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LCA Streetlight Study for Circular Economic to Local Scale †

Lozano-Miralles José Adolfo [1,*], Hermoso-Orzáez Manuel Jesús [1,*] and Brito Paulo [2]

[1] Dpto Ingenieria Gráfica disño y Proyectos, Universidad de Jaén, 23071 Jaén, Spain
[2] IPP Portalegre, Portalegre, Valoriza Research Centre, 7300-555 Portalegre, Portugal; pbrito@ipportalegre.pt
* Correspondence: jalm0017@red.ujaen.es (L.-M.J.A.); mhorzaez@ujaen.es (H.-O.M.J.); Tel.: +34-639-307-670 (L.-M.J.A.); +34-610-389-020 (H.-O.M.J.)
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1. Introduction

Growing technological development causes industrial products to be discontinued and consequently replaced with greater advancements. Following the current trend of reducing greenhouse gas emissions in all fields of industry, construction, agriculture, transport, etc. many cities replace the luminaires of public roads with others with LED technology or induction that reduce such impacts [1]. This results in a stock of systems that are not used and are stored without knowing their end of life.

This study determines, through the LCA (Life Cycle Analysis) of its components, which are the ones that cause a greater environmental impact in order to reduce them and propose alternatives for their manufacture. The results difference between polluting elements in the environment in the categories of toxic and non-toxic. The scenarios include all the life cycle scenarios of the luminaires, including the final disposal of all the waste [2].

LCA studies allow companies to have a starting point for research and eco-design of new products, as well as the environmental improvement of those designed.

In a second phase, alternatives are sought for the reuse of the most suitable elements, which improve the local economy. As a result of this, the recycling of plastic is a solution to the problem of landfills, which has been a common practice in the industry. Replacing virgin plastic with recycled plastic results in greater environmental benefits [3].

This study investigates the environmental impacts of a road luminaire, as well as the impacts caused by its recycling in other end-of-life scenarios alternative to landfill.

2. Experimental

According to ISO 14040 standards (Table 1), LCA is defined as the collection and evaluation of the inputs and outputs for determining possible environmental impacts of a product, process, or system during its life cycle. Thus, LCA is a tool for the analysis of the environmental burden of products in all phases of their life cycle, from the extraction of resources, production of materials, pieces, and the product itself, to the use of the mentioned product and residue management after being discarded, whether re-purposing, recycling, or final disposal [4].

Table 1. International Standart normalization ISO.

Standard	*Description*	*Edition*
ISO 14040:2006	Environmental management, Life Cycle Assessment, Principles and framework.	2006
ISO 14044:2006	Environmental management, Life Cycle Assessment, Requirements and Guidelines.	2006
ISO/TR 14047:2012	Environmental management, Life Cycle Assessment, Illustrative examples on how to apply ISO 14044 to impact assessment situations.	2006

According to the previous approach, the first objective of this work was to determine the impacts of streetlight systems using LCA EPS2000 and CML IA-baseline methods (Life Cicle Methodology), which would provide us with information concerning the quantity and importance of CO_2 emissions to the atmosphere of the studied system. From the analysis of the results, we can determine the environmental impacts which took place during the manufacturing and operation of the system. The information which LCA provides us includes determining investment policies and reducing the impacts on the environment and which materials have recycling potential to incorporate them into a new end-of-life cycle as components of other raw materials.

2.1. Equipment

For the introduction of the data in the calculation software, it is necessary, first of all, to have absolute knowledge of the product, of all its components (materials, weights, origin, manufacturing processes, consumptions, etc.), and its operation [5,6].

*Unidad funcional*_. Viasolp model luminaire is carried out on a 50 w and is formed by a high-density aluminium, tempered glass screen, heatsink, and LEDs. The horizontal arm to which they attach to the pole is not considered a part of the streetlight in this study [7].

