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REPRO-LIGHT

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D5.2 LCA Report

WP5–Environmental assessment

Repro-light:
Re-usable and re-configurable parts for
sustainable LED-based lighting systems

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Abstract

Repro-light is a European research project that aims to support the European lighting industry in moving towards a more sustainable and competitive future within a circular economy.

This report focuses on Objective 3, where Life Cycle Assessment is used to assess the environmental impact of LED lighting, which activities are in the context of the WP5.

The work is divided into two parts:

- Part I presented where the results of a comparative LCA was conducted on two conventional LED linear luminaires used in an industrial lighting system. This document sets the methodology and background datasets to be used in Part II in order to ensure consistency for the comparative analysis.
- Part II presents the results of LCAs conducted for the innovative LED luminaires designed in the Repro-light project compared to the benchmark luminaire with best performance reported in Part I.

Three Repro-light luminaire designs were considered for the LCA models to be compared to the benchmark luminaire (Luminaire B). The main difference in the luminaires leads in the saving of materials and energy due to the innovations developed in the project and a design modular luminaire architecture. The materials in the Luminaire A1(E-line next) are saved in its mechanics, optics and LEDM parts. Luminaire A2 (exchangeability demonstrator) are the same as the Luminaire A1, except the use of plugs for exchangeable LEDM. The luminaire A3 (Illuminated driver design) is not produced during the project but its design is available. Basically, the difference of this luminaire respect the other ones is to save more amount of materials by combination of both components LEDM+C, thereby its environmental performance is also investigated. Sensors and controllers are used for dimming the lighting systems, which were included in the modelling of three innovative luminaires. The other different aspect is in the type of LEDs used in the Repro-light luminaires. Those LEDs have a very small amount of gold in the bond wire compared to the Luminaire B. This fact has a considerable effect on the environmental impact of the luminaires, in particular ADPe impact category, since gold is an element that has a high environmental burden from the raw material extraction to the final product.

The environmental overall results show that Repro-light luminaires performs better than Luminaire B decreasing the environmental impact between 12 and 27% for all environmental impact categories analysed, except in the total ADPe that had higher reduction between 27 and 55% respect to the Luminaire B. On the other hand, the lifetime of the luminaire is elongated due to the lighting dimming system implemented in the project. The luminaire A3 is the one with the best environmental performance due to more saving of materials.

An exchangeability scenario of LEDM and LEDC components, using the environmental model of the Luminaire A2, was compared to a non-exchangeability scenario, which is modelled with the Luminaire A1. LEDM and LEDC components were assumed to be the main responsible for the luminaire failures. The number of those components to be replaced along the lifetime of the luminaire was based on a luminaire failure fraction of 1% calculated from the failure data provided by partners. The results show that the Luminaire A2 production stage is dominant due the plugs for the exchangeable LEDM, making the total ADPe slightly higher (0.15%) in the scenario with exchangeability. However, savings in the production spare parts and disposal stage of the scenario with exchangeability are observed, which is attributed to the save of materials. These results can help to make decision to develop LEDC and LEDM components with shorter lifetime than the luminaire lifetime. In particular, to revise the design of plugs for the exchangeable LEDM, since it is sensible for the ADPe metric. In addition, the production costs should be analysed in order to know if the production of components with those characteristics is compensated.

List of Abbreviations

ABS	Acrylonitrile butadiene styrene
ADPe	Abiotic Depletion Potential elements
ADPf	Abiotic Depletion Potential fossil
AP	Acidification Potential
ECG	Electric Control Gear
EIPD	Environmental impact for producing and disposing
EU	European Union
EP	Eutrophication Potential
GWP	Global Warming Potential
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LEDs	Light Emitting Diodes
LEDC	Light Emitting Diode Control
LEDM	Light Emitting Diode Module
PED	Primary Energy Demand
PET	Polyethylene terephtalate
PMMA	Polymethyl methacrylate
PP	Polypropylene
WEEE	Waste Electrical and Electronic Equipment

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Introduction

This report shows in two parts the environmental LCA performance of linear LED luminaires conducted in task 5.2. Part I is focused on a comparative LCA study of two conventional LED linear luminaires, whereas the Part II is dedicated to compare the LED linear luminaires designed as part of the Repro-light project (referred as Repro-light luminaires from here forward) with the conventional one having the best environmental performance.

The analysis was conducted using environmental Life Cycle Assessment (LCA). LCA quantifies the potential environmental impact of a product system over a defined life cycle. While conventional environmental assessment techniques focus only on parts of a life cycle, such as manufacturing or disposal, LCA considers the entire life cycle including raw material extraction, manufacture, production, use and disposal. This is often called the "cradle-to-grave" approach, and is useful for revealing ´hot spots´ with high environmental impacts that conventional techniques may not consider. The life cycle concept thus gives a more complete picture of the overall environmental impact.

The cradle-to-grave LCAs of the luminaires are in compliance with the International Organization for Standardization's guidelines for LCA as documented in ISO 14040:2006 [1] and ISO 14044:2006 [2]. The ISO standards have been criticized for being too vague resulting in studies using various methods for the same product system and being incomparable. Therefore, the LCAs follow the methodology presented in the general Product Environmental Footprint Category Rules, which can be converted into Environmental Product Declarations (EDPs) or Product Environmental Footprints (PEFs) following the necessary verification and certification steps, if desired. EDPs and PEFs aim to harmonize the methodology that is used for LCA studies of the same product system, both of them are in compliance with the ISO standards for LCA and aim to allow for comparability across studies of the same product system through use of a more detailed methodology.

The Repro-light luminaires are compared with benchmark luminaire for their use in a lighting system for an industrial hall of 120m x 60m with the requirement of providing the same quality of light. The illuminance specified for industrial settings in the technical rules for workplaces, ASR A3.4 [3], of 300 lux was used as the required light output for the comparative study. Dialux software was used to determine the number of luminaires needed to meet the required illuminance, sizing the system according to a Maintenance Factor of 0.8.

The comparison of the Repro-light luminaire designs with the benchmark luminaire is reported in this deliverable in order to determine where savings in material use, type of material, energy consumption and waste production can be made to reduce the environmental impact of LED linear luminaires. In addition, the results from this study were used to inform design scenarios for the Repro-light luminaire, which is modular, exchangeable and dimmable, which helps to enhance the Circular Economy of the linear luminaire developed in the project.

PART I Environmental Assessment of Benchmark LED Luminaires

Goal and Scope Definition

Goal

The goal of the study is to compare the life cycle environmental impact of two benchmark LED luminaires that are used to meet lighting regulation in an industrial setting. The benchmark luminaires differ in rated power and in the material used for the gear tray. A lighting system for each LED luminaire was designed with Dialux software to meet the requirement for lighting as stated in the Technical rules for workplaces standard [3]. The overall goal is to investigate the energy efficiency versus material efficiency of both lighting systems from an environmental perspective.

Scope

Functional Unit

The functional unit for the LCA studies is an illuminance of 300lux in an industrial hall (120m x 60m). The defined lifetime for the luminaires is 70,000h.

System Boundary

The cradle-to-grave system boundary includes the energy inputs and emissions and waste outputs for all stages in the life cycle, including raw material extraction, production of each component of the LED luminaire, assembly of the luminaire, installation, the use of the luminaires in a lighting system, collection and transport for disposal and the final disposal scenario Figure 1. The assembly energy of the LED luminaire was estimated using data from the manufacturer, TRILUX (refer to Table 5). The installation of the lighting system has been estimated using the transportation of the luminaires to the site as in a study by Tähkämö *et al.* [4]. This transport distance has been estimated as 30km. The packaging of both luminaires has not been considered and is assumed to be the same for both luminaires. The production of industrial machinery and equipment is also not included in the system boundary, nor is the transportation within the manufacturing plant. It is further noted that in terms of transportation, reductions in the distances travelled and the use of ground as opposed to air travel will lead to reductions in the environmental impact.

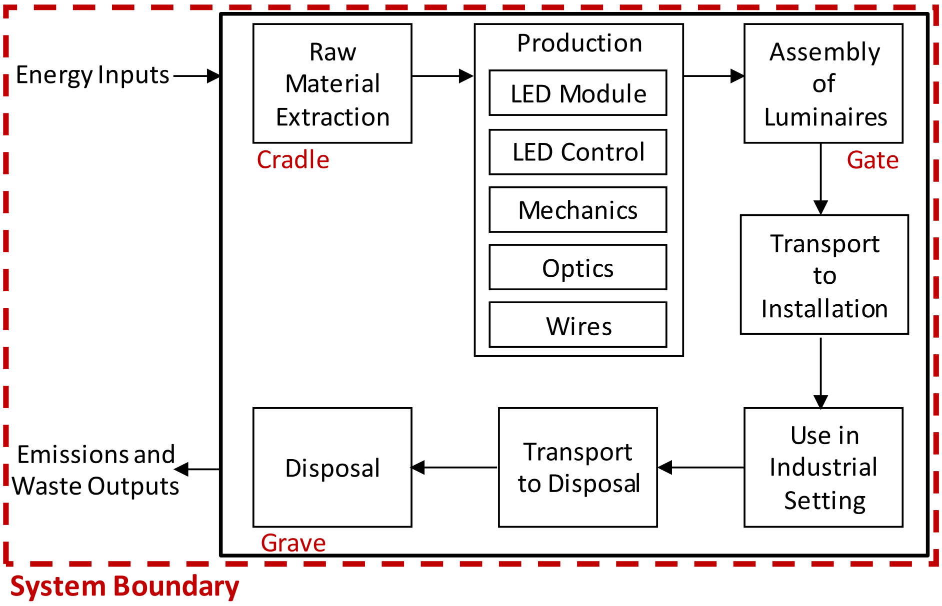


Figure 1: System Boundary for LCA comparison

Assumptions and Limitations

For all the luminaires it has been assumed that the production, electricity generation and waste management is located in Europe. The electricity mix is assumed to be EU-28: Electricity Grid Mix (Figure 2).

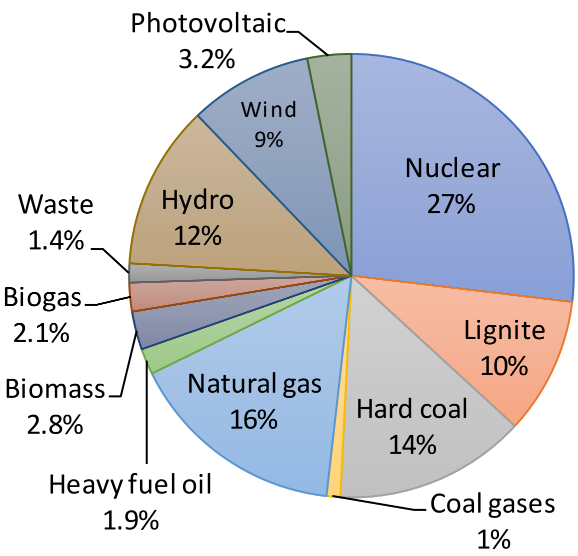


Figure 2: Electricity grid mix used in the LCA (EU-28 mix). Source: Adapted from GaBi Professional Database.

In Spain, AMBILAMP provides a collection and sorting service for lighting products at the end-of-life. The luminaires are collected and taken to a sorting facility where they are dismantled and the components are disposed of accordingly. Transport to the End-of-Life facilities has been assumed to occur by road with a 22t lorry. Distances for transport of materials have been estimated as 60km from collection point to AMBILAMP and 80km from AMBILAMP sorting to final disposal destination.

Data Sources and Data Quality

The results of this study are dependent on the availability and quality of data obtained from project partners, literature and datasets, Thus, primary data of LED luminaire components and materials have been provided by the Repro-light partners, as well as measured by dismantling the luminaire (refer to Table 2). Upstream data was obtained from GaBi ts Professional Database (version 9.2.0.58) as well as EcoInvent 3.5 database. GaBi ts commercial software was used to model and quantify the LCI and LCIA results. In order to improve the results, further work should focus on improving the data quality regarding the electronic components and evaluating the potential for precious materials recovery from the circuit board and LED boards. Studies have shown that recovery is possible at fairly good yields. For example, Gallium and Indium can be recovered from LEDs using a combination of pyrolysis, physical disaggregation, and vacuum metallurgy at greater than 90% yields [5], however, this is not yet common practice. The recovery of precious metals from luminaires also needs to be economically feasible.

Impact Category Selection

The Life Cycle Impact Assessment (LCIA) will include the midpoint Impact Categories defined in Table 1.The chosen characterization models and characterization factors for each impact category are also defined in the table. Endpoint indicators have not been considered in this study.

Table 1: Summary of midpoint impact categories assessed

Impact Category	LCI Results	Characterization Model	Category Indicator	Characterization Factor	Category Indicator Result	Environmental Relevance
Climate Change	Quantity of greenhouse gas (CO_2, CH_4, etc.) per functional unit	IPCC AR5 GWP 100 years	Infrared Radiative Forcing	Global Warming Potential (GWP)	kg CO_2-equivalents per functional unit	Increased radiative forcing due to the increase of greenhouse gases in the atmosphere
Energy Demand	Quantity of energy in MJ (net cal. value) per functional unit	Primary Energy Demand from renewables and non-renewables	Energy Consumption	Primary Energy Demand (PED)	MJ per functional unit	Increased energy consumption from renewable and non-renewable energy sources
Abiotic Resource Depletion	Quantity of elements per functional unit	CML 2001- Jan. 2016, Abiotic Depletion Potential, Elements	Extraction of resources	Abiotic Depletion Potential, Elements (ADP Elements)	kg Sb-equivalents per functional unit	Increased extraction of resources leading to depletion of non-renewable mineral reserves
	Quantity of natural resources (crude oil, etc.) per functional unit	CML 2001- Jan. 2016, Abiotic Depletion Potential, Fossil	Extraction of resources	Abiotic Depletion Potential, Fossil (ADP Fossil)	MJ per functional unit	Increased extraction of resources leading to depletion of non-renewable fossil reserves

Acidification	Quantity of emission (SO_2, NH_3, NO_x, etc.) per functional unit	CML 2001- Jan. 2016, Acidification Potential	Proton release to water and soil (H^+ aqueous)	Acidification Potential (AP)	kg SO_2-equivalent per functional unit	Increased acidity of soil and water due to proton release from anthropogenic emissions
Eutrophication	Quantity of emission (PO_4, etc.) per functional unit	CML 2001- Jan. 2016, Eutrophication Potential	Nutrient release (nitrogen and phosphate)	Eutrophication Potential (EP)	kg PO_4-equivalent per functional unit	Increased biomass formation and loss of biodiversity due to release of nutrients

Life Cycle Inventory

This section first describes the changes to the cradle-to-gate (production of a luminaire) preliminary LCA results that were presented in Deliverable 5.1. Then a detailed description of the inventory data is presented, including the bill of materials for the luminaires, and the data for the assembly, use and end-of-life disposal life cycle stages.

Changes from Deliverable 5.1

LCA is an iterative process, meaning that as more information is obtained and as quality checks are conducted, the model is updated and again checked for quality, consistency and completeness. Deliverable 5.1 presented preliminary results for an LCA study for the production of a luminaire. The changes applied to the LCA model and used in the LCA presented in this Deliverable include:

- Updated quantities of the luminaire components. A luminaire was dismantled and thus more information was obtained regarding the mass of each part.
  - In particular, data for the mass of the wires and the optics were updated. This has led to major changes in the contribution of wires to the overall impact of the production of the luminaires, and smaller changes regarding the optics.
- Background dataset updates.
  - The model for the electronic components was updated. Previous datasets were found to overestimate the environmental impact of electronics, particularly for the LED Control components including the capacitors, varistor and conductors. Updated datasets were used to model the production of these components, resulting in major changes to the contribution of the LED Control to the overall impact of the production stage of the luminaires. The datasets for the LED Module were also updated, but the change in the result was less significant than for the LED Control.
  - The dataset for steel was updated to organic coated steel coil. This dataset is representative of the steel product that is used for the trunking and gear tray of the luminaire. This has changed the overall contribution of the mechanics to the impact of the production of the luminaires.

These changes have been applied to the LCA model used in this study, and thus have improved the confidence in the results presented in this document. The same model and datasets should be used for the LCA of the Repro-light luminaire designs for Part II, where appropriate.

Bill of Materials and Assembly Energy

A luminaire was dismantled and the components weighed and classified as in Table 2 and Table 3 further gives the classification and the mass of the circuit board components in the LED control. The classification was used to determine the dataset to use for the upstream data of these components. Table 4 gives the categories used throughout the LCA study and the mass balance of both luminaires.

Table 2: Materials Inventory for the LED Linear Luminaires

Component	Material	Total Mass (g)	Visual
Plastic Parts (including ABS endcaps to trunking and gear tray)	ABS	91.85	
Metal Parts	Steel	103.41	
Trunking	Organic Coated Steel Coil	1648.00	
Gear Tray	Luminaire A = Powder Coated Aluminium Luminaire B = Organic Coated Steel Coil	1694.25 1044.25	
Plastic housing for Electronic Control Gear (ECG)	PET	4.35	
Steel housing for Electronic Control Gear (ECG)	Steel	93.81	
LED board (33 lights per section, 5 sections, 28.0cm x 5.5cm x 1.5mm)	Circuit board is HASL, one layer	251.43	

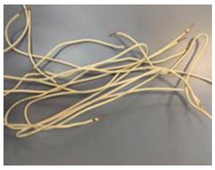
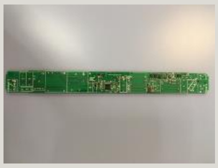
Optical element	PMMA	531.28	
End piece to the optical element (x2)	PP	2.94	
Wiring (approx. 2mm diameter; Total length: 285.7cm)	Copper wires	22.08	
Wiring (approx. 3mm diameter; Total length: 110.6cm)	Copper wires	20.71	
Screws	Stainless steel screws	19.10	
Circuit Board (Dimensions: 25.9cmx2.7cmx1.8mm)	Printed wiring board	30.56	
Capacitors, Conductors, Varistor	Details in Table 3	112.46	

Table 3: Circuit Board components of the LED Control (LEDC) and Classification

Identification	Classification	Total Mass (g)
AISHI CD116E	Aluminium Screw	4.35
10142949C 10142951A 10142947C 10125624B 101062491710	Ring Core Coils with Housing	96.37
Blue PILKOR x4 Silver GD332J1000 Silver GD473J630	Film capacitors boxed	6.43
WALSIN 511K10D	Varistor	1.23
Red HPET 701090142	Film capacitors unboxed	1.44
Black cylindrical with radial extension	Al Capacitor Radial	0.22
Small wound coil with black wrapping	Coil miniature wound SDR	2.43
	Total	112.46

Table 4: Categorization of the LED components and total mass of Luminaire A and B

Category	Component	Mass of Luminaire A (g)	Mass of Luminaire B (g)
Wiring	Copper wires	42.8	42.8
LEDC (LED Control)	Circuit board Capacitors, Conductors, Varistor Plastic housing for ECG Steel housing for ECG	30.6 112.5 4.35 93.8	30.6 112.5 4.35 93.8
Mechanics	Steel parts Plastic parts Screws Gear tray Trunking	103.4 91.9 19.1 1694.3 1648	103.4 91.9 19.1 1044.3 1648
LEDM (LED Module)	Circuit board (5) LED SMD (165)	251.4	251.4
Optics	Optical element End piece to optical element	531.3 2.94	531.3 2.94
	TOTAL	**4626.4**	**3976.4**

For the gear tray and trunking components of the luminaire, further processing is done at the manufacturer prior to luminaire assembly. The trunking for both luminaires is produced through roll-forming of organic, galvanised steel coil. The roll-forming is done at the manufacturer. Similarly, the gear tray for Luminaire B is produced though the same roll-forming process as the trunking at the manufacturer. The energy for roll-forming of steel has been estimated by the manufacturer as 0.0385 kWh per component (gear tray or trunking). The gear tray for Luminaire A, however is composed of powdered coated Aluminium. The powder coating is applied at the manufacturer. The energy for powder coating the Aluminium gear tray has been estimated with a dataset available in the GaBi ts database.

For the assembly of the luminaires, the annual electricity consumption of the production line process was obtained from the manufacturer along with the annual production quantities. This data was used to estimate the energy consumption for both the assembly of the gear tray and the assembly of the trunking. For Luminaire B, the gear tray is assembled as per the production line process shown in Figure 3.

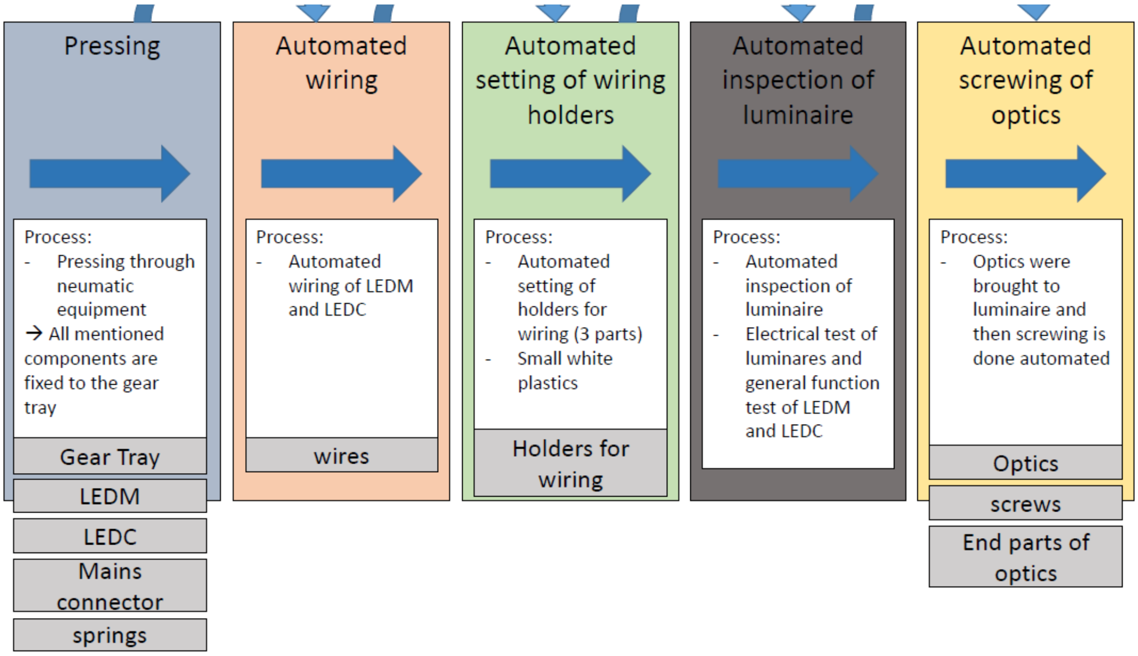


Figure 3: Flow Diagram for the Production Line Assembly of the Gear Tray for Luminaire B

For Luminaire A, the gear tray is assembled manually with the use of electric tools and then undergoes an automated inspection to test the function of the LEDC and LEDM. For the trunking in both luminaires, an automated process for the installation of the wires and connectors is used. The energy consumption for each Luminaire for the assembly process is summarized in Table 5.

Table 5: Energy consumption in kWh for Assembly of Luminaire A and B

Process	Luminaire A	Luminaire B
Automated assembly of Trunking[1]	0.112	0.112
Manual assembly and Inspection of Aluminium Gear Tray	0.110	0 .000
Automated assembly of Steel Gear Tray[1]	0.000	0.0352

[1]Estimated from manufacturer (TRILUX)

Use Phase Inventory

Each luminaire has a lifetime of 70,000 hours, which is better than the industry standard of 50,000 hours that is reported in most LCA studies of LED lighting. This extended life was input as the hours of use for both benchmark LED luminaires modelled.

The specifications for both LED luminaires used in this study are given in the Base Scenario description in Table 6. The number of luminaires and the illuminance (lux) were calculated using Dialux software considering an industry hall of 120mx60m, a minimum required illuminance of 300 lux and a Maintenance Factor (MF) of 0.8 (Figure 4).

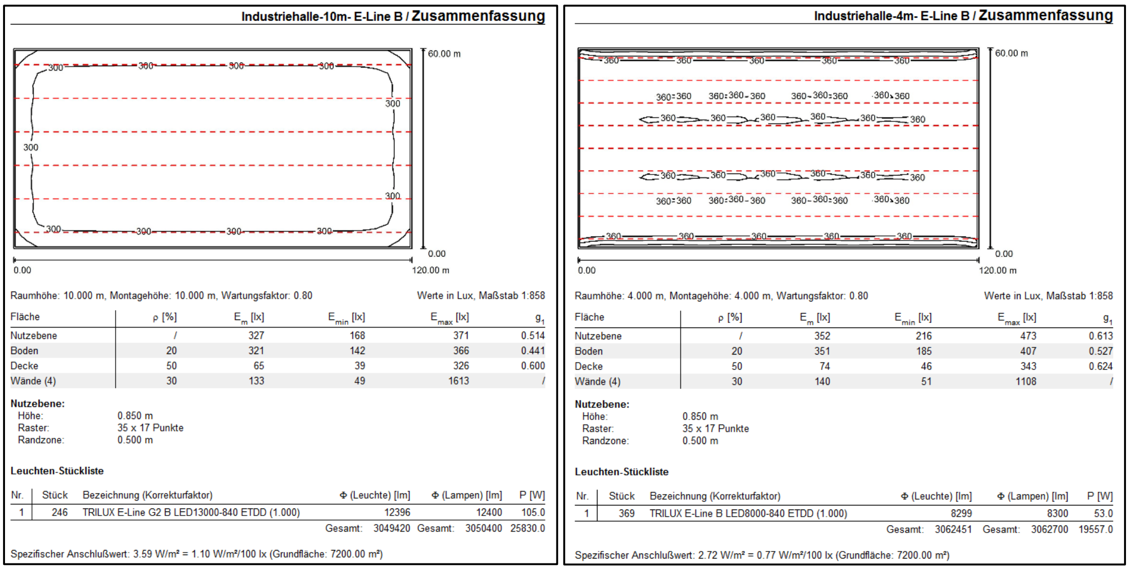


Figure 4: Dialux results for Luminaire A (left) and Luminaire B (right)

It is not possible for both LED lighting systems to meet exactly 300 lux, therefore the rated power was scaled linearly with the illuminance to yield 300 lux, as per Equation 1. The resulting power is given in the Scaled Scenario in Table 6. It is assumed that the scaling does not change the quantity of luminaires or luminaire components used in each lighting system, as per discussions with lighting experts. The scaling of the power is necessary in order to compare the same quality of light output from each lighting system. This power is used to quantify the energy consumption of the lighting systems as per Equation 2.

