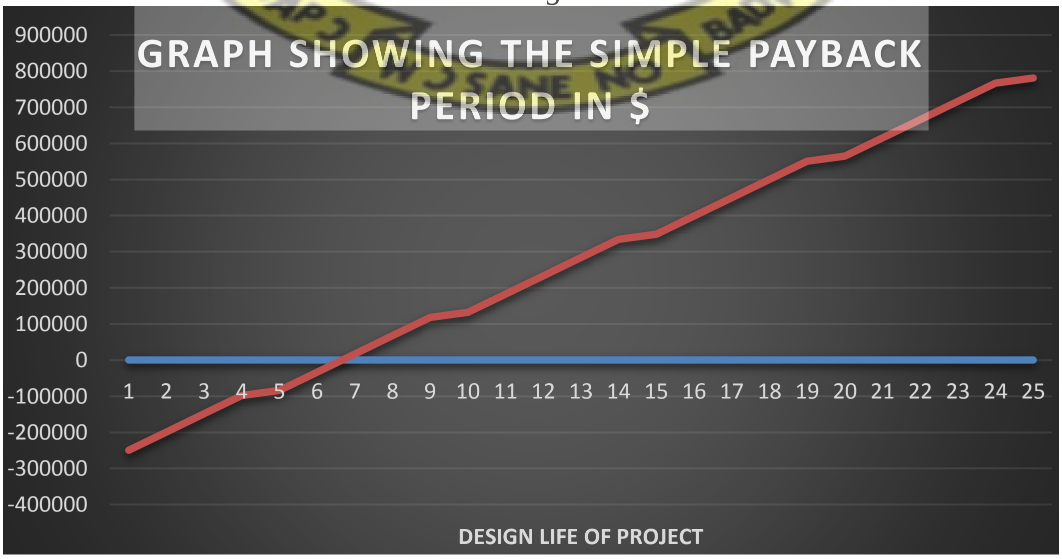
The economic viability of the solar powered LED street lights will be determined by establishing the Simple Payback Period for the life span of the project.

Simple Payback Period: The capital expenditure for the solar power LED is established in table 5. The graph below shows the repayment period for the proposed street light. From the graph.

Table 8: Simple Payback Period Analysis

Year	Initial Investment	Cash flows	Cumulative cash flow
1	249,600	-249,600	
2		50,458	-199,142
3		50,458	-148,684
4		50,458	-98,226
5		14,458	-83,768
6		50,458	-33,310
7		50,458	17,148
8		50,458	67,606
9		50,458	118,064
10		14458	132,522
11		50458	182,980
12		50458	233,438
13		50458	283,896
14		50458	334,354
15		14458	348,812
16		50458	399,270
17		50458	449,728
18		50458	500,186
19		50458	550,644
20		14458	565,102
21		50458	615,560
22		50458	666,018
23		50458	716,476
24		50458	766,934
25		14458	781,392

Figure 5: Graph showing the Simple Payback Period for the Solar Powered LED Streetlights.



CHAPTER FOUR

4.0RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter presents the results of the projects as a result of the procedure followed in the earlier chapter. It is divided into two main parts. The results as discovered from the project as well as their in-depth analysis constituting the discussion.

4.2 Capital expenditure and Operational expenditure of Grid Connected streetlights/ Solar powered LED street lights

From the capital expenditure, the grid connected streetlight appears to be cost-effective $194,000 compared to the capital expenditure of the solar powered street lights value of $249,600.

4.3 Energy Savings

This section describes the amount of energy consumed if the conventional lights are to be replaced by LED lights. For a total of 240 HPS light fitted with a capacity of 400 Watts in use from 6pm – 6am (12 hours).

The energy consumed by the conventional street lights in Wenchi are given below;

$$Anuual\ energy\ consumed = number\ of\ units\ \times wattage \times total\ working\ hours$$

$$= 240 \text{ x } 400\text{x } 12 \text{ x } 365 = 420.48 \text{ MWh/yr}$$

This amount of energy will be saved if all the grid connected streetlights are converted to solar powered LED streetlights.

4.4 Emission

This section also looks at the amount of greenhouse gases that will be saved if the conventional lights are replaced by LED lights. From the EPA et.al. (2010) the coefficient of carbon dioxide emission is 0.275 tCO_2/MWh. Hence

$$The\ total\ carbon\ dioxide\ that\ will\ be\ saved\ a\ year \quad = 0.275\ x\ 336.38\ MWh/yr$$

$$= 92.5\ tCO2$$

The total emissions saved for the life of the solar PV will be 2,312.5 tCO2

4.5 DISCUSSIONS

4.5.1 Technical capabilities of LED/PV Technology

From the literature review, the values in terms of the Colour Rendering Index and the Correlated Colour Temperature of the LED lamps are higher than that of the High Pressure Sodium lamps being used at the study area. The LED provides whiter lights as against the yellow lights provided by the HPS.