Streetlight fixtures consist of three basic components, housing, power supply, and bulb. The configuration of the LEDs to generate the luminaires is carried out based on scalable bases that allow reaching the necessary power in each case. The modules mounted each with a variable number of diodes form the light matrix [8]. (Figure 1)

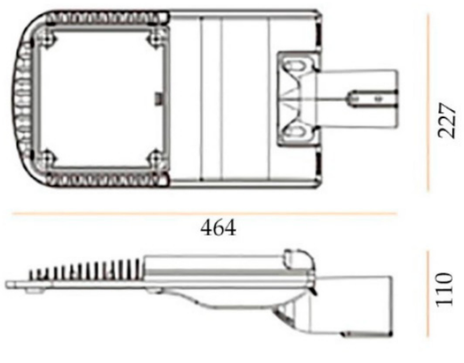

Figure 1. Streetlight Led Solitec.

*System limits*_ The streetlight measures are 110 × 495 × 227, in which 2 LED modules of 95 × 180 mm (5 units) are incorporated (Table 2). The possible options that can be selected to configure a luminaire from two different modular blocks, each mounted with a variable number of diodes, formed the luminous matrix of the luminaire. The other components of the luminaire have not been incorporated into the study since it is estimated that their weight in the set is not significant and/or they are not manufactured with materials that impact the environment. The data used in the information gathering phase for the LCA were provided by the manufacturing company and calculated according to the data in the existing bibliography on the subject [9].

The study involves the stages from the cradle to the grave in order to subsequently obtain alternatives and proposals for recycling, reuse, or return to other materials.

Table 2. Technical specifications of the streetlight.

Functional Characterics	
Light Type	Outdoor
High	110 mm
Long	495 mm
Width	227 mm
Haetsink material	High density aluminum
Heatsink coating	Paint corrosive environments
Optic screen	Template glass
Measures screen	110 x 165 mm
Integrable control	Microcontrolador TI
Security System	Temperature control
Cnnection type	Maweel (MBTS) PFC>0,96
Nominal Power (AC)	50 w
Operative Life ($T_{amb\ 25^{o}}$)	>100.000 hours (L80B 10)

To acquire knowledge about the system, a flow diagram of each process is given in Figure 2.

