TECHNO-ECONOMIC AND ENVIRONMENTAL FEASIBILITY STUDY OF USING SOLAR LED STREETLIGHT IN NIGERIA: A CASE IN THE CITY OF ILORIN KWARA STATE

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Abstract

This work presents techno-economic feasibility study of using solar energy and LED lights for street lightning in Nigeria using the City of Ilorin as a case study. The purpose of adopting solar energy is to relieve the grid from huge energy consumption and to reduce the effects of climate change and global warming on the environment. The recommended LED lamps powered with solar energy can produce brighter lighting than the 250 watt high pressure sodium lamp bulb which is currently in use in the case study area and other parts of the country. Although, the initial investment cost of implementing the recommended LED solar street light is higher than the conventional street lights, the end result in the long run is quiet impressive in term of low maintenance cost, emission and reliability. The study on 400 lamps of 250W each showed that after 25 years of use, LED solar street lights additionally saves USD 293, 674 in addition to other saving: national electric grid energy. Moreover, it protects the environment by preventing 9855000kgCO2 to be produced by the traditional electric street lights over a period of twenty five years.

Keywords: Life Cycle Cost, Cost of Energy, LED, Insolation, Street lighting
Acknowledgements

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1.0 Introduction

Lighting is very important for our daily lives with advantages ranging from visibility to security purposes. Approximately 50 percent of all motor-vehicle fatalities occur during nighttime driving, while only 25 percent of travel occurs at night [1]. Benefits of light for drivers and pedestrians include easing the flow of traffic, reduction of nighttime accidents, security of lives and properties in the night, visibility of adjacent uses, increase safety for motorists and pedestrians particularly at intersections where pedestrians may be crossing. The exact number of people who lack direct access to electric lighting is unknown [2]. About a third of the world’s population depends on fuel-based lighting [2]. Barozzi and Guidi [3] put the total number of people who lack direct access to electric lighting at 2.2 billion. Global electricity lighting electricity production in 1997 totals 2016 TWh, of which 1066 TWh is attributable to IEA member countries. The total lighting energy use equates to the output of approximately 1000 large electric power plants, of which 500 are in IEA member countries. Also, for the industrialized countries with available data, national lighting electricity use ranges from 5% (Belgium, Luxembourg) to 15% (Denmark, Japan, and the Netherlands) of total electricity use, while in developing countries the value ranges as high as 86% (Tanzania). Total lighting-related carbon dioxide (CO2) totals approximately 1775 million tonnes (MT) [2]. Moreover, Evan and Lawrence [2] found out in their work that: Household fuel-based lighting is responsible for annual energy consumption of 96 billion litres of kerosene (or 3603 petajoules, PJ) and in comparison, the total energy use (all sectors and fuels) in Austria is 1200 PJ, in Sweden 2200 PJ, and in the UK 10000 PJ) which also equates to 1.7 million barrels of oil today, comparable to the total production of Algeria, Brazil, Indonesia, or Libya, and about 65% that of Iraq; The primary energy consumed for this fuel-based residential lighting is 64% of that used to provide the 487
TWh of electricity consumed for household electric lighting globally, and 115% of that to make electric lighting for households within IEA countries; The cost of this energy is $48 billion/year (assuming a kerosene price of $0.50/ liter), or approximately $100 per household. This corresponds to 98% of the costs from residential electric lighting globally, and 161% of electric lighting for households within IEA countries; Fuel-based lighting results in 244 million metric tonnes of carbon dioxide emissions to the atmosphere each year, or 58% of the CO₂ emissions from residential electric lighting globally, and 156% of that to make electric lighting for households within IEA countries. Within the developing countries, national fuel based lighting energy use can be on a par with that for electric lighting, and is large even compared to total electricity used for all purposes. Also, it was reported in (World Energy Outlook, 2006) that reducing lighting electricity consumption by 65% would decrease the share of electricity consumption for lighting from 19% to 7% of world total electricity consumption. The resulting electricity savings is enough to close 705 coal-fired power plants of 500 MW each (a 500-MW coal-fired power plant produces 3.15 TWh of electricity per year operating at 72% capacity).

The continuous increase in electric power demand from conventional street lights using sodium vapor lamp, metal halide among others, also contribute to the climate change due to CO₂ emission. These conventional public street lights have been identified as the main contributor to light pollution. Green House Gases (GHGs) like Carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride are released after electrical energy consumption from fossil fuel based power station. Due to the effect of climate change and global warming, countries in the world are beginning to show interest in alternative sources of energy to power the public street lights. For instance, Piyush Goyal, India’s energy minister has recently announced the intention of the country to replace all its conventional streetlights
with LED ones, with the underlying logic being that conserving power is more economical than producing more. He also reported that, India has 35 million street lights which generate a total demand of 3, 400MW and replacing this with LED light can be brought down to 1, 400MW, saving 900million kWh of electricity annually, worth over $850 million in the process. In addition to the economic benefits from elimination of grid-connected electricity costs, there will be savings due to reduced maintenance on a grid-connected street lighting project.

Solar photovoltaic cells provide clean, cheap and environmental friendly electrical energy by converting solar energy directly to electrical energy without emitting any green house gases. The only known demerits they have is high initial cost and long energy payback time, but thse have merits of providing a reliable and sustainable energy as well as provision of clean energy. Using LEDs as light source have many benefits over conventional electric light sources these include: they consume less electrical energy, compact size, no burn out, good performance in the cold, long lifetime, directional light, optical control, operating characteristics e.t.c. LED lighting offers promises to further improve roadway safety and reduce power consumption due to the improved correlated color temperature availability [1]. As a result of rapid improvement in luminous efficacy and global interest in LED for street light application, the Nobel Prize in Physics 2014 was awarded jointly to Isamu Akasaki, Hiroshi Amano and Shuji Nakamura "for the invention of efficient blue light-emitting diodes which has enabled bright and energy-saving white light sources". Using solar energy to power streetlights in the state and country in general would greatly reduce electric power demand from the nation’s national electric grid as it is currently experienced in country at large. This will reduce the usual load-shedding currently practiced all over the country during power distribution and its subsequent economic effects on residential, commercial and industrial consumers. It will also help in reducing the huge amount
incurred in the provision and maintenance of conventional street lights. Once they are disconnected from the national grid, it would bring immense benefits to the country and the economy as a whole as power savings from street light would be available for the other sectors of the economy.

In view of this, this paper present techno-economic feasibility study of replacement of conventional streetlights with solar LED streetlights in Nigeria using the City of Ilorin as a case study. It is hoped that the outcome of this work when adopted will lead to the replacement of conventional street light with LED solar street lighting in the City of Ilorin. Consequently, the City of Ilorin will set new standards in the country and internationally, for the transformation of the major component of public infrastructure in ways that are financially responsible, economic viable, environmental friendly and for the same price or less than regular conventional public street lighting schemes. This will also guarantee continuity of supply since the source of energy is renewable as compared to traditional one that depends on epileptic grid supply.

2.0 Review of LED Solar Street light

2.1 Brief History of street light (Donald et al., [4])

The first record of public street lighting dates back to 10th century Spain, when Cordoba, the capital of the Moorish Empire, installed kerosene lanterns along its main streets. Since then, the street light has undergone several reforms in technology, from lanterns filled with tallow, fat, wax, and pith wicks in 15th century Europe and Colonial America, to coal gas lamps in the 19th century and electrified arc lamps and incandescent bulbs in the late 1800s. The past decade has seen the emergence of a new lighting technology that can be applied to street lighting, the solid-
state light emitting diode (LED), a super-efficient, long-lasting, compact and versatile light source. The largest municipal street lighting system in the United States is found in New York City, with over 300,000 outdoor public lights shining along streets, walkways, public spaces and highways.

