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Carbon and Energy Pay Back Period for the Solar Street Light using Life Cycle Assessment

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Abstract: Electronic street lights are big consumers of energy, costing millions to cities and municipalities around the world. Solar Street light is one of the method to reduce the power consumption by generate the energy using the solar Photovoltaic panel. This system includes the power generators (panel), storage (batteries) and management (controller) as well as the light, poles and weather proof housing for batteries. Life cycle inventories are based on manufacturers data combined with additional calculation and assumption. The Life Cycle Assessment (LCA) methodology used in this research was based on the ISO 14040 and 14044 series. In this paper, the LCA method is used to investigate the environmental impacts of two types of street light technology, conventional street light and solar street light. The cradle to grave analysis for conventional and solar street light includes raw material extraction, production, uses and end of life scenario. The detail investigation has made for the existing solar street light present at Gandhigram Rural University, Dindigul Dist, Tamil Nadu. The specification of the solar street light is 80W capacity, 1.2 m^2 area of panel and 135Ah - 12V battery. The total no of poles is 70. For the above system carbon intensity, Energy Pay Back Period and Carbon Pay Back Period have been calculated and compared with conventional street light. The result from the study will support local decision makers when seeking a balance between the environmental, financial and social requirements of public lighting services.
Keyword – Life Cycle Assessment, Solar Street light, Conventional Street light, Carbon Intensity, Energy Pay Back Period, Carbon Pay Back Period, Cost Pay Back Period.

1. Introduction

Lighting represents almost 20% of global electricity consumption. This consumption is similar to the amount of electricity generated by nuclear power. The latest IEA estimates show the total savings potential in residential and services lighting at more than 2.4 EJ per year by 2030. Recently, several cities have sought to reduce energy use and emissions by replacing their aging streetlights with newer technology. Streets were first illuminated with gas or oil lamps. In 1875, Pavel Yablochkov invented the carbon arc lamp and Thomas Edison improved on the lifespan and light quality of the carbon arc lamp with the incandescent lamp in 1879. Shortly before the turn of the century, there were more than 130,000 streetlights installed in the United States. These lamps operate by heating electrodes or a filament with an electric current, causing it to glow. Improvements in light output occurred through the twentieth century with the introduction of high-intensity-discharge (HID) lamps including the mercury vapor lamp in 1938 and the high-pressure sodium lamps. HID lamps create light by exciting a gas with an electric current passed between metal electrodes. Light is emitted when electrons move from high to low energy states, emitting a specific frequency, or color, of light. This wavelength produces the familiar orange glow of HPS lamps [1]. In spite of this unsatisfactory light color, HID remains the most common type of street light in use today; 90% of roadway lights are HPS or some other form of HID [2].

Fluorescent lamps were developed in 1938. The compact fluorescent variety have existed in various formats since the 1970s.[3]. The CFL is a more complex device than the incandescent. As shown in figure 1, a typical CFL consists of an electronic starter circuit and a phosphor lined tube, filled with argon and a small amount (5- 10mg) of mercury vapor [4]. High voltage electricity is used to excite (ionize) the mercury vapor which then radiates ultra violet light. The UV light is converted to the visible spectrum by a fluorescent coating inside the tube [5]. Recent advances have brought CFL's closer to a broad spectrum light, but the light is typically considered to be of a less quality than that of an incandescent.[6] The greatest advantage of CFLs is found in its energy efficiency during use, with much less energy lost to heat. CFLs typically convert about 45% of the electricity to visible light [6].

The renewable energy technologies like solar PV and Wind energy is combined with energy storage systems which improve their usefulness as electric power sources. In remote places, an autonomous electrical system may be less expensive, have greater efficiency and less impact on the environment than if the load has to be connected to a high capacity grid [7]. To assess the environmental characteristics of energy storage in batteries, the efficiency and the environmental impact during the life cycle of the battery has to be considered. Several authors [8–10] have made life cycle assessments of lead-acid batteries as well as other batteries to be used in electric vehicles. The energy and environmental impacts of lead-acid batteries have also been studied [11]. In this paper the battery has been used for storing the energy produced for the solar PV in the solar street light.

In order to reduce this conventional energy use, and just after new types of lights and lamps appeared, other street lights have been studied and used with different success. For example, solar powered [12, 13] or wind energy street lights [14] have been developed. Hybrid systems have been introduced, using few renewable energy resources for street lighting [15, 16]. These different products are probably the sign of a new market for street lighting using exclusively renewable energy.

This research presents the case study of the pilot project for changing the technology of street light in the Gandhigram Rural University. It is based on life cycle assessment methods, revealing the difference between the environmental impacts of these two technologies, solar street light and conventional street light. This study focuses on the manufacturing, operations and end of life both technologies and evaluating them according to their environmental impacts. Carbon intensity of solar street light has been calculated in order to find the Carbon Payback Period.