Table 6: Specifications for the LED lighting comparison

LED Lighting	Luminaire A	Luminaire B
Base Scenario		
Gear Tray Material	Aluminium (Powder Coated)	Steel (Coated Steel Coil)
Rated Power (P_B)	105 W	53 W
Number of luminaires (N_B)	246	369
Illuminance (I_B)	327 lux	352 lux

Scaled Scenario		
Gear Tray Material	Aluminium (Powder Coated)	Steel (Coated Steel Coil)
Scaled Power (P_S)	96.3 W	45.2 W
Number of luminaires (N_B)	246	369
Illuminance (I_S)	300 lux	300 lux
Total Energy (E_T)	5.97x10^6 MJ	4.20x10^6 MJ

$P_S = P_B \ x \ \frac{I_S}{I_B}$ *(Equation 1);*

$E_T = P_S \ x \ N_B \ x \ t$ *(Equation 2);*

Where P_S is the scaled power of the luminaire in Watts, P_B is the rated power of the luminaire in Watts, I_B is the illuminance quantified using Dialux software and an Maintenance Factor of 0.8 to model the lighting systems, I_S is the illuminance required (300 lux), E_T is the total life time energy consumed in Watt-hours, N_B is number of luminaires, and t is the hours use (70,000h).

End-of-Life Inventory

For the end-of-life of the LED luminaire three waste management scenarios have been defined considering that the luminaire can be disassembled completely allowing a separate treatment of each component. The European regulation regarding the end-of-life treatment of electronic waste considers the collection and material recovery of almost all luminaire types. However, little can be said for the LED end-of-life treatment since they are currently treated as generic electronic material, thus a specific treatment method has not yet been defined.

As seen in Table 2, the LED luminaire consists of different components made of steel and plastic parts, and electronics, such as the circuit board and LED boards. Taking into account that the luminaire can be considered as an electric/electronic lighting equipment, as per WEEE European directive (2002/96/EC), each Member State is responsible for a correct electric and electronic correct waste management, with the aim of collecting it separately from the rest of the waste in order to recover as much materials as possible and enable a proper disposal of the possible hazardous elements. The association responsible for this in Spain is AMBILAMP. AMBILAMP services cover the collection and recycling of luminaires and lamps, including LED luminaire structure and LED lamps.

Following their indications, as a general rule, the end-of-life scenario of the LED luminaire has been set as the whole luminaire, if disposed correctly, can be recycled, with the exception of the PMMA and ABS parts, that are managed in an incinerator considering that this plastic material is difficult to recycle. This indications are considered in Scenario 2 (best practice) in Table 7.

As per the requirements for EPDs and PEFs [6], end-of-life scenarios should be assessed when the exact disposal method of a product is not known or could vary. Therefore, three scenarios for the end-of-life were analysed. All scenarios are specified in Table 7 and follow the “cut-off approach” for considering the input of secondary material (i.e. scrap material) into the production of some products, such as for steel and aluminium (Figure 5).

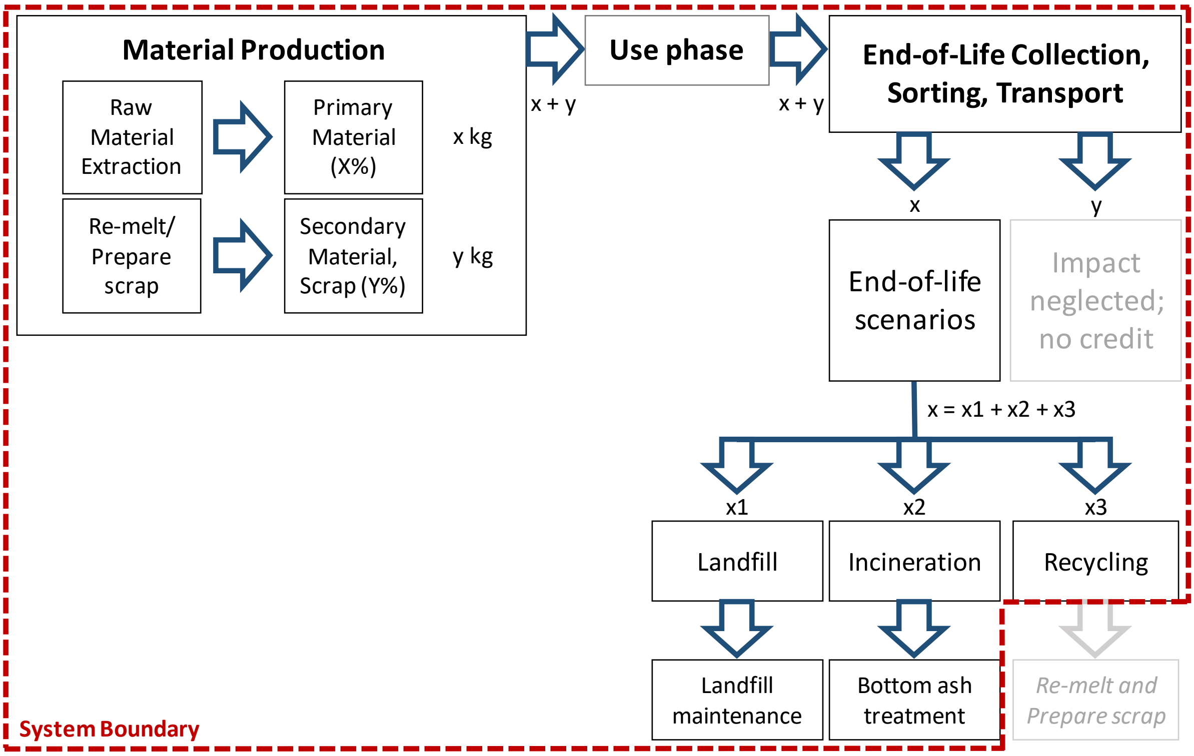


Figure 5: End-of-Life Model (cut-off approach)

The “cut-off approach” considers the net mass (only the mass from use of primary materials) as entering the end-of-life scenarios (Table 7). The net mass (indicated by mass ´x´ in Figure 5) is defined as the total mass of the material minus the mass of scrap material (indicated by mass ´y´ in Figure 5). The use of scrap material in the production stage has avoided the use of primary material. The mass of scrap material used in the production of components for both luminaires is summarized in Table 8. The “cut-off approach” does not credit for recycling material at the end-of-life, but also no environmental burden for recycling has been applied. 0.0

Table 7: Net Mass[1] and Disposal Scenarios for Luminaire Materials at End-of-Life

Material	Net mass (g) Luminaire A	Net mass (g) Luminaire B	Scenario 1 (mixed case)	Scenario 2 (best practice)	Scenario 3 (worst case)
ABS	91.9	91.9	Incineration (60%) Landfill (40%)	Incineration	Landfill
PMMA	531.3	531.3	Incineration (60%) Landfill (40%)	Incineration	Landfill
Steel	1682	2646	Recycling (60%) Landfill (40%)	Recycling	Landfill
Aluminium	1170	0	Recycling (60%) Landfill (40%)	Recycling	Landfill
Electrical waste (WEEE)	394.5	394.5	Recycling (40%) Incineration (60%)	Recycling	Incineration
Copper Wire	42.8	42.8	Recycling (40%) Incineration (60%)	Recycling	Incineration
Other Plastics (PP, PET)	7.29	7.29	Recycling (60%) Incineration (30%) Landfill (10%)	Recycling	Landfill

TOTAL NET MASS (g)	3919.8	3713.8			

[1]Mass ´x´ in Figure 5

Table 8: Mass of Scrap[1] Material in Production of Luminaire Components

Component	Scrap mass (g) Luminaire A	Scrap mass (g) Luminaire B	Scenario 1 (mixed case)	Scenario 2 (best practice)	Scenario 3 (worst case)
Screws	14.6	14.6	Recycling	Recycling	Recycling
Metal parts	21.0	21.0	Recycling	Recycling	Recycling
ECG Housing	19.0	19.0	Recycling	Recycling	Recycling
Trunking	128	128	Recycling	Recycling	Recycling
Gear Tray	524	80	Recycling	Recycling	Recycling
TOTAL SCRAP MASS (g)	**706.6**	**262.6**			

[1]Mass ´y´ in Figure 5

Life Cycle Impact Assessment and Interpretation

As was described in Table 1, six impact categories were chosen for this study with the goal of determining which conventional lighting system performs better from an environmental perspective. The lighting system having better performance will be used to be compared to the Repro-light systems in the Part II study. The comparative LCIA results with contribution analysis for both lighting systems are discussed in this section. In this sense, this section is divided into three subsections. The first one compares the overall cradle-to-grave result with a focus on the energy consumption during the use phase. The second section dedicated to the materials with significant environmental contribution in the ADP elements and the third section showing the results for the end-of-life scenarios that were previously defined in Table 7.

Cradle-to-Grave Results

The environmental impacts for the production, use and disposal of Lighting System A and Lighting System B were quantified in order to determine the contribution of the life cycle stage to the overall impact for each impact category assessed. Lighting System A consists of high power luminaires with powder coated aluminium gear trays (Luminaire A) and Lighting System B consists of lower power luminaires with organic coated steel gear trays (Luminaire B). The results shown in Figure 6 indicate that Lighting System A has a higher impact in all impact categories than Lighting System B, except for ADP elements. Furthermore, for both Lighting Systems, the percent contribution of the impact of the use phase is greater than 98% for all impact categories, except for ADP elements. In contrast, the percent contributions of the production stage range from 1-2% and of the end-of-life stage less than 0.1% in almost all impact categories, ADP elements is again the exception.

For ADP elements, the production of the luminaires for Lighting System A contributes 60% of the overall result, the remaining 40% coming from the use phase. Similarly, for Lighting System B, the production of the luminaires contributes about 77% to the overall result, the remaining 23% from the use phase. On the other hand, the total ADP elements increases a 19% in the Lighting System B respect to A. This can be attributed to the scenario B requires more 123 luminaires, which mean more materials are needed affecting the ADP element category.

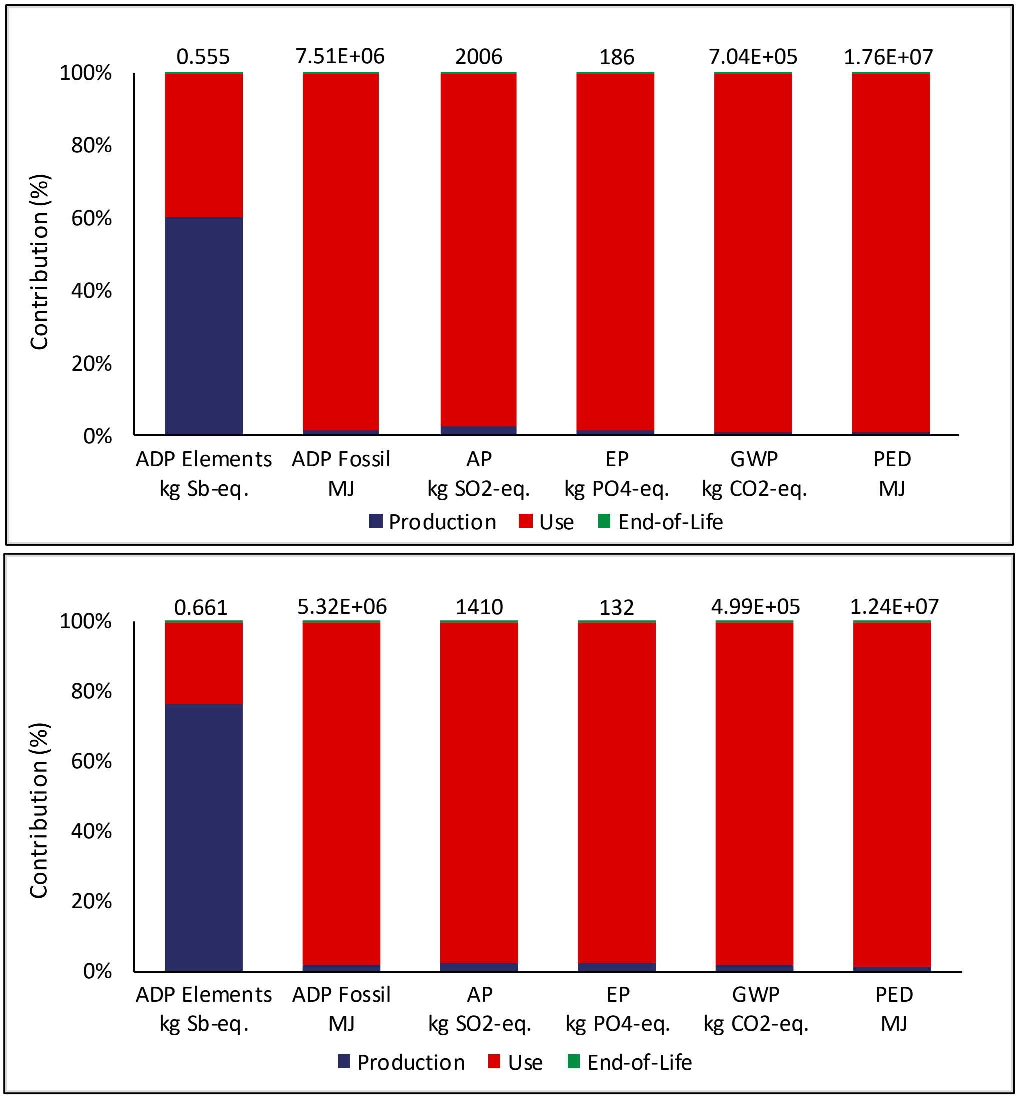


Figure 6: Percent Contribution of Production, Use and End-of-Life to each Impact Category Result for Lighting System A (top) and Lighting System B (bottom)

As can be observed, the use phase contributes significantly to most impact categories. From Equations 1 and 2, it can see that this is calculated based on the lifetime hours of use, rated power and required illuminance. These parameters were used within Dialux Software to design the lighting systems and determine the number of luminaires required for each. However, the hours of use can change depending on many factors besides the defined lifetime of the luminaire, such as user preference, failure of a luminaire component, or upgrade in technology that results in the lighting system being exchanged.

In this sense, the use phase contributes to greater than 98% for the impact categories ADP fossil, AP, EP, GWP and PED for both luminaires. Light System B exhibits around 29% less than the Light System A in those impact categories due the a lower rated power of luminaire used in this system (see Table 6). This result suggests that the electricity consumption during this phase is the key parameter that determines the results for each of these impacts. On the other hand, the ADP elements in the use phase also decreases around 30% for Lighting System B respect to the Lighting System A. However, when looking the total impact for ADP elements, the scenario B is higher than Lighting System A, being 0.66 kg Sb-equivalents for Lighting System B and 0.55 kg Sb-equivalents for Lighting System A. This indicates the savings in materials in one scenario has not significantly outperformed the savings in energy consumption in the other scenario in terms of extraction of elements. Nevertheless, it is important to note here that this is the situation for the electricity mix that was used in the study (EU-28 mix). As the gird mix changes, differences in the results may occur being a significant factor for the results generated.

The impacts versus the hours of use were plotted for two impact categories, GWP and ADP elements, Figure 7 and Figure 8, respectively. In both figures, the quantity at hour zero is practically the impact due to production of the luminaires since the end-of-life has a very lower contribution.

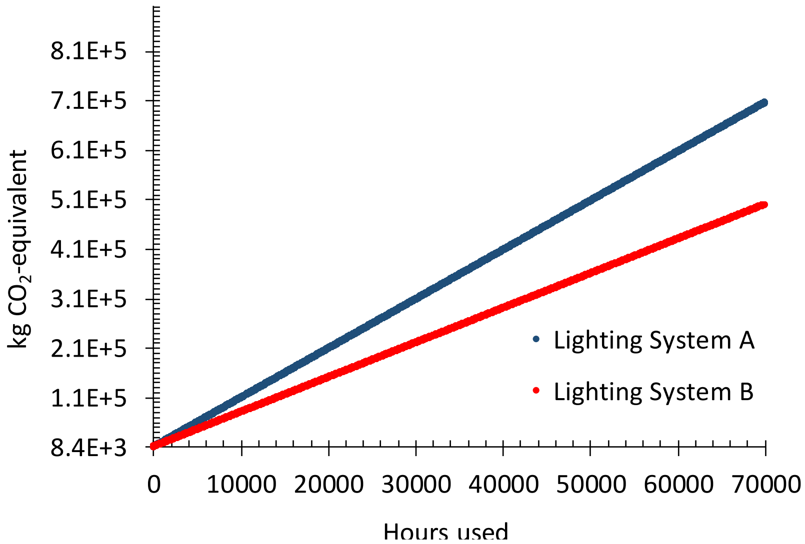


Figure 7: Kilogram Carbon dioxide equivalents versus hours use for lighting systems A and B

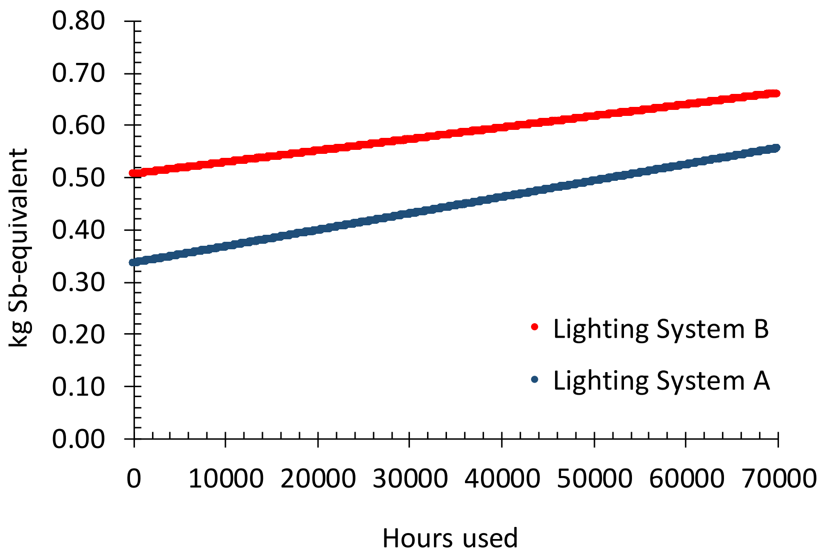


Figure 8: Kilogram Antimony equivalents versus hours use for lighting systems A and B

The impact per hour refers the slope of line that is calculated from the impact for production electricity per kWh, steeper slopes indicating higher electricity consumption per hour. As mentioned above, it should be noted that these results will change based on the electricity grid mixed used. The grid mix as stated previously is the EU-28 mix as in Figure 2. The opposite trend is seen for GWP respect to ADP elements, and will be seen across all other impact categories where the use phase is contributing to the majority of the impact. Figure 7 and Figure 8 shows the importance considering other impact categories when conducting environmental assessment, since the result depending of the category studied.

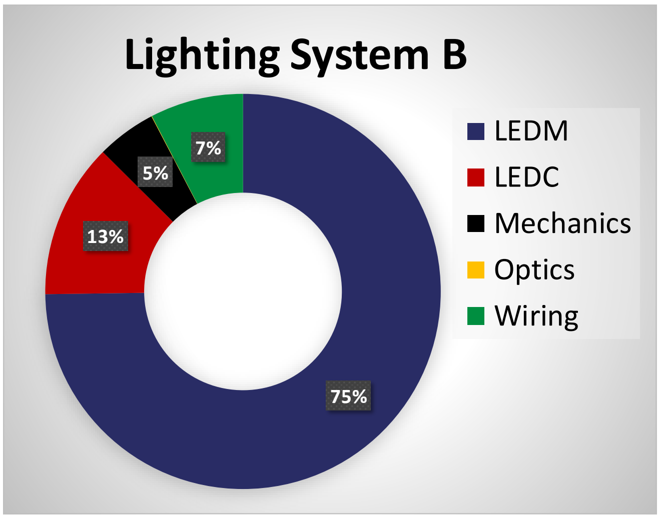
Moreover, it is worth noting in Figure 8 that although the APD elements for the Lighting System B is higher than the System A at zero time, the lower electricity consumption of System B along the use phase shows that the impacts for both luminaires will be gotten close in this category when reaching life time of the luminaire, it will be able more similar with longer lifetimes (more than 70,0000h).

From those results, it has been seen that the phase of use has greater environmental impact, which means that the use of more renewable energy and improvement in the energy efficiency of LED luminaires should be the must in order to reduce the environmental impact. This is a fact expecting in the future, which would give more relevance to other stages of the lifecycle. Because of this, the environmental contribution of the components to the production phase for the luminaires in the lighting systems are investigated in the next section in the ADP elements where the materials to produce such components can influence considerably in this category.

Cradle-to-Gate Results for Abiotic Resource Depletion (Elements)

The contribution of each component to the total result in ADP elements due to production is shown in Figure 9. The breakdown of the material categories is given in Table 4. Both LEDM plus LEDC contribute 88% being LEDC the component with higher impact accounting a 75% in both luminaires. These components consist of electronic components that were assumed to be the same for both Luminaire A and Luminaire B. These results indicate that important actions in terms of luminaire design focused on LEDM and LEDC should be considered to ensure a more efficient use of materials. Capacitor inductors reported to have higher contribution (by 78%) in the LEDC, while the LED SMD and LED board showed 55% and 45%, respectively in the LEDM. That means that the reduction of electronic components will lead to a reduction in the environmental impact. For example, reductions can be made for the size of the circuit boards in the LEDM and LEDC, as well as in the number of components on the circuit board and LED SMD size.

On the other hand, the modularity for LEDM and LEDC should be considered, which would allow the replacement of the parts as opposed to disposal of the entire luminaire and leading to reductions in waste generation as well as material use by keeping parts of the luminaire in use for longer. Actions like those are being taken into account in Repro-light project, which will be studied in the second of the deliverable 5.2 in order to evaluate the exchangeability of these modular parts from environmental point of view.



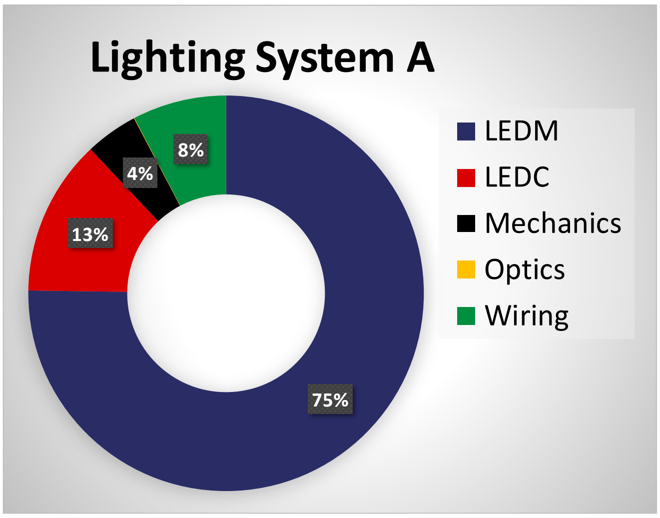


Figure 9: Percent Contribution of luminaire components to Lighting Systems A and B for ADP elements

End-of-Life Scenario Analysis Result

Although compared to the use and production stages of the life cycle, the end-of-life does not contribute very significantly to the overall result. However, it is also interesting to look into the differences compared to the various scenarios with the aim of reducing the overall impact of disposing of the luminaires. The waste management is one of the strategic sectors for the European Community and for local governments, and the results could be interesting for policy decision-making and a value added for this project.

As mentioned above, three alternative scenarios were addressed: mixed case, best practice and worst case. The results of the analysis of the end-of-life are shown in Figure 10 in terms of percentage referred to the worst case (100%), which had a higher impact in all categories, except the GWP. In this impact category the best practice scenario resulted to have higher impact (around 227%) followed of the mixed scenario (188%) respect the worst case. This fact is attributed to the impact for incineration of PMMA and ABS because of the generation CO_2 emissions during this treatment process. Electricity production from incineration process as a LCA credit is not considered in this study.

Moreover, it can see that the best practice scenario exhibits lower impact in ADP elements, PED, ADP Fossil, AP and EP compared to worst and mixed case scenarios. This can be achieved by ensuring that the collection and sorting of lighting products is done separate from the general waste collection, which is mandatory for all member states in Europe. In this sense, the lighting industry should follow a target of 85% for collection of luminaires for recycling [7]. New strategies and designs of luminaires would help the consumer to dispose the product correctly, which would position the best practice scenario the most likely case. In order to improve this further, investigation into recovery of precious metals from the electronic components is required.

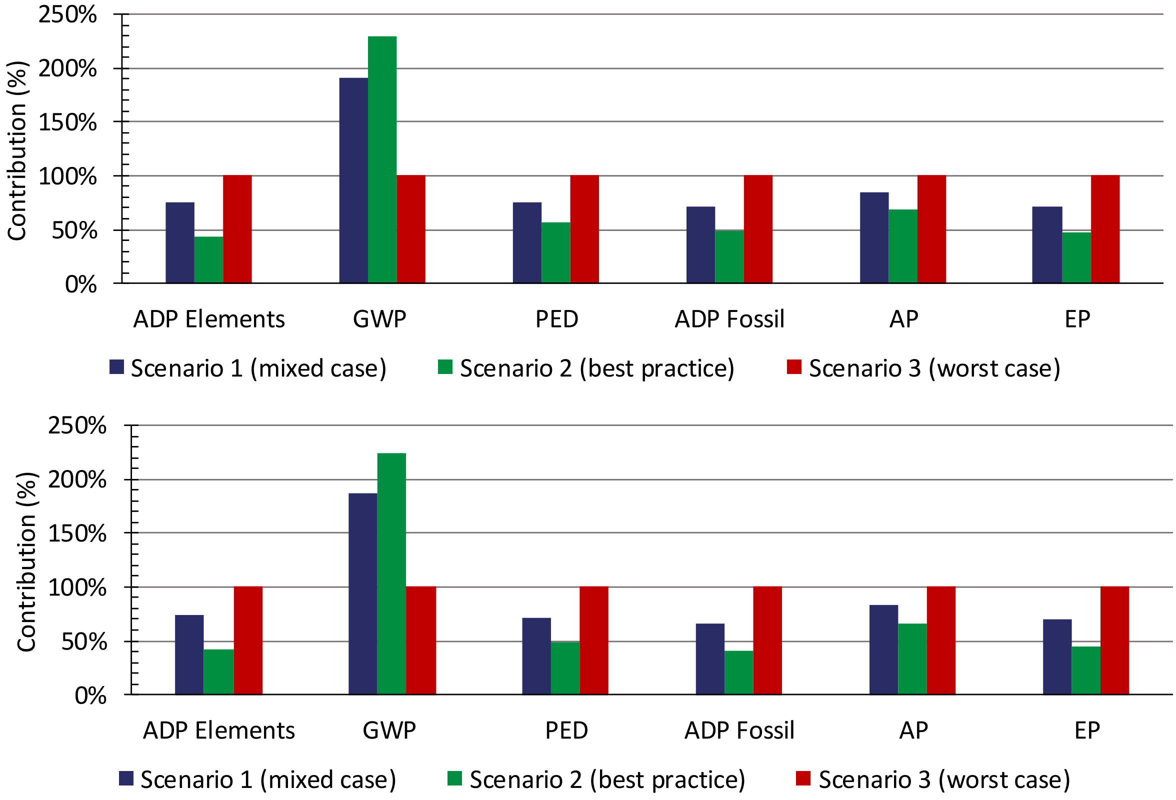


Figure 10: Results of End-of-Life Scenarios for Lighting System A (top) and Lighting System B (bottom)

Conclusions and Recommendations (Part I)

This study is focused on the cradle-to-grave LCA of two conventional luminaires used to meet lighting regulation in an industrial setting. They differ in rated power and in the material used for the gear tray. Luminaire A with a gear tray of Aluminium and luminaire B of steel. Environmental overall results show that Lighting System B performs better than Lighting System A for almost all impact categories (ADP fossil, AP, EP GWP and PED), decreasing the impact in those categories around 29%.