The story of New York encapsulates the evolution of street lighting in America over the last 300 years. In Colonial America, street lighting was the responsibility of citizens, not government. In New York in 1697, every seven households were required to share the expense of a candle to burn in a lantern suspended on a pole from the window of every seventh house. Lamp lighters maintained the system, lighting the candles from within their glass vessels with torches in the evening and blowing out the flames in the morning, trimming the wicks and replenishing the oil. In 1762, New York installed wooden public lamp posts from which whale oil lamps burned dimly. These were replaced with cast-iron lamps in 1827. For the next thirty years, a calendar was used to identify those nights when the moonlight was expected to be bright and the lamps were kept off regardless of any overcast conditions. By 1893 there were 1,500 electric arc lights illuminating New York streets. Over the next 100 years, new technologies, from incandescent to high intensity discharge (HID) fixtures, were introduced, each progressively more efficient, safe, and flexible. In 1999, NYCDOT began updating its high pressure sodium (HPS) luminaires with more efficient models. From 2001 to 2009, the City converted its incandescent traffic signals to LEDs, reducing energy use by 81 percent. Its 2007 Comprehensive Plan, PlanNYC, called for a 30 percent reduction in greenhouse gas emissions by 2030, a goal surpassed the same year by Executive Order 109 and Local Law 55 requiring the reduction of municipal energy use by 30 percent of 2006 levels by 2017. With street lights accounting for approximately 6 percent of its energy use, NYCDOT is looking towards the new
generation of LEDs suitable for street lighting. As of 2010, six LED street lighting pilot projects were underway along major arterials, bridges, and in Central Park, with full scale deployment planned for three sites depending on the test results. As a global city, New York aims to shape the future of more sustainable street lighting infrastructure by helping to evaluate commercial applications of LED technology via the U.S. Department of Energy (DOE) Gateway Program, and by participating in The Climate Group’s (TCG) Light Savers program alongside major international cities like Toronto, London, Mumbai, Bangalore, Hong Kong, and Beijing [4]

2.2 Solar Energy Potential

The Sun radiates energy of about $3.5 \times 10^{14} \text{ kW}$ into space and only $2 \times 10^{14} \text{ kW}$ reaches the earth [5]. Converting even a part of the solar energy at a very low efficiency can produce more energy than could conceivably be harnessed or utilized for power generation and in many other applications. Even if 90 percent of the solar energy reaching the earth is lost by reflection, refraction and absorption in the outer layers of the atmosphere, the quantity available at the surface will be about $2 \times 10^{13} \text{ kW}$, which is equivalent to the burning of some 17 million tonne of coal [5]. This stupendous solar energy, which is non-exhaustible and completely pollution free could drive the civilization for life if it is properly and economically harnessed. Some parts of the country are endowed with an abundance of sunshine throughout the year. The insolation levels in the country range between 3.5kWh/m²/day to 7.0kWh/m²/day [6]. The insolation level varies within a small range throughout the year and is strongly enough available to run solar conversion devices like a photovoltaic system, flat plate collectors efficiently for producing hot water among others. The map of solar insolation of the Nigeria and
World map of potential solar power (solar insolation in kWh/m²/day) are shown in Figures 1 & 2 below.

![Solar Radiation Map of Nigeria](image)

**Figure 1: Solar Radiation Map of Nigeria [7]**

For the socio-economic development of world’s poorest countries, increasing access to electricity is very crucial. An estimated 1.5 billion people in developing countries have no access to electricity, with more than 80 per cent of these living in sub-Saharan Africa or South Asia. [8]. The problem is most acute in remote areas: 89 per cent of people in rural sub-Saharan Africa live without electricity (majorly for lighting purpose), which is more than twice the proportion (46 per cent) in urban areas [8]. Also, as shown in Figure 2 the countries that receive the most solar
energy are often also the ones least able to benefit from it, due to a lack of knowledge, political will, corruption and capacity to harness solar power and convert it into electricity.

Clean, good and quality street lighting contributes to the quality of life (especially in rural areas of the world), by improving personal safety and perceived safety, and improving the appearance of the local environment. For this reason, citizens put high expectations on the local, state and federal government agencies to provide appropriate street lighting especially in the rural areas. Moreover, the demand for street lighting has a great impact on the available electrical generation coupled with the effect of global warming and climate change. The solar energy can be harnessed either by the use of a solar photovoltaic device or solar concentrating thermal technologies. The former is used to convert directly solar energy into electrical energy whiles the latter converts the resource into thermal energy.
2.3 LED Street Lighting Technology

Nowadays, nearly all of the lighting manufacturers worldwide are designing and producing their products with LED technology based on their advantages as compared to the conventional light sources like sodium vapor lamps, metal halide among others. They are also working tirelessly to develop more efficient lighting products integrated with sensor technologies, control systems and renewable energy components so as to reduce cost and greenhouse gas (GHG) emissions. While LED technology offers a wide range of unique potential benefits, literature survey revealed that consumers are primarily interested in the energy-reducing promise and luminous efficacy of LEDs for street lighting and traffic light applications.
with little focus on the performance issues or aesthetic and place making opportunities presented by LEDs and street lighting in general. This emphasis is in response to the high priority concerns of global climate change and financial restraints of governments globally.

The U.S. Department of Energy (DOE) estimates that conversion to LED lighting over the next two decades could reduce energy consumption by one-quarter. There will also be saving of $120 billion in energy costs and diversion of 246 million metric tons of carbon emissions [4]. While older technologies are concurrently being improved, LED lighting sources are expected to continue to surpass other technologies in terms of efficacy [4]. LED light can be used for many applications including unique application as shown in Figures 3 (a) & (b) and for solar street light as shown in Figure 4. LED light source also has longer life span as compared to traditional light sources. The U.S. Department of Energy’s roadmap on solid–state technology stated that the efficacy of white LEDs is expected to reach 100 lumens per watt by the year of 2010 and 140 lumens per watt by year of 2015 [10]. Projections of system efficacy using white LED lamps in the future are shown in Table 1. The properties of some light sources are presented in Table 2 while Figure 5 shows some selected LED technology.

Table 1: System efficacy for stand-alone solar PV lighting with different light sources with projection for future years

<table>
<thead>
<tr>
<th>Year</th>
<th>White LED efficacy (lumen/watt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2003</td>
<td>25</td>
</tr>
<tr>
<td>2006</td>
<td>40</td>
</tr>
<tr>
<td>2010</td>
<td>100</td>
</tr>
<tr>
<td>2015</td>
<td>140</td>
</tr>
</tbody>
</table>

Source: [10]
LED lamps have longer service life and high energy efficiency. The initial costs are presently higher than those of fluorescent and incandescent lamps.

Table 2: Properties of some Light sources

<table>
<thead>
<tr>
<th>Type of Lamp</th>
<th>Luminous Efficacy (lm/w)</th>
<th>Color Rendering Properties</th>
<th>Lamp life (hrs)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Pressure Mercury Vapor (MV)</td>
<td>35-65</td>
<td>Fair</td>
<td>10,000-15,000</td>
<td>• High energy use</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• poor lamp life</td>
</tr>
<tr>
<td>Metal Halide (MH)</td>
<td>70-130</td>
<td>Excellent</td>
<td>8,000-12,000</td>
<td>• High luminous efficacy,</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• poor lamp life</td>
</tr>
<tr>
<td>High Pressure Sodium Vapor (HPSV)</td>
<td>50-150</td>
<td>fair</td>
<td>15,000-24,000</td>
<td>• Energy-efficient,</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• poor color rendering</td>
</tr>
<tr>
<td>Low Pressure Sodium Vapor</td>
<td>100-190</td>
<td>Very poor</td>
<td>18,000-24,000</td>
<td>• Energy-efficient,</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• very poor color rendering</td>
</tr>
<tr>
<td>Low Pressure Mercury Fluorescent</td>
<td>30-90</td>
<td>good</td>
<td>5,000-10,000</td>
<td>• Poor lamp life,</td>
</tr>
<tr>
<td>Tubular Lamp</td>
<td></td>
<td></td>
<td></td>
<td>• medium energy use,</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• only available in</td>
</tr>
<tr>
<td>Light Source</td>
<td>Wattage Range</td>
<td>Efficiency</td>
<td>Lifespan Range</td>
<td>Advantages</td>
</tr>
<tr>
<td>--------------</td>
<td>---------------</td>
<td>------------</td>
<td>----------------</td>
<td>------------</td>
</tr>
<tr>
<td>Energy-efficient Fluorescent Tubular Lamp (T5)</td>
<td>100-120</td>
<td>Very good</td>
<td>15,000-20,000</td>
<td>- Energy-efficient, - Long lamp life, - Only available in low wattages</td>
</tr>
<tr>
<td>Light Emitting Diode (LED)</td>
<td>70-160</td>
<td>good</td>
<td>40,000-90,000</td>
<td>- High energy savings, - Low maintenance, - Long life, - No mercury - High investment cost, - Nascent technology</td>
</tr>
</tbody>
</table>

