Environmental Impact Analysis of a LED Lighting Products

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Abstract

The continuous growth of the use of energy has had a very big impact in the climate change due to the vast amounts of CO_2 emissions. Electricity production is the major player in energy use and lighting consumes the biggest part of electricity. This study assesses – based on prior studies the life cycle energy consumption of a LED lamp product as compared to incandescent lamp and compact fluorescent lamp (CFL) technologies. To provide the uniformity necessary to conduct a life-cycle energy analysis, a functional unit of "20 million lumen-hours" is selected. The results showed that during the operation period of 25,000 hours of each kind of lamp, the negative impact on the environment of the product is highest in the use phase due to electricity use.

Keywords: LCA; LED lighting products; electricity

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1. Introduction

During the past decades, the mitigation and adaptation to climate change constitutes a major challenge for urban areas. At the same time, it is imperative to ensure that the implementation of clean and secure energy supply, is aligned with end-use technologies, so as to meet the needs of current and future generations [1].

Anthropogenic greenhouse gas emissions (GHG) mainly come from the burning of fossil fuels for electricity generation, transport, industry, and households. In the EU, energy consumption generates nearly 80 % of the GHG emissions [2]. Under EU's 20-20-20 package, a binding legislation has been set, in order to ensure that the EU meets its climate and energy targets for the year 2020 aiming to to reduce its greenhouse gas emissions by 20 % from the 1990 level by 2020. In December 2008, the European Council confirmed "the European Union's commitment to increase the 20 % reduction to 30 % within the framework of an ambitious and comprehensive global agreement, which still remains EU policy today" [3].

Based on the abovementioned and taking into consideration the fact that almost 20 % of electricity consumption worldwide is used-up by lighting applications (corresponding to 2651 TWh/year [4]), it is deducted that energy-efficient lighting represents an area of great significance in regards to climate change, sustainable energy policy, and energy efficiency [5]. The consumption of electricity for lighting purposes in EU-15 countries comes up to 12% while in new member states the consumption of electricity for lighting ranges between 21% to 30% of the overall residential electricity consumption [6].

Incandescent lamps have been replaced with CFLs due to their better energy efficiency during usage – as a compact fluorescent lamp consumes about 20% of the energy used by incandescent lamps for the same light output [7]. CFLs have high light production efficiency, as they utilize the advantage of both passive and semi conducting electronic components. The manufacturing of these components involves complex material flows inducing high energy demand [8]. Literature review indicates that LEDs present a great potential to outstrip many conventional lighting technologies in terms of color quality, versatility, life time and energy efficiency. The LED lamps have slightly better environmental impacts than CFLs, while they are considerably lower in case of incandescent lamps. It has been estimated that all environmental indicators have 3 to 10 times reduction in their values when incandescent lamps are replaced with more efficient CFLs or LED lamps [9]. However, CFL lamps have some disadvantages compared to incandescent lamps. The CFL lamps contain 0.7−115 mg of Hg per lamp [10] and the subclass of CFLs on average contains 3−5 mg per lamp. Mercury is a well-known human toxicant that is of special concern for neural development in unborn and growing children [11].

Incandescent lamps are quasi-blackbody thermal radiators. A true blackbody radiator would generate light according to Planck's Law, for various temperatures. Most incandescent lamps use tungsten filaments, and the emissivity of tungsten, the ratio of its radiative output to that of a blackbody at the same temperature, is about 0.44 in the visible region of the spectrum and about 0.33 in the infrared. Tungsten lamps have excellent color quality, reflected in a perfect CRI of 100, are inexpensive, available in a great variety of sizes, shapes, and operating voltages, have a small source size that permits excellent light control with relatively small reflectors and lenses, run equally well on AC or DC power, can be easily dimmed, can have very long life, are insensitive to operating position, are relatively insensitive to ambient temperature, contain no hazardous materials, and light virtually instantly, though not as fast as LEDs. However, incandescent lamps have one major disadvantage; they are very inefficient. Most of the energy consumed by incandescent lamps is radiated in the infrared, while only 5% to 10% is radiated in the visible portion of the spectrum [12].

