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# Comparative LCA between conventional luminaires and a LED luminaire with a prediction on optimisation of environmental impacts

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## ARTICLE INFO

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## ABSTRACT/RESUME

***Abstract:*** *Excessive usage of public lighting systems creates considerable environmental impacts.*

*Impacts before using public lighting, such as carbon dioxide emissions and the depletion of resources, are essentially due to the production of electric energy that is necessary for power supply, as well as transportation and distribution.*

*The manufacture of the components of a public lighting system also constitutes a life cycle, which creates emissions that have significant impacts on the environment.*

*After the use of a public lighting system, the strain regarding the management of end-of-life waste of light fixtures arises. Waste such as glass, plastics, metallic waste, as well as lamps of which certain types contain mercury, sodium, and other substances that are more or less harmful.*

*In addition to the impacts mentioned above, the direct fallouts of exploiting lighting fixtures impact fauna and flora species as well as human health under the effect of artificial light emitted throughout the night.*

*The present articles aims, according to the approach during the life cycle assessment (LCA), to identify which of the existing technologies can make public lighting a factor of comfort, security, wellbeing on one hand, and offer optimal performances on the environmental, energetic, and economic aspects, thus reducing the risks threatening biodiversity and the equilibrium of ecosystems.*

*The retained solution must converge towards an "echo-lighting" as well as towards a "smart lighting" which would answer major worries linked to the deployment and irrational use of conventional public lighting, which is energy-intensive and a generator of potential environmental damages. Smart Lighting consists of guaranteeing a dynamic operation of lights through emerging technologies, which would ensure a supply of artificial light based on the existing natural light, with the possibility of taking into account the presence of users (vehicle, pedestrian, etc) or the lack thereof, as well as the automatic adaptation of light intensity to normative demand and needs.*

## I. Introduction

Public lighting offers multiple advantages linked to security and comfort, most notably in urban areas, however, it currently makes up more than 40% of community budgets and 12% of global consumption of electric energy.

Conventional street lighting consists of static lighting using street lamps that emit constant illumination throughout the night in the absence of users in public spaces.

This lighting style, which functions for more than 4000 hours per year, is characterised by:

- Energy wastage due to the usage method and duration as well as energy-intensive light sources;
- Rapid depletion of equipment creating a significant stream of waste and excessive maintenance costs;
- Light nuisance (light pollution);
- A wide and diverse range of environmental impact.

Studies have shown that, in addition to the various impacts of energy waste, residential and non-residential lighting is responsible for 5% of greenhouse gas emissions [1].

Increased awareness on environmental issues as well as the high costs of energy have pushed professionals to research and establish solutions that are more appropriate for current needs.

Technological development currently offers innovative solutions regarding light sources as well as efficient and rational management of public lighting networks, which aim at optimising consumption while reducing environmental impacts and maintaining a very high level of comfort.

This article highlights the birth of the environmental issue of light pollution [2], and illustrates environmental, economic, and energy impacts of public lighting systems during the phases of their life cycles, as well as the solutions which have provided performances that are likely to make the implementation, operation, maintenance, and life cycle management less polluting, with an optimisation of energy and reasonable costs.

The phases of the life cycle of a public lighting system [3]:

- The manufacture of the system's components and the installation of public lighting fixtures;
- Usage, management, and maintenance of the system;
- End of life of the installation and the management of waste.

All of these contribute to the generation of critical environmental impacts.

Prior examination of the initial state has shown that dominant public lighting systems are characterised by:

- Excessive usage of energy-intensive light fixtures (functioning at full capacity from sunset to early morning, with unnecessary intensities);
- Regulations and standards that don't pay enough attention to environmental aspects [2] produced by public lighting;
- Conventional (manual) management and maintenance of fixtures with resulting financial and environmental fallouts ;
- A strong production of lighting nuisance impacting wildlife and human health (light pollution);
- Rising of waste volume.

Public lighting constitutes more than 12% of global electric energy consumption and more than 40% of local governments and communities.

Considering that direct and indirect environmental impacts that are caused by public lighting have become increasingly severe and complex, the challenge that arises consists of bringing durable solutions that reconciles potential advantages (comfort, security…) with proven minimal environmental impacts.

## II. Method

The study of the issue adopts the methodology of Life Cycle Assessment in accordance with the requirements and guidelines enacted by the ISO 14044 norm, which, after a comparative analysis of both existing and emerging technologies, aims to bring answers and advantageous solutions in line with environmental, financial, and energy challenges related to public lighting. Furthermore, these said solutions must be supported by prior measures, adopting regulations and a set of standards that prioritise the durability of public lighting systems [2].

**Functional unit:** The reference functional unit that is most commonly adopted for the LCA of public lighting fixtures is the kilometre of lit road with a minimal luminous flux of 20,000 Lumens for a determined duration, usually corresponding to the lifetime of a light fixture (15 years) and in accordance with conception criteria for street lighting [4].

Kilometre of lit road is also frequently used as a base unit for financial calculations.

Other functions units could be used to support the comparison and make certain environmental parameters more legible.

**System limit (scope of the study)**

The system boundaries include raw material production, material processing, the energy required for manufacture and use, and end-of-life disposal of the compared the "lamps" and fixtures.