Source: [11]
Figure 3 (a) & (b): Unique applications of LED lighting [4]
Figure 4: Applications of LED in Solar Street Light [12]

Figure 5: Selected LED Technology
2.4 Advantages of LEDs over Traditional Lighting Sources

The Solid-state lighting (SSL) technology uses semiconductor light-emitting diodes instead of electrical filaments, plasma, or gas to create light. For street light applications, LEDs have several advantages over conventional lighting technologies using high sodium vapor lamp, mercury lamp e.t.c. The advantages of LEDs over conventional lighting technologies are briefly explained below [4].

a) Compact size

The light output of individual light-emitting diodes is low compared to incandescent and compact fluorescent bulbs [4]. The compact size of diodes means that multiple diodes can be clustered together into an LED array. Nowadays, individual LEDs are also becoming more powerful, with a higher lumen output. As a result, LED arrays have the potential to have a much lower profile than other lighting technologies while using less energy.

b) Durability and shock-resistance

Solid-state lighting technology does not contain delicate glass enclosures or filaments. LEDs are made of polycarbonate which is vibration resistant, making them ideal for road-side applications.

c) Free of ultraviolet (UV) emissions

SSL products do not emit UV. UV radiation can damage fabrics and cause eye and skin damage.
d) Directional light

Traditional lights emit light in all directions while LEDs emit light in a specific direction. This reduces the need for reflectors and diffusers, resulting in less wasted light thereby improving the efficiency.

e) Lower operating costs: energy efficiency

LEDs use 50 to 90 percent less energy than other light sources while maintaining the same light output.

f) Lower operating costs: longer life

LEDs have two to three times longer life than conventional light sources (except induction). Estimates vary because the technology is new and constantly improving, but it is commonly reported that LEDs can last 20 to 30 years depending on the quality of the product, power usage, and other factors. However, the practical LED life expectancy for street lighting application is typically estimated at 10 years, when 30% lumen deterioration is anticipated. The reduced re-lamping costs of long-lived LEDs are a contributing factor to the lower maintenance cost of LEDs. A longer life also means less landfill waste.

g) Wide color temperature range

White LED light sources are available with a fixed color temperature (CT) and color rendering index (CRI), typically from 3,000 to 6,500 Kelvin (K). A further option are white light LEDs arrays that can be continuously controlled to offer warm (2,700 - 3,000 K) to cool white light (5,000 K+).
h) Control options

LEDs output can be modified. The inbuilt control systems can manipulate LED color temperature, light intensity (dimming capability which automatically increases and reduces light energy and output). It is possible to control shutdown and resume operation, detect lumen depreciation and sense occupancy with the help of a sensor.

i) No toxic metals or chemicals

One of the pitfalls of other street lighting sources, including those that are more energy efficient, is that they contain mercury, lead, and other toxic chemicals. While a single bulb may not pose a serious contamination threat, the cumulative effect of the estimated 500 million street lights in use worldwide finding their way into landfills on a three to five year cycle poses an enormous pollution problem. As LEDs do not contain hazardous waste, they can be completely recycled.

j) Monochromatic light

LEDs emit nearly monochromatic light, making them highly efficient for colored light applications. As a result, LEDs can produce a full spectrum of color for celebratory and aesthetic purposes.

k) No burn out

Rather than burning out, LEDs gradually dim over time. LEDs are measured on the L70 standard, which indicates the average hours of operation until the light output (lumens) deteriorates to 70 percent of its original quantity.
1) Near instant-on and rapid cycling

LED lights achieve 100 percent brightness nearly instantly when activated. They are also unaffected by repeatedly being turned on and off (rapid cycling), unlike traditional lighting technologies which have a shorter lifespan and higher energy needs.

m) Good performance in the cold

In colder temperatures, LED lights perform more efficiently and last longer.

### 3.0 Description of the Study Area

The selected case study is the City of Ilorin which is the capital City of Kwara State in North Central Nigeria. The City was selected as a case study because of convenience and availability of data. It lies within 8° 30’N 4°33’E and 78.500°N 4.550°E. In terms of land size, it covers 765 square kilometers. The solar irradiance data for Ilorin as obtained from NASA Surface meteorology and Solar Energy [13] (month/day/year) from 01/01/2001 through 30/12/2005 is represented by Figure 6. It can be seen from Figure 1 above that the average solar radiation in Ilorin is very high (around 5.5 kWh/m$^2$/d), which is suitable for photovoltaic generation, and the clearness index shows that the study area is a sunny area, with a promising energy production. It is shown in Figure 6 that the maximum solar radiation occurs in March with the irradiation of 6.04 kWh/m$^2$/d which is a very high value, and the lowest average radiation is in the month of August with 3.76kWh/m$^2$/d. It’s clear from the site analysis and solar radiation data that the proposed location has a great potential for a PV energy generation project. Scaling was done on this data to consider the long-term average annual resource (5.05kWh/m$^2$/d) for the proposed site. HOMER introduces the clearness index from the latitude information of the site under investigation as shown in Figure 6. Street lights in the City are not operating at its
optimum level and the State Government seeks to repair malfunctioning street lights in the City. The City currently has about 1625 Double luminaire, of 250W high pressure sodium vapour lamp, 220VAC/Luminaire with a distance of 40m between the poles and 356 single luminaire, of 250W high pressure sodium vapour lamp, 220VAC/Luminaire with a distance of 40m between the poles. A summary of inventory of the streetlights in Ilorin is shown in Appendix A. There are more major streets without streetlights and the number of potential solar street lighting opportunities in the city is in the hundreds. The annual streetlights energy consumption costs were not readily available and also costs of maintenance (replacement of lamps, damaged poles and stolen cables) were not available.

The techno-economic feasibility study would be carried out to compare the cost involved in installing, operating and maintaining a new conventional streetlight using HPS lamp and cost involved in the installation of LED solar powered streetlight. For this purpose of this work, Offa Garage to Challenge round about streetlight route in the City, is chosen for the analysis. The total number of poles is 200 double 250W HPSV (400 lamps of 250W HPSVL each) with a distance of 40m between the poles.

![Figure 6: Average Daily Radiation of the Study Area](image-url)
4.0 System Design

4.1 Illumination Level for Street Lighting and Mounting Height of Lamps

The level of illumination required depends basically on the class of street lighting installations. In class A installations i.e in important shopping centres and road junctions, illumination level of 30lm/m\(^2\) is required while in a poorly lighted suburban streets, illumination level of 4lm/m\(^2\) is sufficient. Also, an average well lighted street will required illumination level between 8 to 15 lm/m\(^2\). When the distance apart is not more than 8 times the height of the luminaries, then the installation is excellent. The level of illumination required as per ISI, for various types of traffic routes is shown in Table 3.

Table 3: Level of Illumination required as per ISI, for various types of Traffic Routes

<table>
<thead>
<tr>
<th>Classification of Lighting Installation</th>
<th>Types of Road</th>
<th>Average Level of Illumination on Road Surface</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group A(_1)</td>
<td>Important traffic routes carrying fast traffic</td>
<td>30</td>
</tr>
<tr>
<td>Group A(_2)</td>
<td>Other main roads carrying mixed traffic like main city streets, arterial roads, e.t.c.</td>
<td>15</td>
</tr>
<tr>
<td>Group B(_1)</td>
<td>Secondary roads with considerable traffic like principal local traffic routes, shopping streets e.t.c</td>
<td>8</td>
</tr>
<tr>
<td>Group B(_2)</td>
<td>Secondary road with light traffic</td>
<td>4</td>
</tr>
</tbody>
</table>

Source: [5]
4.2 Stand alone Solar Street Light system design

Stand alone solar street light system design is a process of determining capacity (power, voltage and current) of each component of a stand-alone solar streetlight system with the view to meeting the load requirement for which the design is made. The steps that are required for the design of stand-alone solar streetlight are briefly formulated and discussed below.