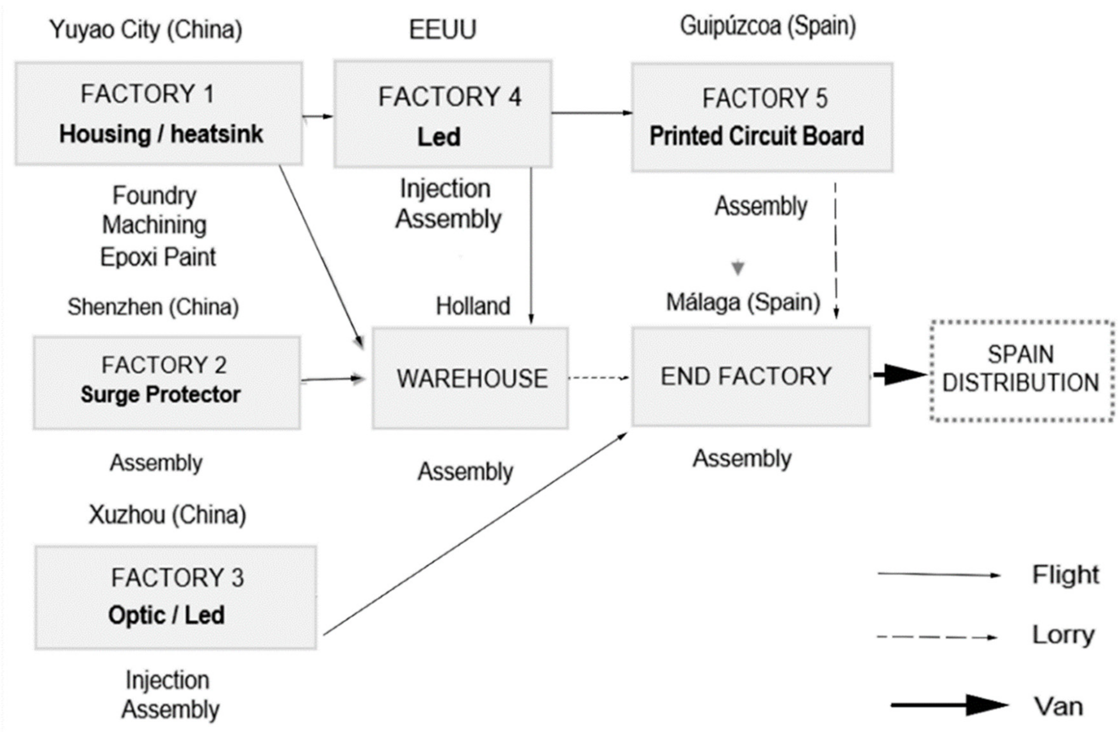

Figure 2. Transport diagram.

Throughout the life cycle, the distances necessary for the extraction, processing, and manufacturing of the materials necessary to obtain the luminaire have been calculated. Figure 3 shows the diagram with the life cycle considering all the processes, which include the final packaging, the distribution in the Iberian Peninsula, its use, and the final disposal in landfill/warehouse.

Throughout the life cycle, the distances necessary for the extraction, processing, and manufacturing of the materials necessary to obtain the luminaire have been calculated. Figure 3 shows the diagram with the life cycle considering all the processes, which include the final packaging, the distribution in the Iberian Peninsula, its use, and the final disposal in landfill/warehouse.

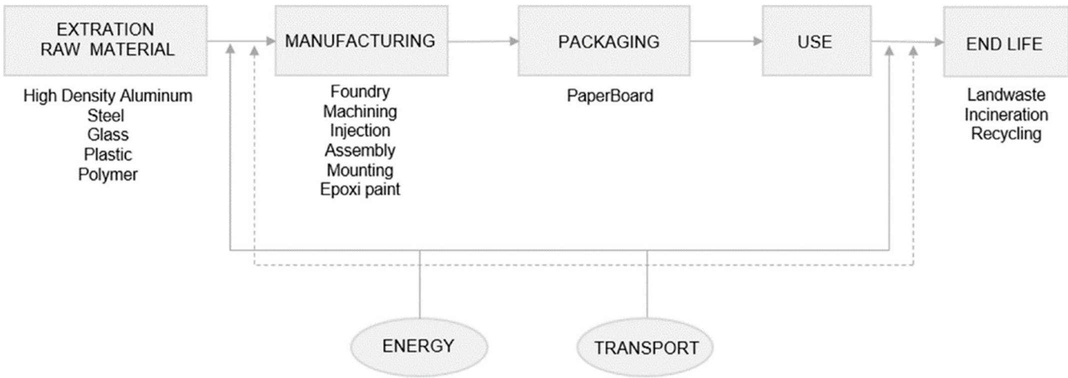

Figure 3. Life cycle diagram of process flow.

2.2. Annual Energy Consumption

The calculation of the annual energy consumption has been considered within the following limits: working is from 18.00 h to 8:00 h with a service life of 20 years (88.000 h).

The inventory of entrances and exits during the extraction of the materials was adapted to the procedures defined in the Ecoinvent database [10], which was prepared under a cooperation agreement between The Swiss Federal Institute of Technology Zurich (ETH Zurich), Paul Scherrer Institute (PSI) Swiss Federal Laboratories for Materials Testing and Research (EMPA), and Swiss Federal Agroscope Research Station (ART), and it contains more than 2.5 million data sets for products and services in the energy, agriculture, transportation, construction materials, chemicals, pulp and paper, waste treatment, and agricultural sectors for different continents [11].

This tool allows us, once the data has been entered, to obtain the environmental pollution units through various impact categories. These are calculated according to the selected calculation method [12].

The distribution for the use of the luminaires has been considered to be carried out in the Iberian Peninsula, calculating the values of kilometers of displacement through commercial vehicles. Once the luminaire's useful life has been completed, an end-of-life scenario of storage in the warehouse/re-incorporation of recyclable material as raw material is contemplated. The environmental behavior of material collection and energy consumption in the reincorporation of the material into the productive cycle (circular economy) are studied. (Figure 4)

Analysis methods. By using the SimaPro v8.30 software program, and supported by two calculation methods, we conducted a sensitivity study that indicated a possible deviation from the results obtained. The EPS 2000 method and the CML IA-baseline method are the best options for calculating the environmental impacts associated with the life phases described.