***Figure 1.*** *illustrates compared parts of each type of light fixture ((A): HPS lights, (B): LED lights).*

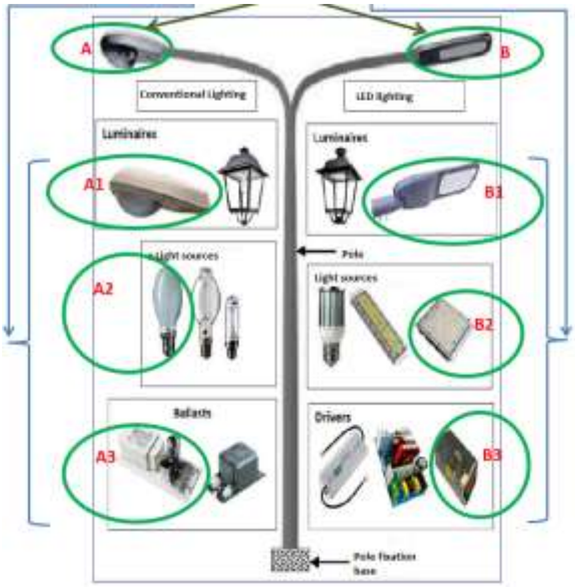

***Figure 1.*** *Components considered in the LCA comparative study in the case of a conventional street light pole (HPS) and one with LED*

Transportation of raw materials to a factory for manufacture is included in the Ecoinvent database, but transportation of the fixtures from China to Algeria should be taken into account. The aluminium content was found to be approximately the same for the light fixtures and its impact was therefore excluded from the base case. In addition, the maintenance of the two light fixtures involves the replacement of the lamp at the end of its life and its impact can be estimated in relation to the functional unit (60,000 hours) by the distance necessary to travel to install and replace the lamp, 2 times for LED versus 3 times for HPS. This is a random guess as the exact location and time are not known.

**Time range:** Although the consulted literature predicts a lifetime of 20 to 30 years for a public lighting fixture, its lifetime is often dependent on multiple factories, such as the functioning conditions (maintenance, climate, characteristics of the surrounding environment, marine air, vandalism...), we consider that a 15-year period corresponds to an optimal functioning period for a public lighting installation. This time corresponds to a 60,000 hours long operation (15 years × 365 days × 11 hours = 60,225 hours rounded to 60,000 hours).

The HPS (long life) lamp's life is 32,000 hours according to the lamp manufacturer. Given their robust structure, the lifetimes of the HPS light cover and the magnetic ballast have been estimated to be very long, extending over more than 30 years of operation, or 4000 hours per year. The HPS lamp requires a compensation capacitor and an igniter to function properly.

The lifetimes of the igniter, compensation capacitor, ballast and driver have been aligned with the average lifetime of a fixture and estimated at 15 years (60,000 hours of operation).

**Geographic limit:** in our study, we supposed that all lamps and light fixtures were manufactured in China and used in Algeria, and that waste is collected and treated at their end of life in Algeria. Certain data has been adopted into the study in consideration of geographic similarities.

The study of inventory and data collection for production, operation and end of life, disposal or recycling are carried out taking into account the current period (2022) as well as data from bibliographic references published between 2010 and 2022.

The intermediate impact categories used for comparison are those established by the Eco-Indicator method (EI-99) and the CML method, which are widely recognized and guarantee reliable results. Remember that Dutch scientists have jointly developed an approach called "CML+EI" which consists of integrating "CML2002" and "Eco-Indicator 99".
Eco-Indicator 99 also provides damage characterisation factors (Endpoints) according to three approaches [5], namely:

1. Hierarchical effect;
2. Egalitarian effect;
3. Individualistic effect.

**Inventory (LCI):** this is the basic step of any LCA. the inventory data of the light fixtures compared are obtained from the dismantling of different units of public lighting fixtures operating with different light sources (LED, HPS lamp, and CMH) and supplemented, if necessary, by bibliographical sources, which themselves essentially draw from databases such as Ecoinvent, ELCD, etc.

Regarding the inventory data, the assessment of the impact categories are calculated and modelled by the Simapro software.

After the realisation of the inventory (LCI), it will be essential to attribute the results of the Life Cycle Inventory to the selected impact categories (classification) in order to then be able to calculate the score for each element (elementary score) before moving on to the summation of characterisation scores belonging to the same intermediate category (grouping). This approach is valid for all phases of the life cycle. Ultimately and after aggregation, each intermediate category will be represented by a single score encompassing the entire life cycle of the light fixture.

The base equation to calculate all impact categories is as follows:

$$SI_i = \sum_s FI_{s,i} \text{ x } M_s \qquad (1)$$

With

- $SI_i$ = the intermediate characterisation score for category i

- $FI_{s,i}$ = the intermediate characterisation factor of the substance s in the intermediate category i

- $M_s$ = the mass emitted or extracted from the substance s

**Normalisation:** This part consists of calculating the relative importance of a category indicator compared to a reference value, which is not always the same according to studies. This step is necessary to carry out the grouping (classification of impact categories). Normalisation makes it possible to represent the impacts on the same graph.

**Weighting:** consists of converting and aggregating the category indicators using numerical weighting factors, which depend on the social, political and ethical values given to the intermediate impact categories, in order to obtain a single score per product [6].

The modelling software allows the normalisation, weighting and aggregation of category indicators.

This article aims to examine the relevance of resorting to the use of non-conventional luminaires and light sources (LED-based) by highlighting their environmental scores compared to those of conventional luminaires such as luminaires operating with high-pressure sodium (HPS) lamps and luminaires operating with ceramic metal halide (CMH) lamps.