The use phase is the life cycle stage with higher contribution (more than 98%), which is consistent with several studies found in specialized literature on environmental impacts of lighting products. In contrast, abiotic ADP elements have higher percentage in the production phase (60-73%) for both luminaires being the total impact of this category in the luminaire B 16% higher respect the luminaire A. This is attributed to the System B uses more 123 luminaires than the System A, consequently more amount of materials that influences on the ADP elements.

The impacts versus the hours of use were also investigated. Here the results depend of the impact categories studied and this in turn of the electricity mix (EU-28 mix was used in this study). WGP and ADP elements were chosen showing an opposite trend for GWP respect to ADP elements. In this latter, the impacts of both luminaires will be gotten close when reaching life time of the luminaire, being more similar with longer lifetimes (more than 700000h). It is worth noting that ADP elements in the use phase of the luminaire is related to the metal resources used to produce the energy (electricity consumption). For that reason, the performance environmental depends of the electricity mix of the country where the Repro-light technology will be implemented.

Regarding the end-of-life, several scenarios were compared. The results revealed that the best practice scenario reduce the impact between 30% and 60% respect to the worst case in the categories ADP elements, PED, ADP fossil, AP and EP. In contrast, the scenario mixed together and the best practice are higher respect to the worst case when analysing the GWP category, 1.9 and 2.3 times respectively. It is attributed to the impact for incineration of PMMA and ABS because of the generation CO_2 emissions during this end-of-life treatment.

The above results suggest applying important actions in terms of energy and material efficiency in the context of the circular economy and eco-design strategies in order to achieve more sustainable luminaires. On the one hand, more renewable energy and improvement in the energy efficiency of LED luminaires should be the must in order to reduce the environmental impact. On the other hand, the improving of the recovery rates (recycling technologies) is suggested to improve the availability of these elements from secondary sources. These elements can be kept in use and although this does not necessarily mean that they will be of high enough quality to reuse in the luminaire, they can be reused in other applications. Depending on the element to be recovered, this is not always economical, thereby this aspect should be considered, i.e., to increase the recovery rates of elements, it must be economically viable. This is one problem with these recycling technologies to be improved. In addition, it should be considered an optimal design of products to separate the optical part from the mounting case and from electrical components. The optical part could be standardized, so different companies could be able to deliver retrofit solutions.

PART II Environmental Assessment of Repro-light LED luminaires vs. Benchmark LED Luminaire

Goal and Scope Definition

Goal

The goal of the study is to compare the life cycle environmental impact of the Repro-light luminaires that are used to meet lighting regulation in an industrial setting with a benchmark LED luminaire of Steel (Coated Steel Coil). The Repro-light luminaires description and schemes are shown in Figure 11, which were discussed and agreed in the WP3/WP5 teleconferences.

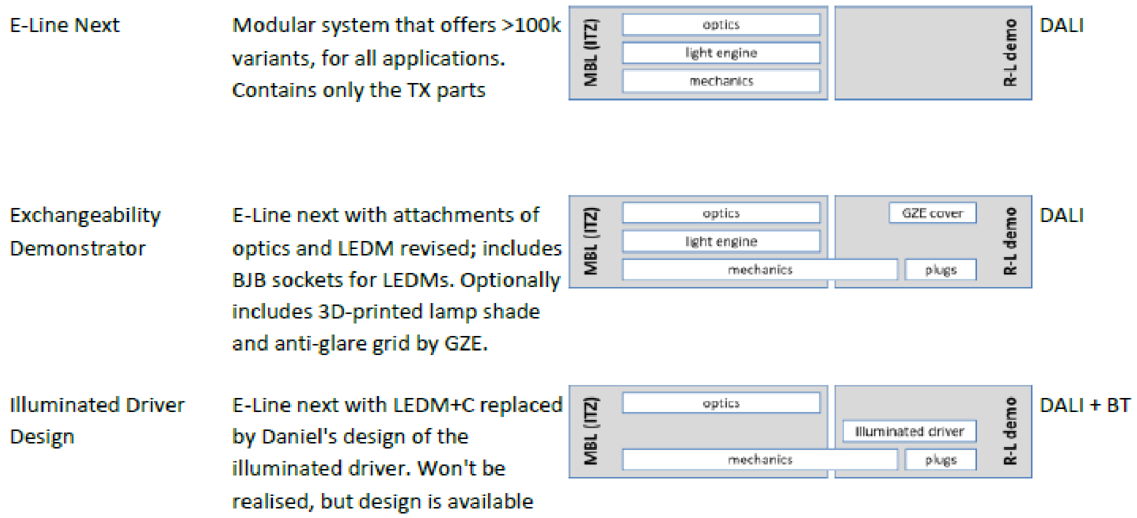


Figure 11 Repro-light luminaires for LCA study comparison

The luminaires described in Figure 11 are named hereafter as Luminaire A1 (E-Line Next), Luminaire A2 (Exchangeability demo) and Luminaire A3 (Illuminated Driver design) and Luminaire B (Benchmark).

A lighting system for each LED luminaire was designed with Dialux software to meet the requirement for lighting as stated in the Technical rules for workplaces standard [3]. The overall goal may help investigate the energy efficiency versus material efficiency of both lighting systems from an environmental perspective.

Scope

Functional Unit

The functional unit for the LCA studies is an illuminance of 300lux in lighting system for an industrial hall (120m x 60m) constituted by 369 luminaires. The defined lifetime for the luminaires is 70,000 hours.

System Boundary

The cradle-to-grave system boundary includes the energy inputs and emissions and waste outputs for all stages in the life cycle, including raw material extraction, production of each component of the LED luminaire, assembly of the luminaire, installation, the use of the luminaires in a lighting system, collection and transport for disposal and the final disposal scenario (Figure 1). The installation of the lighting system has been estimated using only the transportation of the luminaires to the site as in a study by Tähkämö *et al.* [4]. This transport distance has been estimated as 30km. The assembly energy of the Repro-light luminaires was not considered due to technical issues to measure the values of energy in the new automatic production line during the period of execution of the LCA studies. This assumption will be consistent with the LCA studies since the magnitude of assembly energy is expected to accomplish the cut-off criteria defined later in this section.

The packaging of both luminaires has not been considered and is assumed to be the same for all luminaires. The production of industrial machinery and equipment is also not included in the system boundary, nor is the transportation within the manufacturing plant. It is further noted that in terms of transportation, reductions in the distances travelled and the use of ground as opposed to air travel will lead to reductions in the environmental impact.

Assumptions and Limitations

For all the luminaires, it has been assumed that the production, electricity generation and waste management is located in Europe. The electricity mix is assumed to be EU-28: Electricity Grid Mix (Figure 2). However, later there will be a section dedicated to make a study with different electricity mix grid in the use phase, since the energy consumption is more important in this life cycle stage. This is in order to know how energy sources influences on the impact categories in the global environmental performance of the Repro-light luminaires.

In Spain, AMBILAMP provides a collection and sorting service for lighting products at the end-of-life. The luminaires are collected and taken to a sorting facility where they are dismantled and the components are disposed of accordingly. Transport to the end-of-life facilities has been assumed to occur by road with a 22t lorry. Distances for transport of materials have been estimated as 60km from collection point to AMBILAMP and 80km from AMBILAMP sorting to final disposal destination.

Data Sources and Data Quality

The results of this study are dependent on the availability and quality of data obtained from project partners, literature and datasets. Thus, primary data of LED luminaire components and materials have been provided by the Repro-light partners, as well as measured by dismantling the luminaire (refer to Table 9). Upstream data was obtained from GaBi ts Professional Database (version 9.2.0.58) as well as EcoInvent 3.5 database. GaBi ts commercial software was used to model and quantify the LCI and LCIA results.

In order to improve the results, further work should focus on improving the data quality regarding the electronic components and evaluating the potential for precious materials recovery from the circuit board and LED boards. Studies have shown that recovery is possible at fairly good yields. For example, Gallium and Indium can be recovered from LEDs using a combination of pyrolysis, physical disaggregation, and vacuum metallurgy at greater than 90% yields [5], however, this is not yet common practice. The recovery of precious metals from luminaires also needs to be economically feasible.

Cut-of- Criteria

In order to ensure that all relevant environmental impacts, the following cut-off criteria for energy flows were used: energy flows with less than 1% of the cumulative energy of all the inputs and outputs of the LCI, (considering the type of flow), were excluded because their environmental impact is negligible.

Impact Category Selection

The Life Cycle Impact Assessment (LCIA) will include the midpoint Impact Categories defined in Table 1 in Part I. The chosen characterization models and characterization factors for each impact category are also defined in the table. Endpoint indicators have not been considered in this study.

Life Cycle Inventory

This section describes the inventory including the bill of materials for the Repro-light luminaires, the data for the assembly assumption, use and end-of-life disposal life cycle stages. The inventory is given for the Repro-light luminaires based on the information received from industrial partners during regular teleconferences and emails during WP5 and WP3 execution. It is agreed that some components among Repro-light and benchmark luminaire are the same. However, new information on other key components (depending of the characteristics of each new luminaire) was provided. The main differences and similarities are described as follow:

1) Luminaire A1: LEDC and wiring are the same as Benchmark. However, new data were received for the LEDM, mechanic parts and optics. Those components have important modifications regarding material reduction. In addition, data for sensor/controllers for a dimming lighting system were also provided.

2) Luminaire A2: LEDC, sensor/controllers, mechanics, optics, wiring are assumed the same as Luminaire A1. LEDM is as the Luminaire A1, but including plugs to make it an exchangeable component. Data for plugs and failure rates for modelling the exchangeability scenario were also provided.

3) Luminaire A3: sensor/controllers, mechanics, optics, wiring and plugs are as exchangeability demo. However, since the objective of this luminaire design is to save material, new data and extra information for LEDM+C (no housing required) were received.

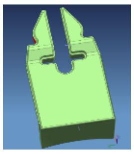
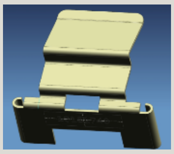
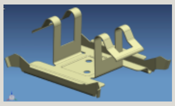
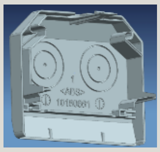
As mentioned above, data of sensor and controllers for an industry hall: 120m x 60m were also received to be considered in the LCA models. It is worth highlight that the LCI for the Luminaire B is not shown in this report since it was described in Part I.

Bill of Materials

Luminaire A1

Table 9, Table 10 and Table 11 show the bill for the Luminaire A1 broken down into the components LEDM, mechanic parts and optics.

Table 9 Materials Inventory for the Luminaire A1: Mechanics, optics and LEDM

Category	Component	Material	Quantity	Visual
Mechanics	Plastic Parts (including ABS endcaps to trunking and gear tray)	Conformed by different plastics.	Detail in Table 10	 
	Metal Parts	Conformed by different materials	Detail in Table 11	  
	Trunking	Trunking main material: Steel organic coated coil DX52D+Z100	1648.00 g	
	Gear Tray	Steel organic coated coil DX52D+Z100	See in Table 11	
Optics	Optical element OPT 7651 L W 733x60 PM Dimensions: 733mm x 60mm	PMMA 8N	2 x172 g	

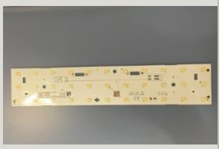
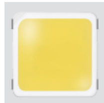
LEDM	Circuit Board (Dimensions: 719mmX23mm)	Printed wiring board	2 x 37g	
	LEDs	96 x LM301B on one board 0.018 g per each LED Dataset classification from GaBi ts: LED SMD high-efficiency with lens max 0.5A (59mg) Flip Chip 3.5x3.5x2.0		

Table 10 Breakdown for the plastic part of mechanics for Luminaire A1

Component	Identification	Quantity	Main material	Mass (g)
Plastic parts (connectors, end piece to trunking, etc.)	7921- (Wire holder)	1	ABS weiß RAL 9010	1.00
	10181134 - Druckstück 7650Fix PC	4	Polycarboant PC UV	2.07
	132882 - Buchsenteil 7691/58 EDD 5pol mont	1	Polyamid 66 (PA 66)	12.00
	24952 - Leitungshalter selbstkl 432-2748-600	1	PA6.6	1.00
	30005892 - Buchsent 7/5pol WAGO 267-205/002-000	1	Polyamid 66 (PA 66)	11.00
			Total	27.07

Table 11 Breakdown for the metal part of mechanics for Luminaire A1

Component	Identification	Quantity	Main material	Mass (g)
Metal parts	07921/58- Guidance for hold spring	2	1.4310 (Stainless Steel)	18.00
	10158592- St-Band 0,63x106,0+0,3 stacopl (gear tray)	1	DX52D+Z100 RAL9010 (Galvanized Steel)	758.00
	10182260- Wärmeableitblech 7750Flex 280mm	1	DX51D+Z	114.00
	10181740- Haltefeder 7650Fix LED f Versch	4	1.4310 (Galvanized Steel)	20.00
	VG-Befestigung 7691 EVG 30x28	1	1.43101100-1300 N/qmm (Galvanized Steel)	8.00
	30005285- Halterung 7691 f Buchsenteil	1	1.4310 (Galvanized Steel)	4.00
			Total	922.00

Luminaire A2

As mentioned before, the most component materials for the Luminaire A2 is as the Luminaire A1. However, this luminary needs plugs to have an exchangeable LEDM. The number of LED boards and connectors depends on the design and length of the luminaire and LED printing circuit boards. In this sense, a number of two connectors or plugs are considered for the exchangeability luminaire demo of 1400 mm (single channel). The material characteristics and quantity of one connector is listed in Table 12.

Table 12 Materials inventory for Electro-mechanical connector (Zhaga book 21 connector) for Luminaire A2

Component	Part	Main material	Mass (g)
Electro-mechanical connector (two contacts)	Housing	Polycarbonate with flame retardant PC-FR	1.30
	Two contacts	Material 1: Cu alloy Material 2: Surface tin plating Material 3 Silver alloy Material 4: X10 Crni 18 8 Stainless steel	0.18 0.006 0.002 0.16
	Clamp bracket	X10 Crni 18 8 Stainless steel	0.6
		Total	2.250

Luminaire A3

The illuminated driver design is an E-line Next with LEDM+C, which objective is saving material incorporating the ECG components on the LEDM. This luminaire will be not constructed but its design will be available being necessary to study the environmental impact due to the optimization of materials from the LCA perspective.

In this sense, it was necessary to look the combination of the LEDM and LEDC and fixing material for the comparison of the illuminated driver with the LEDC of the benchmark. This allowed to identify some parts leaving away for the illuminated driver design, such as:

1) LEDC housing (2 steel parts)

2) LEDC isolation foil (plastic ECG housing)

3) Fixing parts consisting of sheet metal, metal clamp and 2 plastic parts

The wires are considered almost the same as benchmark, while the printing circuit board of the LEDC is assumed to be an 80% of the sum of LEDC + LEDM board area. Regarding the electronic components itself, they are very similar to the benchmark, thereby it has been suggested to use the same as the Luminaire A1 for a more reasonable comparison.

On the other, the illuminated driver has a Bluetooth (BT) module as indicated in Figure 11. For a properly comparison, this devise is not considered for the LCA study since similar functionalities should be the same for both Illuminated driver design and benchmark using the DALI interface.

The modified bill of materials for the Luminaire A3 is shown in Table 13, Table 14 and Table 15.

Table 13 Breakdown for the plastic part of mechanics for the Luminaire A3

Component	Identification	Quantity	Main material	Mass (g)
Plastic parts (connectors, end piece to trunking, etc.)				
	10181134 - Druckstück 7650Fix PC	4	Polycarboant PC UV	2.07
	132882 - Buchsenteil 7691/58 EDD 5pol mont	1	Polyamid 66 (PA 66)	12.00
	30005892 - Buchsent 7/5pol WAGO 267-205/002-000	1	Polyamid 66 (PA 66)	11.00
			Total	25.07

Table 14 Breakdown for the metal part of mechanics for the Luminaire A3

Component	Identification	Quantity	Main material	Mass (g)
Metal parts	07921/58- Guidance for hold spring	2	1.4310 (Stainless Steel)	18.00
	10158592- St-Band 0,63x106,0+0,3 stacopl (gear tray)	1	DX52D+Z100 RAL9010 (Galvanized Steel)	758.00
	10181740- Haltefeder 7650Fix LED f Versch	4	1.4310 (Galvanized Steel)	20.00
	VG-Befestigung 7691 EVG 30x28	1	1.43101100-1300 N/qmm (Galvanized Steel)	8.00
	30005285- Halterung 7691 f Buchsenteil	1	1.4310 (Galvanized Steel)	4.00
			Total	808.00

Table 15 Materials Inventory for LEDM+C of Luminaire A3

Component	Identification	Description	Mass (g)
LEDM	Circuit Board (Dimensions: 719mmX23mm)	Printed wiring board	37.00
LEDM+C	Circuit LEDM+C	Printed wiring board 80% of LEDM +LEDC area of E-line Next	83.00*
LEDs	192 LEDs of 0.018 g LED SMD high-efficiency with lens max 0.5A (59mg) Flip Chip 3.5x3.5x2.0, 0.018 g per each LED		3.50
		Total	123.50

(*) The LEDM+C mass was estimated using the density of LEDM and LEDC of E-line Next

After the detail of inventory described above, the following Table 16 is generated to give the categories used throughout the LCA study and the mass balance of the Luminaire A1, Luminaire A2 and Luminaire A3. It can be seen the optimization of materials when comparing the Repro-light luminaires with the Luminaire B. The savings of material in terms of percentage go from 17% up to 22% respect to the mass benchmark luminaire which mass is 3976.4g, such as reported in Part I.

Table 16: Categorization of the LED components and total mass for Repro-light luminaires

Category	Component	Luminaire A1 (g)	Luminaire A2 (g)	Luminaire A3 (g)
Wiring	Copper wires	42.80	42.80	42.80
LEDC (LED Control)	Circuit board Capacitors, Conductors, Varistor Plastic housing for ECG Steel housing for ECG	30.60 112.50 4.35 93.80	30.60 112.50 4.35 93.80	--- --- --- ---
Mechanics	Steel parts Plastic parts Gear tray Trunking	164.00 27.07 758.00 1648.00	164.00 27.07 758.00 1648.00	50.00 25.07 758.00 1648.00
LEDM (LED Module)	Circuit board (2) LED SMD (192) Plugs	74.00 3.45 ---	74.00 3.45 4.50	--- --- ---
LEDM+C	Circuit board LED SMD (192) Plugs Capacitors, Conductors, Varistor	--- --- --- ---	--- --- --- ---	120 3.45 4.50 112.5
Optics	Optical element	344.00	344.00	344.00
	TOTAL	**3302.57**	**3307.0**	**3108.20**

Sensor and controller

The material inventory of sensor and controller system is not included in the inventory of Repro-light luminaries described above because the sensors are used for light dimmable in the industrial hall. Table 17 and

Table 18 show in detail the material inventory for one sensor, one controller and one LiveLink DALI push-button couple, while

Table 19 indicates the amount of these components for an industry hall: 120m x 60m for lighting system dimmable.

Table 17 Material inventory of one sensor, one controller and one LiveLink DALI push-button coupler for a lighting system dimmable

Component	Description	Main material	Mass (g)	Visual
Sensor	Plastic housing	PC recyclable	95.49	

	Metal support (interpiece)	Steel	19.00	
	Printing Circuit Board (a) Dimensions: 45 mm x 45 mm		9.06	
	Printing Circuit Board (b) Dimensions: 100 mm x 84 mm		28.23	
Sensor controller	Plastic housing	PC recyclable	31.18	
	Plastic joins	PC recyclable	0.58	
	Plastic connectors	PC recyclable	1.03	
	Printing Circuit board (c) Dimensions: 75 mm x 27 mm		10.17	
	Printing Circuit (d) Dimensions: 176 mm x 27 mm		22.26	
	Electronic components		To see the detail in Table 18	
LiveLink DALI push-button coupler	Housing	PC recyclable	6.36	
	Circular circuit board		13.98	

Table 18 Circuit board components of the sensor controller and classification

Identification	Classification*	Total Mass (g)
AISHI 1438YPET Black Cylindrical capacitor (No code)	Aluminium Screw	2.33 2.45

ICT PRC Ed 10120088 B R02140	Ring Core Coils with Housing	6.48 2.93
B32921 X2 MK/SH B32921 X2 MK/SH We 102 We 102	Film capacitors boxed	0.89 1.19 0.45 0.41
A07 RU K320, 12 44	Varistor	1.23
	Total	18.27

(*) The classification is used to determine the dataset to use for the upstream data of these components.

Table 19 Quantity of sensors and controllers of a lighting system dimmable to be used in an industry hall: 120m x 60m.

Component	Visual	**Quantity**
Sensor	 Front back	18
Controller device	  Front back	7
LiveLink DALI push-button coupler		7

Regarding the tray and trunking components of the luminaire, as mentioned in Part I, further processing is done at the manufacturer prior to luminaire assembly. It is also assumed for the trunking for repro-light luminaires as in benchmark are produced through roll-forming of organic, galvanised steel coil. The roll-forming is done at the manufacturer. Similarly, the gear tray for Repro-light luminaries are produced though the same roll-forming process as the trunking at the manufacturer. The energy for roll-forming of steel has been estimated by the manufacturer as 0.0385 kWh per component (gear tray or trunking).

However, the luminaire assembly process itself is different since the E-Line next is produced on a pilot production line, which is theoretically developed within Repro-Light, such as shown in Figure 12.

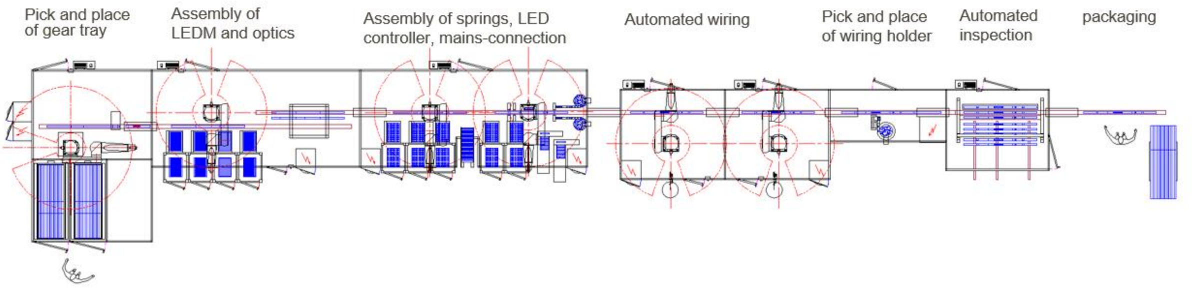


Figure 12 Pilot production line for Luminaire A1

The main difference respect to the Luminaire B process is that every single production step is planned to be automated and no manual steps are involved. The exchangeability demonstrator would be produced in a similar process, although it has been decided does not make the Luminaire A3 in the new production line. The values for the energy consumption would be estimated to be nearly to the E-line, probably a bit higher for the exchangeability demonstrator.

Regarding the Luminaire A3, it has also been decided not to cover with respect to the new production line. However, in general terms, it would look similar as well with adjustments from technical point of view. The process flow would be similar to the automated flow for the Luminaire A1. This is, the process flow itself would be the same, with the exception, that the assembly of the LED controller would be cancelled.

The exact values of energy assembly for the Luminaire A1 corresponding to the new pilot production line are not available due to the lack of a measuring device connected to the specific workplaces or assembly machines. It is expected the energy assembly value to be not so higher than the conventional assembly line. These values are less than 1% of the accumulated sum of energy flows considered in the LCA study, which is agreed with the cut-off criteria defined above. This means that the energy flow for assembly was excluded since their environmental impact is negligible.

Use Phase Inventory

Without dimming

It was explained in Part I that each benchmark luminaire had a lifetime of 70,000 hours, which is better than the industry standard of 50,000 hours that is reported in most LCA studies of LED lighting. This extended life was input as the hours of use for Luminaire B and Luminaire A1 model for a comparable functionality (without dimming).

The specifications for the Repro-light luminaires and Luminaire B are given in the Base Scenario description in Table 20. As explained in Part I, the number of luminaires and the illuminance (lux) were calculated using Dialux software considering an industry hall of 120mx60m, a minimum required illuminance of 300 lux and a Maintenance Factor (MF) of 0.8 (Figure 13).