a) Site inspection and radiation analysis

The first step and the most important part of the design is site inspection and radiation analysis [14, 15]. This will help to determine whether a stand-alone system is viable or not. According to the radiation data of the location one can find out the number of sunny days in a year. Also, the amount of electrical energy that can be generated depends on the radiation intensity throughout the year. The maximum, minimum and average temperature values are required to measure the cell temperature which will affect the module voltage and current output. Shadow analysis will help to find out the time duration for which solar radiation falls on solar arrays. Azimuth angle and altitude angle are required to find out the sun path at that location [14, 16].

b) Calculation of load requirement

The electrical load requirement (power rating of the fitting) will determine the power of PV system to be installed. The load demand per pole \( E_d \) can be estimated by multiplying the wattage of the fittings \( P_{load} \) by the hours of usage \( t \). i.e

\[
E_d (Wh) = P_{load} (W) \times t (h)
\]  \hspace{1cm} (1)
c) Choice of system voltage and components

Once the load is known, DC Voltage of the PV system has to be fixed. Generally, the DC fittings used for solar streetlight are rated in 12 or 24V. In this work 12VDC fittings are considered.

d) Determine capacity of Battery

The Deep cycle battery is the one that can be repeatedly recharged over and over again for years when it is frequently discharged to low energy level. It is this type of battery that is specifically designed to be used in solar energy applications. The battery capacity (ah) should be designed to store sufficient energy to operate the load (light fittings in this case) at night, and days without sunlight. Battery storage is normally measured in Ah (ampere hour). The charge storage capacity, which is the energy storage capacity, of the battery bank ($B_{cap}$) is determined by the daily energy requirement and number of days for backup power i.e number of days of autonomy ($N_{auto}$) as given below.

$$B_{cap} (Ah) = \frac{E_d * N_{auto}}{V_{dc} * DOD}$$ (2)

$E_d$ is the total daily energy demand. $V_{dc}$ is system voltage in volt. The amount of energy that can be allowed for running the load is called depth of discharge (DOD) of the battery. In some cases a number of batteries have to be connected in series for system voltage specification and in parallel for current specification. In such cases the number of batteries to be connected in series ($N_{bs}$) is obtained by system DC voltage and voltage of individual battery using the following equation.
\[ N_{bs} = \frac{V_{dc}}{\text{Voltage of each battery}} \]  

While the number of batteries which will be connected in parallel \( N_{bp} \) can be obtained by the following equation

\[ N_{bp} = \frac{B_{cap}}{\text{Ah capacity of each battery}} \]  

The total number of batteries required \( N_b \) can then be calculated by the following equation

\[ N_b = N_{bs} \times N_{bp} \]  

If the battery efficiency \( \eta_{bat} \) is assumed to be about 85\%, then energy required from solar PV array \( E_{bat} \) to charge the battery bank is given by the following equation:

\[ E_{bat} \ (kWh) = \frac{V_{dc} \times B_{cap}}{\eta_{bat}} \]  

e) Determine capacity of solar photovoltaic

A solar photovoltaic module is required to convert solar energy to electrical energy (dc) to charge the battery during the day. The formula to determine the capacity of the solar modules required is formulated below.

\[ P_{pv} \ (kW) = \frac{E_d + E_r}{I_n} \]  

\[ E_r \ (kWh) = \frac{E_d}{5} \]

\( E_r \) = energy of recovery to compensate for the days with low or without sunlight, modules mismatches, dirt, shading and losses due to wiring and blocking diodes.

\( I_n \) = average daily solar insolation in kWh/m\(^2\)/day = (5.05 kWh/m\(^2\)/d)

f) Charge controller specification.
Charge controller controls the flow of current. A good voltage regulator must be able to carry the maximum current ($I_{max}$) generated by the solar array. Sizing of the voltage regulator can be obtained by multiplying the short circuit current of the modules connected in parallel by a safety factor of 1.25 [14, 17]. A good charge controller must be designed to match the output voltage of the PV array as well as that of the battery bank. Maximum Power Point Tracking (MPPT) charge controller is specified based on PV array voltage handling capacity.

g) DC cable sizing.

The DC cable that connects photovoltaic modules and batteries through the voltage regulator must be properly sized so as to carry the maximum current generated by the modules. The correct size and type of cable must be selected so as to reduce the losses across the cable and also to enhance the performance and reliability of a photovoltaic system. In standalone solar streetlight, the properly sized cables do come with solar module and the fittings. The only cable left to be sized is the one that connects charge controller to the battery.

4.3 Technical considerations

The life cycle cost involved in installing, operating and maintaining a new LED solar powered streetlight, spacing between two solar street light poles based on the required illumination level are considered next.

a) Load Demand

The load demand is estimated using equation 1 above. Using 120-watt LED lamp (double luminaire) per pole, for 12 hours daily, powered by a solar PV will require daily energy of
2.88kWh per pole using equation 1. Total daily demand \( (E_{td}) \) for 200 poles is 576kWh. The specifications of the LED solar lamp and and streetlight under this demand are shown in Table 4.

Table 4: LED Solar Lamp Specification per Pole and Energy Requirement

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power rating of LED Solar Lamp</td>
<td>120W</td>
</tr>
<tr>
<td>Number of LED Solar Lamp per Pole</td>
<td>2</td>
</tr>
<tr>
<td>Voltage</td>
<td>12-24VDC</td>
</tr>
<tr>
<td>Luminous Efficacy</td>
<td>80-110 lm/m²</td>
</tr>
<tr>
<td>Color Rendering Index (CRI)</td>
<td>&gt;75 Ra</td>
</tr>
<tr>
<td>Power Factor</td>
<td>&gt;95%</td>
</tr>
<tr>
<td>Life span</td>
<td>&gt;50,000 hrs</td>
</tr>
<tr>
<td>Grade</td>
<td>IP65</td>
</tr>
<tr>
<td>Product</td>
<td>Super Bright Solar, LED Lamp</td>
</tr>
<tr>
<td>Daily energy requirement/pole</td>
<td>2.88kWh/pole</td>
</tr>
<tr>
<td>Total daily energy requirement</td>
<td>576kWh</td>
</tr>
</tbody>
</table>

b) Battery Specification

The charge storage capacity, which is the energy storage capacity, of the battery bank \( (B_{cap}) \) is determined by the daily energy requirement and number of days for backup power i.e number of days of autonomy \( (N_{auto}) \) (2 days). This can be determined by using equation 2 above. The summary of the battery sizing is given in the Table 5 below.
Table 5: Battery summary per pole

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hours of usage</td>
<td>12 hours</td>
</tr>
<tr>
<td>Battery type</td>
<td>MIGHTY MAX</td>
</tr>
<tr>
<td>Each battery capacity</td>
<td>200AH</td>
</tr>
<tr>
<td>Operating voltage</td>
<td>12VDC</td>
</tr>
<tr>
<td>Autonomy (back up for rainy or cloudy days)</td>
<td>2 days</td>
</tr>
<tr>
<td>Required capacity of battery bank</td>
<td>600AH</td>
</tr>
<tr>
<td>Depth of discharge</td>
<td>80%</td>
</tr>
<tr>
<td>Total number of battery required per pole</td>
<td>3 batteries</td>
</tr>
<tr>
<td>Energy required to charge the battery per pole</td>
<td>12.71kWh</td>
</tr>
</tbody>
</table>

c) Solar PV specification

Solar PV array should be designed based on the energy requirement to charge the battery bank. Different parameters are required to design the solar PV array in cost effective manner. The specification and sizing of the solar PV is summarized in the following Table 6 below.
Table 6: solar module specification

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power rating per PV module</td>
<td>$180W_p$</td>
</tr>
<tr>
<td>Maximum working voltage</td>
<td>18V</td>
</tr>
<tr>
<td>Open circuit voltage</td>
<td>22V</td>
</tr>
<tr>
<td>Maximum working current</td>
<td>11.12A</td>
</tr>
<tr>
<td>Short circuit current</td>
<td>11.9A</td>
</tr>
<tr>
<td>Efficiency</td>
<td>17.7%</td>
</tr>
<tr>
<td>Technology</td>
<td>Grade A Monocrystalline CSUN SE cells, 4BB PV Solar module</td>
</tr>
<tr>
<td>Power tolerance</td>
<td>10%</td>
</tr>
<tr>
<td>Total Solar PV array capacity</td>
<td>685W per pole</td>
</tr>
<tr>
<td>Array voltage output (VPV)</td>
<td>12VDC</td>
</tr>
<tr>
<td>Array current output (IPV)</td>
<td>55.48A</td>
</tr>
<tr>
<td>Total no of module per pole</td>
<td>4</td>
</tr>
</tbody>
</table>

d) Spacing between two solar street light poles

In estimating the distance between poles in LED solar street light design, components of Light Loss Factor (LLF) have to be considered. The source performance degrades as part of the wear and tear from the use of the system or due to dirt and/or maintenance factors. These must be accurately accounted for in the lighting design in order to meet the energy reduction goals.
while maintaining or improving roadway safety [1]. Based on ANSI/IES RP-8-00, American National Standard Practice for Roadway Lighting the expression for LLF is given below as:

\[ LLF = LLD \times LDD \times LATF \times LCD \times HE \times VE \times BF \]  