The objective is to reach decision-making elements allowing the adoption of energy-saving luminaires and lamps that are more environmentally friendly, less polluting and have a longer life [7] to replace energy-consuming incandescent lamps that use mercury, sodium, etc.

Through bibliographic research, it appears that the potential environmental impacts of public lighting systems are as follows:

### II.1. Environmental impacts of public lighting systems:

A literature journal targeting dozens of research articles has identified the potential environmental impacts that occur during the use phase of public lighting installations as well as upstream and downstream of operation.

**II.1.1.** Upstream impacts are related to the manufacture of components as well as the production, transport and distribution of electricity. The carbon footprint and the metal footprint are at the top of the impacts.

**II.1.1.1. Carbon footprint:** Figure 2 illustrates the quantity in gram equivalent of carbon dioxide emitted into the atmosphere for each kWh of electricity produced according to the different electricity generation processes (Construction, transport, dismantling and operation). The average for Europe is 0.45 kg CO2 eq./kWh el.

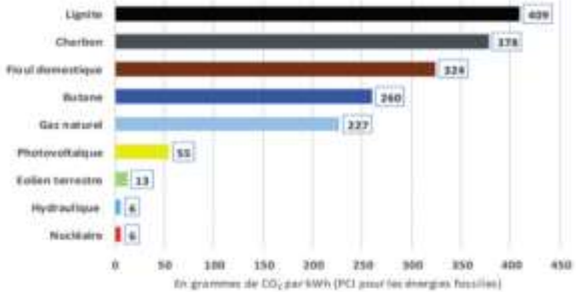

***Figure 2.*** *Quantity in g of emitted CO2 for every kWh produced according to different processes of electricity generation (Source: Base carbone ADEME, 2019)*

**II.1.1.2. Metal footprint:** Figure 3 illustrates the extracted quantity in kilogram of metal for every kWh of electricity produced according to the different processes of electricity generation (production, transport, dismantling, and operation).

***Figure 3.*** *Quantity in kg of extracted metal for every kWh of electricity produced according to different processes of electricity generation (Source: Ecoinvent 3.5 APOS method)*

**II.1.2.** Environmental impacts during the investment, operation, and maintenance of public lighting systems, are linked to:

- Manufacture of equipment;
- Installation of systems;
- Usage;
- Maintenance;

Environmental impacts of these phases are many, the most infamous of which are carbon dioxide emissions, impacts on wildlife (fauna and flora), as well as on human health:

**II.1.2.1. Carbon dioxide emissions** come mainly from the manufacture and shipping of the products and components of public lighting systems, energy consumption, the process of installation and maintenance.

Table 1 and Figure 4 highlight the carbon footprint of a public lighting fixture throughout its estimated 20-year lifetime established by the French Agency for the Environment and Energy Control (ADEME).

***Table 1.*** *Average CO2 rate and quantity in kg emitted by a conventional light fixture during the life cycle phases of public lighting for a 20-year lifetime. (Source: ADEME)s*

| **Life-cycle phase** | **Quantity (kg) of emitted CO2** | **Rate (%)** |
|---|---|---|
| Manufacture | 40 | 8 |
| Installation and removal | 5 | 3 |
| Maintenance | 20 | 4 |
| Energy consumption necessary to produce light | 420 | 85 |
| **Total** | **485** | **100** |

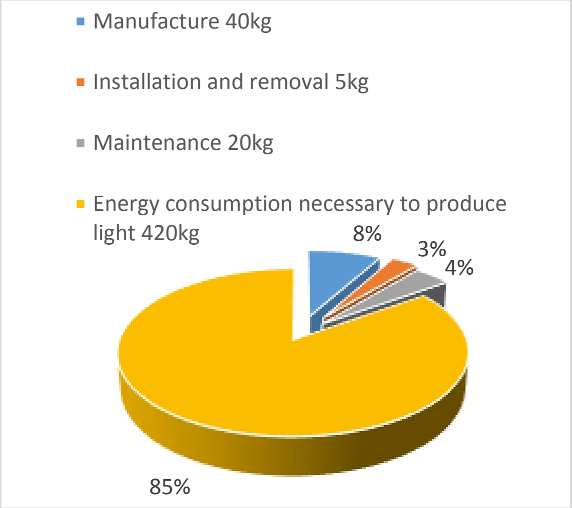

***Figure 4.*** *Average CO2 quantity emitted in kg by a conventional luminaire during the phases of its public lighting life cycle for a 20-year lifetime. (Source: ADEME)*

In addition, artificial light at night causes negative effects on fauna, flora and human health. Its impacts on biodiversity are diverse and varied, due to the fact that 30% of vertebrates and 60% of invertebrates live partially or totally during the night and on all ecological environments (terrestrial, marine, and freshwater).

### II.1.2.2. Impacts on wildlife (fauna)

The most visibly affected species are nocturnal migratory birds, which use the stars during their migration and are therefore disoriented by artificial light sources directed towards the sky creating a halo preventing the visibility of the starry sky. They are also attracted to light sources, tens of millions of birds worldwide die each year from crashing into lighted buildings or becoming exhausted while circling around lighted areas [8];

- Other species are threatened by the fragmentation of their habitat or their biological faunal corridors due to lighting networks and roads, which are also breeding, feeding and resting sites [9].
- Some species (seabirds, young sea turtles, etc.) that move to migrate or looking for their food thanks to the natural light of the night (starry sky, reverberation from the sea...) are therefore disoriented and repelled by the artificial light, thus leading to their disappearance from their usual environments [10];

### II.1.2.3. Impacts on human health

Chrono-biologists have shown that artificial light experienced after sunset can cause internal malfunctions, such as:

- Inhibition of the pineal gland responsible for the secretion of melatonin, thus delaying falling asleep and restful sleep and causing exhaustion…
- The disturbance of the human circadian rhythm, born of the natural alternation between day and night [11].