EPS 2000 method assesses four main impact categories which correspond to the loss of ecosystem regeneration (PDFm^{2}yr), the damage caused to people's health (DALY), depletion of natural resources (MJ/Kg), and the depletion of biodiversity (PDFm^{2}yr).

To establish the environmental impact of the luminaire, three different aspects have been taken into account: the analysis of the inventory, the evaluation of the impact, and the interpretation of the analysis. (Figure 5)

Raw Materials	Kg
Housing/Power supply/LEDs	
Aluminum, high density	3.98
Steel	0.85
Template glass	0.27
Copper	0.21
Paperboard	0.10
Polystyrene	0.08
Total	5.49
Energy	**MJ**
Medium voltage electricity mix	4.400
Transport	**tkm** [1]
By plane	3.462
By lorry (40 t)	2.280
By van (<3,5 t)	2.440
Waste	**Kg**
Electronic aystem	1.24

[1] tkm: Unit of transport of 1 ton material per 1 km (Source: self-made).

Figure 4. Inventory of materials (compilation).

Impact Categories	Unit
Ecosystem production capacity	* PDF·m^2·yr
Human health	Person/yr
Damage recourses	MJ/Kg
Biodiversity depletion	* PDF·m^2·yr

* PDF·m^2·yr. Potentially disappeared fraction of species of m^2 during a year.

Figure 5. EPS 2000 method.

In order to perform a correct analysis of the results, the software allows simplifications and groupings of the results based on the characteristics of the impacts and grouping according to the categories of the selected method. (Figure 6)

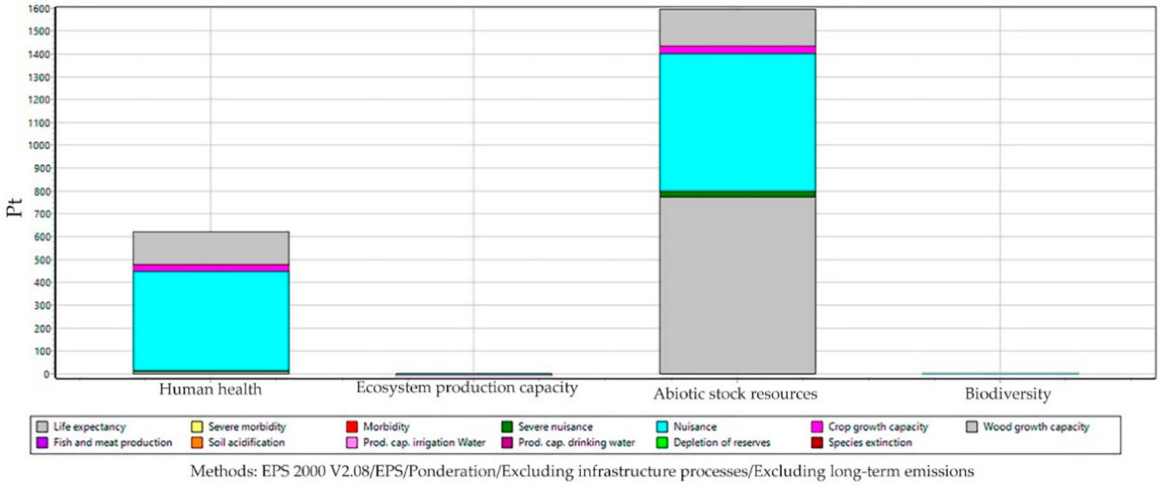

Figure 6. Ponderation, EPS 2000 Method.