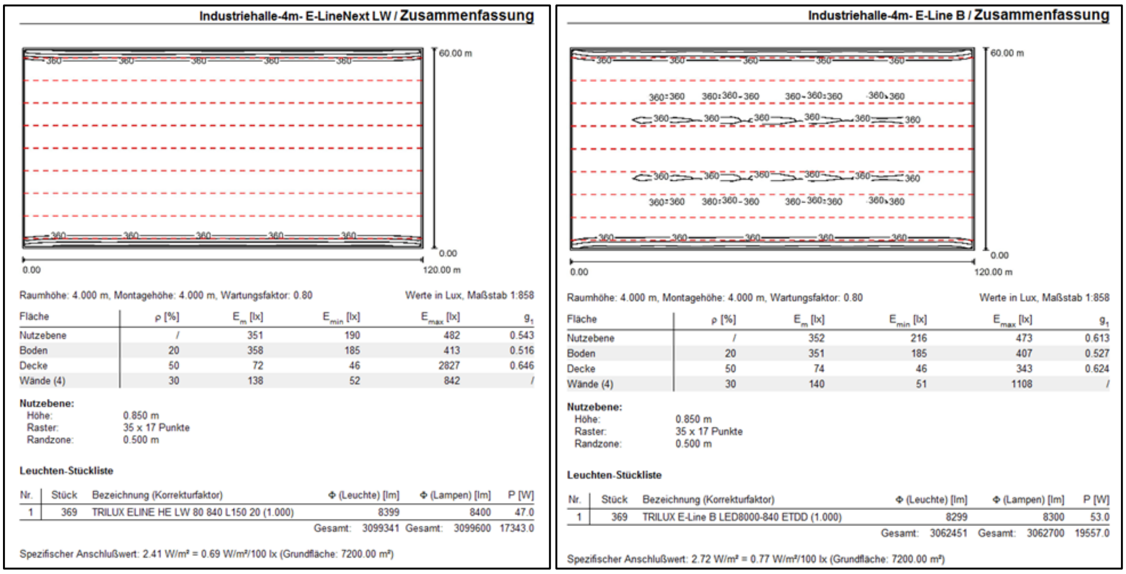


Figure 13: Dialux results for Repro-light luminaires (left) and Luminaire B (right)

It is not possible for the LED lighting systems to meet exactly 300 lux, therefore the rated power was scaled linearly with the illuminance to yield 300 lux, as per Equation 1. The resulting power is given in the scaled scenario in Table 20. It is assumed that the scaling does not change the quantity of luminaires or luminaire components used in each lighting system, as per discussions with lighting experts. The scaling of the power is necessary in order to compare the same quality of light output from each lighting system. This power is used to quantify the energy consumption of the lighting systems as per Equation 2 described in Part I.

Table 20: Specifications for the LED lighting comparison

LED Lighting	Repro-light Luminaires	Luminaire B
Base Scenario		
Gear Tray Material	Steel (Coated Steel Coil)	Steel (Coated Steel Coil)
Rated Power (P_B)	47W	53 W
Number of luminaires (N_B)	369	369
Illuminance (I_B)	351 lux	352 lux
LED Lighting	Repro-light luminaires	Luminaire B
Scaled Scenario		
Gear Tray Material	Steel (Coated Steel Coil)	Steel (Coated Steel Coil)
Scaled Power (P_S)	40.2 W	45.2W
Number of luminaires (N_B)	369	369
Illuminance (I_S)	300 lux	300 lux
Total Energy (E_T) Without diming	3.7 x10^{6}MJ	4.2 x10^6 MJ

With dimming

The saving of materials obtained in the new designs of the Repro-light luminaries will bring an environmental benefit associated to their production stage. In addition, the use phase of Repro-light luminaires is the other life cycle stage with a significant improvement due to energy savings coming the implementation of innovations during the project. This is through the use of light management system Live Link from TRILUX. This system can turn on and off the lights based on data from a presence sensor (presence control), and it can dim them according to data from a light sensor (daylight control). The latter function tries to keep the illuminance on the working plane constant, taking into account the natural light entering through the window [8].

Other important benefit is the elongation of lifetime for the Repro-light LED luminaires. It is expected that the reduced electrical power consumption of dimmed luminaires in systems with daylight control leads to reduce the LED temperatures, which then leads to reduce the degradation rates and eventually to long the lifespan of LEDs.

Models to calculate the energy saving percentage by daylight control and elongation of LED lifetime were developed during the project by TRILUX [8]. It was found for an industrial scenario with operating time from 6-22h an energy saving percentage of 21%[8]. In addition, the influence of the geographical locations was also studied. Figure 14 compares the energy saving potentials for locations in Germany, Sweden and Spain. A daily operating time from 6 - 22 h was also assumed for the calculation.

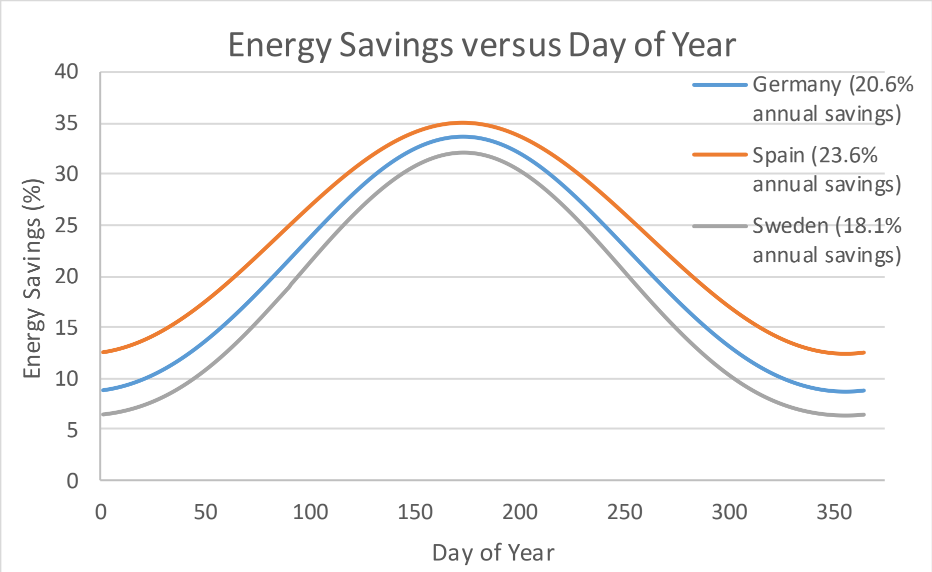


Figure 14 Expected energy saving percentage over the year for three different locations.

The degradation rate of LED at any time of the day and day of the year for the luminaire in a daylight-controlled system can be calculated by the daylight control model function reported in [8], with daily operating times 6 - 22h for 365 days. The maximum scaled power for calculations was assumed 40W, which is the same for the all Repro-light luminaires. Figure 15 shows the profile of the LED degradation rate along 365 days. Based on the above, the numerical solving gives result L'_{80} = 101965h for operation at dimming levels by daylight regulation, which means an elongation percentage of 46% respect to the lifetime of benchmark studied (with 70,000h).

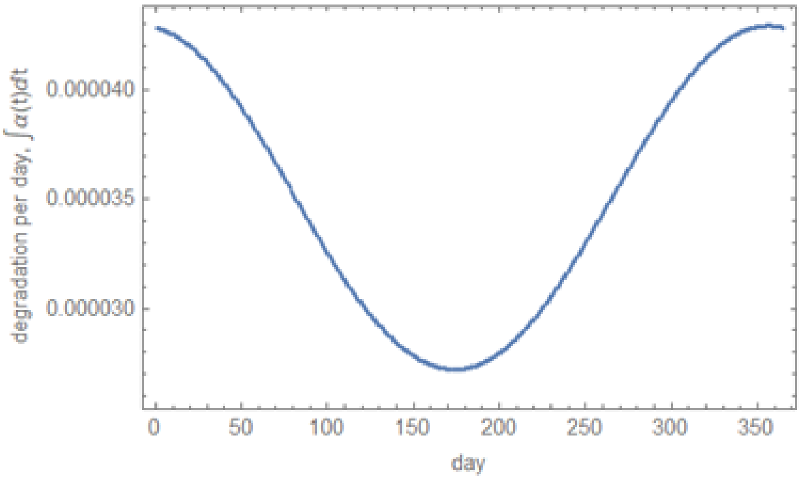


Figure 15 LED Degradation rate for the luminaire in a daylight-controlled system

Under this premise, the energy consumption during the use phase for the Repro-light luminaires with dimming was calculated considering the energy savings per total years in MJ. For that, it was used an energy saving percentage of estimated-average of Spain, Sweden and Germany (Figure 14) of 21% and the lifetime elongation mentioned above. The total energy with diming is reported in Table 21 for the Luminaire A1 with dimming along its elongated life time.

Table 21 Energy consumption for Luminaire A1 with dimming

Total operating time with dimming (h)/(years)	Hours per year at 16h per day (h)	Ps (W)	Energy savings per year* (%)	Energy savings per year (MJ)	Energy Savings per total years (MJ)	Total Energy with diming (MJ)
(101965)/(17.5)	5840	40	21	64763	1.1E06	4.3 E06

(*) estimated- average of Spain, Sweden and Germany

The lifetime of Luminaire B was of L_{80}= 70,000h, which means that the luminous flux output will decrease to 80% of its initial value within 70,000h of operation. This was the lifetime of the industrial lighting hall assumed for the previous LCA calculations for benchmark luminaires. Nevertheless, the Luminaire A1 with dimming is extended due to daylight regulation, such as explained above. Both Luminaires have different time scale. Therefore, the energy consumption of the Luminaire A1 with dimming is scaled for a use time comparable to Luminaire B. To do this, the energy savings per year were considered for the calculation. The energy consumption results in 2.9E06 MJ for an operating time of 70,000h. The energy saving can be noted when compared to the energy consumption of the Luminaire A1 without dimming in Table 20.

Exchangeability demo

The exchangeability of key luminaire components for servicing (maintenance) reasons is of potential interest for circular economy, which is in line with the strategies of the Lighting Europe given in its white paper (Serviceable Luminaires in a Circular Economy) published in 2017.

Both LEDC and LEDM are considered to be the main components why a luminaire may fail. However, as reported in D2.2, if the luminaire is well designed the abrupt failures of those components are not very common. In any case, the LEDC and LEDM exchangeability may be of potential interest for serviceable luminaires to enhance the Circular Economy.

Two scenarios consisting of maintenance-free luminaire (scenario (a)) and exchangeable components for servicing (scenario (b)) were suggested in D2.2. The first one entails exchangeability for servicing being not necessary in a properly designed luminaire. The second one involves the scheduled exchange of modules where LEDM and/or LEDC are designed with a shorter lifetime (see D2.2). This latter is with a possible advantage that the components could be designed cheaper and involving less material resource. However, the sustainability of this solution should be analysed. The environmental aspect is one of pillar of the sustainability for the serviceable luminaire scenario; therefore, this aspect is addressed in the WP5 in order to know the impact from LCA environmental point of view.

Data for LEDM and LEDC with shorter lifetimes and less material resources to produce them are not available in the project. Therefore, a different approach to study the servicing of luminaire is considered in this study based on possible failures that can occur attributed to LEDC and LEDM components, which are designed in principle to work along the life time of the luminaire. The bill of materials for LEDC and LEDM components, available in Table 9, is used for the analysis.

In this sense, the serviceability of Luminaire A2 is studied considering exchangeable LEDC and LEDM components. As mentioned above, they are designed to have their lifetime as the luminaire in an industrial lighting hall (70,000h), where abrupt failures of luminaires due to those components could occur, being necessary to know the failure fraction. Failure data provided by TRILUX in August 2019 was analysed, which allow to estimate a failure fraction of 1% using mathematic calculation, such as explained in Appendix A. This means that in a scenario with 369 luminaires in industrial hall, 4 of them could be failed.

It is worth noting that the LED-based luminaire lifetime may also depend to major mechanical or optical part fails that is not serviceable, or the time when replacement parts are no longer available, or the time when luminaires that are more energy efficient or have additional features and benefits can be economically justified to replace the current one. Therefore, this study considers that the replacement of an entire luminaire and the exchangeable parts (LEDC and LEDM) is because of an abrupt failure occurred where the other no serviceable components, energy efficiency and characteristics are valid until the end of luminaire useful life.

The potential failure modes, reported by the LED Systems Reliability Consortium (LSRC), were used as a way to understand the lifetime of the luminaire and determine the number of LEDC and LEDM to be replaced.

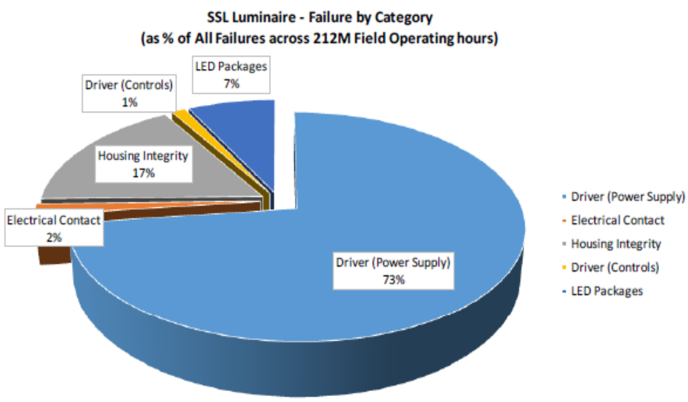


Figure 16 LED luminaire failure modes, across 212 million field hours

The information comes from the experience of members of the LSRC and reports based on discussions about important failure mechanisms [9]. Members were asked for which failure modes they most frequently observed; the results were update by the LSRC and are shown in Figure 16.

Although it cannot be generalized across all types of lighting products, these values in Figure 16 are taken as a reference for this study. Driver control + supply represent to the LEDC and the LED packages. LEDC with percentage of failures of 73 and 7% for LEDM are used. Based on these percentages, it can be estimated that for the four failed luminaires, three of them could be caused by the LEDC and the other one by one LEDM.

The serviceable Luminaire A2 will be compared to the Luminaire A1 in a lighting system for industrial hall with dimensions indicted above. Both of them are serviceable luminaires since the LEDC component can be repaired and exchanged in the Luminaire A1. The difference is that the Luminaire A2 produced in the Repro-light has an exchangeable LEDM with plugs fixed to it to be easily connected/disconnected by the customers. With this new characteristic, the Luminaires A2 presents two components that can be repaired (LEDC and LEDM).

Under this premise, a new system boundary has to be defined to compare both Luminaire A1 and Luminaire A2 in a lighting set for industrial hall. This system boundary is similar to the one in Figure 1, but including the stage intended to produce the spare parts. This stage is to indicate the production of LEDC spare and the replaceable Luminaire for the Luminaire A1 lighting system or LEDC/LEDM spares for the Luminaire A2 lighting system. In addition, the plugs to give the exchangeability functionality to the LEDMs are also included in the model, such as shown in Figure 17.

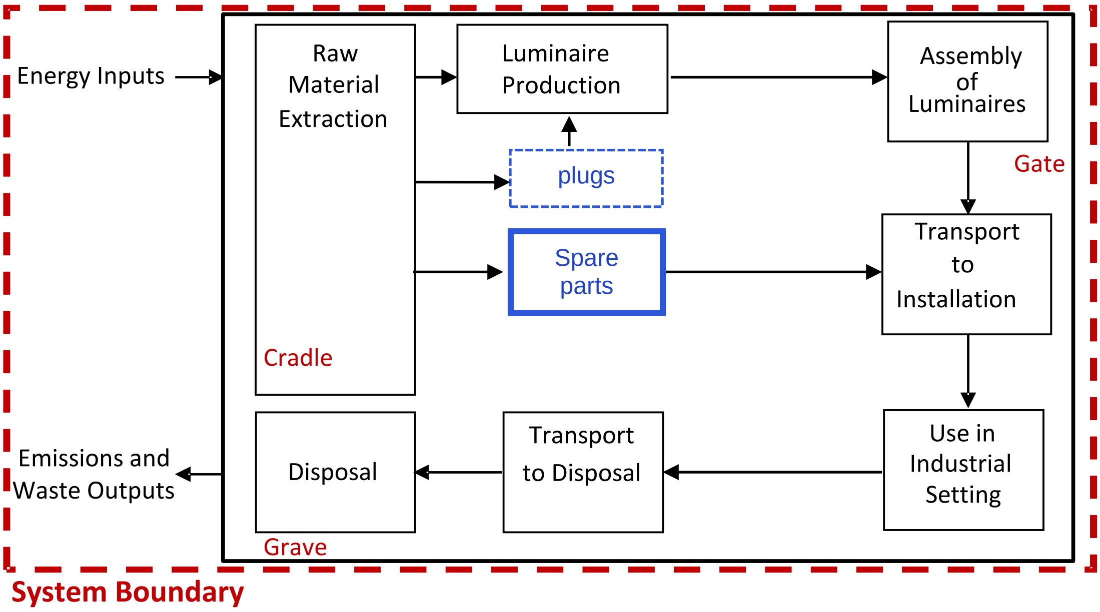


Figure 17 System Boundary to compare Luminaire A2 lighting system to Luminaire A1.

Based on the above, two lighting system scenarios of 369 luminaires are defined where 4 of them may fail along of the luminaire life time. The first scenario consists of Luminaires A1 where one entire luminaire has to be replaced due to the non-exchangeable LEDM fail and the other 3 luminaries where their LEDCs are replaced. The luminaire A2 lighting system is the second scenario being replaced 3 LEDCs and 1 LEDM. The first scenario will be referred hereafter as scenario without exchangeability, whereas the second one as the scenario with exchangeability. Daylight regulation is considered in both scenarios, consequently the sensor production is the same for both of them.

End-of-Life Inventory

Best practice for the end-of-life of benchmark luminaires was the scenario with better performance compared to other scenarios based on 100% landfill or incineration or a mixed in a determined proportion (See Part I). In this sense, the scenario best practice is considered to be used in the comparative LCA Cradle-to-Grave of the Repro-light luminaires vs Luminaire B and as assumed previously, it was considered that the luminaire can be disassembled completely allowing a separate treatment of each component.

As seen in Table 9, the LED luminaire consists of different components made of steel and plastic parts, and electronics, such as the circuit board and LED boards. Taking into account that the luminaire can be considered as an electric/electronic lighting equipment, as per WEEE European directive (2002/96/EC), each Member State is responsible for a correct electric and electronic correct waste management, with the aim of collecting it separately from the rest of the waste in order to recover as much materials as possible and enable a proper disposal of the possible hazardous elements. The association responsible for this in Spain is AMBILAMP. AMBILAMP services cover the collection and recycling of luminaires and lamps, including LED luminaire structure and LED lamps.

Following their indications, as a general rule, the end-of-life scenario of the LED luminaire has been set as the whole luminaire, if disposed correctly, can be recycled, with the exception of the PMMA and ABS parts, that are managed in an incinerator considering that this plastic material is difficult to recycle. This indications are considered in in the best practice scenario as shown in Table 22 and follow the “cut-off approach” for considering the input of secondary material (i.e. scrap material) into the production of some products, such as for steel and aluminium (Figure 5).

The “cut-off approach” considers the net mass (only the mass from use of primary materials) as entering the end-of-life scenario (Table 22). The net mass (indicated by mass ´x´ in Figure 5) is defined as the total mass of the material minus the mass of scrap material (indicated by mass ´y´ in Figure 5). The use of scrap material in the production stage has avoided the use of primary material. The mass of scrap material used in the production of components for both luminaires is summarized in Table 23. The “cut-off approach” does not credit for recycling material at the end-of-life, but also no environmental burden for recycling has been applied. 0.0.

Table 22: Net Mass[1] for the disposal best practice scenario for Repro-light luminaire Materials at End-of-Life

Material	Net mass (g) Luminaire A1	Net mass (g) Luminaire A2	Net mass (g) Luminaire A3	End-of-Life (best practice)
ABS	1.00	1.00	---	Incineration
PMMA	344.00	344.00	344.00	Incineration
Polycarbonate PC UV	2.02	4.62	4.620	Recycling
PA6.6	24.00	24.00	23.00	Recycling
Cup in plugs	---	0.36	0.36	Recycling
Steel	2426,30	2426,30	2260.35	Recycling
Silver alloy	---	0.004	0.004	Recycling
Stainless steel	---	0.400	0.40	Recycling
Electrical waste (WEEE)	220.60	220.60	235.90	Recycling
Copper Wire	42.80	42.80	42.80	Recycling
Other Plastics (PP, PET)	4.35	4.35	---	Recycling
TOTAL NET MASS (g)	**3065.00**	**3068.40**	**2911.40**	

[1]Mass ´x´ in Figure 5

Table 23: Mass of Scrap[1] Material in Production of Luminaire Components

Component	Scrap mass (g) Luminaire A1	Scrap mass (g) Luminaire A2	Scrap mass (g) Luminaire A3	End-of-Life (best practice)
Metal parts	33.0	33.00	10.15	Recycling
ECG Housing	19.0	19.00	---	Recycling
Trunking	127.0	127.00	127.00	Recycling
Gear Tray	58.50	58.50	58.50	Recycling
Stainless steel in plugs	---	1.125	1.125	Recycling
TOTAL SCRAP MASS (g)	**237.50**	**238.60**	**196.70**	

[1]Mass ´y´ in Figure 5

Life Cycle Impact Assessment and Interpretation

The comparative LCIA results with contribution analysis for Repro-light lighting systems are discussed in this section from environmental point of view through the six impact categories described in Table 1. In this sense, this section is divided into two subsections. The first one compares the overall cradle-to-grave results with focus in the production, use phase and end-of-life of the Repro-light luminaires vs the Luminaire B. The exchangeability scenario sis also studied in this section. The second section is dedicated to show the global environmental performance of the Luminaire A1 for different electricity mix grids.

Cradle-to-Grave Results

Luminaire A1 Vs Luminaire B (without dimming)

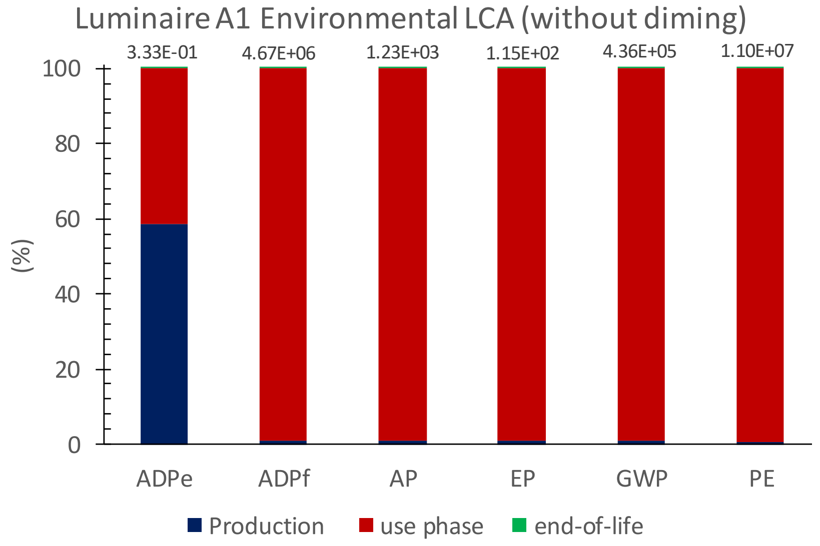
The environmental impacts for the production, use and disposal of Lighting Systems conformed by the Luminaire A1 (without diming) and the Luminaire B were quantified for each impact category assessed. Luminaire A1 and Luminaire B consist of scaled power luminaires of 40W and 45.2 as reported in Table 20. Both of them with organic coated steel gear trays and a lifetime of 70,000h.

The results shown in Figure 18 indicate that Lighting System Lighting System Luminaire A1 has lower impact in all impact categories than Luminaire B. Furthermore, the percent contribution of the impact of the use phase is around 99% for all impact categories, except for ADPe. In contrast, the percent contributions of the production stage range from 0.5 - 1% in all categories, except for ADPe and of the end-of-life stage less than 0.1% in all impact categories, which is similar to the Luminaire B.

For ADPe, the production for Lighting System Luminaire A1 contributes 59% of the overall result, the remaining 41% coming from the use phase. Similarly, for Lighting System Luminaire B, the production of the luminaires contributes about 77% to the overall result, the remaining 23% from the use phase. The end-of-life stage also is less than 0.1% in all impact categories.

An important reduction of total ADPe (50%) is observed for Luminaire A1 respect to the luminaire B. This reduction is due to the main actions conducted in the Repro-light project, such as the use of less materials in mechanic parts and optics. Figure 19 shows the ADPe distribution by components when the Luminaire A1 is compared with the Luminaire B. Mechanics is reduced in 31% and optics 35% respect to the Luminaire B. The material in Luminaire A1 also contributes to a lower end-of-life impact since the material disposal (such as the electronic component waste in the Luminaire A1), is reduced.

The use phase ADPe impact is also decreased in 12% in Luminaire A1 (Figure 19) because of its power of 40W being lower than the Luminaire B (45.2W).