### II.1.3. Downstream environmental impacts are linked to end-of-life waste:

These are impacts related to the dismantling, sorting, transport, storage and recycling of components of the public lighting network, namely: supports, cables, lights, lamps, electronic components, glass, plastics, etc.
The recycling or storage of certain waste in increasing quantities imposes technical and financial constraints.

Public lighting waste is currently considered as Electronic Waste (e-waste), the recycling and/or disposal of which follows specific processes.

## III. Results

After dozens of consulted scientific publications, it appears that the implementation of new public lighting technologies has allowed, in addition to a financial optimisation, the reduction of consumption and in turn the reduction of environmental impacts.

### III.1. Energy savings following the replacement of conventional lights by LED lights:

According to a study by the Association Française de l'Eclairage (French Association of Lighting), the gains in energy consumption that could occur following the replacement of fluorescent mercury ball lamps and High Pressure Sodium (HPS) lamps with a new complete LED installation equipped with a power variation system, are 79% and 71% respectively as shown in Table 2.

***Table 2.*** *Percentage of energy consumption gains in optimisation scenario*
*Source: French Association of Lighting (AFE)*

<table>
<tr><th rowspan="2">Renovation type (A and B)</th><th colspan="2">Gains in kW of power</th><th colspan="4">Gains in kWh with varying power operation</th></tr>
<tr><th>1st scenario: No limitation of the obtained level</th><th>2nd scenario: With level limitation to standard values EN 13 201-2</th><th>1st scenario: 2 operation capacities (50 and 100%) on 75% of the lights</th><th colspan="3">2nd scenario: 3 operation capacities (30, 50, and 100%) on all the lights</th></tr>
<tr><td colspan="7">(A) Replacing fluorescent ball-shaped mercury lamps with:</td></tr>
<tr><td>A1 Hermetic luminaires with clear HPS lamps</td><td>40%</td><td>43 to 46%</td><td>49%</td><td colspan="3">70%</td></tr>
<tr><td>A2 Hermetic luminaires with clear metal-halide lamps</td><td>48%</td><td>-</td><td>55%</td><td colspan="3">74%</td></tr>
<tr><td>A3 Hermetic luminaires with LED source</td><td>52%</td><td>-</td><td>60%</td><td colspan="3">72%</td></tr>
<tr><td>A4 New fully LED luminaire with new installation</td><td>58%</td><td>-</td><td>64%</td><td colspan="3">79%</td></tr>
<tr><td colspan="7">(B) Replacing sealed HPS luminaires or iodide lamps (old performance) with:</td></tr>
<tr><td>B1 Hermetic luminaires for clear tubular HPS lamps</td><td>19%</td><td>23 to 27%</td><td>31%</td><td colspan="3">59%</td></tr>
<tr><td colspan="3">B2 Hermetic luminaires for LED sources</td><td>34%</td><td>-</td><td>44%</td><td>67%</td></tr>
<tr><td colspan="3">B3 New fixture fully LED</td><td>41%</td><td>-</td><td>50%</td><td>71%</td></tr>
</table>

The experiment carried out in the city of Douai, France which consisted in the comparative study of several possible scenarios on a pilot network [12] resulted in the replacement of 217 light points operating with conventional lights by LED equipped with a power variation system (decrease in operating power to 30% from 11:00 p.m. to 6:00 a.m.).

The savings in energy consumption and cost would be less than 85.46% and 84.83% respectively, which therefore allows us to deduce that the environmental performance will have a similar trend.

### III.2. Results of LCAs that compare environmental performances of light sources:

The environmental performance of various public lighting technologies (light sources) has been the subject of several LCAs and comparative LCA studies published through scientific articles that we have profoundly exploited whilst preparing this paper.

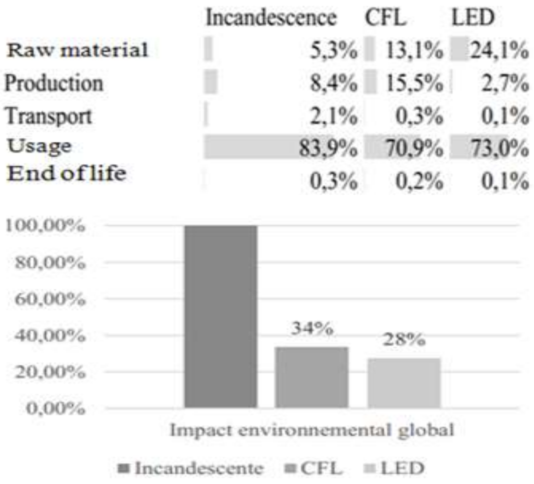

***Figure 5.*** *Share of total environmental impact per life cycle phase, and comparison of total environmental impacts for an incandescent lamp, CFL lamp, and LED lamp.*

The results of comparing the environmental performance of the various types of lamps used in public lighting show that LED lamps have more favourable characteristics from an environmental, financial, and energy point of view throughout all phases of the life cycle.