As we can see, the greatest impacts occur on the depletion of resources, based on the consumption of fossil fuels due to the excessive transport of the different components of the streetlight. With a smaller percentage, but not negligible, we observed that the impacts on human health must also be reduced and the possible alternatives analyzed. With less importance, we find the impacts on the capacity of regeneration of the ecosystem and the reduction of biodiversity. (Figure 7)

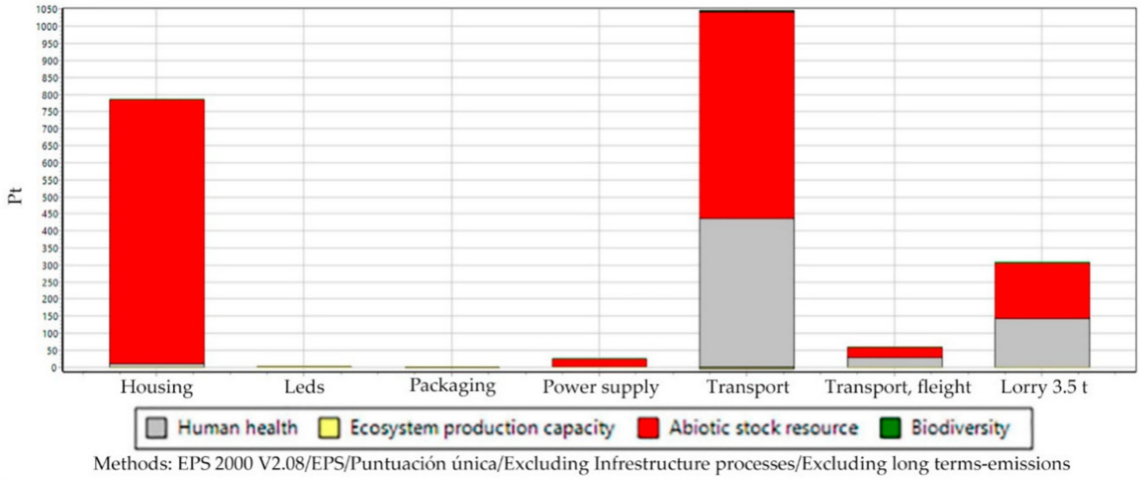

Figure 7. Single score EPS 2000 method.

Through the single score, we determine which are the life cycle processes of the streetlight that have the greatest impact. As we have previously described, the transport by plane to the assembly plant in Spain has the greatest impact, up to 72% greater than the rest. In addition, road transport is added by truck or van for product distribution. This fundamentally affects human health. On the other hand, the manufacture of the housing of the lighting company generates an important impact on the reduction of abiotic resources. The rest of the impact is of little relevance. Figure 7 gives us more detailed information on those categories that are most affected. Adding the impacts produced both in the manufacturing processes and in the transport of the carcass (housing) and the transformer (power supply) results in 87% of impacts on the reduction of reserves and 13% on the life expectancy. (Figure 8)