(9)

where:

- \( LLD \) = lamp lumen depreciation
- \( LDD \) = lamp dirt depreciation
- \( LATF \) = luminaire ambient temperature effects
- \( LCD \) = luminaire component depreciation
- \( HE \) = heat extractional factors (optional)
- \( BF \) = ballast factors (optional)
- \( VE \) = voltage factors (optional)

The value of LLD is fixed based on the lamp type and is 0.70 for LED lamp i.e. the point at which lumen depreciation has reached 30%. LATF is based on ambient temperatures and is usually 1.0 for most installations. Also, the value of LDD depends on the installation environment as shown in Figure 7. If the light loss factor from one design to another differs by 5 percent, the design with the higher light loss factor would require 5 percent more initial equipment, 5 percent more energy to operate, and 5 percent more maintenance. This means that the light loss factor and therefore the LDD factor has a significant impact on the overall cost of the project, which can mean the difference between new technology insertion or continued use of legacy systems at higher energy costs [1]. Ballast factor is usually assumed to be 1.0. Since most
of the environments in which luminaires are placed are clean the luminaire component depreciation value is assumed to be 0.99.

![Figure 7: Luminaire Dirt Depreciation Factors Based on Time and Environment](image)

Lamp lumen depreciation factor ($LLD$) = 0.7

Luminaries dirt depreciation factor ($LDD$) = 0.9

luminaire ambient temperature effects ($LATF$) = 1

luminaire component depreciation ($LCD$) = 0.9

ballast factors $BF = 1$

Substituting these factors in equation 9 gives

$$LLF = 0.7 \times 0.9 \times 1 \times 0.9 \times 1 = 0.567$$

Now,

$$Spacing \ (S) = \frac{LL \times LLF}{E \times W_r} \quad (10)$$
Also,

\[ \text{Lamp wattage} = 100W \]
\[ \text{Lamp Lumen output (LL)} = 13200 \text{ lumen} \]
\[ \text{Lux level required (E)} = 30 \text{ lux} \]
\[ \text{Width of the road (W_r)} = 6.2m \]
\[ \text{Height of the pole (H)} = 10m \]

\[ S = \frac{13200 \times 0.567}{30 \times 6.2} = 402m \approx 40m < 8H \]

The design is considered excellent since the distance apart is not more than 8 times the height of the luminaires.

**5.0 Life Cycle Cost**

5.1 Life Cycle Cost for standalone solar powered LED Street light

The life cycle cost (LCC) method is employed in this work to determine the cost of the proposed stand-alone LED solar street light. The LCC of a system consists of the total costs of owning, maintaining and operating the system over its lifetime, expressed in today’s money [18-22] i.e all the future costs will be brought to present values so as to compare it with a base case.

The LCC of the stand alone solar street light includes the sum of all the present worths (PWs) of the costs of the PV modules, batteries, MPPT charger controllers, the cost of the installation, operation and maintenance (O&M) of the system. The lifetime \( N \) of all the PV system items is considered to be 25 years, except that of the battery which is considered to be 5
years. For estimating the LCC cost of the solar powered LED streetlights the under listed is assumed:

*Life time of galvanized steel pole* = 50 years

*Life time of solar panel* = 25 years

*Life time of LED lamp* > 10 years

*Life time of battery* = 5 years

*The life span of charge controller* > 10 years

*Inflation rate (if)* = 3%

*Discount or interest rate (ir)* = 6%.

a) Present Worth of Batteries

For the battery replacement, extra 4 groups of batteries (250AH, 800 pieces) would be purchased and replaced after 5 years, 10 years, 15 years and twenty years respectively.

Initial cost of batteries (*C*$_{bat}$ = 282,000)

The PW of the first, second, third and fourth battery replacement that would be purchased after N years i.e when N=5, 10, 15, 20 years is given by [18, 19, 20]:

$$C_{bat\,1\,PW} = C_{bat} \left( \frac{1+if}{1+ir} \right)^5$$

$$C_{bat\,2\,PW} = C_{bat} \left( \frac{1+if}{1+ir} \right)^{10}$$

$$C_{bat\,3\,PW} = C_{bat} \left( \frac{1+if}{1+ir} \right)^{15}$$

(11) (12) (13)
\[ C_{bat4PW} = C_{bat} \left(\frac{1+if}{1+i\rho}\right)^{20} \]  

(14)

where \( C_{bat} = \text{initial cost of 800 pieces of 200AH batteries} \)

b) Present worth of Controller

It is assumed that the controller would be replaced once throughout the lifetime of the project. The PW of controller after 12 years (\( C_{controllerPW} \)) i.e when \( N=12 \) years is given by:

\[ C_{controllerPW} = C_{controller} \left(\frac{1+if}{1+i\rho}\right)^{12} \]  

(15)

where \( C_{controller} = \text{initial cost of 12/24VDC, 48A 200 pieces charge controller} \)

c) Present worth of LED Lamp

It is assumed that LED lamp would be replaced once throughout the lifetime of the project i.e when \( N=13 \) years. The PW of the LED when \( N=13 \) years can be calculated using the expression:

\[ C_{LED1PW} = C_{LED} \left(\frac{1+if}{1+i\rho}\right)^{13} \]  

(16)

where \( C_{LED} = \text{initial cost of 400 pieces of 120W, 12-24VDC LED lamp} \)

d) Other costs

Other costs (\( C_{others} \)) are those for the following: battery box (\( C_{box} \)); 4mm\(^2\), double core flexible copper conductor cable (\( C_{cab} \)); 10m double arm galvanized steel pole (\( C_{pol} \)); complete
concrete reinforcement (cement, iron rod, sand, excavation plank, nails, bolts and nuts, water) $C_{\text{reinforcement}}$, miscellaneous ($C_{\text{msl}}$) and solar rack $C_{\text{srk}}$

$$C_{\text{others}} = C_{\text{box}} + C_{\text{cab}} + C_{\text{pol}} + C_{\text{srk}} + C_{\text{rfc}} + C_{\text{lab}} + C_{\text{msl}}$$  \hspace{1cm} (17)

e) Installation cost

The installation cost ($C_{\text{install}}$) is assumed to be 10 percent of total PV cost ($C_{\text{SPV}}$)

f) Cost of Solar PV module

This is once investment in 25 years. The cost is indicated as $C_{\text{SPV}}$

g) Present Worth of Maintenance Cost

The PW of the maintenance cost can be estimated using maintenance cost per year ($M_{\text{yr}}$) and the lifespan of the project which is 25 years as modified from [18, 20]:

$$C_{\text{MPW}} = \frac{M}{\text{yr}} \left( \frac{1+if}{1+ir} \right) \left[ \frac{1-(1+if)^N}{1-(1+ir)^N} \right]$$  \hspace{1cm} (18)

where $\frac{M}{\text{yr}}$ is assumed to be 2% of the total PV cost

h) Life cycle cost

The LCC of the stand alone LED solar street light can be calculated by:
\[ LCC = C_{SPV} + C_{bat} + C_{bat\,1PW} + C_{bat\,2PW} + C_{bat\,3PW} + C_{bat\,4PW} + C_{controller} + C_{controller\,PW} + \\
C_{LED} + C_{LED\,PW} + C_{others} + C_{install} + C_{MPW} \quad (19) \]