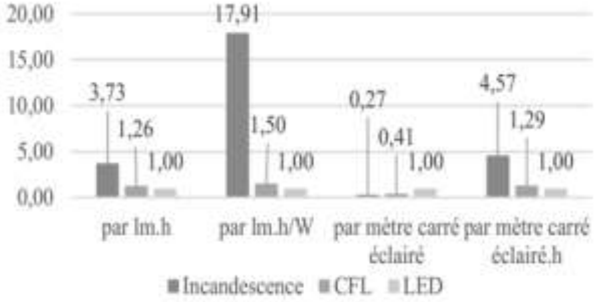

***Figure 6.*** *Comparing the environmental impact of an incandescent lamp, a CFL lamp, and LED lamp per lm.h, per lm.h/W, per square metre of lit surface, per metre of lit surface throughout one hour*

Following studies that highlighted the many disadvantages of incandescent light fixtures, some countries have resorted to withdrawing them from all professional or residential use.

### III.3. Comparative LCA results of the environmental performance of luminaires of different technologies:

### III.3.1. Comparative LCA between HPS luminaire and LED luminaire:

This comparative LCA has analysed the manufacture, usage and end of life (EoL) of light fixtures consisting of a light source (HPS lamp or LED strip), equipment (ballast or driver), accessories and an enclosure for each light fixture (cf. Figure 1).

The manufacturing phase encompasses the acquisition of raw materials, the manufacturing processes of materials and parts, the transportation of materials and parts, and the packaging of both the intermediate product and the final product. Usage represents only the electricity consumption during operation. End-of-life modelling focuses on the transportation and disposal of materials.

**Light fixture components and manufacturing process:** Inventory and manufacturing data for HPS and LED luminaires are shown, respectively, in Tables 3 & 4.

It should be noted that the inventory data is essentially obtained from the dismantling of an HPS luminaire and an LED. The luminaires are chosen from the models frequently used by the Public Establishment for the Construction and Maintenance of Public Lighting in Algiers – ERMA. Some data from the bibliographic research were scaled and integrated into this study (Dale et al., 2011; Lundie et al., 2004; Tuenge et al., 2013; Unit lighting, 2013) [13] [ 14] [15] (references drawn from databases dedicated to LCA such as Ecoinvent).

The main manufacturing process involved when making the two types of lighting systems. Since the specific manufacturing processes are largely unknown, the generic “metal product manufacturing, average metal working/RER S” in the Ecoinvent database is used for all metal components.

***Table 3.*** *Materials Inputs and corresponding Ecoinvent Datasets*

| Component | Mass (g) | Material | Ecoinvent Unit Process |
|---|---|---|---|
| 250W HPS luminaire, total weight = 6537g | | | |
| Reflector | 225 | Aluminium | Aluminium alloy AlMg3, at plant/RER S |
| Top housing +Bottom housing | 980 | Aluminium | Aluminium alloy AlMg3, at plant/RER S |
| Plastic insulator | 412 | Plastic | Polyvinylchloride, at regional storage/RER S |
| Screws | 15 | Brass | Brass, at plant/CH S |
| Ceramic bulb holder | 55 | Ceramics | Sanitary ceramics, at regional storage/CH S |
| Bracket Pieces | 75 | Steel | Steel, converter, low-alloyed, at plant/RER s |
| Capacity | 1600 | Electronic | Capacitor, electrolyte type,>2cm height, at plant/GLO S |
| Non-PCB Capacitor | 3175 | Electronic | Capacitor, electrolyte type,>2cm height, at plant/GLO S |
| NREP 200W LED luminaire 43L (total weight = 4923 g) | | | |
| Fitting parts | 4150.5 | Aluminium | Aluminium alloy AlMg3, at plant/RER S |
| Housing | 67.5 | Aluminium | Aluminium alloy AlMg3, at plant/RER S |
| Bracket | 63.5 | Aluminium | Aluminium alloy AlMg3, at plant/RER S |
| Wiring | 21 | Copper | Copper, primary, at refinery/GLO S |
| LED bulb | 122.5 | LED | Light emitting diode, LED, at plant/GLO S |
| Glass tube | 63.5 | Glass | Glass tube, borosilicate, at plant/DE S |
| Aluminium block (PBC) | 386 | Aluminium | Aluminium alloy AlMg3, at plant/RER S |
| Capacitor | 9.5 | Electronic | Capacitor, electrolyte type,<2cm height, at plant/GLO S |
| Resistor | 19.5 | Electronic | Resistor, unspecified, at plant/GLO S |
| Inductor | 19.5 | Electronic | Inductor, unspecified, at plant/GLO S |

***Table 4.****Manufacturing Processes and Corresponding Ecoinvent Datasets*

| Component | Mass (g) | Ecoinvent Unit Process |
|---|---|---|
| 250W HPS | | |
| Reflector, Top housing +Bottom housing, Screws, Bracket Pieces | 1295 | Metal product manufacturing, average metal working/RER S |
| Plastic insulator | 412.5 | Injection moulding /RER S |
| Capacity, Non-PCB Capacitor | 4775 | Production efforts, capacitor/GLO S |
| 200W LED | | |
| Fitting parts, Housing, Bracket, Aluminium block (PBC) | 4667.5 | Metal product manufacturing, average metal working/RER S |
| Wiring | 21 | Wire drawing, copper/RER S |
| LED bulb | 122.5 | Production efforts, diodes/GLO S |
| Glass tube | 63.5 | Tempering, flat glass/RER S |
| Capacitor | 9.5 | Production efforts, capacitors/GLO S |
| Resistor | 19.5 | Production efforts, resistors/GLO S |
| Inductor | 19.5 | Production efforts, inductor/GLO S |

Additional data and energy data of HPS and LED lamp lighting systems are taken from publications often referring to the Ecoinvent database [16].