LEDs are discrete wavelength emitters, meaning they produce light in a narrow bandwidth based on the chemistry of their underlying p-n junction. White light, on the other hand, consists of many different wavelengths (colors) of light which, when blended together, are perceived by the human eye as being "white". As discussed in the next section of this report, there are several different methods for producing white light from LEDs, however it is recognized that the vast majority of white light LEDs manufactured today are based on the combination of a blue-emitting gallium nitride (GaN) or indium gallium nitride (InGaN) LED source used in combination with a yellow-emitting cerium-doped yttrium aluminum garnet (Ce3+ YAG) phosphor [13].

This study aims to assess the environmental impacts of incandescent, compact fluorescent and LED lamps as well as their emitted emissions. The main objective of this study is to comparatively assess three different types of lamps, so as to determine not only the most economically advantageous technology but also the most environmentally friendly. All the data we used were thought to adequately represent the processes involved in the life cycle of the lamps.

2. Materials and Methods

Life Cycle Assessment (LCA) is a tool for identifying and quantifying potential environmental burdens and can be used, in order to evaluate the environmental loads of processes and products during their whole life-cycle [14]. LCA can be used as a technical tool to estimate the cumulative environmental impacts resulting from all stages of the product's life-cycle, often including some impacts not considered in more traditional analyses (e.g., raw material extraction, material transportation, ultimate product disposal, etc.) [15].

The LCA methodology is based on ISO 14040 and consists of four distinct analytical steps: defining the goal and scope, creating the life-cycle inventory, assessing the impact and finally interpreting the results [16]. Employed to its full, LCA examines environmental inputs and outputs related to a product or service life-cycle from cradle to grave, i.e., from raw material extraction, through manufacture, usage phase, reprocessing where needed, to final disposal. ISO 14040 defines LCA as: "A technique for assessing the environmental aspects and potential impacts associated with a product, by: compiling an inventory of relevant inputs and outputs of a product system; evaluating the potential environmental impacts; and interpreting the results of the inventory analysis and impact assessment phases". LCA is often employed as an analytical decision support tool [17].

2.1 Goal and Scope

The aim of this study to assess the environmental impacts of three different types of lamps for buildings; in order to evaluate the contribution of each lamp to the total impact and to compare incandescent lamps (GLS) with CFL and LED type of lamps. The performance parameters of lamps under consideration are presented in **Table 1**. The lamps are considered to have a Classic A shape with E27 socket. To ensure comparability of the three lamp types a lifetime of 25,000 hours is taken a reference parameter which is evened out by the number of lamps used. It is noted that all lamps provide comparable luminous flux and all are warm white lamps but the fact of a cold. Perception of the light from different emission spectra of the lamp types is not considered. Turn-on and off cycles are excluded from the study. The production of the GLS and CFL takes place in Europe; whereas the production of the LED lamp in China. The location of the use phase, end of life, and any other processes is considered to be Europe. All data related to materials, energy source, and processes used to produce the lamps are acquired directly from OSRAM [18]. SimaPro 7.3.0 database is used [19].

	GLS	**CFL**	**LED lamp**
Power Consumption (W)	40	8	8
Light flux (lm)	345	420	420
Lamp life time (h)	1,000	10,000	25,000
Number of lamps	25	2,5	1
Color Temperature (K)	2700	3000	3000
Color Rendering Index - CRI	84	84	80
Lamp	OSRAM Classic A 40 W	Dulux Superstar Classic A.	Parathom Classic A55