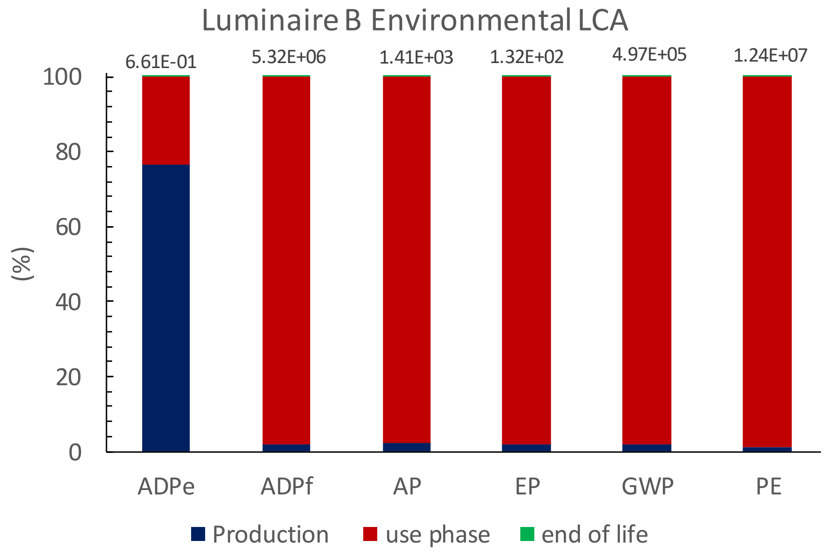


Figure 18: Percent Contribution of Production, Use and End-of-Life to each Impact Category Result for Lighting System Luminaire A1 without diming (top) and Lighting System Luminaire B (bottom). Absolute total values on top of bars

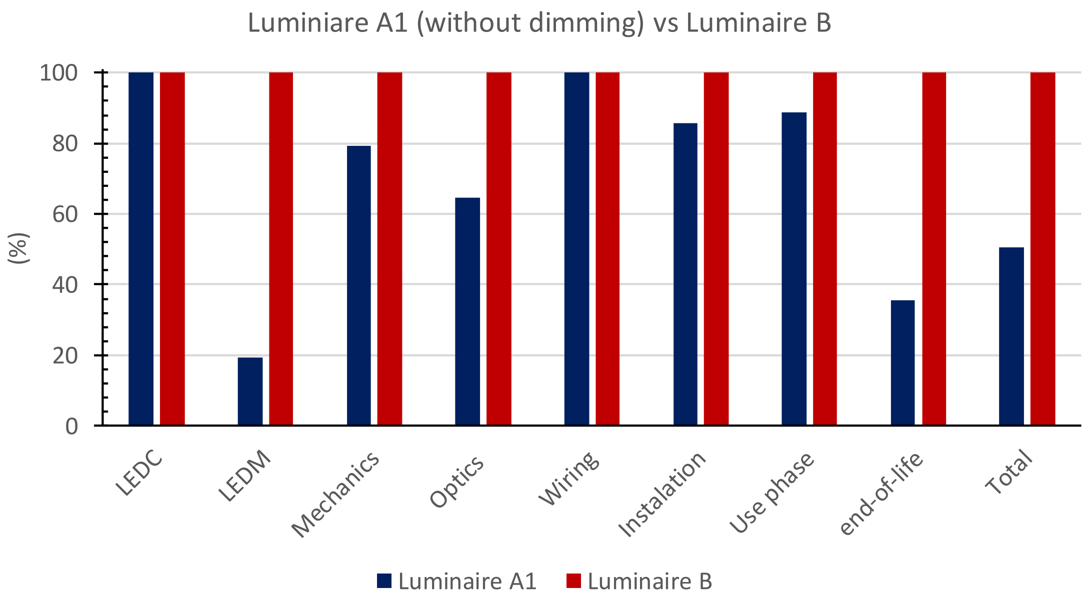


Figure 19 Percentage contribution of components, use phase and end-of-life of ADP element category for Luminaire A1 (without dimming) vs Luminaire B

The transport was only considered as an input in the installation stage, which shows lower impact in the Luminaire A1 than Luminaire B. This is attributed to the luminaires developed in Repro-light project weigh less than Luminaire B. The important reduction in ADPe is attributed to the LEDM of the Luminaire A1 with a 19% respect to the Luminaire B (100%). When the ADP element distribution by components is analysed for both luminaires, it can be observed a different distribution percentage in Luminaire A1 compared to the Luminaire B, such as shown in Figure 20. LEDM in Luminaire B has the highest ADP element impact of 75% and a 13% in the LEDC whereas the LEDM and LEDC of the Luminaire A1 have now 37% and 33%, respectively.

The above is attributed mainly to the reduction of LED board mass (5 boards in benchmark passing to 2 boards in the new luminaire) and the type of LED SMD used in the Repro-light luminaires. The absolute values of ADPe for LEDM parts (LED board and LED SMD) for both luminaires are reported in Table 24. Firstly, it can be seen that the LED board of Luminaire A1 decreases around 60% in all impact categories respect to Luminaire B, which is caused by the use of less LED boards in Luminaire A1. Secondly, the LED MSD is reduced drastically in all categories, which makes the LED board has the highest impact in the LEDM of the Luminaire A1.

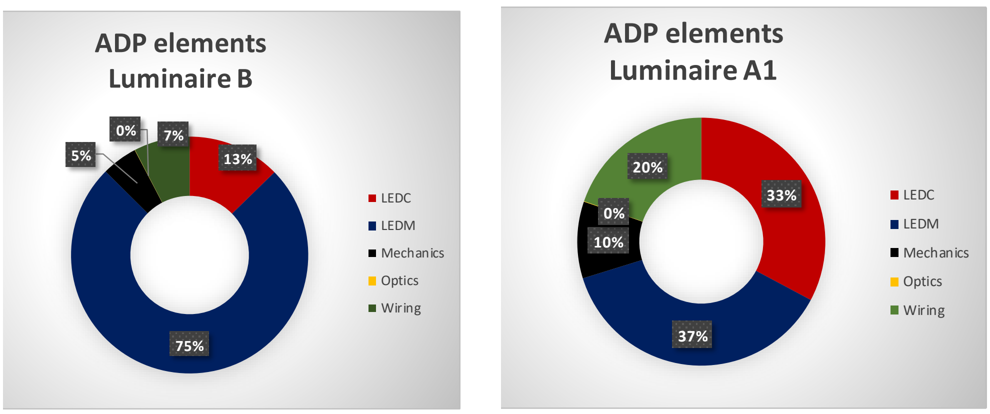


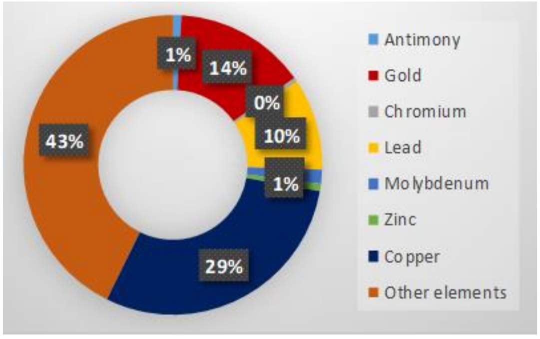
Figure 20 ADP element distribution by components. Luminaire A1 (right) and Luminaire B (left)

Industrial partner reported that the LED SMD of the Repro-light luminaires has not gold in the bond wire or at least it has a very low amount of this element. Therefore, the LED MSD modelled in the Repro-light luminaires was performed using a dataset as reported in Table 9 (LED SMD high-efficiency with lens max 0.5A (59mg) Flip Chip 3.5x3.5x2.0), which has a lower proportion of gold. In contrast, the Luminaire B uses LED MSD with gold in the bond wire, thereby the dataset "LED SMD high-efficiency with lens max 0.5A (59mg) Au bond wire 3.5x3.5x2.0" was used.

Table 24 Environmental impacts of LEDM parts for Luminaire A1 and Luminaire B

	Luminaire A1		Luminaire B	
Impact Category	**LED Board**	**LED SMD**	**LED Board**	**LED SMD**
ADPe	0.0731	6.608E-05	0.170	0.208
ADPf	12422.0	1901.2	30811.5	9114.3
AP	5.9	0.6	14.3	4.8
EP	0.5	0.04	1.23	0.35
GWP	1229.5	157.5	3025.	782.2
PE	15703.6	3027.5	40398.5	11079.5

According to the dataset, a piece of LED MSD with gold bond wire 3.5x3.5x2.0 is three order of magnitude more than the Flip Chip 3.5x3.5x2.0. When the ADP flows for material resources of the LED MSD dataset was explored, it was observed that the non-renewable elements have higher contribution and it was noticed that gold is the main responsible of this fact. In contrast, the LED MSD (Flip Chip) without gold in the bond wire shows a different distribution where the gold has a lower impact, such as shown in Figure 21. This fact explains the so low value of the ADPe of the LED SMD in the Luminaire A1, despite the Luminaire A1 has higher number of LEDs than in Luminaire B, as shown in Table 24.



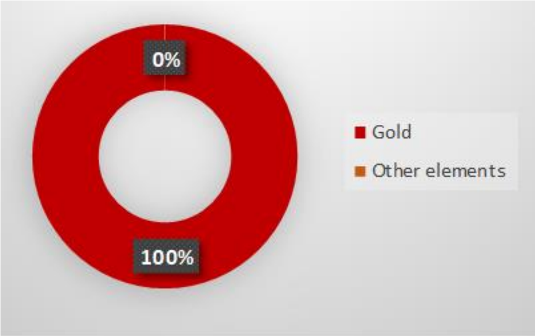


Figure 21 ADPe flow percentage to non-renewable elements for one piece of LED MSD gold bond wire (right) and LED MSD flip chip (left)

The above indicates that the material reduction or the efficient use of critical materials, such as avoiding of gold in the MSD LEDs, brings environmental benefits in ADP element category, resulting in savings in the consumption of non-renewable natural resources.

For more detailed information, the Appendix B shows the environmental impact absolute values for the LEDC, mechanics, optics parts and wiring for both the Luminaire A1 and Luminaire B as well as for the installation, use phase and end-of-life.

Luminaire A1 (with dimming)

The main difference of the Luminaire A1 with diming is the use of sensors and controllers in the lighting system to keep the illuminance on the working plane constant, taking into account the natural light entering from outside. As commented in the use phase inventory section, this innovation elongates the lifetime of the luminaire and energy savings are also achieved such as shown in Table 21. The remaining components in LEDC, LEDM, Mechanics, Optics and Wiring are the same as in Luminaire A1 without dimming, thereby the environmental impact contribution of those components are as that luminaire.

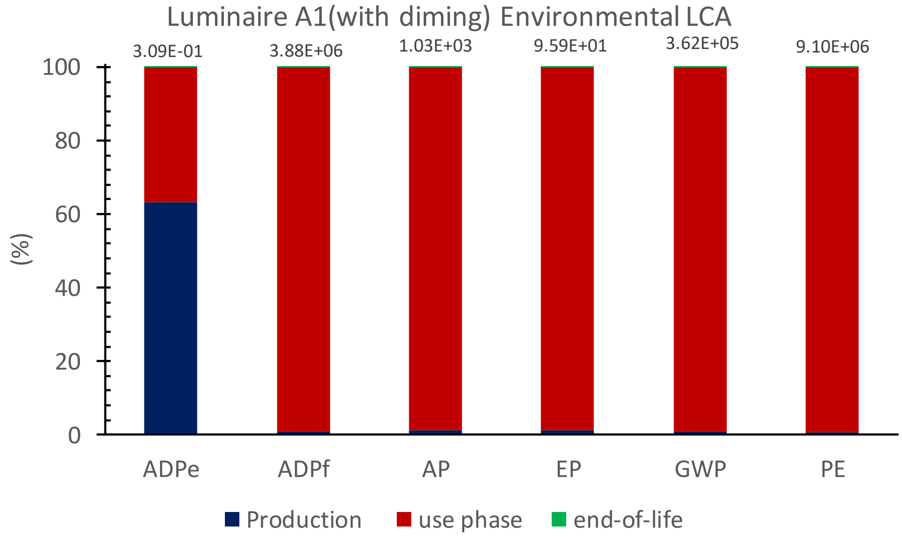


Figure 22 Contribution percent of Production, Use and End-of-Life to each Impact Category Result for Lighting System Luminaire A1 with diming (Absolute total values on top of bars)

Since the LCI of the Luminaire A1 (with dimming) is the same as Luminaire A1 (without dimming), the overall environmental impact contribution has a profile very similar to the lighting system without dimming as shown in Figure 22. The use phase continues being the stage with higher contribution in all categories (99%), except to the ADP element. The production goes from 0.5-1%, except to the ADPe with a 63%. The contribution of materials associated to the sensors and controller production for the lighting system with dimming is not significant (less 0.1%), because the environmental burden is distributed for the 369 luminaires along the lifetime.

The overall environmental LCA performance of the Luminaire A1 with dimming is better, since energy savings in the use phase are achieved, which makes all absolute values of impact categories are decreased when compared to the Luminaire A1 without dimming and the Luminaire B. Another benefit is that the lifetime is extended to 101965h due to reasons already explained above.

This saving of energy in the use phase allows also reduce material resources in upstream processes to produce such energy, which affects the ADPe category. As seen in the Luminaire A1 without dimming, the use phase was reduced in 12% compared to the Luminaire B (Figure 19), but the Luminaire A1 with dimming has a greater reduction around 26% in the use phase. The materials and energy saving make its total ADP element is 47% respect to the Luminaire B, such as shown in Figure 23. A similar behaviour is extended for the rest impact categories. More detailed information for the use phase values for Luminaire A1 with and without dimming is shown in the Appendix B.2.

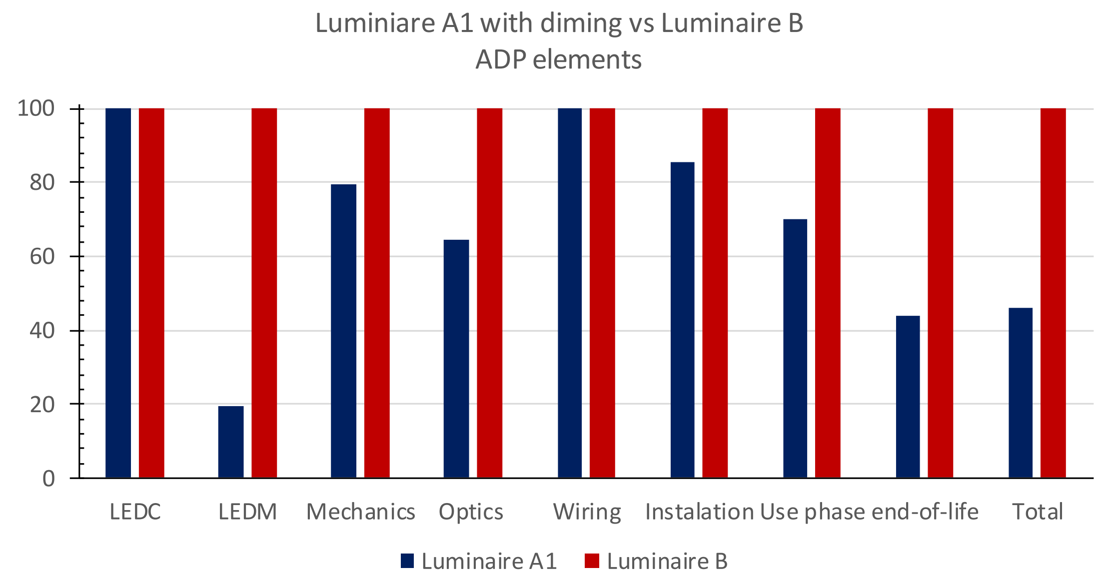


Figure 23 Contribution percentage of components, use phase and end-of-life of ADP element category for Luminaire A1 (with dimming) vs Luminaire B

Luminaire A2 (serviceability)

As mentioned above, the Luminaire A2 is the same as the Luminaire A1, except for the use of plugs needed for the exchangeable LEDM, which inventory is detailed in Table 12.

As observed in Figure 24, the environmental contribution of plugs included in the LEDM for all impact categories is between 0.4-1% and it is less 0.3% considering the overall life cycle performance of the luminaire, which makes that the life cycle environmental profile of the Luminaire A2 is practically the same as the Luminaire A1.

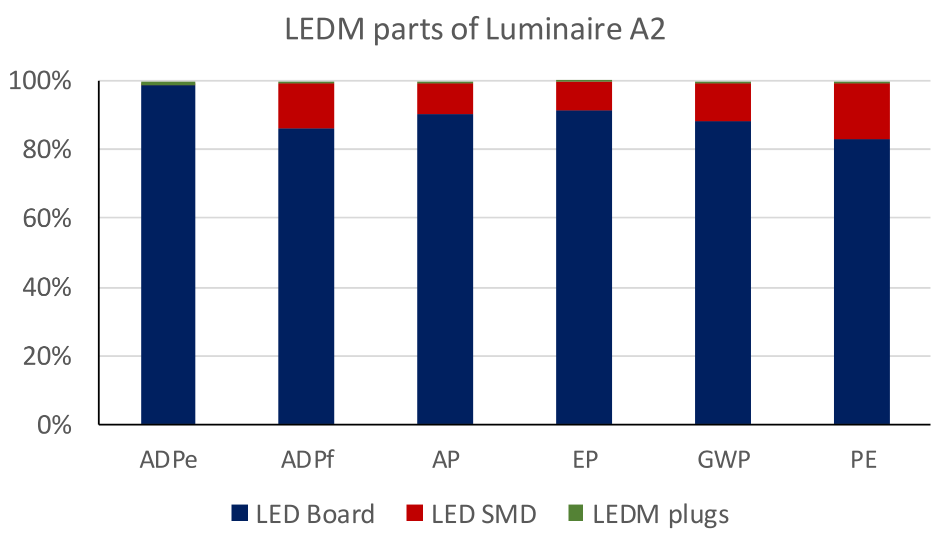


Figure 24 LEDM parts contribution of the Luminaire A2

Figure 25 shows the percentage contribution for both scenarios without exchangeability and with exchangeability along life cycle. Absolute values are indicated on top of bars. It can be seen that the scenario with exchangeability shows the same impacts for all categories, except ADPe where a slightly higher impact is evidenced respect to the scenario without exchangeability. This latter is mainly attributed to the production of plugs for the exchangeable LEDMs.

The energy efficiency of exchangeable demonstrator (Luminaire A2) is unknown since measurements couldn't be done because this luminaire is not finished. According the industrial partner, an energy loss is expected around 2% meaning 2% higher power consumption in the use phase. This fact would show different results in the environmental contribution of the Luminaire A2 life cycle. Nevertheless, the same energy consumption was considered in the use phase for both scenarios in this study, which generates a similar contribution profile as the Luminaire A1. The percent contribution of the impact of the use phase is around 99% for all impact categories, except for ADPe. In contrast, the percent contributions of the production of luminaries range from 0.5 - 1% in all categories, except for ADPe (63%) and end-of-life less than 0.1% in all impact categories. The percentage contribution to produce

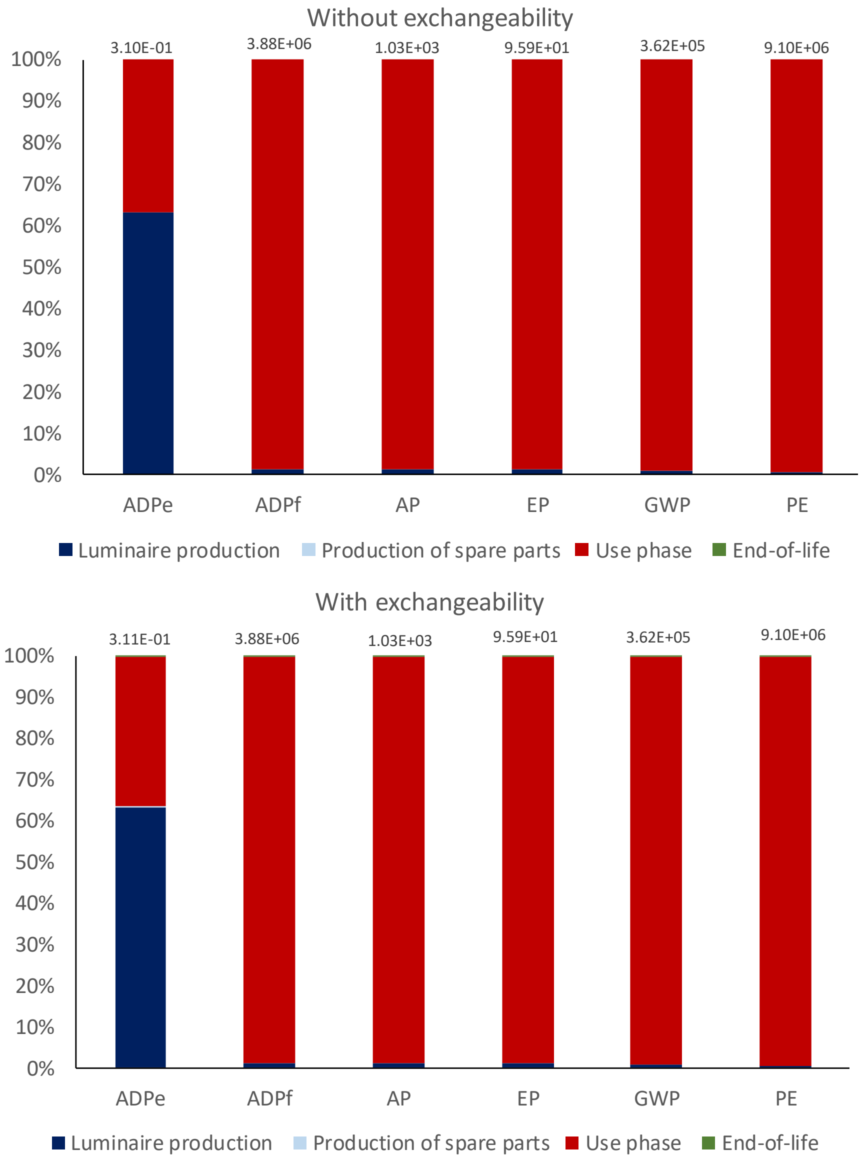


Figure 25 : Percent Contribution of Luminaire Production, Production of spare parts, Use and End-of-Life to each Impact Category Result for the scenario without exchangeability (top) and without exchangeability (bottom). Absolute total values on top of bars

the spare parts range from 0.02 to 0.3% for the scenario without exchangeability and 0.02 to 0.2% for the scenario with exchangeability depending of the category analysed.

Since the use phase has been considered to be the same for both scenarios and it has the highest contribution in almost all impact categories, this stage is removed from the comparison analysis in order to appreciate the percentage differences between the stages to produce the luminaire and spare part and end of life, where the Repro-light innovations related to the exchangeability have an effect, such shown in Figure 26.

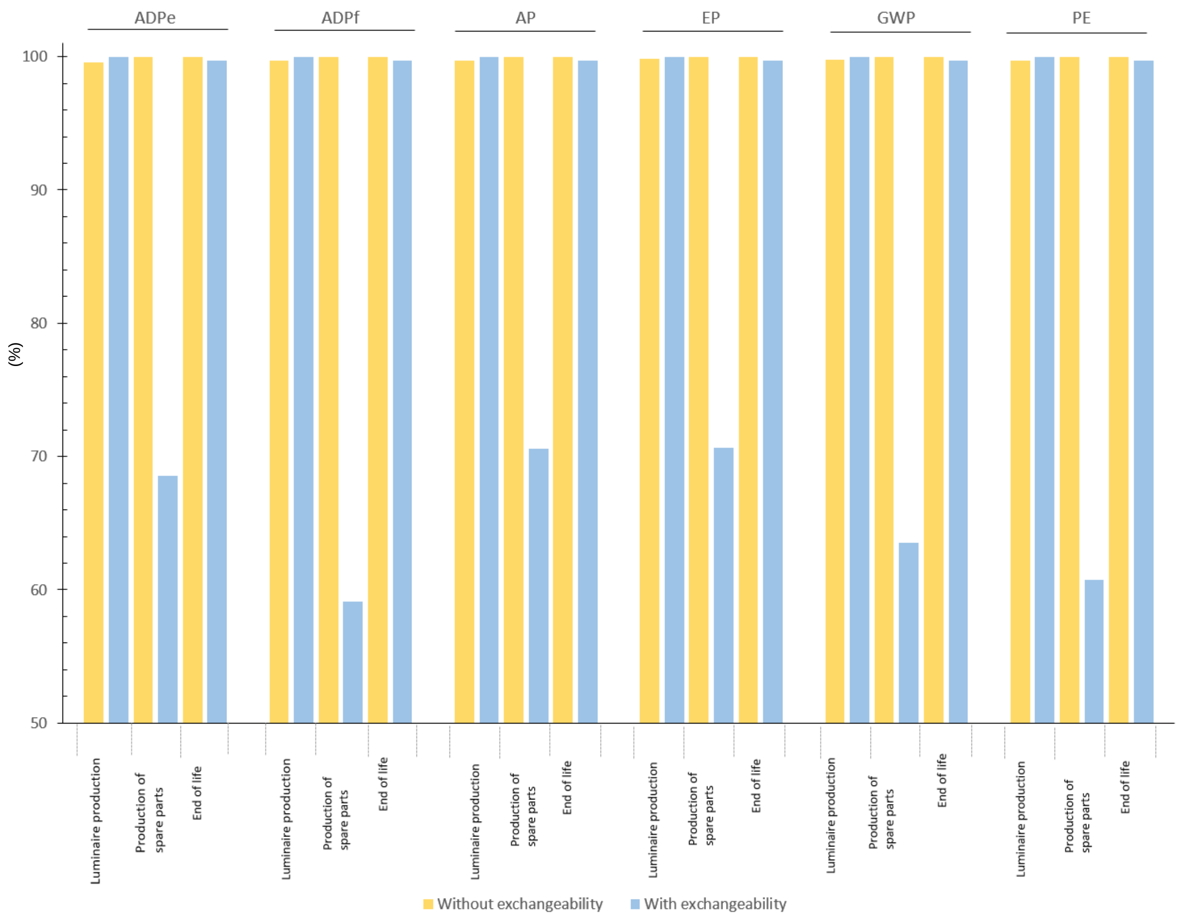


Figure 26 Environmental impact category percentages of the scenario with exchangeability respect to the scenario without exchangeability (use phase stage is not included)

Producing the luminaire in the scenario with exchangeability is slightly higher in all impact categories between 0.3 and 0.4%, which is attributed to the plugs for the exchangeable LEDMs. In contrast, this scenario exhibits lower impacts for the spare part production in all categories, ranging from 59% to 70% and a slightly lower impact for the end-of-life stage also in all categories. This latter is due to the less material disposal in the end-of-life.

Figure 27 gives the absolute values of ADPe category to compare both scenarios. It can be seen that the spare part production in the scenario with exchangeability has an ADPe of 7.22E-04 kg Sb eq, which is less a 31% than the scenario without exchangeability. This is because a luminaire does not need to be replaced in the exchangeable scenario, only LEDM and LEDCs are repaired. However, the luminaire production has a higher ADPe impact of 1.96E-01 kg Sb eq, making the total ADPe of the scenario with exchangeability higher 0.3%. This suggests that ADPe of the exchangeable demo is sensible to the design of plugs in terms of quantity and type of material used for its production. Therefore, it is recommended extra efforts to improve the design of plugs from environmental point of view in the Luminaire A2 that allow a benefit in the net ADPe impact category.

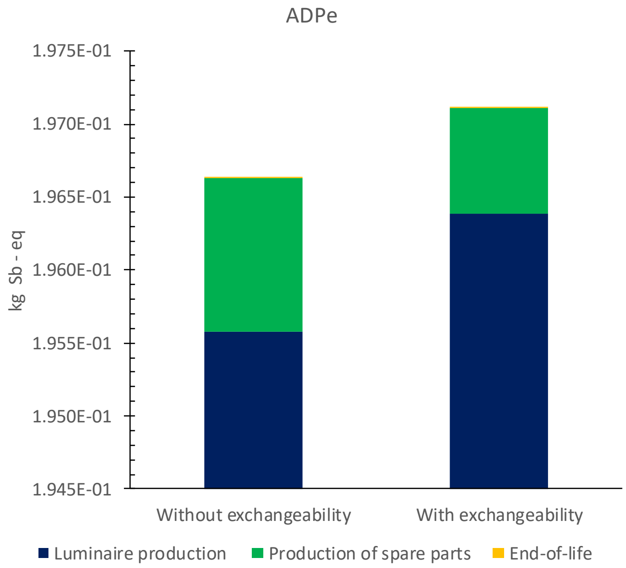


Figure 27 Comparison in terms of kg Sb eq between the scenario without exchangeability and with exchangeability (Use phase is not included).