The considered intermediate impact categories include global warming, acidification, carcinogenic and non-carcinogenic substances, toxicity effects, eutrophication, ozone layer depletion, ecotoxicity and smog.

The damage categories have not been assessed, which reduces the uncertainties associated with the assessment of potential environmental damage.

According to a study carried out by Leena Tahkamo, the comparative LCA of HPS lamp and LED luminaires according to 10 environmental indicators gave the following result

***Table 5.*** *Comparing the life cycles of an HPS and LED luminaire according to 10 environmental indicators (considered lifetime = 30 years or 1 gigalumen per hour) (CML Method)*

| **Impact category** | **Abbreviation** | **Unit** | Life cycle impacts per Glmh | | Manufacturing impacts per Glmh | |
|---|---|---|---|---|---|---|
| | | | **HPS Luminaire** | **LED Luminaire** | **HPS Luminaire** | **HPS Luminaire** |
| Acidification | PA | kg $SO_2$ eq. | 34,6 | 28,7 | 0,781 | 3,48 |
| Climate change | GWP | kg $CO_2$ eq. | 7920 | 6620 | 175 | 822 |
| Eutrophication | PE | kg $PO_4$ eq. | 24,0 | 19,7 | 0,506 | 2,15 |
| Freshwater aquatic ecotoxicity | FAETP | kg 1,4-DCB eq. | 4110 | 3410 | 129 | 434 |
| Human toxicity | HTP | kg 1,4-DCB eq. | 5490 | 4870 | 410 | 1076 |
| Marine aquatic ecotoxicity | MAETP | $10^3$ tonnes kg 1,4-DCB eq. | 13,2 | 11,1 | 354 | 1480 |
| Photo-oxidant formation | POCP | kg $C_2H_4$ eq. | 1,47 | 1,23 | 0,0591 | 0,176 |
| Depletion of abiotic resources | ADP | kg Sb eq. | 58,7 | 48,5 | 1,74 | 5,90 |
| Stratospheric ozone depletion | ODP | g CFC-11 eq. | 0,408 | 0,329 | 0,0434 | 0,0556 |
| Terrestrial ecotoxicity | TETP | kg 1,4-DCB eq. | 144 | 110 | 1,39 | 4,08 |
| Average (CML) | / | / | 100% | 83% | 33% | 100% |
| Eco-indicator 99 | / | Points | 433 | 364 | 14,4 | 50,3 |

The state of the art has shown that in view of the multiple drawbacks of incandescent luminaires (see paragraph 3.2 of this article), they have been downgraded for about ten years and will end up being withdrawn from all use, the study was limited to verifying and confirming the disinterestedness shown by industrialists with regard to this technology.

The aggregated data in Table 5 shows that in terms of the overall life cycle, the LED luminaire has more advantages than that with HPS.

The manufacturing stage is the only phase of the life cycle that is in favour of the HPS luminaire and which, in view of the rapid evolution of industrial processes for LED manufacture, will not be able to maintain this advantageous position.

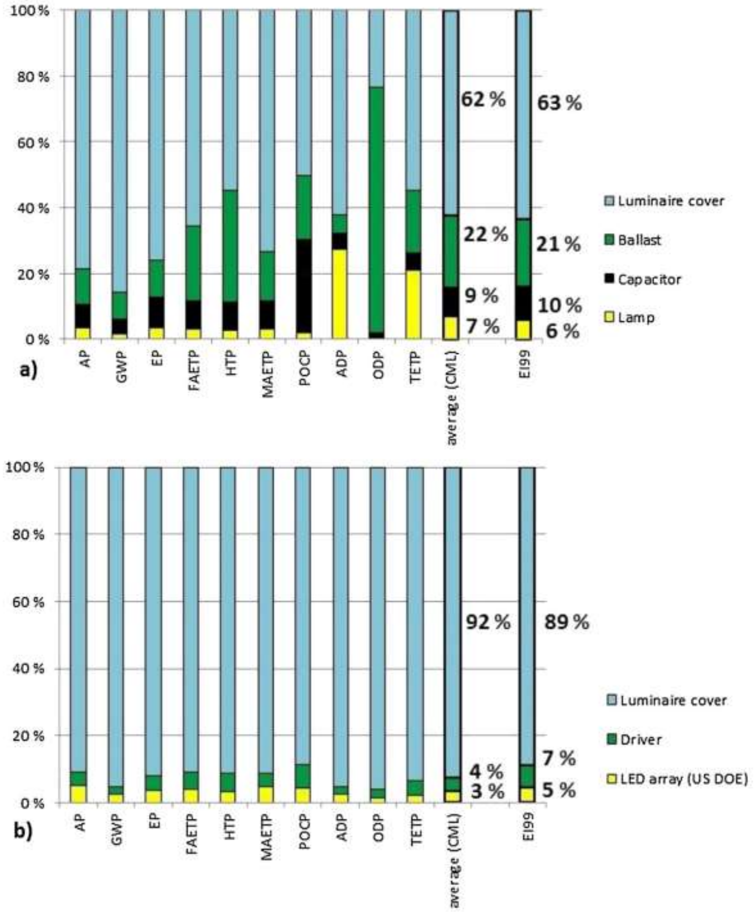

***Figure 7.*** *Environmental impacts of the manufacturing of (a) HPS and (b) LED luminaires.*

The comparison of the usage phase of the two types of luminaires on the basis of the functional unit which consists in illuminating one kilometre of road during the lifetime resulted in the representation illustrated in Figure 8.