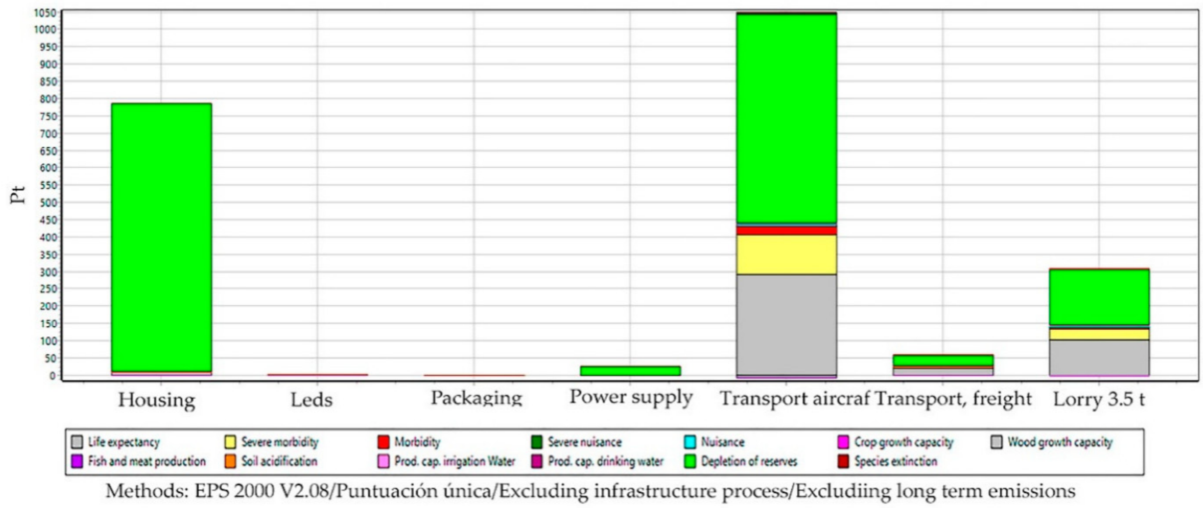

Figure 8. Single score categories, EPS 2000 method.

Table 3 shows the values for the methodology, as well as the products that produce these impacts.

Table 3. More affected categories and the more weighed factors related to energy consumption, EPS 2000 method.

Damaged Categories	Units (kPt) Housing	Unit (kPt) Supply Power	% d of the Greater Environmental Impacts
Human health	0.195	0.215	Emissions to air CO_2 (60.15%), PAH Polycyclic aromatic hydrocarbons (66.5%)
Exhaustion of Resources	2.05	2.28	Mining Petroleum (62.55%), Coal (22.98%), Natural gas (14.47%)

To simplify results, contributions to environmental impact indicators and their values have been sorted into four groups. The performed analysis included the different stages of the life of each constituent but it must be borne in mind that the variation of conditions of their use as well as the length of an operational lifetime may change the results. (Figure 9)

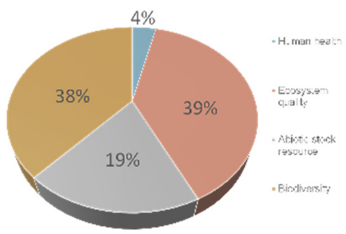

Figure 9. % impacts, EPS 2000 method.

CML IA baseline method offers us information on environmental impacts, as shown in Figure 10.

Impact Categories	Unit
Global warming/climate change	Kg CO_2 equiv.
Ozone depletion	Kg CFC-11 equiv.
Water acidification	Kg SO_2 equiv.
Creation of photochemical oxidant	Kg C_2H_4 equiv.
Water eutrophication	Kg PO_4 equiv.

Figure 10. CML 2001-IA baseline method.

The results obtained with this method gives us the information as shown in Figure 11.

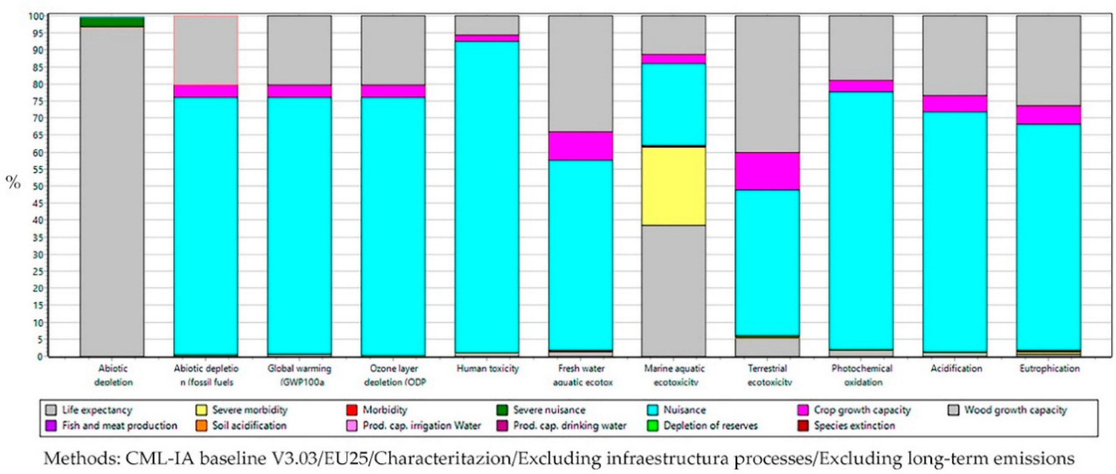

Figure 11. Characterization using CML 2001-IA baseline method.