2. Methodology

2.1Life Cycle Assessment

The life cycle assessment is based on the ISO 14040 standard, and includes a goal and scope, life cycle inventory (LCI), life cycle impact assessment (LCIA), and interpretation [17]. LCA has been used in many industries since the early 1990"s to gage the environmental impact of the entire life cycle of a product including manufacture, use, and disposal. LCA is based on an inventory of the inputs of the raw materials, capital goods, factories, transportation, and energy and fuels needed to create a product. [18]. Figure 1 shows the life cycle stages. The input, modification, and emissions of energy and materials are known as process flows.

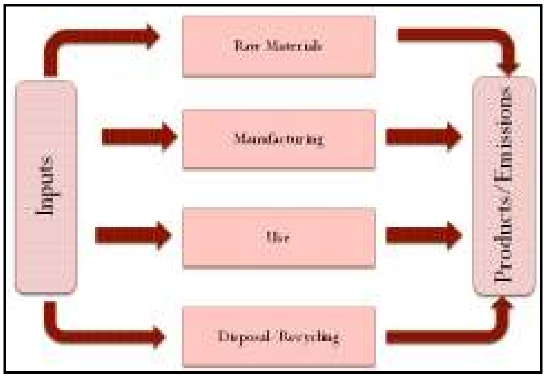

Figure 1 Stage wise life cycle assessment

Streetlights are expected to create the most emissions of their life cycle during their use phase because they use a large amount of electricity, produced by burning coal, relative to the energy and materials used in production. In contrast, a personal computer requires more energy during the manufacturing phase than is expected to be used during the use phase. [19]

The comparative LCA section describes the goal and scope and the databases, modeling, and assessment methods used to evaluate the technologies. The lifecycle inventory section describes the data collected and the models built from the data using the chosen methods.

The impacts of the technologies in three impact categories are given in the results section. The technologies are compared on a one-to-one replacement with HPS lights, since they are the most common currently installed technology.

2.2 Objectives of the study, the functional unit and system boundaries

The objectives of this study was to evaluate the life-cycle environmental impacts of the public lighting service process for two different technologies (solar street light and conventional street light , including their comparison from the environmental perspective, during all the phases mentioned above (production, operation, and end-of-life). This was in order to help local decision makers to find a balance between environmental and financial requirements based on the energy consumption. The systems under consideration were street light in the Gandhigram Rural University. The total 70 nos of solar street light has installed in the campus by replacing the conventional street light. The system has considered the 74 Watts solar panel, 11w CFL lamb, 150Ah, 12v Battery and street light pole with 4 meter height. The functional unit is to provide the 900 luminous lighting to the inside the university.

3. Result and Discussion

3.1 Material inventory

Based on the available data, the material inventory for solar street light is divided into four components: solar panel, Pole, Battery and lamp. Figure 2 shows the graphical representation of the material consumption of single solar street light system. The material consumption per solar street light is shown clearly in the figure. Battery and pole are equally contributes 45% and solar panel contributes 10 % of the overall weight. The weight of the CFL contribution is negligibale.

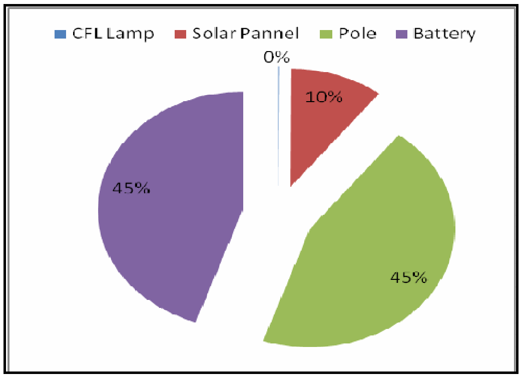

Figure 2 Material inventories for the solar street light

3.2 Energy inventory

The energy consumption of the solar street light is shown figure 3. From the graph the maximum energy is consumed by solar panel manufacturing followed by battery and pole. Comparing the other component the CFL is consumed negligible amount of energy. The recycling potential is high in the battery and steel material. Nearly 36 % of primary energy can be saved by recycling of the material. It is clearly indicate in the figure 3.