The model shows that on the aggregated (single) score as well as on all environmental impact categories, the LED luminaire manufactured in 2020 has significant advantages making it more sustainable than the other conventional luminaires.

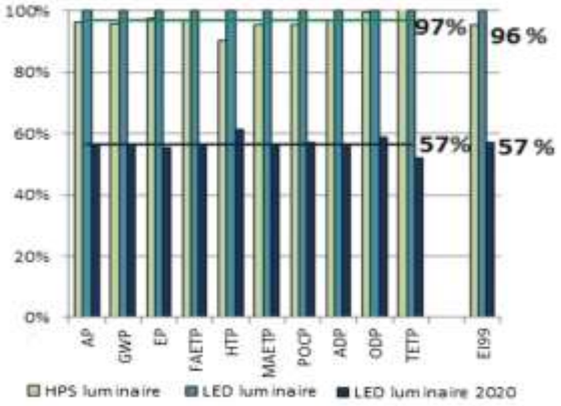

***Figure 8.*** *Comparison of HPS and LED luminaire environmental impacts per kilometre of lit road*

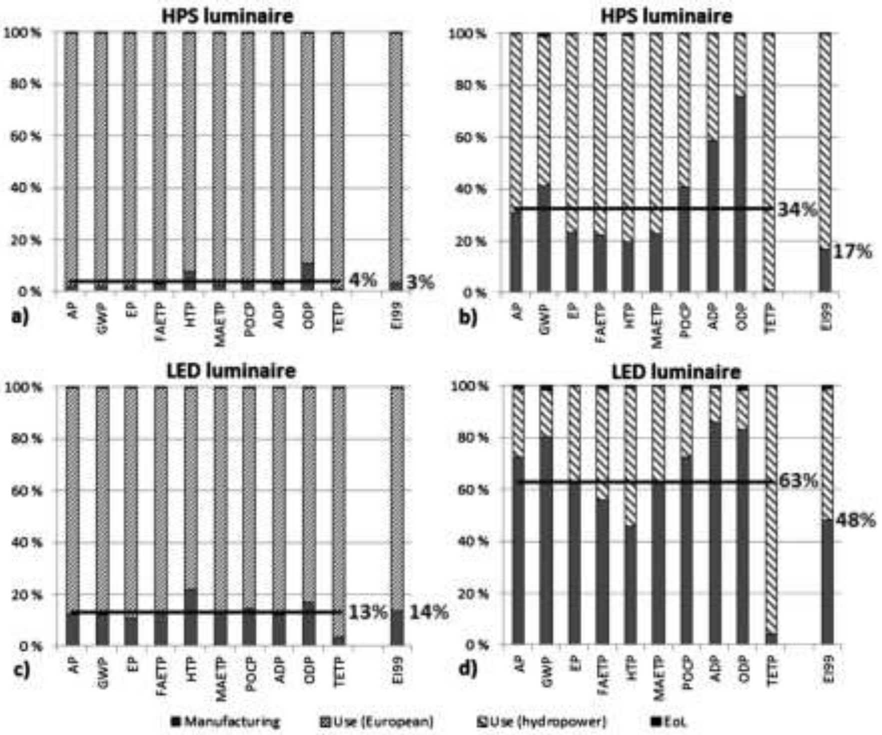

***Figure 9.*** *Environmental impacts of manufacturing, usage and end-of-life of:*
*(a) HPS luminaire using European average electricity,*
*(b) HPS luminaire using electricity generated from hydropower,*
*(c) LED luminaire using European average electricity, and*
*(d) LED luminaire using electricity generated from hydropower.*

### III.4. LCA comparing HPS luminaires and CMH luminaires:

In the article comparing the life cycle of LED and CMH luminaires used for road lighting [17], Sabina Abdul Hadi reported favourable results for LED luminaires in terms of energy consumption and CO2 emissions particularly during the use phase (Figure 10). In the manufacturing phase, LED has less environmental performance (Figure 11).

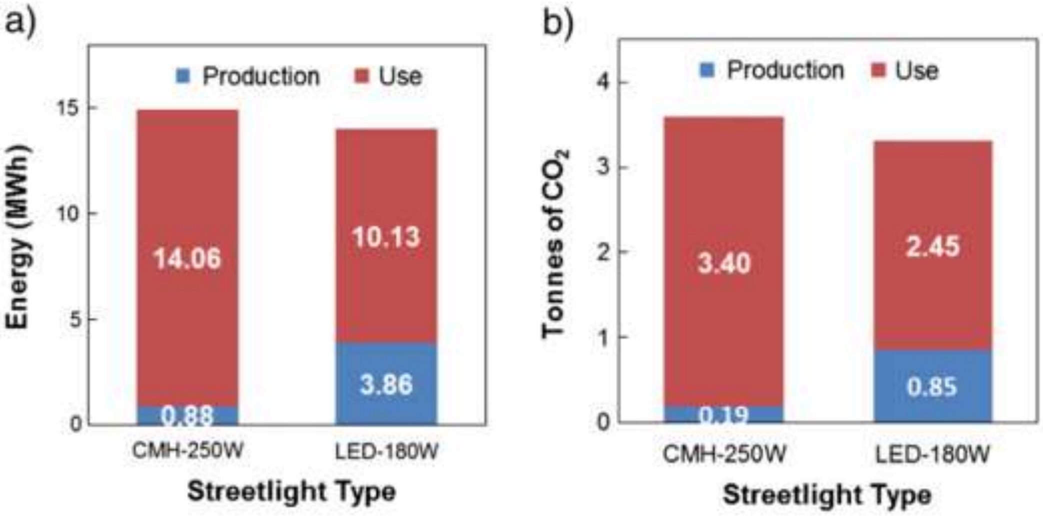

***Figure 10.*** *Energy consumption (a) and carbon dioxide emissions (b) during manufacture and operation of CMH and LED streetlights powered by electricity from grid.*