Figures 12 and 13 shows the values for the CML 2001-IA baseline method, as well as the products that produce these impacts Table 4.

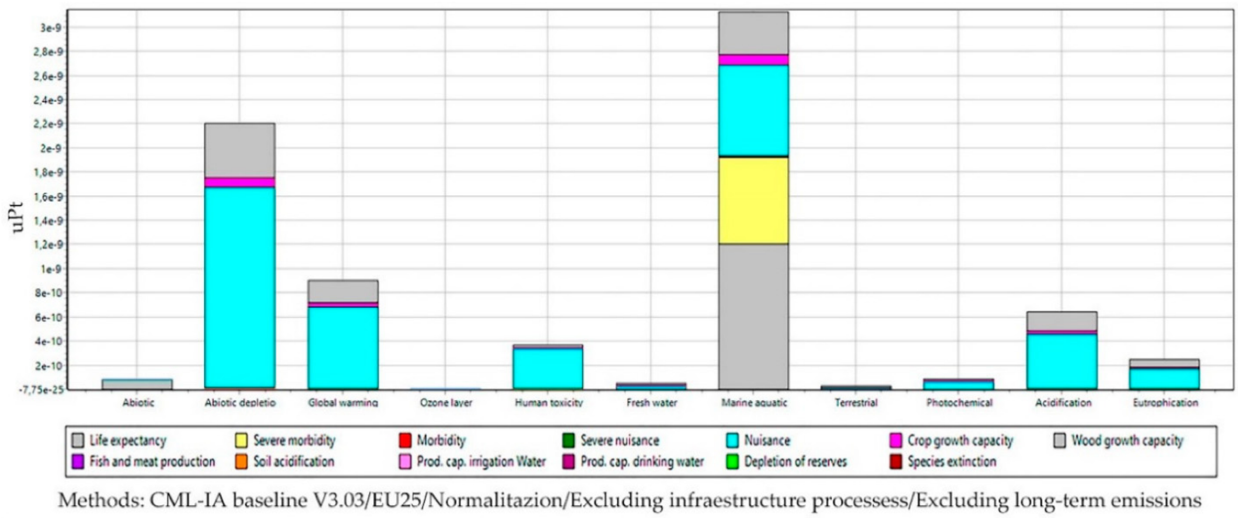

Figure 12. Normalization using CML 2001-IA baseline method.

Table 4. More affected categories and the more weighed factors related to energy consumption as per the CML IA-baseline method.

Damaged Categories	Units (kPt) Housing	Unit (kPt) Supply Power	% d of the Greater Environmental Impacts
Human health	0,195	0,215	Emissions to air CO_2 (60.15%), PAH Polycyclic aromatic hydrocarbons (66.5%)
Exhaustion of Resources	2,05	2,28	Mining Petroleum (62.55%), Coal (22.98%), Natural gas (14.47%)

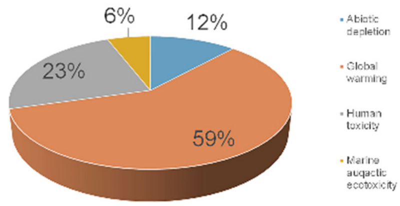

Figure 13. % impacts, CML IA-baseline method.

3. Results and Discussion

Analysis of environmental impact. This section aims to determine all the possible environmental impacts related to the parameters obtained in the previous section. This study was carried out in accordance with priority strategies of the EPS 2000 method [12–15]and in the following sequence of tasks: classification, characterization (indicators are selected according to each category of impact), standardization, and valuation.

This methodology has environmental strategies for the design of products as a priority, and the latest version of the EPS method evaluates the impact on the environment through its effects in one or several human health themes. The categories of impact are identified from the following issues: production capacity of the ecosystem (including information related to agriculture, fish or meat, and the decrease in timber field), protection of human health (including human diseases), natural resources and abiotic resource in stock, with the environmental cost, resources, and biodiversity (including the extinction of species).