Also, the Annualized Life Cycle Cost (ALCC) of the stand alone LED solar street light in terms of the present day dollars can be calculated, using the following equation [16, 17]:

\[ ALCC = LCC \left[ \frac{1 - \left(1 + \frac{1}{1 + r}\right)^{-N}}{1 - \left(1 + \frac{1}{1 + r}\right)^{-1}} \right] \quad (20) \]

The cost of energy (COE) which is the constant price per unit of energy i.e cost of 1kWh of energy can be calculated using the following equation:

i) Energy cost

\[ COE(kWh) = \frac{ALCC}{365E_{id}} \quad (21) \]

5.2 Conventional Street light

a) Components procuring and installation costs (Initial investment cost)

The components needed for conventional streetlight are:

i. High pressure sodium lamp
ii. Galvanize steel pole
iii. 3-phase transformer
iv. Armored cable

v. Labour/Installation

vi. Concrete bases

b) Maintenance costs

The maintenance cost of the conventional streetlight includes the cost of replacement of high pressure sodium vapor lamp and wages of workers. The average lifespan of the high pressure vapor lamps is assumed to be five year HPSL would be replaced four times throughout the lifetime of the project i.e when \( N = 5, 10, 15, 20 \) years. The PW of the HPSL when throughout the life span of the project can be calculated using the expression:

\[
C_{\text{HPSL} \, 1PW} = C_{\text{HPSL}} \left( \frac{1+if}{1+ir} \right)^5
\]

\[
C_{\text{HPSL} \, 2PW} = C_{\text{HPSL}} \left( \frac{1+if}{1+ir} \right)^{10}
\]

\[
C_{\text{HPSL} \, 3PW} = C_{\text{HPSL}} \left( \frac{1+if}{1+ir} \right)^{15}
\]

\[
C_{\text{HPSL} \, 4PW} = C_{\text{HPSL}} \left( \frac{1+if}{1+ir} \right)^{20}
\]

where \( C_{\text{HPSL}} = \text{initial cost of 400 pieces of HPSL 250W, 220VAC} \)

Likewise, the PW of workers’ wages throughout the life span of the project for the replacement of the lamps when \( N = 5, 10, 15 \) and 20 years can be calculated using the following expression. The total cost of maintenance of conventional streetlight is shown in Table 10

\[
C_{\text{wages} \, 1PW} = C_{\text{wages}} \left( \frac{1+if}{1+ir} \right)^5
\]
\[ C_{\text{wages 2PW}} = C_{\text{wages}} \left( \frac{1+if}{1+ir} \right)^{10} \]  
(27)

\[ C_{\text{wages 3PW}} = C_{\text{wages}} \left( \frac{1+if}{1+ir} \right)^{15} \]  
(28)

\[ C_{\text{wages 4PW}} = C_{\text{wages}} \left( \frac{1+if}{1+ir} \right)^{20} \]  
(29)

c) Cost of transformer losses

The losses at rated voltage for various ratings of transformers of 11 kV class are as shown below subject to tolerance as per relevant IS and are calculated at 75°C as per limits specified in IS 2026 [23].

<table>
<thead>
<tr>
<th>Voltage Ratio in Volts</th>
<th>kVA Ratings</th>
<th>No load losses in watts</th>
<th>Losses in watts</th>
</tr>
</thead>
<tbody>
<tr>
<td>11000/433</td>
<td>200</td>
<td>550</td>
<td>2800</td>
</tr>
<tr>
<td>11000/433</td>
<td>315</td>
<td>950</td>
<td>3800</td>
</tr>
<tr>
<td>11000/433</td>
<td>630</td>
<td>1600</td>
<td>6000</td>
</tr>
</tbody>
</table>

From the above table,

\[ \text{Total energy losses} = \text{No load losses} + \text{load losses} \]

\[ PW \text{ of total energy losses} = PW \text{ of no load losses} + PW \text{ of load losses} \]

And the resent worth of energy losses is calculated as
\[ PW \text{ of total energy losses for 25 years} = \sum_{n=1}^{25} 626 \left( \frac{1+if}{1+ir} \right)^n + 3189 \sum_{n=1}^{25} \left( \frac{1+if}{1+ir} \right)^n \]

\[ = $67,085 \]

d) Energy consumption cost

The total energy demand for the conventional street light using 250W High Pressure Sodium Vapor Lamp (HPSV) can be estimated using equation 22 below. Using 250-watt HPSV lamp (double luminaires) per pole, for 12 hours daily, powered by main electric grid will required daily energy of 6kWh per pole. Total daily demand \( E_{\text{total con}} \) for 200 poles is 1200kWh. The main components of expenditure that would be considered for the conventional streetlight design are: the cost of procuring products, installation costs, the energy consumption cost Operating and Maintenance costs, transformer energy losses.

\[ E_{\text{total con}} (\text{kWh}) = N_{\text{unit}} \times P (\text{W}) \times t (\text{h}) \times 10^{-3} \quad (30) \]

where:

\( E_{\text{total con}} = \text{the total daily energy demand for the conventional streetlight} \)

\( N_{\text{unit}} = \text{number of units} \)

\( t = \text{hour of operation} \)

\( P = \text{rated power of the lamp} \)

The cost of a unit of energy for street light is USD 0.13/kWh (IBEDC, 2016). The cost of electricity per pole per day will be USD 0.78. The cost for total daily demand for all the light poles will be USD 156 per day. The total cost of electricity in one year (365 days) is USD 56,940
\[ PW \text{ cost of energy for 25 years (\$)} = \sum_{n=1}^{25} 56940 \left( \frac{1+if}{1+ir} \right)^n \]

\[ = \sum_{n=1}^{25} 56940 (0.9717)^n = 1,001,256 \]

e) life cycle cost

The life cycle cost (LCC) of conventional streetlight in present worth is the sum of: initial investment cost, energy consumption cost, transformer energy losses and maintenance cost.

6.0 Results and Discussions

6.1 Results for LED Solar Streetlight

The life circle cost of LED Solar Streetlight for the lifespan of 25 years which comprises of initial investment cost, replacement, operation and maintenance cost throughout the lifetime of the project and the cost of energy is summarized in Table 7.

Table 7: Life Cycle Cost of LED Solar Streetlight

<table>
<thead>
<tr>
<th>S/N.</th>
<th>Description of materials with full specification</th>
<th>Quantity</th>
<th>Rate $</th>
<th>Amount $</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Initial Investment Cost</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.</td>
<td>Complete Super Bright Solar Lamp120W, 12-24VDC, LED, 80-</td>
<td>400</td>
<td>207</td>
<td>82,800</td>
<td>2 per pole</td>
</tr>
<tr>
<td></td>
<td>Description</td>
<td>Quantity</td>
<td>Unit Price</td>
<td>Total Price</td>
<td>Notes</td>
</tr>
<tr>
<td>---</td>
<td>-----------------------------------------------------------------------------</td>
<td>----------</td>
<td>------------</td>
<td>-------------</td>
<td>--------------------------------------------</td>
</tr>
<tr>
<td>1</td>
<td>110 lm/m², &gt;75 Ra, power factor &gt;95%, life span, &gt;50,000 hrs</td>
<td></td>
<td></td>
<td></td>
<td>(Zhongshan Huijian Photoelectric Technology Co., Ltd.)</td>
</tr>
<tr>
<td>2</td>
<td>200 AH, 12 VDC, Deep cycle sealed AGM battery, MIGHTY MAX</td>
<td>600</td>
<td>349.99</td>
<td>209,994</td>
<td>3 batteries per pole</td>
</tr>
<tr>
<td>3</td>
<td>180 Wp, 18 V DC 4 BB PV Solar module</td>
<td>800</td>
<td>79.2</td>
<td>63,360</td>
<td>4 modules per pole</td>
</tr>
<tr>
<td>4</td>
<td>12/24 VDC, 48 A MPPT Solar charge controller</td>
<td>200</td>
<td>250</td>
<td>50,000</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>4 mm², double core flexible copper conductor cable</td>
<td>400m</td>
<td>1.25</td>
<td>500</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>10 m, double arm galvanized steel pole</td>
<td>200</td>
<td>250</td>
<td>50,000</td>
<td>Each arm should be of 1.3 m extension</td>
</tr>
<tr>
<td>7</td>
<td>Battery box</td>
<td>400</td>
<td>50</td>
<td>20,000</td>
<td>2 box per pole</td>
</tr>
<tr>
<td>8</td>
<td>Solar rack</td>
<td>200</td>
<td>90</td>
<td>18,000</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Complete concrete reinforcement (cement, iron rod, sand, excavation plank, nails, bolts and nuts, water)</td>
<td>200</td>
<td>75</td>
<td>15,000</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Labour cost</td>
<td>200</td>
<td>100</td>
<td>2,000</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Installation cost</td>
<td>200</td>
<td>16,800</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Initial Investment Cost**

528,454
B.  