Luminaire A3

Luminaire A3 is a luminaire design modelled in WP5 in order to show the environmental benefits due to and higher material efficiency. Therefore, the material saving is the premise in this luminaire, such as listed in the material bill (Table 16). On the other hand, the same innovative features developed in the project, such as dimming using sensors and plugs for exchangeability of the LEDM + C are also included in the modelling. In this sense, it was assumed that sensor/controllers, mechanics, optics, wiring and plugs are as the Luminaire A2, but new data related to the materials for LEDM+C (no housing required) were included in the model.

As expected, the Luminaire A3 has better environmental performance compared to the previous Repro-light luminaires and the Luminaire B, such as shown in Figure 28, since total absolutes values of all impact categories are slightly lower. However, the global distribution of the environmental burden remains very similar to the previous luminaires. The use phase continues having a 99% of contribution in all impact categories, except to the ADP, the remaining correspond to the production and end-of-life ranging 0 - 1%. Again, the ADPe of the production has an important contribution of 38% whereas the use phase has a 62%. In contrast, the end-of-life shows less than 0.1% in this impact category as well as in the other ones.

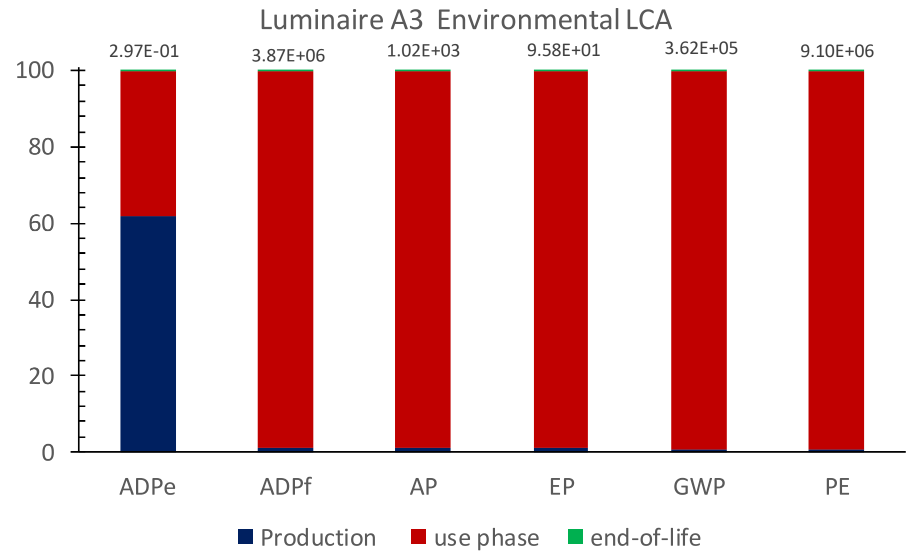


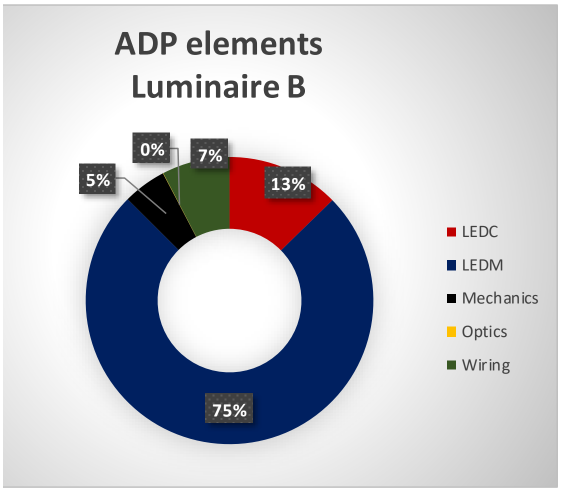
Figure 28 Contribution percent of Production, Use and End-of-Life to each Impact Category Result for Lighting System Luminaire A3. Absolute total values on top of bars

Table 25 shows the ADPe absolute values for the three luminaires by components, installation, use phase and end-of-life. As it can be seen, the main contribution to reduce this environmental category is the LEDM+C in Luminaire A3 with less impact due to the materials saving, compared to the other Repro-light luminaires. A more significant reduction in the impact categories is evidenced when compared to the Luminaire B.

Table 25 ADPe of the life cycle stage for the Repro-light Luminaires vs Luminaire B

Cycle stage	Component	Luminaire A3	Luminaire A1	Luminaire A2	Luminaire B
Production	LEDM+C	0.124822	---	---	---
	LEDC	---	6.41E-02	6.41E-02	6.42E-02
	LEDM	---	7.32E-02	7.40E-02	3.78E-01
	Mechanics	1.95E-02	1.96E-02	1.96E-02	2.47E-02
	Optics	1.34E-04	1.34E-04	1.34E-04	2.07E-04
	Wiring	3.85E-02	3.85E-02	3.85E-02	3.85E-02
	Sensor stienel	2.81E-06	2.81E-06	2.81E-06	---
	Sensor control	1.06E-06	1.06E-06	1.06E-06	---
	Installation	1.84E-07	2.02E-07	1.96E-07	2.36E-07
Use phase		1.14E-01	1.14E-01	1.14E-01	1.55E-01
end-of-life		1.07E-05	1.11E-05	1.12E-05	2.79E-05
TOTAL		0.297	0.309	0.310	0.661

The above is also evidenced when ADP element distribution by components of the Luminaire A3 is analysed, such as shown in Figure 29. The LEDM+C has a contribution of 68% (Right), whereas the LEDC + LEDM contributions in the Luminaire B result in a total of 88% (Left).



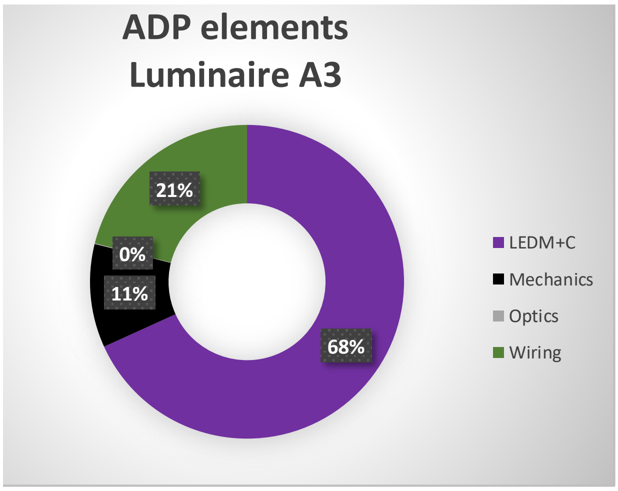


Figure 29 ADP element distribution by components. Luminaire A3 (right) and Luminaire B (left)

Electricity mix scenarios study

As mentioned above, the electricity mix grid E28 was used for the environmental modelling of the lighting system of the different Repro-light vs Benchmark luminaires in the previous section. It could be observed the use phase has the main environmental contribution in the life cycle of the luminaire, which is due to the energy consumption. Therefore, the influence of the energy source on the impact categories for a lighting system constituted by Luminaire A1 (Eline-Next) is studied in this section. To do this, a differenced electricity mix grids of 4 countries (Sweden, France, Spain and Italy) were chosen. All of them were taken from GaBi dataset which documentation states an electricity mix dated in 2015, that are showed in Appendix C.

Sweden electricity mix is characterised mainly by a 55% of renewable energies with the highest percentage in hydropower, followed by nuclear energy almost a 35%. On the other hand, this controversial source of energy represents meanwhile a 77% in the electricity mix of France. Whereas, wind power, hydropower, nuclear, natural gas and electricity from waste are the most representative energy sources in the Spain electricity mix, being the nuclear energy by 20.4%, natural gas 18.7% followed by the wind power by 17.6%. Regarding the Italy, natural gas and hard coal are the energy source with higher weight in its electricity mix, 39% and 15% respectively among other fossil fuels.

Overall environmental results of Luminaire A1 in terms of percentage comparing the electricity mix grid mentioned above are shown in Figure 30. E28 electricity mix grid scenario is also included in the chart as reference to 100% and, absolute values are also shown in Table 26.

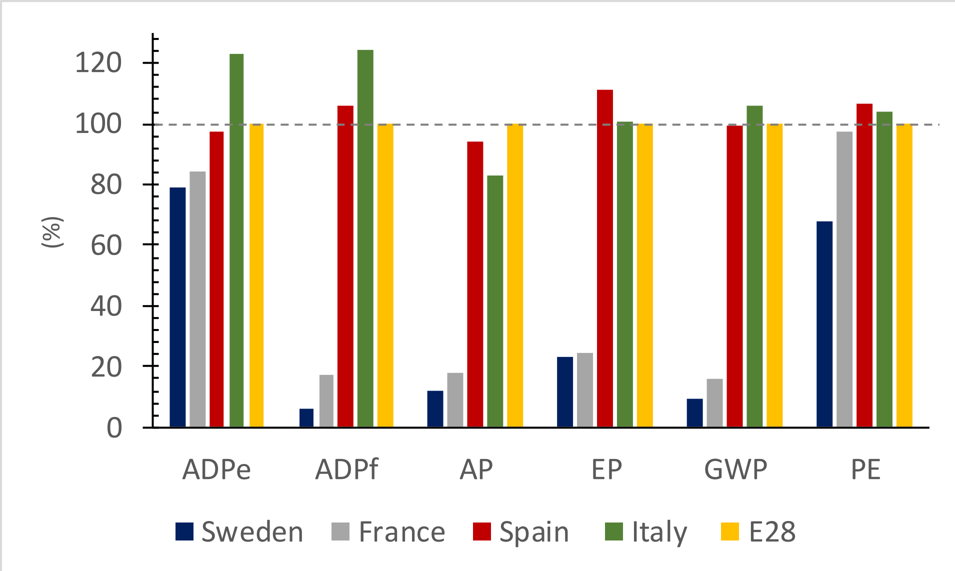


Figure 30 Percentage contribution of the overall environmental performance for the Luminaire A1 comparing different electricity generation sources

The results depend of the impact categories analysed. The Sweden and France scenarios show lower impact in all categories respect to the E28 scenario used in the study, being Sweden scenario with the lowest impact in ADPf, AP, EP and GWP ranging from 6 to 23%. This is attributed mainly to the characteristics of the Sweden electricity mix with low fossil fuel source. The ADP element of the Sweden is also lower than E28 scenario but still with a high impact of 80%, that is attributed to the use of higher nonrenewable elements, such as antimony, chromium, copper and gold used in the upstream process. France scenario also exhibit 97% in ADP element because the use of uranium characterized as nonrenewable energy resource and because of the nonrenewable elements as the ones mentioned in the Sweden scenario. In addition, both Sweden and France scenarios have considerable impact in the PE category due to the use of Uranium (nonrenewable energy resource) and hydropower, solar and wind power categorized as renewable energy resources.

Table 26 Global environmental results for the Luminaire A1 comparing different electricity generation sources

	E28	Sweden	Spain	Italy	France
ADPe	3.09E-01	2.45E-01	3.02E-01	3.82E-01	2.16E-01
ADPf	3.88E+06	2.32E+05	4.10E+06	4.82E+06	5.45E+04
AP	1.03E+03	1.26E+02	9.67E+02	8.48E+02	2.10E+03
EP	9.59E+01	2.25E+01	1.07E+02	9.67E+01	1.67E+00
GWP	3.62E+05	3.50E+04	3.59E+05	3.83E+05	2.00E+04
PE	9.10E+06	6.20E+06	9.68E+06	9.44E+06	6.76E+06

In contrast, Italy and Spain scenarios are similar to the E28 electricity mix grid scenario in the AP, GWP, EP and PE categories. Italy scenario is higher in ADP element and ADP fossil (around 124%) because the use of nonrenewable elements resources (antimony, chromium, copper, etc.) and natural gas as nonrenewable energy resource, which also makes the GWP and PE slightly higher (105 and 103% respectively) due to the natural gas and coal hard.

In conclusion, the source of energy influences in the environmental performance of the luminaire. The use of an electricity mix similar to the Sweden with higher contribution of renewable energy source bring important impact reduction in the categories ADPf, AP, EP and GWP of the Luminaire A1. However, this electricity mix is not free of other type of nonrenewable energy source, such as the nuclear energy

(Uranium) besides the use of nonrenewable elements, which contribute directly on the ADPe and PE categories.

Conclusions and Recommendations (Part II)

This study is focused on the cradle-to-grave LCA of Repro-light luminaires used to meet lighting regulation in an industrial setting conformed by 369 luminaires with an illuminance of 300lux compared to a lighting system of conventional luminaire. The main difference in the Repro-light luminaires leads in the saving of materials and energy due to the innovations developed in the project and a design modular luminaire architecture.

The environmental overall results show that Repro-light luminaires perform better than Luminaire B decreasing the impact between 12 and 27% for all categories, except in the total ADPe that was reduced between 27 and 55% respect to the Luminaire B. The luminaire A3 (Illuminated driver design) is the one with the best environmental performance due to additional saving of materials. On the other hand, the energy savings may elongate the lifetime of the Repro-light luminaires in a 46% respect to Luminaire B.

When the distribution of environmental burdens is analysed for the production, use and end-of-life life cycle stages, it was observed that the use phase is the life cycle stage with higher contribution (around 99%) for all impact categories, except for ADPe. This is consistent with several studies found in specialized literature on environmental impacts of lighting products. The percent contributions of the production stage range from 0.5 - 1% in all impact categories, except for the ADPe. However, the end-of-life stage is less than 0.1% in all impact categories, which is similar to the Luminaire B.

The exception is observed in the category ADPe because the production of luminaires contributes considerably in this category around 63% for Luminaire A1 with dimming, and a 61% for the Luminaire A3, which is attributed to the saving of material when combining the LLEDM+C respect to the other Repro-light luminaires. The reaming contribution between 37 and 39% is due to the use phase. In general terms, the material and energy savings entails an important reduction of the total ADPe of 53% for the Luminaire A1 (with dimming) respect to Luminaire B. It is similar for the other Repro-light luminaires.

The important reduction in the total ADPe is mainly attributed to the LEDM with a 19% respect to the Luminaire B. This is because of the saving of LED board mass and the type of LED SMD used in the Repro-light luminaires with less amount of gold in the new LED bond wire. This latter modifies the ADPe distribution by components of the Luminaire A1 compared to the Luminaire B, resulting a 37% for the LEDM contribution and 33% for LEDC, while it is a 75% and 13% in the Luminaire B, respectively. This is the same behaviour for the luminaire A2, since LEDC is as the Luminaire A1 and the LEDM is very similar. On the other hand, the ADP element distribution by components for Luminaire A3 shows a LEDC+C contribution of 68%.

The serviceability of the Luminaire A2 was studied in a lighting system for industrial hall, considering exchangeable LEDC and LEDM components (scenario with exchangeability). This luminaire was compared to a lighting system of Luminaire A1, which LEDC can be repaired whereas the LEDM cannot be serviceable (scenario without exchangeability). Both scenarios show the same global environmental impact in all impact categories studied, except in ADPe showing a slightly higher impact of 0.15% in the scenario with exchangeability. This is attributed to the production of plugs for the exchangeable LEDMs. However, percentage differences between both scenarios (no including the use phase) reveal that the spare part production is lower in all impact categories ranging from 59% to 70% and a slightly lower impact for the end-of-life stage in all categories analised. This latter is attributed to the saving of one luminaire in the scenario with exchangeability, since only LEDM and LEDCs are replaced.

When the analysis is focused in the ADPe category, it was observed that the luminaire production in the scenario with exchangeability is dominant whereas the spare part production is 31% lower than the scenario without exchangeability. This means that ADPe of the exchangeability demo is sensible to the design of plugs in terms of quantity and type of material used for its production. Therefore, it is suggested extra efforts to improve the design of plugs from environmental point of view in the Luminaire A2 to achieve a benefit in the net ADPe impact category.

The global environmental impacts depend of the use phase of the luminaire, which is related to the resources used to produce the energy (electricity consumption). For that reason, the performance environmental depends of the electricity mix of the country where the Repro-light technology will be implemented. In this sense, several scenarios of different electricity mix grid (Sweden, France, Italy and Spain) were conducted to know the global environmental impact of the Repro-light luminaire. It was observed that the use of an electricity mix similar as the Sweden, with higher contribution of renewable energy source, brings important impact reduction in the categories ADPf, AP, EP and GWP. However, this electricity mix is not free of other type of nonrenewable energy source, such as the nuclear energy (Uranium) besides the use of nonrenewable elements, which contribute directly on the ADPe and PE categories.

The above results show the importance of actions to be taken in terms of material and energy efficiency in the context of the circular economy and eco-design strategies in order to achieve more sustainable luminaires. On the one hand, more renewable energy and improvement in the energy efficiency of LED luminaires should be the must in order to reduce the environmental impact. On the other hand, the improving of the recovery rates (recycling technologies) is suggested to improve the availability of these elements from secondary sources. These elements can be kept in use and although this does not necessarily mean that they will be of high enough quality to reuse in the luminaire, they can be reused in other applications. Depending on the element to be recovered, this is not always economical, thereby this aspect should be considered, i.e., to increase the recovery rates of elements, it must be economically viable. This is one problem with these recycling technologies to be improved. In addition, it should be considered an optimal design of products to separate the optical part from the mounting case and from electrical components. The optical part could be standardized, so different companies could be able to deliver retrofit solutions.

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Appendix A

Appendix A.1 Failure fraction calculation

The failure fraction was estimated using data provided from TRILUX in August 2019 and a fitted Weibull distribution that allows to study what is the distribution of failures of a component. To do this, it was considered 3.882.293 E-Lines in operation over 7 years. The oldest order was 2309 days from the date of getting the data out of the system, 17.07.2019.

In detail, the data are listed in TableA 1in Appendix A.2, where the first column is the number of days of operation, the second column is the number of failures on days *ti* and the third column is the number of items that were suspended on day *ti*. The suspended items are because their observation was ended. They were put into operation *ti* days and did not fail until 24.07.2019, the day the reclamation data was analysed.

As mentioned above, a total 3,882,293 luminaires were put into operation, 22 713 failures were observed, thereby 3,859,580 luminaires were still in operation ("suspended from the test"). The failure was attributed to the light engine consisting of LEDM and LEDC (Control gear), since more information was not available.

The failure fraction was estimated using the Weibull distribution, which is described in the Life Data Analysis Reference document [10]. When the Weibull plot was performed using Benard's Approximation as Median Ranks, it was found the data could be fitted with two lines due the nature of the data, which generated Weibull parameters (alpha and beta) for each lines generated. In other words, the data were not adjusted to one line.

To solved this situation, an adapted Kaplan-Meier estimator from [10] can be used as an alternative to the median ranks. This estimator considers both number of failures and number of survivors (censored data). In this sense, the reliability function or survivors S(t) of a population of luminaires put into operation at once (of which none are suspended) may be calculated using the Equation A1.5, which is based on the Kaplan-Meier estimator.

$S_i = \prod_{j=1}^{i}(1 - h_i \Delta t_i)$ *(Equation A1.1);*

Where h_i *is the* empirical failure rate (hazard function), that is calculated as shown in the Equation A1.2.

$h_i = \frac{f_i}{n_i^{(cum)}} \cdot \frac{1}{\Delta t_i}$ *(Equation A1.2);*

$\Delta t_i = t_i - t_{i-1}$ and $n_i^{(cum)}$ is the number of items that are still in the test after *ti* days. This parameter is calculated by the Equation A1.3

$n_i^{(cum)} = n^{total} - f_i^{(cum)} - sus_i^{(cum)}$ *(Equation A1.3);*

n^{total} is the total number of luminaires operating (3,859,580 luminaires) and $f_i^{(cum)}$ *and* $sus_i^{(cum)}$ are calculated as shown in Equation A1.4 and *(Equation A1.5)*;

$f_i^{(cum)} = \sum_{j=1}^{i} f_j$ *(Equation A1.4);*

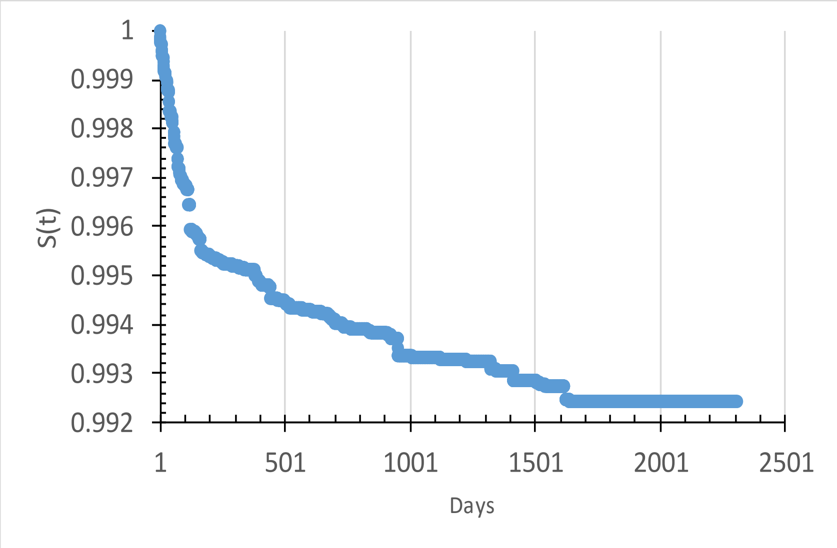
$sus_i^{(cum)} = \sum_{j=1}^{i} sus_j$ *(Equation A1.5);*

The unreliability function following the Weibull distribution can be calculated as shown in the Equation A1.6.

F(t) = 1-S(t) =1- $e^{-\left(\frac{t}{\eta}\right)^{\beta}}$ *(Equation A1.6);*

Then the above equation can be linearized to calculate the Weibull parameters (η and β), such as explained in the Analysis Reference document [10].

For easy calculation, a mathematical program was used, which follows the Kaplan-Meier model described above. It generated the reliability function plotting for the data reported in TableA 1, such as shown in FigureA 1.



FigureA 1 Survivors S(t) of luminaires population

The Weibull parameters η and β were obtained as explained above. The values are 0.23427 and 2.191E+12 respectively. In this sense, the fraction of failures F(t) to any day can be calculated using the Equation A1.6. This means that after 70.000 hrs, that corresponds to 4375 days assuming an industry 2-shift scenario (16h/day), the fraction of failures is estimated to 1%.