Single score. In this step, the relative importance of each category of impact is determined. A unit called Eco-point indicator (kPt) is used. It should be taken into account that the absolute value of the points is quite irrelevant, as the main aim is to compare relative differences between the products or components.

As a common point of the results obtained, we can determine energy consumption in the form of electricity, which is the most relevant factor for the LCA. On the other hand, air emissions to the atmosphere produced by the boiler system are more significant.

With the scenario of 100% virgin raw material formulation, results indicate that the greatest environmental effects were achieved in the categories corresponding to the extraction of materials (37%), the generation of inorganic material in suspension within of the atmosphere (25%), the use of fossil fuels (24%), and ecotoxicity (7%). Such impacts occurred in the stages of extraction, transformation, and transport of materials.

After breaking down the results, we can say that in the extraction of materials, the largest contribution corresponded to plastic (83.1%), aluminum (11.6%), and copper (5.09%). Regarding the breathable inorganic material, it was determined that the main components are NOx and SOx emissions.

The *CML IA-baseline* indicates that the consumption of fossil resources is 41.92% for biomass boiler and 34.34% for heat pump, and are the main impact factor, which is increased to 58.3% with the consumption of minerals, respiratory effects caused by inorganic substances air emissions such as SOx and NOx, together with climatic change due to CO_2 emissions, which show higher values for biomass boiler system with a value of 23.6%. Finally, with lower values, it is carcinogenic with 5.10%, due to heavy metals emissions in air and water. The quality of ecosystems is mainly affected by ecotoxicity (4%), acidification and eutrophication (1.8%), and land occupation (0.2%). Damages caused by ecotoxicity are mainly because of heavy metals emissions in air and water, while the damages by acidification and eutrophication are principally due to NOx and SOx emissions [16,17].

(a) The national production of some elements and/or systems is scarce, reducing in some cases to the mere assembly of elements. It is necessary to incorporate eco-design to reduce the amount of material used and to achieve a greater location of the components that avoid the important impacts of transport.
(b) The components of the luminaires have different manufacturing areas, which causes a considerable increase in the impacts of transport to the final assembly site.
(c) The end of life of components such as the carcass does not present alternatives to landfill or incineration, due to the material with which it is manufactured (plastic).
(d) It is necessary for the environmental analysis of the alternative of recycling and incorporation to other materials, as an alternative to the reuse of the plastic components (housing).
(e) When not finding LCA studies on similar luminaires, it is necessary to carry out other comparative LCA studies that provide us with environmental information on these products and that can be used for decision-making along with other aspects such as economic, technical, and maintenance, etc. [18–21].

4. Conclusions

The use of recycled material in the manufacture of some components of the luminaires provides a significant reduction in the overall impacts of the product, in terms of the kPt indicator, of 231%. In the design phase of the luminaires, where the materials, the composition of the recycled material, and other relevant considerations are selected, these aspects affect the processes to be used, the quality of the product, and its relationship with the environment.

LCA methods with two methodologies have been used in the present work to determine the impacts of two systems of production of heat, a heat pump system, and a biomass boiler system. Despite different methodologies used, the result has confirmed that similar impacts occur in the systems, showing differences in individual components. According to this, it can be seen that the main damage of the two systems takes place during the manufacture and operation of the boiler pellet, in the category of resource depletion, as well as CO_2 emission, which causes climate change. Other minor impacts are on life expectancy and the use of coolant in the heat pump. In addition, we obtain impacts on human health, respiratory effects caused by the emission into the air of inorganic substances such as SO_x and NO_x, and carcinogenesis that is practically similar in the two systems.

The waste generated by the replacement of the luminaires with others that incorporate new technologies are very abundant and represent up to 72% of the total volume. These elements must be reincorporated into the manufacturing life cycle of the same luminaires or other life cycles that may be complementary due to their characteristics and affinities. Eco-design is environmentally beneficial and has an economic benefit since most of the improvements refer to the decrease in material [22–25]

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