<table>
<thead>
<tr>
<th></th>
<th>Replacement, Operation and Maintenance Cost throughout the lifetime of the project</th>
<th>3200</th>
<th>594, 281</th>
<th>Eqn. (11+12+13+14)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Replacement of 200AH, 12 VDC, Deep cycle sealed AGM battery, MIGHTY MAX for every five years throughout the life span of the system (25 years)</td>
<td>800</td>
<td>57, 010</td>
<td>Eqn. 16</td>
</tr>
<tr>
<td>2.</td>
<td>Replacement of Complete Super Bright Solar Lamp120W, 12-24VDC, LED, once throughout the life span of the system (25 years)</td>
<td>200</td>
<td>35, 429</td>
<td>Eqn. 15</td>
</tr>
<tr>
<td>3.</td>
<td>Replacement 12/24 VDC, 48A MPPT Solar charge controller once throughout the life span of the system (25 years)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td>Present Worth of Maintenance Cost</td>
<td></td>
<td>59, 080</td>
<td>Eqn. 18</td>
</tr>
</tbody>
</table>

C.  

<table>
<thead>
<tr>
<th></th>
<th>Life Cycle Cost</th>
<th>1, 274, 254</th>
<th>Eqn. 19</th>
</tr>
</thead>
</table>

D.  

<table>
<thead>
<tr>
<th></th>
<th>Annualized Life Cycle Cost</th>
<th>70, 419</th>
<th>Eqn. 20</th>
</tr>
</thead>
</table>

E.  

<table>
<thead>
<tr>
<th></th>
<th>COE</th>
<th>0.33/kWh</th>
<th>Eqn. 21</th>
</tr>
</thead>
</table>


6.2 Results for conventional streetlight

The initial investment cost and total cost of maintenance of conventional streetlight are shown in Table 8 and 9 respectively. The results for the life cycle cost of conventional streetlight using high pressure vapor sodium vapor lamp which comprises of initial investment cost, total cost of maintenance cost (replacement cost + workers wages), energy consumption cost is estimated as USD 1, 567, 928.

Table 8: Initial Investment Cost

<table>
<thead>
<tr>
<th>S/N.</th>
<th>Description of materials with full specification</th>
<th>Quantity</th>
<th>Rate $</th>
<th>Amount $</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>250W, 220V AC High Pressure Sodium Lamps</td>
<td>400</td>
<td>210</td>
<td>84,000</td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>10m, double arm galvanized steel pole.</td>
<td>200</td>
<td>250</td>
<td>50,000</td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td>200kVA, 11/.415kV, 3-Phase Transformer</td>
<td>1</td>
<td>4,800</td>
<td>4,800</td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td>Materials required for the installation of transformer (including rod earthing, basement and three phase energy meter)</td>
<td></td>
<td></td>
<td>7,000</td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td>4-core 35mm$^2$ copper</td>
<td>8400mtrs</td>
<td>2</td>
<td>16,800</td>
<td>To</td>
</tr>
<tr>
<td>S/N</td>
<td>Description of materials with full specification</td>
<td>Quantity</td>
<td>Rate $</td>
<td>Amount $</td>
<td>Remarks</td>
</tr>
<tr>
<td>-----</td>
<td>-------------------------------------------------</td>
<td>----------</td>
<td>--------</td>
<td>----------</td>
<td>---------</td>
</tr>
<tr>
<td>1.</td>
<td>Replacement of complete High Pressure Sodium Vapor Lamp (four times) throughout the life span of the system (25 years)</td>
<td>1600</td>
<td></td>
<td>237,732</td>
<td>Eqn.(22+23+24+25)</td>
</tr>
<tr>
<td>2.</td>
<td>Present worth of workers’ wages for the</td>
<td>1600</td>
<td></td>
<td>2,264</td>
<td>$20/pole for the cost of installation.</td>
</tr>
</tbody>
</table>

Table 9: Total Cost of Maintenance of Conventional Streetlight

6. Labor cost
   | 200 | 200 | 40,000 |
7. Installation cost
   | 200 | 200 | 40,000 |
8. Complete concrete reinforcement (cement, iron rod, sand, excavation plank, nails, bolts and nuts, water) per pole.
   | 200 | 100 | 20,000 |
9. Initial investment cost
   |        |        | 259,600 |
replacement of lamps throughout the life time of the project (25 years) |  |  | Eqn. (26+27+2+29)

| Total cost of maintenance cost (replacement cost + workers wages) |  |  | 239,987 |

6.3 Comparison of life cycle cost of LED solar streetlight and conventional streetlight

The results reveals that for the design life of the project (25rys) the solar power system is more viable at a LCC of **USD 1,274,254** against **USD 1,567,928** for conventional power. The solar photovoltaic investment generate saving of **USD 293,674**.

6.4 Electrical Energy Savings

The amount of energy consumed if the conventional street lights in the study area are to be replaced by LED lights is estimated in this section. For a total of 400 HPSL light fittings of 250 Watts rated power each and hour of operation of 12 hours daily. The annual energy consumption by the conventional street lights is given below.

\[
\text{annual energy consumption} = 400 \times 250 \times 12 \times 365
\]

\[
= 438000kWh/yr = 438MWh/yr
\]

Which implies that **438MWh/yr** of energy will be saved if all 200 poles double luminaries grid connected streetlights are converted to solar powered LED streetlights.
6.5 Environmental analysis

Petroleum-based products are one of the main causes of anthropogenic carbon dioxide (CO₂) emissions to the atmosphere [24-25]. Electrical energy saving for 1 kWh = 0.8 ~ 0.9 kg CO₂. [26]. Hence:

\[\text{total CO}_2 \text{ that would be saved a year} = 394200kg \text{ CO}_2\]

\[\text{total CO}_2 \text{ that would be saved throughout the life span of the project (25yrs)} = 9855000kg\text{CO}_2\]

From environmental perspective, from the present case studied, conventional streetlight only released in the nature 394200kg CO₂ during a year, and 9855000kgCO₂ throughout the life time of the project. Converting the conventional streetlight to LED solar streetlight would save emission of about 394200kg CO₂ annually.

6.6 Technical capabilities of LED solar streetlight

Color Rendering Index and the Correlated Color Temperature of the LED lamps are higher than that of the High Pressure Sodium lamps being used at the study area. The recommended LED provides whiter and brighter lights as against the yellow lights provided by the conventional HPS.
Conclusions

The economic and environmental points of view have shown solar LED streetlight system benefits are higher as compared to the conventional streetlight. Also, with rapid improvement in luminous efficacy of LED lamps and reduction in the price of solar modules, the LCC of solar LED streetlight would be more and cheaper. The energy saved by converting the traditional streetlight to LED solar streetlight can be diverted into other sectors to meet up with energy deficit.