Table 1. Performance parameters for lamps under consideration **[19]**

2.2 System boundaries

The system boundaries, as illustrated in **Fig. 1**, include the stages of raw material production, manufacturing & assembly, transport and use. The stage of end of life was not taken into consideration- as it is considered that the lamps are recycled (according to the EU Directive 2002/96/EC-WEEE). All lamps are divided into parts for the base, bulb, filling, including packaging and transportation. The packaging consists of a cardboard box, and transportation includes all transportation processes within the manufacturing phase, including transport of the final product to the customer in Europe. The use phase does not take into consideration the heating value or direct emissions. The emissions, as outcome from the use phase, are resulting only from power supply. For the use phase the power mix of the European Union was taken into consideration. For the European average power mix, 1 kWh electricity has a CO_2 output of 0.55 kg.

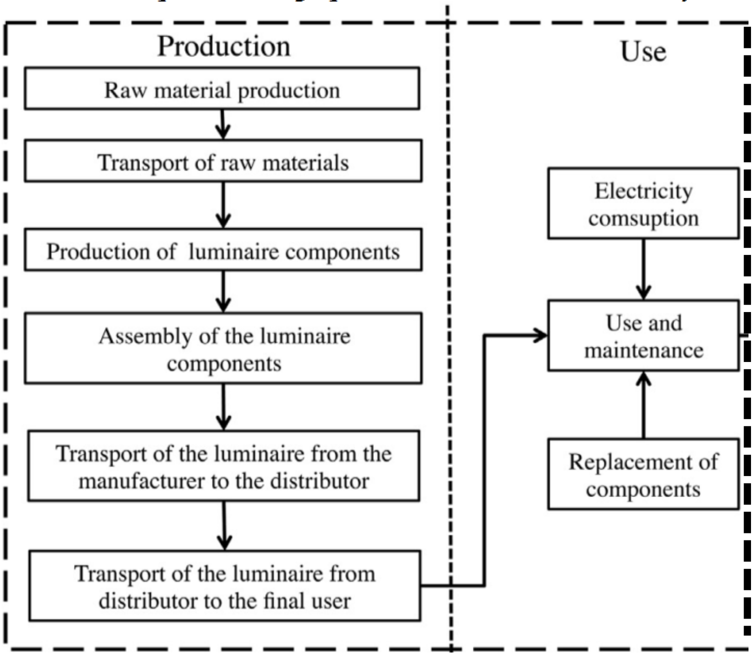


Figure 1. System boundaries

2.3 Impact categories

The impact categories selected to describe the energy and environmental performance of the products under investigation are: Global Warming Potential (GWP); Acidification Potential (AP); Eutrophication Potential (EP); Photochemical Ozone Creation Potential (POCP) and Human Toxicity Potential (HTP).

2.4 Inventory Analysis

The inventory analysis is made in accordance with ISO 14040. For this purpose, the products were investigated by directly analyzing the manufacturing processes. Although similar, the three types of lamps do not have components in common, given that each element used is specifically designed for the type of product. The industrial process to build the lamps consists of a series of single processes for the production of metal parts and plastics, and a final stage of manual assembly and packaging. For each process, the mass flows and energy input and output relating to the unit of product are analyzed. The inventory analysis of the LED lamp is presented in **Table 2**.

Components	Items	SimaPro material	Weight (kg)
Packaging	Card	Packaging, corrugated board, mixed fiber, single wall, at plant	0.605
Packaging	Bags	Polyethylene, LLDPE, granulate, at plant	0.021
Packaging	Manuals	Packaging, corrugated board, mixed fiber, single wall, at plant	0.022
Housing	Reflector	Polycarbonate, at plant	0.126
Housing	Housing	Aluminum, production mix, at plant	1.200
Fasteners	Fasteners, washers, springs	Steel, low-alloyed, at plant	0.080
Fasteners	Metal clips	Aluminum, production mix, at plant	0.003
Fasteners	Plastic clips	Polycarbonate, at plant	0.007
Fasteners	Plastic clips	Polypropylene, granulate, at plant	0.001
Light source	Thermal conductive tape	Silicone product, at plant	0.011
Light source	heat sink	Aluminum, production mix, at plant	0.213
Light source	LED cover	Polycarbonate, at plant	0.063
Light source	LED array	Light emitting diode, LED, at plant	0.06
Electrical connection	Wiring	wire drawing, copper/RER	0.033
Driver	Circuit	Printed wiring board, at plant	0.184
Driver	Fastener	Steel, low-alloyed, at plant	0.002
Driver	Connector	Polycarbonate, at plant	0.0065
Driver	Housing	Polycarbonate, at plant	0.134
Transportation	Raw materials and components	Lorry transport, Euro 0,1,2,3,4 mix, 22 t total weight, 17.3 t max payload RER	847 km kg
		Lorry transport, Euro	1.100 km kg