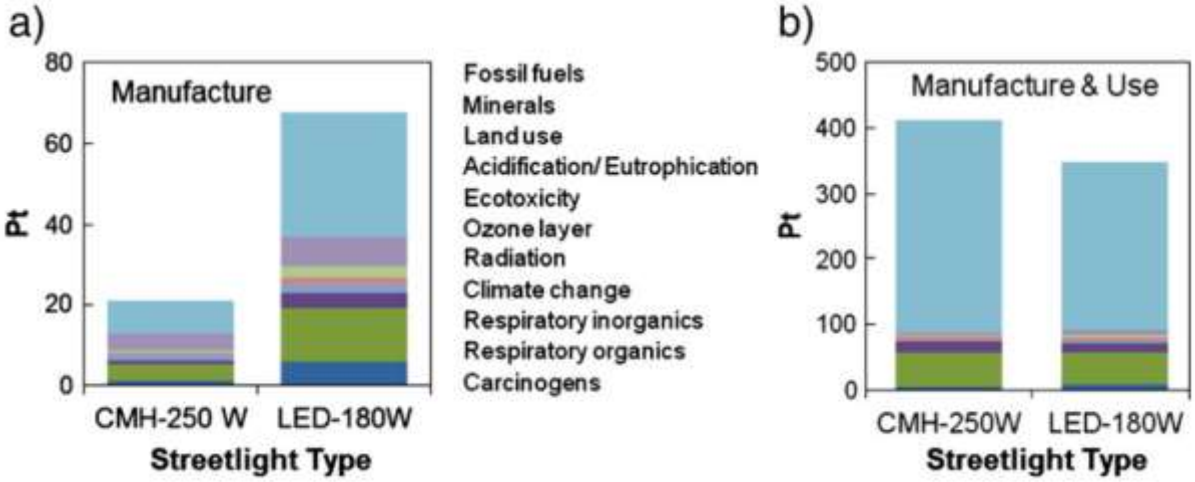

***Figure 11.*** *Impact assessment by single score method for CMH and LED light fixtures during the manufacturing stage (a) and both manufacture and operational life (b) (Hierarchist view).*

## IV. Discussion and conclusions

It appears from this study that public lighting systems have a multiplicity of environmental impacts whose level of criticality differs from one technology to another.

Reducing energy consumption during the use phase is a key element and would have a knock-on effect in reducing the majority of other environmental impacts.

The comparison of the various environmental scores linked to the phases of the life cycle and of the aggregated scores shows that LED technology has the most environmental advantages compared to other technologies (HPS and CMH), particularly during the use phase.

The aggregated impact score relating to the overall life cycle of the LED luminaire is 69 points lower compared to the HPS luminaire, despite the latter showing advantages during the manufacturing phase (14.4 points against 50.3 points for the LED). This does not disqualify the LED system from its favourable position in that the advantages of usage would be more ecologically profitable throughout the lifetime.

Simulation under various scenarios of energy mixes will further support the trend of environmental indicators produced by the various public lighting systems.

The most significant reference functional unit for public lighting luminaires is the kilometre of lit road during the life of the luminaire and according to the design criteria for road lighting. Assessment carried out on this basis will give more accuracy to the characterisation indicators.

The illustration in Figure 8 shows that technological developments continue to bring energy and environmental performance to more interesting levels.

The LED luminaires of 2020 would produce significantly lower environmental impacts (41%) than HPS luminaires per lit kilometre, especially since LED luminaires are more easily adaptable with control devices (dimming, remote management, etc.), which significantly reduces the environmental impacts of energy consumption and maintenance.

The lifetime of the LED luminaire can reach 50,000 hours of operation, which considerably reduces the impacts resulting from manufacturing, maintenance and end-of-life treatment.

The rapid evolution of the shapes of the luminaires and their accessories suggests that the possibility of recovery for reuse of certain parts of the luminaire has not been taken into account because the availability of a suitable spare part at the end of its lifespan of 30 years is not assured. Therefore, the study is based on the fact that the whole of the luminaire will be replaced by a new unit.

The LCA results indicated that, on the basis of a lit kilometre, conventional luminaires (HPS and CMH) provide less environmental performance than those of LED technologies and that technological developments continue to further improve their ecological properties.

In his article on "Comparative LCA of lighting technologies" published in 2016, Hao Zhang concluded that LED lighting technology has an overall better environmental performance and could reduce 38% to 47% of all indicators compared to HPS luminaires and up to 90% for lighting systems with incandescent lamps over the entire life cycle.

The extrapolation and the analysis of the progressive tendencies of all parameters allow us to predict that as the LED technology progresses, the environmental benefits should become significant and that energy and environmental issues related to public lighting will be mostly minimised.

By using quality LED lighting products associated with smart technologies (dimming, presence detection, power variation, remote management, Internet of Things, etc.), public lighting systems will be an essential lever for sustainability and the optimisation of efforts to combat climate change and its disastrous consequences.

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