In the context of energy crisis, climate change and with the belief that reserve of fossil fuel cannot sustain the development in the future, converting the conventional streetlight in the country to solar powered LED streetlight will greatly increase savings in energy and eliminate high maintenance cost associated with conventional street lighting. Also, in the environmental point of view, there will be savings in CO₂ emissions since negligible emissions are released into the atmosphere by using solar modules. In conclusion, the solar powered LED lights are viable solution in terms of emissions, cost and continuity of supply.
**Appendix A: Features of Streetlight Projects in the City of Ilorin**

<table>
<thead>
<tr>
<th>S/N</th>
<th>Location of the Streetlight Project in Ilorin</th>
<th>Number of Poles</th>
<th>Height of the Pole (m)</th>
<th>Types of Lamp used (Sodium vapor, Mercury vapor lamp, Metal Halide e.t.c)</th>
<th>Number of Luminaire per pole (single or double)</th>
<th>Power Rating of the lamp (W)</th>
<th>Distance between the poles</th>
<th>Types of street (Main, Residential, Federal Highway)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Offa Garage to Challenge round about</td>
<td>200</td>
<td>10</td>
<td>High Pressure Sodium Lamp</td>
<td>Double</td>
<td>250</td>
<td>40</td>
<td>Main</td>
</tr>
<tr>
<td>2.</td>
<td>Unity Road</td>
<td>27</td>
<td>8</td>
<td>High Pressure Sodium Lamp</td>
<td>Double</td>
<td>250</td>
<td>40</td>
<td>Main</td>
</tr>
<tr>
<td>3.</td>
<td>Upper Taiwo Road</td>
<td>62</td>
<td>10</td>
<td>High Pressure Sodium Lamp</td>
<td>Double</td>
<td>250</td>
<td>40</td>
<td>Main</td>
</tr>
<tr>
<td>4.</td>
<td>Lower Taiwo to Post Office Bridge</td>
<td>31</td>
<td>10</td>
<td>High Pressure Sodium Lamp</td>
<td>Double</td>
<td>250</td>
<td>40</td>
<td>Main</td>
</tr>
<tr>
<td>5.</td>
<td>Lower Taiwo to Balogun Fulani Road</td>
<td>35</td>
<td>8</td>
<td>High Pressure Sodium Lamp</td>
<td>Double</td>
<td>250</td>
<td>40</td>
<td>Residential</td>
</tr>
<tr>
<td>6.</td>
<td>Gerialimi to General Hospital</td>
<td>64</td>
<td>10</td>
<td>High Pressure Sodium Lamp</td>
<td>Double</td>
<td>250</td>
<td>40</td>
<td>Main</td>
</tr>
<tr>
<td>Round-about</td>
<td>Distance</td>
<td>Area</td>
<td>Lamp Type</td>
<td>Quantity</td>
<td>Power</td>
<td>Notes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-------------</td>
<td>----------</td>
<td>------</td>
<td>-----------</td>
<td>----------</td>
<td>-------</td>
<td>-------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Tanke to University of Ilorin Road</td>
<td>176</td>
<td>10</td>
<td>High Pressure Sodium Lamp</td>
<td>Double</td>
<td>250</td>
<td>40</td>
<td>Main</td>
<td></td>
</tr>
<tr>
<td>8. Gerialimi to Eyenkorin Road</td>
<td>144</td>
<td>12</td>
<td>High Pressure Sodium Lamp</td>
<td>Double</td>
<td>250</td>
<td>40</td>
<td>Federal Highway</td>
<td></td>
</tr>
<tr>
<td>9. Ita Amodu to Oja Oba Round-about</td>
<td>42</td>
<td>8</td>
<td>High Pressure Sodium Lamp</td>
<td>Single</td>
<td>250</td>
<td>40</td>
<td>Residential</td>
<td></td>
</tr>
<tr>
<td>10. Oja Oba Round-about to General Hospital Round-about</td>
<td>78</td>
<td>10</td>
<td>High Pressure Sodium Lamp</td>
<td>Double</td>
<td>250</td>
<td>40</td>
<td>Main</td>
<td></td>
</tr>
<tr>
<td>11. Niger Road</td>
<td>15</td>
<td>8</td>
<td>High Pressure Sodium Lamp</td>
<td>Single</td>
<td>250</td>
<td>40</td>
<td>Residential</td>
<td></td>
</tr>
<tr>
<td>12. Gerialimi to Adam Road</td>
<td>67</td>
<td>10</td>
<td>High Pressure Sodium Lamp</td>
<td>Double</td>
<td>250</td>
<td>40</td>
<td>Main</td>
<td></td>
</tr>
<tr>
<td>13. Irewolede to Unity Road</td>
<td>100</td>
<td>10</td>
<td>High Pressure Sodium Lamp</td>
<td>Double</td>
<td>250</td>
<td>40</td>
<td>Main</td>
<td></td>
</tr>
<tr>
<td>14. Challenge to Sango Road</td>
<td>84</td>
<td>10</td>
<td>High Pressure Sodium Lamp</td>
<td>Double</td>
<td>250</td>
<td>40</td>
<td>Main</td>
<td></td>
</tr>
<tr>
<td>No.</td>
<td>Route Description</td>
<td>Distance</td>
<td>Traffic</td>
<td>Lamp Type</td>
<td>Type</td>
<td>Power</td>
<td>Life (Hrs)</td>
<td>Residency</td>
</tr>
<tr>
<td>-----</td>
<td>-----------------------------------</td>
<td>----------</td>
<td>---------</td>
<td>--------------------</td>
<td>--------</td>
<td>-------</td>
<td>------------</td>
<td>-----------</td>
</tr>
<tr>
<td>15</td>
<td>Fate/Government House to Challenge Junction Road</td>
<td>155</td>
<td>8</td>
<td>High Pressure Sodium Lamp</td>
<td>Double</td>
<td>250</td>
<td>40</td>
<td>Main</td>
</tr>
<tr>
<td>16</td>
<td>State Library to Post Office Road</td>
<td>13</td>
<td>8</td>
<td>High Pressure Sodium Lamp</td>
<td>Double</td>
<td>250</td>
<td>40</td>
<td>Main</td>
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<tr>
<td>17</td>
<td>Post Office Bridge</td>
<td>53</td>
<td>10</td>
<td>High Pressure Sodium Lamp</td>
<td>Single</td>
<td>250</td>
<td>40</td>
<td>Main</td>
</tr>
<tr>
<td>18</td>
<td>A-Division to Post Office Bridge</td>
<td>19</td>
<td>10</td>
<td>High Pressure Sodium Lamp</td>
<td>Double</td>
<td>250</td>
<td>40</td>
<td>Main</td>
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<td>39</td>
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<td>250</td>
<td>40</td>
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<tr>
<td>20</td>
<td>Ojagboro to Gambari Junction</td>
<td>65</td>
<td>8</td>
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<td>Double</td>
<td>250</td>
<td>40</td>
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<td>21</td>
<td>Emir’s Road to Gambari Junction</td>
<td>24</td>
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<td>250</td>
<td>40</td>
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<tr>
<td>22</td>
<td>Pakata to Oke Pakata Road</td>
<td>65</td>
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<td>Single</td>
<td>250</td>
<td>40</td>
<td>Residential</td>
</tr>
<tr>
<td>No.</td>
<td>Location</td>
<td>Length</td>
<td>Width</td>
<td>Lamp Type</td>
<td>Quantity</td>
<td>Rating</td>
<td>Notes</td>
<td></td>
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<tr>
<td>-----</td>
<td>----------------------------------</td>
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<td></td>
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<td>Omoda to Oloje Road</td>
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<td>Double</td>
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<td>26</td>
<td>Ojatuntun Road</td>
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<td>10</td>
<td>High Pressure Sodium Lamp</td>
<td>Double</td>
<td>250</td>
<td>Main</td>
<td></td>
</tr>
<tr>
<td>27</td>
<td>Olorunsogo to mandate Road</td>
<td>73</td>
<td>10</td>
<td>High Pressure Sodium Lamp</td>
<td>Double</td>
<td>250</td>
<td>Main</td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>General Hospital Complex</td>
<td>40</td>
<td>8</td>
<td>High Pressure Sodium Lamp</td>
<td>Double</td>
<td>250</td>
<td>Residential</td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>General Hospital Complex</td>
<td>35</td>
<td>8</td>
<td>High Pressure Sodium Lamp</td>
<td>Single</td>
<td>250</td>
<td>Residential</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>Adewole to Adeta junction</td>
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<td>8</td>
<td>High Pressure Sodium Lamp</td>
<td>Double</td>
<td>250</td>
<td>Residential</td>
<td></td>
</tr>
<tr>
<td>31</td>
<td>Henry George to Adewole Road</td>
<td>30</td>
<td>8</td>
<td>High Pressure Sodium Lamp</td>
<td>Double</td>
<td>250</td>
<td>Residential</td>
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</tr>
<tr>
<td>32</td>
<td>Federal Staff School Road</td>
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<td>8</td>
<td>High Pressure Sodium Lamp</td>
<td>Double</td>
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<td>Residential</td>
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</tr>
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<td>33</td>
<td>RHEMA Chapel</td>
<td>51</td>
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<td>Single</td>
<td>250</td>
<td>Residential</td>
<td></td>
</tr>
</tbody>
</table>
### References