Transportation	Distribution	0,1,2,3,4 mix, 22 t total weight, 17.3 t max payload RER	
Electricity for manufacturing		Electricity, production mix RER	1.7 kWh
Natural gas for manufacturing		Natural gas, combusted in industrial equipment	0.27 m^3

Table 2. Raw material and process inputs for LED luminaire manufacturing

3. Results

The results of this study indicate that LED lamps cause a lower total life cycle environmental impact compared to GLS and CFL type of lamps. It is noted that 82-99% of the environmental impact is related to the use stage, due to the electric energy consumption during the life cycle of the lamps. The results indicate that 1%- 18% of the total impact is attributed to the stage of manufacturing. The high impact of the 25 GLS on GWP (**Fig. 2**) during manufacturing is mainly caused by aluminum in the base and power consumed in all processes. The most relevant processes for the CFL are the ballasts, most influenced by the printed circuit board and all power-consuming processes.

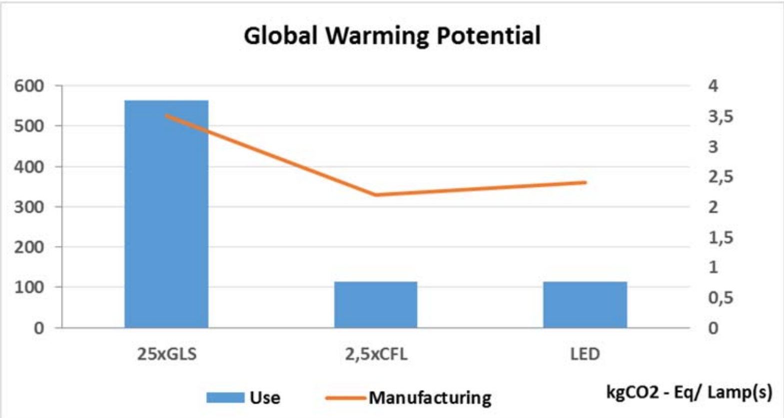
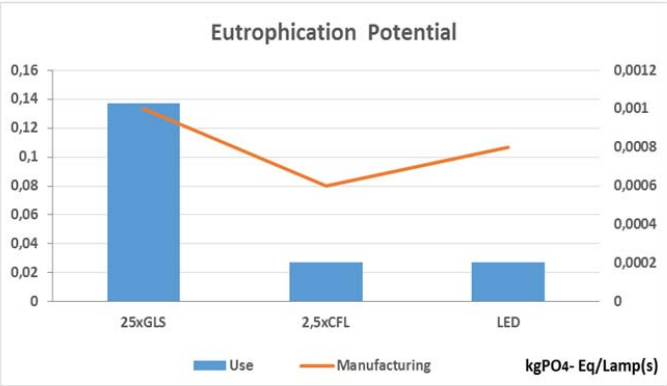