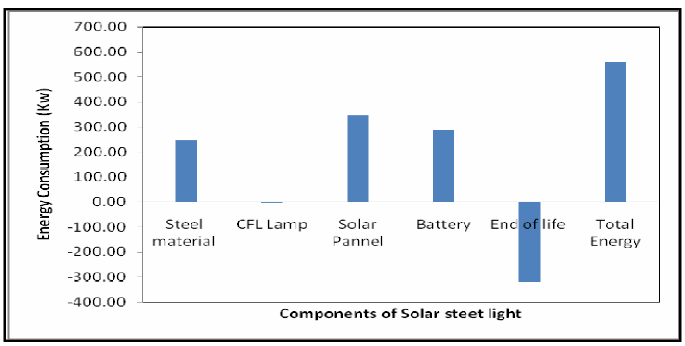

Figure 3 Energy inventory for the solar street light

3.3 Carbon inventory

Among the various environmental impacts, in this paper considers the carbon emission from the various activities in the life cycle of the solar street light. From the graphical representation of figure 4, the maximum carbon emission is accounted in the manufacturing of solar panel. The pole and battery has contributing equally. Nearly 43% of carbon can be saved in the recycling of solar street light components.

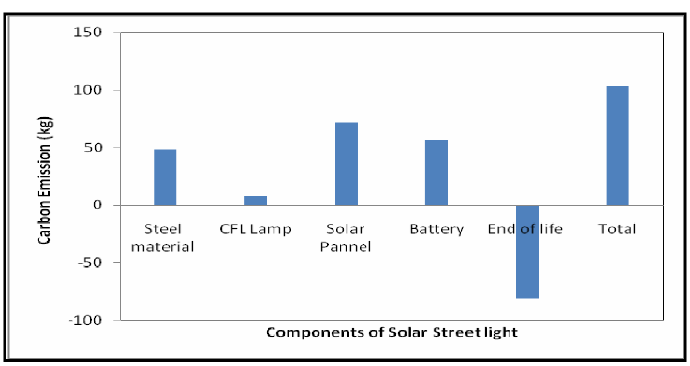

Figure 4 Carbon inventory for solar street light

3.4Energy Payback Period (EPBP)

Energy Payback Period is nothing but, a measure of how long a process needs to run to compensate the energy consumed by the system in a life cycle stage. The EPBP has been calculated using the equation 1. From the table 1 the EPBP for the 74W solar street light is 10 years.

$$EnergyPaybackPeriod = \frac{EnergyConsumedPerSolarStreetlight(KW)}{Energysavedbysolarstreetlightperyear(KW)}$$

Table 1 EPBP for the Solar Street light

Life cycle energy consumption per street light (KW)	Energy saved by street light (KW per year)	EPBP (Year)
562.25	56.21	10.00

3.5Carbon payback period (CPBP)

Carbon Pay Back Period is nothing but, a measure of how long a CO2 mitigating process needs to run to compensate the CO2 emitted to the atmosphere during a life cycle stage. The average light hours of street light is considered as 14 hour. The CPBP has been estimated using the equation no 2. 74W solar street light is required to run 2 years to recover from the carbon emitted during the life cycle stage.

$$CPBP = \frac{LifeCycleCO_2emission}{GrossCO_2emissionavoidedperYear}$$

Table 2 CPBP for the Solar Street light

Life cycle carbon emission per street light (kg)	Power saving during the operation of solar street light(KW per year)	Carbon emission based on the conventional power production (kg/KW)	Carbon emission avoided per year	CPBP (Year)
103.24	56.21	0.926	52.05	2.0

3.6Comparison of Solar street light and conventional street light

When considering the conventional street light, battery and solar panel will not applicable to the system. All the energy consumption and carbon emission of the two components can be avoided in the life cycle. In addition to that, 56 KW/year power will be consumed at the time of operation. Table no 3 give the clear picture of comparison of the conventional street light and solar street light. When considering energy beyond 9.5 year of operation conventional street light consuming addition energy. When considering the carbon emission beyond 1.5 year of operation will count the carbon emission.

Table 3 Comparison of solar street light and conventional street light

Life cycle energy consumption of Solar panel & Battery (KW)	Power consumption by 11W Conventional street light (KW/year)	Time required to Compensate the two components power consumption (year)
537.53	56.21	9.56
Life cycle carbon emission by Solar panel & Battery (kg)	**Carbon emission using coal based power per year**	**Time required to Compensate the two components carbon emission (year)**
80.88	52.05	1.55

Conclusion

This study provided an LCA analysis of two street-light technologies in regard to their environmental impacts. The results show that the overall environmental impacts are higher by the conventional street light when compared to the solar street light. The phase, which contributes most to overall environmental impacts by both technologies, is the operational one. Solar street light technology is at the forefront when reducing global warming potential in term of carbon emission. It is save the energy at the time of operation which contributes the lower impact on the climate change.

This LCA study is also of practical value for the Gandhigram Rural University, because it presents an objective evaluation enabling a simple comparison of two technologies in order to decrease environmental impacts and costs in term of energy. However, Solar street light technology requires higher initial investment costs and the payback time is longer, therefore, most of the projects government has contributing the fund in order to save natural resource and global warming impact.

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