Appendix A.2 Data for failure fraction calculation

TableA 1 Data for failure fraction calculation.

t [days]	failed after t days (ti)	suspended after t days	placed in operation t days ago	t [days]	failed after t days	suspended after t days	placed in operation t days ago
0	20	0	0	37	57	0	0
1	7	0	0	38	686	0	0
2	29	0	0	39	32	0	0
3	468	0	0	40	700	2605	2605
4	32	0	0	41	38	2553	2553
5	150	192	192	42	87	2277	2277
6	151	1571	1571	43	52	2302	2302
7	204	3494	3494	44	114	2297	2297
8	418	5235	5235	45	33	0	0
9	45	2021	2021	46	39	0	0
10	86	0	0	47	31	2575	2575
11	120	0	0	48	112	0	0
12	170	3200	3200	49	53	3298	3298
13	119	2374	2374	50	233	1469	1469
14	169	2719	2719	51	88	3345	3347
15	228	2307	2307	52	30	0	0
16	60	4304	4304	53	20	0	0
17	295	0	0	54	38	7203	7209
18	74	15	15	55	25	3868	3871
19	158	3271	3271	56	703	3608	3608
20	187	1798	1798	57	24	2910	2914
21	69	2372	2372	58	43	2973	2973
22	44	4097	4097	59	158	0	0
23	54	3353	3354	60	66	0	0
24	30	0	0	61	190	5177	5177
25	90	0	0	62	324	4268	4268
26	60	3580	3580	63	68	2514	2515
27	87	0	0	64	91	4880	4881
28	374	2266	2278	65	37	2015	2015
29	60	1215	1215	66	16	0	0
30	25	3129	3129	67	12	0	0
31	433	0	0	68	18	5574	5574
32	33	0	0	69	70	3006	3008
33	38	2678	2684	70	47	2181	2183
34	68	3262	3262	71	822	3895	3895
35	88	3235	3236	72	11	1021	1024
36	28	4353	4354	73	31	0	0

t [days]	failed after t days	suspended after t days	placed in operation t days ago	t [days]	failed after t days	suspended after t days	placed in operation t days ago
74	20	0	0	115	12	0	0
75	623	5547	5550	116	24	0	0
76	18	2652	2655	117	8	4438	4443
77	81	0	0	118	1035	3737	3737
78	22	2474	2474	119	30	2676	2676
79	45	1777	1777	120	25	4971	4974
80	217	0	0	121	25	2086	2088
81	18	0	0	122	2	0	0
82	36	4143	4144	123	5	0	0
83	66	2583	2583	124	25	4857	4858
84	126	3633	3635	125	1724	3108	3109
85	301	4824	4824	126	18	2034	2034
86	23	0	0	127	7	3954	3955
87	9	0	0	128	15	4029	4038
88	9	421	421	129	3	0	0
89	16	0	0	130	5	0	0
90	25	4001	4001	131	80	3916	3966
91	10	3117	3122	132	8	3387	3389
92	82	3042	3042	133	14	2978	2994
93	42	1887	1888	134	5	3766	3769
94	13	0	0	135	26	1959	1964
95	30	0	0	136	8	0	0
96	26	4615	4615	137	6	0	0
97	9	1799	1799	138	25	5331	5344
98	39	2038	2039	139	7	3760	3763
99	28	2918	2918	140	9	3428	3430
100	4	1945	1946	141	25	3530	3531
101	61	0	0	142	11	4890	4890
102	33	0	0	143	3	0	0
103	6	7210	7212	144	35	0	0
104	14	2103	2103	145	18	4316	4319
105	24	2044	2045	146	15	2888	2892
106	8	2976	2977	147	17	3826	3827
107	11	2602	2618	148	41	3213	3214
108	26	0	0	149	13	2523	2525
109	71	0	0	150	12	0	0
110	47	4739	4740	151	6	0	0
111	24	3131	3131	152	8	4194	4843
112	15	2474	2475	153	8	2530	2530
113	60	2434	2435	154	170	2786	2791
114	6	1533	1536	155	23	4424	4425

t [days]	failed after t days	suspended after t days	placed in operation t days ago	t [days]	failed after t days	suspended after t days	placed in operation t days ago
156	5	2225	2227	197	9	0	0
157	5	0	0	198	13	0	0
158	2	0	0	199	11	0	0
159	12	4188	4189	200	1	0	0
160	38	2510	2510	201	13	372	372
161	7	2685	2694	202	15	857	857
162	5	2816	2818	203	1	0	0
163	3	3244	3251	204	10	0	0
164	17	0	0	205	21	0	0
165	5	0	0	206	10	0	0
166	3	5856	5859	207	16	0	0
167	886	2097	2148	208	20	1430	1431
168	4	2187	2195	209	6	343	343
169	3	4003	4003	210	15	537	537
170	0	2602	2607	211	13	3570	3572
171	11	0	0	212	6	3600	3600
172	15	0	0	213	16	0	0
173	2	2596	2605	214	3	0	0
174	7	2894	2899	215	1	4428	4680
175	31	3813	3813	216	2	2425	2425
176	15	2852	2856	217	12	2898	2899
177	14	3086	3091	218	5	2362	2362
178	5	0	0	219	3	2239	2240
179	8	0	0	220	8	0	0
180	3	6460	6470	221	3	0	0
181	26	3041	3041	222	11	4770	4784
182	5	2908	2933	223	17	3400	3401
183	6	3529	3533	224	10	3574	3577
184	8	4414	4507	225	8	2847	2849
185	4	0	0	226	5	2392	2393
186	3	0	0	227	7	0	0
187	11	6462	6577	228	5	0	0
188	9	1970	1990	229	3	4729	4731
189	8	4726	4778	230	2	3664	3730
190	5	4015	4016	231	3	4204	4209
191	6	4594	4622	232	1	3911	3920
192	10	0	0	233	7	4783	4785
193	9	0	0	234	1	15	15
194	3	3907	3909	235	3	0	0
195	25	4250	4252	236	2	3388	3393
196	3	1643	1747	237	8	4825	4898

t [days]	failed after t days	suspended after t days	placed in operation t days ago	t [days]	failed after t days	suspended after t days	placed in operation t days ago
238	5	4105	4239	279	1	4569	4575
239	59	6006	6015	280	6	3517	3519
240	1	5758	5759	281	3	4812	4814
241	0	0	0	282	2	3939	3939
242	5	0	0	283	3	0	0
243	4	6327	6329	284	2	0	0
244	1	3960	3965	284	2	0	0
245	21	3790	3818	285	5	5154	5155
246	4	5237	5238	286	4	7111	7126
247	2	3584	3592	287	3	0	0
248	7	0	0	288	11	2534	2536
249	0	0	0	289	16	4968	4978
250	3	7918	7942	290	2	0	0
251	45	3845	3845	291	1	742	743
252	11	4038	4038	292	2	4127	4130
253	12	3091	3095	293	5	3566	4086
254	2	3898	3900	294	8	2521	2528
255	3	0	0	295	2	3293	3299
256	10	0	0	296	4	4333	4340
257	10	4020	4020	297	2	0	0
258	29	719	720	298	1	0	0
259	4	5869	5887	299	2	3818	3820
260	3	1394	1398	300	0	3128	3137
261	6	4034	4038	301	2	2568	2573
262	2	0	0	302	4	3261	3262
263	1	0	0	303	3	3435	3447
264	6	4643	4650	304	0	6	6
265	3	3306	3312	305	1	0	0
266	2	4747	4752	285	5	5154	5155
267	2	4960	4961	286	4	7111	7126
268	1	2329	2334	287	3	0	0
269	7	0	0	288	11	2534	2536
270	2	0	0	289	16	4968	4978
271	10	3648	3652	290	2	0	0
272	0	6160	6161	291	1	742	743
273	5	3268	3273	292	2	4127	4130
274	2	1761	1761	293	5	3566	4086
275	1	3218	3220	294	8	2521	2528
276	2	0	0	295	2	3293	3299
277	0	5	6	296	4	4333	4340
278	4	5626	5630	297	2	0	0

t [days]	failed after t days	suspended after t days	placed in operation t days ago	t [days]	failed after t days	suspended after t days	placed in operation t days ago
298	1	0	0	339	2	0	0
299	2	3818	3820	340	7	0	0
300	0	3128	3137	341	0	3426	3427
301	2	2568	2573	342	31	3515	3515
302	4	3261	3262	343	4	3444	3445
303	3	3435	3447	344	4	3162	3163
304	0	6	6	345	1	2445	2448
305	1	0	0	346	3	0	0
306	10	2822	2822	347	1	0	0
307	1	2611	2626	348	11	2964	2965
308	8	3744	3746	349	0	2176	2182
309	0	3078	3090	350	3	2897	2902
310	0	4181	4264	351	2	2996	2999
311	0	0	0	352	2	3155	3156
312	4	0	0	353	1	0	0
313	0	5335	5337	354	2	0	0
314	8	3801	3809	355	0	3379	3379
315	5	3189	3194	356	4	2688	2690
316	58	2983	2984	357	8	4187	4195
317	2	2300	2308	358	2	4555	4570
318	4	0	0	359	2	2281	2282
319	1	0	0	360	2	0	0
320	1	4671	4673	361	1	13	13
321	9	3431	3442	362	0	4037	4038
322	5	3578	3579	363	3	2217	2217
323	1	3780	3780	364	2	4008	4008
324	1	4073	4075	365	0	3061	3062
325	11	0	0	366	1	5586	5588
326	3	0	0	367	1	0	0
327	4	2764	2779	368	14	0	0
328	7	2136	2164	369	3	6555	6561
329	8	3973	3976	370	6	3244	3246
330	6	2492	2495	371	2	5184	5188
331	0	3976	3976	372	2	4647	4692
332	1	0	0	373	0	4026	4040
333	1	0	0	374	2	0	0
334	5	3412	3412	375	1	0	0
335	1	2198	2256	376	2	4928	4933
336	7	2840	2851	377	1	1964	1967
337	2	1903	1930	378	9	2407	2407
338	0	1623	1623	379	2	4235	4236

t [days]	failed after t days	suspended after t days	placed in operation t days ago	t [days]	failed after t days	suspended after t days	placed in operation t days ago
380	20	3661	3664	421	1	3170	3179
381	2	0	0	422	2	0	0
382	2	0	0	423	0	0	0
383	14	4572	4592	424	4	0	0
384	262	3967	3985	425	0	3077	3104
385	11	3902	3905	426	2	1782	1792
386	2	5904	5913	427	3	1980	1981
387	1	3068	3076	428	0	2899	2899
388	5	14	14	429	0	3348	3351
389	1	0	0	430	0	0	0
390	1	3497	3502	431	1	0	0
391	0	4739	4748	432	1	2157	2166
392	217	2594	2596	433	0	0	0
393	0	1001	1004	434	11	2816	2825
394	0	2744	2749	435	27	3404	3405
395	1	0	0	436	2	3734	3736
396	0	0	0	437	0	0	0
397	1	2848	2985	438	4	0	0
398	74	2806	2811	439	3	4837	4840
399	4	2875	2883	440	0	3517	3524
400	1	4421	4421	441	16	1904	1914
401	21	3095	3097	442	1	0	0
402	1	0	0	443	1	3005	3009
403	0	0	0	444	5	0	0
404	2	3328	3331	445	6	0	0
405	1	4623	4627	446	662	3665	3678
406	166	2609	2615	447	0	1830	1835
407	2	3389	3391	448	14	3313	3316
408	9	3352	3354	449	0	2979	2987
409	12	0	0	450	1	2016	2016
410	3	0	0	451	0	13	13
411	2	2734	2737	452	1	0	0
412	6	0	0	453	1	6713	6722
413	4	2380	2381	454	2	4362	4374
414	8	3563	3566	455	1	6625	6630
415	3	2122	2131	456	11	2995	2996
416	2	0	0	457	1	2518	2538
417	1	0	0	458	0	0	0
418	0	6609	6878	459	5	0	0
419	9	2642	2654	460	1	5965	5967
420	3	3242	3244	461	2	1123	1124

t [days]	failed after t days	suspended after t days	placed in operation t days ago	t [days]	failed after t days	suspended after t days	placed in operation t days ago
462	0	3401	3479	503	0	3770	3772
463	0	2135	2137	504	0	3239	3240
464	1	2732	2742	505	0	1593	1594
465	0	0	0	506	2	3299	3305
466	1	0	0	507	2	0	0
467	4	5136	5157	508	0	0	0
468	6	3027	3029	509	1	6753	6765
469	3	2262	2267	510	4	4979	4995
470	6	2935	2937	511	12	2973	2979
471	1	0	0	512	0	3174	3181
472	1	0	0	513	1	4776	4780
473	0	0	0	514	3	0	0
474	8	0	0	515	7	0	0
475	13	7211	7216	516	0	5630	5638
476	1	1128	1128	517	5	3284	3292
477	0	4456	4456	518	0	1736	1737
478	0	3166	3172	519	3	3355	3362
479	0	8	8	520	156	1902	1905
480	0	0	0	521	3	0	0
481	1	3078	3089	522	3	0	0
482	4	3475	3484	523	0	5479	5479
483	21	3745	3749	524	11	1751	1751
484	0	1267	1277	525	5	3241	3242
485	1	2758	2760	526	3	2420	2424
486	0	0	0	527	1	3782	3789
487	7	0	0	528	1	0	0
488	0	3240	3241	529	0	0	0
489	0	2246	2276	530	0	4196	4225
490	3	2110	2112	531	0	7090	7103
491	0	1613	1613	532	2	4719	4720
492	0	3196	3197	533	11	4677	4686
493	0	0	0	534	0	3180	3196
494	8	0	0	535	1	0	0
495	0	5084	5086	536	3	0	0
496	0	3811	3812	537	0	4228	4236
497	7	2307	2310	538	6	3673	3680
498	0	3921	3926	539	4	4398	4436
499	1	3386	3393	540	3	2210	2218
500	154	0	0	541	0	3777	3796
501	1	0	0	542	0	0	0
502	0	5417	5422	543	1	0	0

t [days]	failed after t days	suspended after t days	placed in operation t days ago	t [days]	failed after t days	suspended after t days	placed in operation t days ago
544	0	3958	3959	585	0	0	0
545	4	3052	3059	586	1	6533	6579
546	2	3703	3705	587	0	1474	1487
547	13	3867	3868	588	0	4537	4543
548	0	2776	2778	589	8	4297	4298
549	0	0	0	590	1	2751	2754
550	0	0	0	591	2	0	0
551	0	6005	6027	592	1	0	0
552	3	2509	2509	593	0	5707	5727
553	0	5563	5572	594	1	3721	3724
554	0	5345	5363	595	0	1962	1968
555	0	5241	5255	596	1	2839	2855
556	4	0	0	597	7	4453	4456
557	0	0	0	598	4	0	0
558	0	8370	8382	599	1	0	0
559	0	4324	4330	600	0	5661	5672
560	1	5321	5323	601	7	5189	5200
561	0	3612	3616	602	3	6331	6332
562	6	0	0	603	5	4919	4930
563	1	0	0	604	1	2933	2947
564	0	0	0	605	24	0	0
565	1	725	725	606	1	0	0
566	0	0	0	607	3	6132	6136
567	5	0	0	608	0	3700	3714
568	1	0	0	609	6	3923	3936
569	13	0	0	610	1	3338	3346
570	1	0	0	611	3	5693	5753
571	2	0	0	612	1	0	0
572	6	126	126	613	1	0	0
573	1	1994	1994	614	1	5059	5060
574	0	1783	1785	615	0	3656	3658
575	0	4232	4248	616	2	2195	2198
576	5	2665	2668	617	1	5296	5303
577	1	0	0	618	0	4747	4747
578	0	0	0	619	3	0	0
579	1	3743	3751	620	1	0	0
580	0	2312	2312	621	1	6910	6914
581	7	2088	2092	622	5	2292	2294
582	1	5839	5853	623	0	0	0
583	2	5698	5733	624	5	0	0
584	0	0	0	625	1	5716	5728

t [days]	failed after t days	suspended after t days	placed in operation t days ago	t [days]	failed after t days	suspended after t days	placed in operation t days ago
626	3	0	0	667	0	5256	5273
627	0	0	0	668	2	0	0
628	0	3298	3302	669	1	0	0
629	8	3683	3688	670	1	5845	5851
630	1	3793	3793	671	1	4313	4318
631	1	5971	6794	672	1	3758	3771
632	0	6844	6852	673	120	5115	5118
633	5	0	0	674	3	3297	3316
634	1	1	1	675	2	0	0
635	1	5459	5463	676	1	0	0
636	0	3294	3324	677	7	4475	4480
637	0	3194	3198	678	1	1735	1738
638	1	3715	4752	679	1	3588	3596
639	0	5873	5877	680	1	4909	4976
640	1	0	0	681	7	6156	6181
641	1	0	0	682	0	0	0
642	2	3902	3904	683	12	0	0
643	1	3514	3517	684	1	5612	5641
644	0	4543	4556	685	0	4676	4684
645	0	3323	3326	686	2	3509	3521
646	15	5965	5987	687	0	3739	3747
647	16	0	0	688	58	3373	3373
648	0	0	0	689	3	0	0
649	0	4829	4838	690	3	0	0
650	6	3821	3849	691	1	5792	5808
651	1	4767	4771	692	47	3017	3022
652	0	0	0	693	1	3264	3270
653	0	6770	6780	694	1	3627	3636
654	2	2	2	695	5	2513	2515
655	1	0	0	696	1	0	0
656	0	3616	3625	697	0	0	0
657	1	5544	5547	698	19	6808	6814
658	0	3049	3049	699	0	3154	3156
659	6	3746	3757	700	4	4406	4407
660	0	3016	3021	701	116	2845	2848
661	0	0	0	702	0	3496	3497
662	0	0	0	703	2	0	0
663	0	4768	4771	704	1	0	0
664	1	4435	4438	705	0	4325	4327
665	2	4115	4362	706	1	4205	4208
666	3	6303	6320	707	3	3629	3636

t [days]	failed after t days	suspended after t days	placed in operation t days ago	t [days]	failed after t days	suspended after t days	placed in operation t days ago
708	0	2533	2535	749	0	2388	2390
709	0	3762	3762	750	32	2908	2915
710	2	0	0	751	0	4203	4252
711	0	0	0	752	0	0	0
712	0	6221	6254	753	0	0	0
713	1	3301	3301	754	6	3502	3503
714	0	3229	3236	755	2	3147	3161
715	1	2996	3003	756	2	6953	6961
716	0	2692	2693	757	2	3058	3075
717	0	0	0	758	0	2944	2946
718	0	8	8	759	0	0	0
719	0	3993	4191	760	2	0	0
720	0	2612	2651	761	5	4676	4693
721	0	2930	2935	762	1	0	0
722	6	2882	2886	763	15	2593	2596
723	0	5225	5232	764	6	2578	2580
724	0	679	679	765	0	5617	5632
725	1	0	0	766	0	0	0
726	6	5232	5247	767	0	0	0
727	4	3929	3930	768	0	5765	5766
728	0	4614	4700	769	2	4661	4674
729	6	3626	3634	770	2	3308	3315
730	0	3328	3333	771	0	5948	5954
731	0	0	0	772	0	0	0
732	116	0	0	773	1	0	0
733	0	4321	4326	774	0	0	0
734	1	3239	3256	775	4	5395	5401
735	2	3749	3751	776	2	3091	3095
736	0	4383	4389	777	1	3651	3651
737	0	2887	2891	778	0	5769	5773
738	1	0	0	779	0	2878	2881
739	0	0	0	780	2	0	0
740	0	3407	3409	781	1	0	0
741	0	5336	5359	782	2	4225	4243
742	1	4062	4067	783	0	8	8
743	11	5267	5269	784	0	2706	2712
744	0	3835	3835	785	0	3646	3648
745	0	0	0	786	0	4217	4222
746	5	0	0	787	0	0	0
747	1	3483	3489	788	0	0	0
748	0	2659	2691	789	0	3068	3082

t [days]	failed after t days	suspended after t days	placed in operation t days ago	t [days]	failed after t days	suspended after t days	placed in operation t days ago
790	0	4210	4212	831	0	5166	5169
791	0	4651	4655	832	61	4028	4031
792	0	4167	4177	833	0	5650	5656
793	0	3631	3633	834	0	2400	2435
794	0	0	0	835	0	3945	3949
795	0	0	0	836	6	0	0
796	0	5805	5808	837	1	0	0
797	0	2261	2301	838	1	3653	3653
798	1	4509	4510	839	0	1562	1562
799	0	4153	4155	840	0	2100	2104
800	0	5080	5083	841	0	2701	2704
801	0	0	0	842	0	3284	3288
802	0	0	0	843	0	0	0
803	0	5300	5302	844	0	0	0
804	0	5507	5514	845	21	4726	4727
805	0	4864	4869	846	1	4291	4295
806	1	2897	2899	847	0	4351	4354
807	1	0	0	848	0	4030	4039
808	0	0	0	849	0	6790	6802
809	0	0	0	850	0	0	0
810	0	4126	4149	851	0	0	0
811	0	5544	5545	852	0	2176	2185
812	0	3326	3330	853	0	1644	1644
813	3	3548	3559	854	0	2094	2095
814	0	5134	5134	855	0	5110	5112
815	0	0	0	856	1	3493	3493
816	1	0	0	857	30	0	0
817	1	6665	6665	858	0	0	0
818	5	5162	5169	859	1	4517	4522
819	1	4058	4060	860	0	4356	4376
820	18	3811	3823	861	0	2354	2359
821	0	0	0	862	0	2769	2780
822	3	0	0	863	0	3454	3456
823	0	0	0	864	0	0	0
824	0	0	0	865	0	0	0
825	0	5211	5277	866	0	5480	5482
826	0	2153	2425	867	0	3925	3927
827	0	4577	4592	868	1	4960	4973
828	0	3057	3065	869	0	2621	2635
829	0	0	0	870	0	2367	2368
830	0	0	0	871	0	0	0

t [days]	failed after t days	suspended after t days	placed in operation t days ago	t [days]	failed after t days	suspended after t days	placed in operation t days ago
872	0	0	0	913	0	0	0
873	1	2455	2455	914	1	0	0
874	0	2049	2051	915	0	5028	5032
875	0	2677	2677	916	0	2504	2524
876	2	2463	2469	917	3	1915	1915
877	0	4758	4760	918	2	4194	4200
878	0	0	0	919	0	3974	3984
879	10	0	0	920	1	0	0
880	0	3294	3355	921	1	0	0
881	0	2407	2410	922	30	8248	8264
882	0	2842	2842	923	0	4419	4422
883	1	2531	2534	924	85	2392	2393
884	0	2700	2701	925	0	2937	2944
885	0	0	0	926	0	1332	1333
886	0	0	0	927	2	0	0
887	0	6621	6640	928	0	0	0
888	0	2369	2376	929	0	63	63
889	0	2636	2642	930	0	0	0
890	0	2411	2413	931	1	0	0
891	0	2159	2165	932	1	0	0
892	0	0	0	933	6	0	0
893	0	0	0	934	0	0	0
894	0	4037	4039	935	0	0	0
895	0	3918	3933	936	0	1011	1011
896	0	2561	2563	937	0	173	173
897	0	4536	4562	938	9	4157	4160
898	0	4028	4039	939	0	3198	3204
899	0	0	0	940	0	2938	3055
900	0	0	0	941	0	0	0
901	0	3016	3031	942	0	0	0
902	0	3204	3204	943	1	2538	2602
903	1	7322	7352	944	16	3861	3877
904	2	4291	4315	945	0	2543	2547
905	1	2575	2576	946	3	3785	3791
906	0	0	0	947	0	3424	3430
907	1	0	0	948	1	0	0
908	0	3405	3422	949	0	0	0
909	1	1229	1231	950	0	4775	4776
910	3	5642	5645	951	0	2283	2285
911	1	2219	2232	952	0	1919	1919
912	1	4716	4835	953	272	5407	5410

t [days]	failed after t days	suspended after t days	placed in operation t days ago	t [days]	failed after t days	suspended after t days	placed in operation t days ago
954	272	3174	3176	995	0	4092	4096
955	0	0	0	996	0	4425	4430
956	0	0	0	997	0	0	0
957	0	8150	8164	998	0	0	0
958	0	3724	3737	999	0	5355	5366
959	1	3698	3701	1000	0	703	706
960	1	3485	3518	1001	0	3205	3221
961	5	5115	5145	1002	0	5279	5290
962	0	0	0	1003	0	4887	4942
963	0	0	0	1004	0	1	1
964	0	3252	3253	1005	0	4	4
965	1	3735	3739	1006	0	4906	4943
966	0	3051	3061	1007	0	4763	4766
967	0	3907	3973	1008	1	2866	2876
968	0	3776	3778	1009	0	2825	2831
969	0	0	0	1010	0	3650	3659
970	0	0	0	1011	0	0	0
971	0	5236	5358	1012	1	0	0
972	0	3664	3671	1013	0	3291	3319
973	0	4334	4340	1014	0	3586	3600
974	0	7128	7144	1015	0	1763	1766
975	0	2653	2664	1016	0	2816	2817
976	2	0	0	1017	0	0	0
977	0	0	0	1018	0	0	0
978	0	4253	4269	1019	0	13	13
979	0	4608	4610	1020	2	4794	4802
980	0	3652	3660	1021	2	2844	2875
981	0	5599	5610	1022	0	3481	3493
982	0	2471	2478	1023	0	2148	2165
983	0	0	0	1024	0	2724	2733
984	0	0	0	1025	0	0	0
985	0	4103	4121	1026	0	0	0
986	0	3989	4280	1027	1	2916	2925
987	0	3625	3633	1028	17	5470	5474
988	0	0	0	1029	0	1162	1168
989	0	4642	4654	1030	0	1143	1144
990	0	12	12	1031	0	3758	3784
991	0	2	2	1032	2	0	0
992	0	2890	2893	1033	0	0	0
993	0	1879	1954	1034	0	2304	2304
994	0	3462	3477	1035	0	2356	2372

t [days]	failed after t days	suspended after t days	placed in operation t days ago	t [days]	failed after t days	suspended after t days	placed in operation t days ago
1036	0	6502	6505	1077	0	1436	1439
1037	0	2214	2222	1078	0	3938	3941
1038	0	2253	2255	1079	0	1162	1163
1039	0	0	0	1080	0	6517	6520
1040	0	0	0	1081	0	0	0
1041	0	4324	4333	1082	0	0	0
1042	1	1172	1175	1083	0	3935	3942
1043	0	1878	1883	1084	0	2154	2155
1044	0	5001	5006	1085	0	3477	3489
1045	0	2584	2603	1086	0	2390	2390
1046	0	0	0	1087	0	3779	3783
1047	0	0	0	1088	0	-1	8
1048	0	4240	4240	1089	0	0	0
1049	2	2694	2695	1090	0	4313	4317
1050	0	2575	2582	1091	1	1554	1556
1051	0	2556	2559	1092	0	1372	1375
1052	0	3252	3258	1093	0	877	877
1053	0	0	0	1094	0	5256	5258
1054	0	0	0	1095	0	0	0
1055	1	3467	3475	1096	1	1	1
1056	0	2183	2191	1097	0	2618	2623
1057	0	2222	2435	1098	0	3433	3434
1058	0	2495	2500	1099	2	2697	2709
1059	0	1951	1952	1100	0	1602	1604
1060	0	0	0	1101	1	3547	3548
1061	0	0	0	1102	0	0	0
1062	0	4830	4836	1103	2	0	0
1063	0	1409	1412	1104	0	5804	5804
1064	0	2218	2222	1105	0	887	896
1065	0	1325	1325	1106	0	3928	3933
1066	0	2258	2261	1107	0	2241	2245
1067	0	0	0	1108	0	2689	2693
1068	0	0	0	1109	0	0	0
1069	1	8968	8973	1110	0	0	0
1070	1	1726	1727	1111	0	7010	7013
1071	0	1909	1914	1112	0	1497	1507
1072	0	1478	1479	1113	1	1750	1751
1073	1	2703	2709	1114	0	2769	2774
1074	0	0	0	1115	0	3531	3532
1075	2	0	0	1116	0	0	0
1076	3	5346	5504	1117	0	0	0

t [days]	failed after t days	suspended after t days	placed in operation t days ago	t [days]	failed after t days	suspended after t days	placed in operation t days ago
1118	0	4783	4790	1159	0	0	0
1119	0	1997	2001	1160	0	2715	2721
1120	0	3957	3962	1161	7	2559	2560
1121	0	2061	2068	1162	0	2001	2003
1122	0	2863	2865	1163	1	2363	2365
1123	0	0	0	1164	0	841	841
1124	0	0	0	1165	0	0	0
1125	4	5922	6295	1166	0	0	0
1126	2	3399	3400	1167	0	2723	2735
1127	0	2937	2937	1168	0	0	0
1128	0	2895	2895	1169	0	1440	1588
1129	0	3763	3767	1170	0	2614	2618
1130	3	1	1	1171	0	6172	6179
1131	0	0	0	1172	0	0	0
1132	0	6268	6276	1173	1	24	25
1133	2	1432	1443	1174	0	2900	2904
1134	0	3254	3256	1175	0	1705	1705
1135	0	2430	2449	1176	0	2578	2585
1136	0	3185	3187	1177	0	1354	1354
1137	0	0	0	1178	5	2670	2671
1138	0	0	0	1179	0	0	0
1139	0	4260	4262	1180	0	0	0
1140	0	664	667	1181	0	1764	1764
1141	0	2292	2298	1182	0	1522	1523
1142	0	1362	1365	1183	0	1802	1806
1143	0	2356	2377	1184	0	4772	4774
1144	0	0	0	1185	0	1768	1771
1145	1	0	0	1186	0	0	0
1146	0	3162	3165	1187	0	0	0
1147	0	4	4	1188	0	3892	3916
1148	0	956	959	1189	0	1805	1831
1149	0	2589	2595	1190	4	3793	3816
1150	0	5040	5061	1191	3	2868	2869
1151	1	0	0	1192	0	1216	1225
1152	0	0	0	1193	0	0	0
1153	0	2593	2595	1194	0	0	0
1154	0	1969	1969	1195	0	3101	3109
1155	2	2665	2667	1196	1	2500	2515
1156	0	1970	1973	1197	0	2069	2069
1157	0	0	0	1198	0	1031	1032
1158	0	0	0	1199	0	2242	2250