Figure 2. Global Warming Potential



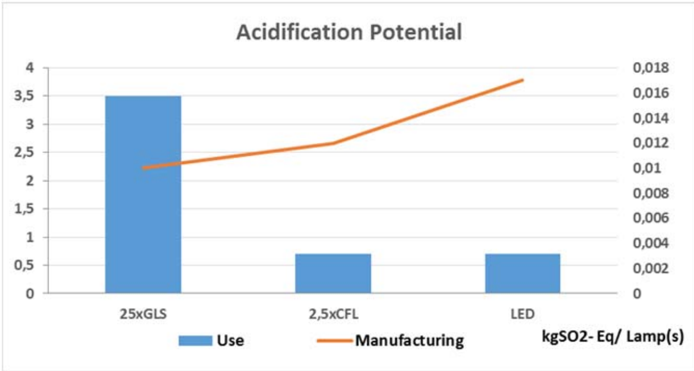


Figure 3 illustrates that GLS have a high impact to EP. Relevant contributors to the eutrophication on the LED manufacturing side are chemicals in common waste of the LED frontend process**. Figure 4** indicates that the AP for the LED lamp during manufacturing is higher than for the other two lamps. The power consumed for the production of the aluminum heat sink, ballast, metals such as gold or copper, and the bulk carrier, as well as the common power consumption are the main contributors of the LED lamp to acidification.

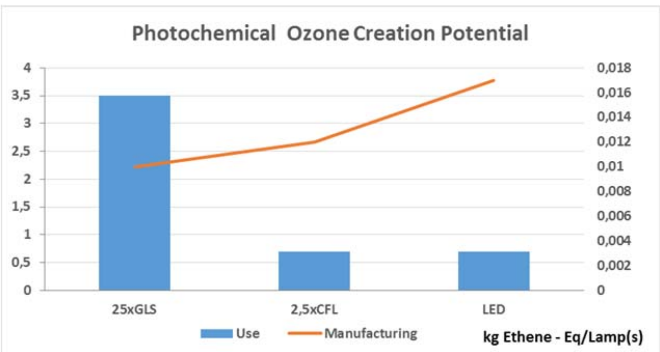
The LED lamp shows higher values for the POCP of the manufacturing phase than the other two lamps due to chemicals in common waste of the LED frontend process (**Fig. 5**). In regards to

Figure 3. Eutrophication Potential

ng p

Figure 4. Acidification Potential

environmental impact categories. For the CFL and LED lamp the HTP of the manufacturing phase is almost 10% of the HTP over the life cycle.



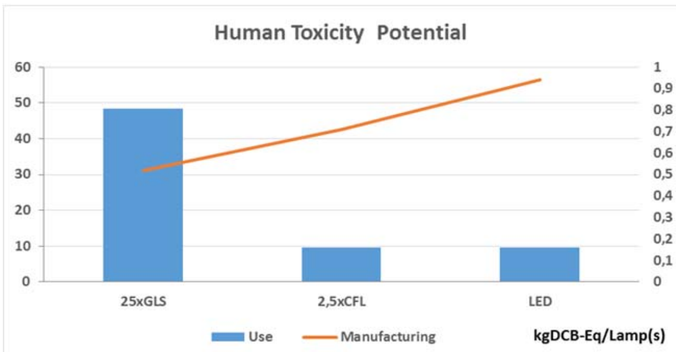


Figure 5. Photochemical Ozone Creation Potential

Figure 5. Photochemical Ozone Creation Potential

Figure 6. Human Toxicity Potenti

4. Conclusions

This study evaluates and compares three different types of lamps. The assessment takes into account all the stages of the life cycle of the lamps. A luminaire with a LED light source is compared with a similar CFL luminaire and a GLS. The use of LED lamps can reduce the environmental impacts. Also, 1%- 18% of the total impact is attributed to the stage of manufacturing phase; whereas 82-99% of the environmental impact is related to the use stage. In contrast to the primary energy consumption of incandescent lamps of around 3,302 kWh, CFL and LED lamps use less than 670 kWh of primary energy during their entire life. Thus 80% of energy can be saved by using CFL or LED lamps.

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