4.5.2 Financial Analysis

The analysis reveals that for the design life of the project (25rys) the solar power system is more viable at a cost of USD 1,149,600 against USD 1,505,440. The solar investment generate saving of USD 355,848. Even though the installation cost of the solar powered LED streetlights is higher, the absence of cable and minor maintenance and electricity costs make it much more efficient.

4.5.3 Energy/Emission Analysis

From the use of 240 HPS lamps on the selected street, an amount of 420.480 MWh/year of electricity would be consumed and an amount of 10,512 MWh would be consumed during the selected period for the analysis. In Ghana the Green House Gas (GHG) emission factor is estimated to be 0.275 tCO2/MWh and if solar powered streetlights are used to replace the grid connected streetlights; the greenhouse gas emission reduction would be 115.63 tCO_2 in the first year of replacement. The total CO_2 emission saved a year will be 92.5 tCO_2. During the life time (25years) of the system, a total of about 2,312.5 tCO_2 will be saved.

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This thesis concluded that the use of solar powered LED Street provides significant savings in energy as well as reduction in the cost of maintenance associated with conventional street lighting. There are also savings achieved towards the environment because fewer emissions are released into the atmosphere in the use of the system. The standalone nature of the system make it easy to use in areas that are outside the coverage of the national grid. Moreover, in time of collapse of the grid system, the system will work unceasingly where the grid connected street lights stop working due to collapse. The use of LED lights will decrease the need for maintenance as well. In conclusion, the solar powered LED lights are technically viable solution to saving money, saving electrical power, and saving the environment.

For the total carbon dioxide emission in the municipality, it was realised that about 115.632 tCO_2 was released by the conventional street lamps in the municipality. When these conventional lamps are replaced by LED lamps, a total of about 92.5 tCO_2 will be saved a year in the municipality.

The project also concluded that the 80W LED lamps would meet the lumen requirement as provided in BS 5489-1. The efficacy of these lamps far exceeds the requirements provided by the specifications hence it would be more appropriate to replace such conventional street lamps (HPS) by the LED lamps.

Even though the initial investment of the solar streetlight is higher than that of the grid-connected streetlights, there are benefits in the form of energy savings and reduction in CO_2 emission.

The payback period for the solar streetlight would be achieved during within the seventh year.

It could finally be realised that the LED/PV technology would be capable of replacing the conventional lighting system taking into consideration the efficacy and the power outputs of the lamps. The current solar led streetlights being sold on the market have the technical capabilities of providing the needed lighting for both vehicles and pedestrians on the road ways.

5.2 Recommendations

From the discussions above, the research concluded that the use of PV powered LED streetlights are both technically and financially viable. The system provides significant savings in the form of energy, money and emission reduction. Considering the current deficiencies in meeting energy demands, the energy saved by using this system can be channelled into other productive area. The savings made in terms of money can also be used to promote the use of the system in other parts of the study area. Based on these benefits Ghana should adopt the use of solar powered LED lights for street lighting purposes.

For the systems to effectively work, there will be the need to train engineers or stakeholders in the use and advantages of solar PV systems and the use of LED lights since the design of appropriate system requires expertise.

This research should serve as a pilot study to lay the groundwork for more complete research in the future. Data gathered from this these research can serve as a baseline for other feature developments.

It is also recommended that studies are conducted to explore the use of Grid-interactive PV powered street lighting.

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APPENDIX

Table 9: High Pressure Sodium Light vs LED Street Light

Items	High Pressure Sodium Light - HPS	LED Street Light
Photometric Performance	Bad	Excellent
Radiator Performance	Bad	Excellent
Electric Performance	Electric Shock Easy (High Voltage)	Safe (Low Voltage)
Working Life	Short (5,000 hours)	Quite Long (>50,000 hours)
Working Voltage Range	Narrow (±7%)	Wide (±20%)
Power Consumption	Quite High	Quite Low
Startup Speed	Quite Slow (Over 10 minutes)	Rapid (2 seconds)
Strobe	Yes (Alternating Current Drive)	No (Direct Current Drive)
Optical Efficiency	Low	High
Color Index / Distinguish Feature	Bad, Ra <50 (The Color Of Object Is Faith, Boring, Hypnosis)	Good, Ra >75 (The Color Of Object Is Fresh, Veritable And Comfortable)
Color Temperature	Quite Low (Yellow Or Amber , Uncomfortable)	Ideal Color Temperature (Comfortable)
Bad Glare	Strong Glare (Dazzle)	No Harmful Glare
Light Pollution	Strong	No

Heating	Serious (>300°C)	Cold Light (<60°C)
Lampshade Turn Dark	Easy (Absorb Dust)	No (Static Proof)
Lamp Aging Turn Yellow	In A Short Time	No
Shockproof Performance	Bad (Fragile)	Good (No Filament Nor Glass)
Environment Pollution	Contains Lead Element Etc.	No
Maintenance Cost	High	Quite Low
Product Cubage	Big	Small (Slim Appearance)
Product Weight	Heavy	Light
Cost-Effective	Low	High
Integrated Performance	Bad	Excellent

Source: www.dmxledlights.com