t [days]	failed after t days	suspended after t days	placed in operation t days ago	t [days]	failed after t days	suspended after t days	placed in operation t days ago
1200	0	0	0	1241	0	2498	2500
1201	0	0	0	1242	0	0	0
1202	0	2005	2012	1243	0	0	0
1203	0	478	478	1244	1	4482	4534
1204	0	1323	1323	1245	0	1719	1724
1205	0	2537	2543	1246	0	2477	2490
1206	0	0	0	1247	0	2260	2264
1207	0	0	0	1248	0	2403	2404
1208	0	0	0	1249	0	0	0
1209	0	0	0	1250	0	0	0
1210	0	1650	1650	1251	0	4895	4918
1211	1	1456	1508	1252	0	2276	2279
1212	1	1514	1517	1253	0	1773	1783
1213	0	2086	2088	1254	0	1635	1639
1214	0	0	0	1255	0	2950	2962
1215	0	0	0	1256	0	0	0
1216	0	2609	2611	1257	0	0	0
1217	0	1149	1176	1258	0	3290	3293
1218	3	4697	4697	1259	0	3805	3810
1219	0	2069	2073	1260	0	3462	3463
1220	0	2632	2634	1261	0	1488	1492
1221	0	0	0	1262	0	2060	2061
1222	0	0	0	1263	0	0	0
1223	1	4013	4017	1264	0	0	0
1224	0	467	473	1265	0	2034	2039
1225	0	2272	2273	1266	4	1894	1905
1226	2	3595	3599	1267	0	3824	3864
1227	0	1963	1982	1268	0	1343	1346
1228	0	0	0	1269	0	2402	2426
1229	0	0	0	1270	0	0	0
1230	0	3450	3454	1271	0	0	0
1231	0	1599	1625	1272	0	3375	3380
1232	1	1283	1290	1273	0	2936	2941
1233	0	2391	2397	1274	0	4437	4462
1234	0	1881	2326	1275	0	2295	2296
1235	0	0	0	1276	0	1952	1957
1236	0	0	0	1277	0	0	0
1237	0	4184	4185	1278	0	0	0
1238	0	1830	1859	1279	0	2306	2306
1239	0	2014	2014	1280	0	951	953
1240	0	2292	2294	1281	0	2208	2210

t [days]	failed after t days	suspended after t days	placed in operation t days ago	t [days]	failed after t days	suspended after t days	placed in operation t days ago
1282	0	1147	1148	1323	0	2686	2695
1283	0	4953	4956	1324	2	2956	2966
1284	2	0	0	1325	125	1507	1516
1285	0	0	0	1326	0	0	0
1286	0	3505	3508	1327	0	0	0
1287	0	2639	2645	1328	0	1359	1362
1288	0	3852	3853	1329	0	1666	1675
1289	0	1652	1654	1330	0	2944	2976
1290	0	240	240	1331	0	2465	2468
1291	4	0	0	1332	1	3354	3358
1292	0	0	0	1333	0	0	0
1293	1	0	0	1334	0	0	0
1294	0	0	0	1335	0	3465	3482
1295	0	2003	2003	1336	0	2082	2084
1296	0	0	0	1337	0	2886	2889
1297	13	0	0	1338	0	2779	2784
1298	0	0	0	1339	0	1474	1476
1299	0	0	0	1340	0	0	0
1300	0	0	0	1341	0	0	0
1301	0	0	0	1342	0	3926	3944
1302	1	530	530	1343	0	2300	2388
1303	0	44	44	1344	0	3503	3511
1304	1	1456	1487	1345	0	2898	2932
1305	0	0	0	1346	0	4719	4727
1306	0	0	0	1347	0	0	0
1307	0	1976	1984	1348	1	0	0
1308	0	1391	1392	1349	0	3456	3459
1309	0	1062	1063	1350	0	1319	1320
1310	0	1815	1818	1351	0	4803	4909
1311	0	4038	4038	1352	0	1765	1765
1312	0	0	0	1353	0	3098	3112
1313	0	0	0	1354	0	0	0
1314	0	2851	2871	1355	0	0	0
1315	0	1502	1506	1356	0	6335	6346
1316	0	2092	2094	1357	0	3839	3841
1317	0	2488	2510	1358	0	2130	2146
1318	0	2683	2697	1359	0	2569	2583
1319	0	0	0	1360	0	2350	2351
1320	0	0	0	1361	0	0	0
1321	0	4305	4949	1362	0	0	0
1322	0	906	907	1363	0	2969	2971

t [days]	failed after t days	suspended after t days	placed in operation t days ago	t [days]	failed after t days	suspended after t days	placed in operation t days ago
1364	0	1255	1260	1405	1	4349	4351
1365	0	6893	6910	1406	0	1958	1961
1366	0	3204	3204	1407	0	1601	1603
1367	0	1616	1616	1408	0	4135	4139
1368	0	0	0	1409	0	1758	1759
1369	0	0	0	1410	0	0	0
1370	0	3386	3389	1411	0	0	0
1371	0	2361	2363	1412	0	2273	2287
1372	0	1933	1933	1413	0	1185	1213
1373	0	4428	4439	1414	118	1994	1997
1374	0	3498	3519	1415	0	2730	2739
1375	0	0	0	1416	0	1682	1684
1376	0	0	0	1417	0	0	0
1377	2	3860	4010	1418	5	0	0
1378	1	2439	2442	1419	0	3524	3535
1379	1	3109	3117	1420	0	2265	2289
1380	0	2887	2890	1421	0	1248	1250
1381	3	2221	2226	1422	0	2495	2507
1382	0	0	0	1423	0	2437	2441
1383	0	0	0	1424	0	0	0
1384	0	4944	4948	1425	0	0	0
1385	0	3788	3802	1426	0	2588	2590
1386	1	1679	1710	1427	0	1576	1579
1387	0	1777	1789	1428	0	1688	1688
1388	0	3018	3020	1429	1	1685	1834
1389	0	0	0	1430	0	944	1555
1390	0	0	0	1431	0	0	0
1391	0	4397	4400	1432	0	0	0
1392	0	1286	1290	1433	0	3557	3566
1393	0	903	903	1434	0	1875	1878
1394	0	3767	3784	1435	1	823	823
1395	0	2823	2826	1436	0	1701	1703
1396	0	0	0	1437	0	2333	2342
1397	0	0	0	1438	0	0	0
1398	0	3267	3282	1439	0	0	0
1399	0	2426	2426	1440	0	7814	7824
1400	0	2165	2260	1441	0	1569	2460
1401	2	2408	2410	1442	0	1332	1339
1402	0	4392	4395	1443	0	1750	1760
1403	1	0	0	1444	0	1254	1256
1404	0	0	0	1445	0	0	0

t [days]	failed after t days	suspended after t days	placed in operation t days ago	t [days]	failed after t days	suspended after t days	placed in operation t days ago
1446	0	0	0	1487	0	0	0
1447	0	1425	1426	1488	0	0	0
1448	0	2057	2061	1489	0	3378	3378
1449	0	2728	3346	1490	0	1441	1452
1450	0	3336	3339	1491	0	1303	1306
1451	0	1671	1679	1492	0	1315	1316
1452	0	0	0	1493	0	1952	1953
1453	0	0	0	1494	0	0	0
1454	1	2530	2532	1495	0	0	0
1455	0	1326	1334	1496	0	2461	2466
1456	0	2365	2373	1497	0	1682	1688
1457	0	3187	3187	1498	0	2114	2120
1458	0	2681	2683	1499	0	1123	1126
1459	0	0	0	1500	0	1805	1816
1460	0	0	0	1501	0	0	0
1461	0	3278	3289	1502	0	0	0
1462	0	1373	1374	1503	0	4420	4427
1463	0	973	976	1504	0	0	0
1464	0	2281	2285	1505	0	1106	1106
1465	0	1962	1966	1506	0	2665	2685
1466	0	0	0	1507	0	1326	1331
1467	0	0	0	1508	6	0	0
1468	0	2432	2511	1509	0	0	0
1469	1	920	923	1510	0	1543	1546
1470	0	2271	2284	1511	0	1839	1853
1471	0	1685	1686	1512	0	1470	1471
1472	0	2282	2292	1513	0	2968	2973
1473	0	0	0	1514	0	0	0
1474	0	0	0	1515	0	0	0
1475	0	2580	2582	1516	6	0	0
1476	0	2071	2074	1517	0	4643	4689
1477	3	1707	1713	1518	0	955	958
1478	0	2444	2446	1519	12	1537	1540
1479	0	1473	1482	1520	1	1102	1106
1480	0	0	0	1521	1	837	839
1481	0	0	0	1522	2	0	0
1482	0	3225	3232	1523	0	0	0
1483	0	1030	1031	1524	0	3302	3304
1484	0	1297	1297	1525	0	0	0
1485	0	873	876	1526	0	3449	3456
1486	0	1735	1768	1527	0	1364	1372

t [days]	failed after t days	suspended after t days	placed in operation t days ago	t [days]	failed after t days	suspended after t days	placed in operation t days ago
1528	5	1346	1360	1569	1	770	779
1529	0	0	0	1570	0	2257	2259
1530	0	0	0	1571	0	0	0
1531	0	4530	4531	1572	1	0	0
1532	0	824	831	1573	0	1730	1730
1533	0	926	930	1574	0	746	746
1534	0	1659	1661	1575	1	3314	3330
1535	0	1370	1377	1576	0	1232	1250
1536	0	0	0	1577	0	2490	2498
1537	0	0	0	1578	0	0	0
1538	0	0	0	1579	0	0	0
1539	0	3757	3765	1580	0	3245	3269
1540	0	2912	2912	1581	0	1682	1690
1541	0	1675	1686	1582	0	1619	1619
1542	0	2448	2449	1583	0	1033	1045
1543	5	0	0	1584	0	3904	3925
1544	0	0	0	1585	0	0	0
1545	0	2328	2331	1586	0	0	0
1546	0	2084	2092	1587	0	3178	3199
1547	0	1625	1631	1588	0	613	620
1548	1	1417	1421	1589	0	2666	2670
1549	0	1856	1867	1590	0	2138	2149
1550	2	0	0	1591	0	1079	1087
1551	1	0	0	1592	0	0	0
1552	0	2214	2226	1593	0	0	0
1553	0	1579	1585	1594	0	1560	1561
1554	0	1188	1190	1595	0	1467	1472
1555	0	2300	2303	1596	0	1549	1554
1556	0	3363	3369	1597	0	1423	1430
1557	0	0	0	1598	0	2233	2238
1558	1	0	0	1599	0	0	0
1559	0	2943	2943	1600	0	0	0
1560	0	1030	1030	1601	0	1752	1758
1561	0	1168	1176	1602	0	612	612
1562	0	2394	2399	1603	0	2711	2739
1563	0	0	0	1604	0	1459	1472
1564	0	0	0	1605	0	1852	1853
1565	0	0	0	1606	0	0	0
1566	0	0	0	1607	0	0	0
1567	0	2358	2373	1608	0	2693	2706
1568	1	1027	1027	1609	0	1033	1040

t [days]	failed after t days	suspended after t days	placed in operation t days ago	t [days]	failed after t days	suspended after t days	placed in operation t days ago
1610	0	827	828	1651	0	802	804
1611	0	836	848	1652	0	1732	1733
1612	3	895	897	1653	0	2024	2032
1613	0	0	0	1654	0	1243	1249
1614	0	0	0	1655	0	0	0
1615	0	2771	2781	1656	0	0	0
1616	0	754	755	1657	0	0	0
1617	0	2664	2668	1658	0	0	0
1618	0	1012	1016	1659	0	0	0
1619	0	1112	1117	1660	0	0	0
1620	0	0	0	1661	0	0	0
1621	0	0	0	1662	0	0	0
1622	90	2188	2193	1663	0	0	0
1623	0	2048	2063	1664	0	0	0
1624	0	2560	2568	1665	0	0	0
1625	0	1158	1159	1666	0	0	0
1626	0	1125	1135	1667	0	777	779
1627	0	0	0	1668	0	1723	1737
1628	0	0	0	1669	0	0	0
1629	0	3195	3207	1670	0	0	0
1630	0	1840	1847	1671	0	1170	1178
1631	0	2503	2524	1672	0	2229	2238
1632	0	1927	1927	1673	0	1496	1506
1633	0	1523	1527	1674	0	1236	1237
1634	0	0	0	1675	0	1481	1486
1635	0	0	0	1676	0	0	0
1636	0	2384	2386	1677	0	0	0
1637	0	1513	1513	1678	0	1778	1793
1638	0	692	693	1679	0	2105	2106
1639	0	1412	1431	1680	0	1180	1185
1640	0	2175	2183	1681	0	1180	1186
1641	1	0	0	1682	0	936	937
1642	0	0	0	1683	0	0	0
1643	0	2123	2127	1684	0	0	0
1644	0	2357	2620	1685	0	1907	1912
1645	0	1260	1352	1686	0	1161	1164
1646	0	2990	3001	1687	0	1308	1317
1647	0	1332	1332	1688	0	1327	1331
1648	0	0	0	1689	0	784	786
1649	0	0	0	1690	0	0	0
1650	0	4434	4452	1691	0	0	0

t [days]	failed after t days	suspended after t days	placed in operation t days ago	t [days]	failed after t days	suspended after t days	placed in operation t days ago
1692	0	1702	1709	1733	0	0	0
1693	0	1098	1100	1734	0	605	609
1694	0	1852	1857	1735	0	624	634
1695	0	788	795	1736	0	1339	1339
1696	0	1437	1443	1737	0	2352	2352
1697	0	0	0	1738	0	1717	1718
1698	0	0	0	1739	0	0	0
1699	0	524	526	1740	0	0	0
1700	0	464	467	1741	0	1590	1603
1701	1	801	802	1742	0	2523	2537
1702	0	1051	1052	1743	0	1015	1025
1703	0	2112	2118	1744	0	1335	1498
1704	0	0	0	1745	0	710	710
1705	0	0	0	1746	0	0	0
1706	0	1569	1571	1747	0	0	0
1707	0	878	884	1748	0	0	0
1708	0	518	521	1749	0	1291	1293
1709	0	1436	1439	1750	0	1435	1437
1710	0	1111	1112	1751	0	985	985
1711	0	0	0	1752	0	1695	1723
1712	0	0	0	1753	0	0	0
1713	0	1230	1257	1754	0	0	0
1714	0	1114	1117	1755	0	1591	1595
1715	0	1085	1087	1756	0	1169	1194
1716	0	1482	1489	1757	0	1667	1669
1717	0	1686	1690	1758	0	1275	1276
1718	0	0	0	1759	0	1363	1364
1719	0	0	0	1760	0	0	0
1720	0	2552	2558	1761	0	0	0
1721	2	2115	2118	1762	0	1602	1607
1722	0	2241	2246	1763	0	1256	1258
1723	0	1568	1575	1764	0	733	735
1724	0	1828	1838	1765	0	1317	1357
1725	0	0	0	1766	0	1392	1400
1726	0	0	0	1767	0	0	0
1727	0	1989	1992	1768	0	0	0
1728	0	1061	1066	1769	0	853	860
1729	0	520	528	1770	0	1757	1759
1730	0	2583	2588	1771	0	-272	928
1731	0	1187	1193	1772	0	612	616
1732	0	0	0	1773	1	1254	1255

t [days]	failed after t days	suspended after t days	placed in operation t days ago	t [days]	failed after t days	suspended after t days	placed in operation t days ago
1774	0	0	0	1815	0	1232	1237
1775	0	0	0	1816	0	0	0
1776	0	1707	1715	1817	0	0	0
1777	0	770	772	1818	0	624	689
1778	0	1472	1484	1819	0	903	905
1779	0	1396	1464	1820	0	1249	1250
1780	0	1533	1535	1821	0	1305	1306
1781	0	0	0	1822	0	676	677
1782	0	0	0	1823	0	0	0
1783	0	657	658	1824	0	0	0
1784	0	1894	1914	1825	0	942	942
1785	0	2095	2103	1826	0	470	472
1786	0	144	144	1827	0	2110	2353
1787	0	1048	1057	1828	0	951	951
1788	0	0	0	1829	0	408	409
1789	0	0	0	1830	0	0	0
1790	0	1084	1085	1831	0	0	0
1791	0	2581	2588	1832	0	510	510
1792	1	1243	1256	1833	0	1951	1951
1793	0	707	708	1834	0	1813	1816
1794	0	998	1001	1835	0	1081	1124
1795	0	0	0	1836	0	855	855
1796	0	0	0	1837	0	0	0
1797	0	2376	2379	1838	0	0	0
1798	0	1688	1707	1839	0	888	891
1799	1	1093	1095	1840	0	535	535
1800	0	811	814	1841	0	761	762
1801	0	1201	1203	1842	0	410	410
1802	0	0	0	1843	0	224	224
1803	0	0	0	1844	0	0	0
1804	0	434	435	1845	0	0	0
1805	0	1655	1657	1846	0	467	469
1806	0	627	637	1847	0	565	1229
1807	0	884	885	1848	0	1937	1954
1808	0	1272	1273	1849	0	726	729
1809	0	0	0	1850	0	1020	1024
1810	0	0	0	1851	0	0	0
1811	0	1337	1337	1852	0	0	0
1812	0	508	508	1853	0	2521	2522
1813	0	631	633	1854	0	0	0
1814	0	815	819	1855	0	595	598

t [days]	failed after t days	suspended after t days	placed in operation t days ago	t [days]	failed after t days	suspended after t days	placed in operation t days ago
1856	0	1263	1266	1897	0	736	748
1857	0	1223	1231	1898	0	200	200
1858	0	0	0	1899	0	1062	1062
1859	0	0	0	1900	0	0	0
1860	0	1803	1813	1901	0	0	0
1861	0	563	573	1902	0	1502	1510
1862	0	1906	1919	1903	0	0	0
1863	0	814	814	1904	0	165	165
1864	0	0	0	1905	0	149	149
1865	0	0	0	1906	0	390	390
1866	0	0	0	1907	0	0	0
1867	0	580	587	1908	0	0	0
1868	0	785	786	1909	0	193	196
1869	0	230	231	1910	0	518	519
1870	0	654	654	1911	0	437	439
1871	0	864	881	1912	0	360	360
1872	0	0	0	1913	0	0	0
1873	0	0	0	1914	0	0	0
1874	0	2692	2693	1915	0	0	0
1875	0	0	0	1916	0	0	0
1876	0	557	557	1917	0	1034	1043
1877	0	816	816	1918	0	627	645
1878	0	496	496	1919	0	152	153
1879	0	0	0	1920	0	1618	1619
1880	0	0	0	1921	0	0	0
1881	0	277	277	1922	0	0	0
1882	0	2208	2211	1923	0	609	611
1883	0	991	992	1924	0	921	921
1884	0	804	806	1925	0	1212	1213
1885	0	923	926	1926	0	138	138
1886	0	0	0	1927	0	758	758
1887	0	0	0	1928	0	0	0
1888	0	1055	1055	1929	0	0	0
1889	0	594	603	1930	0	744	746
1890	0	1420	1421	1931	0	522	523
1891	0	467	519	1932	0	1111	1112
1892	0	313	315	1933	0	853	860
1893	0	0	0	1934	0	127	127
1894	0	0	0	1935	0	0	0
1895	0	339	352	1936	0	0	0
1896	0	1871	1874	1937	0	807	808

t [days]	failed after t days	suspended after t days	placed in operation t days ago	t [days]	failed after t days	suspended after t days	placed in operation t days ago
1938	0	827	834	1979	0	1311	1312
1939	0	396	399	1980	0	176	176
1940	0	384	384	1981	0	632	644
1941	0	1030	1055	1982	0	884	895
1942	0	0	0	1983	0	351	354
1943	0	0	0	1984	0	0	0
1944	0	284	287	1985	0	0	0
1945	0	842	842	1986	0	298	301
1946	0	445	457	1987	0	82	82
1947	0	921	921	1988	0	231	231
1948	0	673	676	1989	0	215	215
1949	0	0	0	1990	0	889	889
1950	0	0	0	1991	0	0	0
1951	0	654	654	1992	0	0	0
1952	0	850	855	1993	0	265	265
1953	0	603	604	1994	0	228	228
1954	0	1586	1590	1995	0	17	17
1955	0	629	644	1996	0	779	780
1956	0	0	0	1997	0	284	287
1957	0	0	0	1998	0	0	0
1958	0	1442	1457	1999	0	0	0
1959	0	259	259	2000	0	138	138
1960	0	908	909	2001	0	401	403
1961	0	718	719	2002	0	245	245
1962	0	326	327	2003	0	496	497
1963	0	0	0	2004	0	203	203
1964	0	0	0	2005	0	0	0
1965	0	91	91	2006	0	0	0
1966	0	224	225	2007	0	731	732
1967	0	169	169	2008	0	83	83
1968	0	771	771	2009	0	466	488
1969	0	528	528	2010	0	1263	1264
1970	0	0	0	2011	0	542	542
1971	0	0	0	2012	0	0	0
1972	0	124	125	2013	0	0	0
1973	0	1154	1170	2014	0	1095	1095
1974	0	429	429	2015	0	595	596
1975	0	423	430	2016	0	343	343
1976	0	91	92	2017	0	118	118
1977	0	0	0	2018	0	33	33
1978	0	0	0	2019	0	0	0

t [days]	failed after t days	suspended after t days	placed in operation t days ago	t [days]	failed after t days	suspended after t days	placed in operation t days ago
2020	0	0	0	2061	0	0	0
2021	0	145	145	2062	0	0	0
2022	0	0	0	2063	0	1324	1325
2023	0	0	0	2064	0	320	320
2024	0	0	0	2065	0	365	366
2025	0	458	458	2066	0	549	550
2026	0	0	0	2067	0	85	85
2027	0	0	0	2068	0	0	0
2028	0	75	75	2069	0	0	0
2029	0	0	0	2070	0	606	606
2030	0	0	0	2071	0	63	63
2031	0	0	0	2072	0	818	827
2032	0	0	0	2073	0	790	803
2033	0	0	0	2074	0	320	320
2034	0	0	0	2075	0	0	0
2035	0	123	124	2076	0	0	0
2036	0	210	210	2077	0	105	105
2037	0	152	152	2078	0	21	298
2038	0	985	985	2079	0	318	590
2039	0	672	672	2080	0	1058	1058
2040	0	0	0	2081	0	63	63
2041	0	0	0	2082	0	0	0
2042	0	276	278	2083	0	0	0
2043	0	356	357	2084	0	0	0
2044	0	254	255	2085	0	598	604
2045	0	140	140	2086	0	488	488
2046	0	435	436	2087	0	141	142
2047	0	0	0	2088	0	124	130
2048	0	0	0	2089	0	0	0
2049	0	161	161	2090	0	0	0
2050	0	189	189	2091	0	370	370
2051	0	366	366	2092	0	653	663
2052	0	586	586	2093	0	280	280
2053	0	103	103	2094	0	126	126
2054	0	0	0	2095	0	1181	1188
2055	0	0	0	2096	0	0	0
2056	0	236	236	2097	0	24	25
2057	0	622	625	2098	0	541	541
2058	0	316	317	2099	0	209	210
2059	0	550	550	2100	0	18	18
2060	0	139	139	2101	0	468	468

t [days]	failed after t days	suspended after t days	placed in operation t days ago	t [days]	failed after t days	suspended after t days	placed in operation t days ago
2102	0	207	210	2143	0	51	51
2103	0	0	0	2144	0	18	18
2104	0	765	766	2145	0	0	0
2105	0	429	429	2146	0	0	0
2106	0	45	45	2147	0	423	423
2107	0	230	230	2148	0	31	31
2108	0	604	605	2149	0	33	33
2109	0	246	246	2150	0	183	183
2110	0	0	0	2151	0	15	15
2111	0	0	0	2152	0	0	0
2112	0	825	826	2153	0	0	0
2113	0	0	0	2154	0	113	113
2114	0	61	61	2155	0	9	9
2115	0	7	7	2156	0	137	137
2116	0	218	218	2157	0	630	630
2117	0	0	0	2158	0	106	106
2118	0	0	0	2159	0	0	0
2119	0	392	392	2160	0	0	0
2120	0	33	33	2161	0	181	182
2121	0	128	128	2162	0	20	20
2122	0	74	74	2163	0	165	165
2123	0	309	310	2164	0	241	241
2124	0	0	0	2165	0	80	80
2125	0	0	0	2166	0	0	0
2126	0	15	15	2167	0	0	0
2127	0	163	163	2168	0	26	26
2128	0	272	272	2169	0	12	12
2129	0	505	505	2170	0	187	187
2130	0	264	264	2171	0	299	299
2131	0	0	0	2172	0	31	31
2132	0	0	0	2173	0	0	0
2133	0	303	303	2174	0	0	0
2134	0	8	8	2175	0	11	11
2135	0	504	504	2176	0	142	142
2136	0	425	425	2177	0	108	108
2137	0	89	89	2178	0	13	13
2138	0	0	0	2179	0	231	231
2139	0	0	0	2180	0	0	0
2140	0	75	75	2181	0	0	0
2141	0	426	426	2182	0	17	17
2142	0	153	153	2183	0	82	82

t [days]	failed after t days	suspended after t days	placed in operation t days ago	t [days]	failed after t days	suspended after t days	placed in operation t days ago
2184	0	155	155	2225	0	141	141
2185	0	56	56	2226	0	446	446
2186	0	154	154	2227	0	0	0
2187	0	0	0	2228	0	5	5
2188	0	0	0	2229	0	0	0
2189	0	23	23	2230	0	0	0
2190	0	7	7	2231	0	216	216
2191	0	38	38	2232	0	53	53
2192	0	69	69	2233	0	126	126
2193	0	291	291	2234	0	132	132
2194	0	0	0	2235	0	0	0
2195	0	0	0	2236	0	0	0
2196	0	70	71	2237	0	0	0
2197	0	21	21	2238	0	998	998
2198	0	41	41	2239	0	0	0
2199	0	15	15	2240	0	356	356
2200	0	82	82	2241	0	8	8
2201	0	0	0	2242	0	4	4
2202	0	0	0	2243	0	0	0
2203	0	4	4	2244	0	0	0
2204	0	3	3	2245	0	160	160
2205	0	225	225	2246	0	11	11
2206	0	0	0	2247	0	0	0
2207	0	0	0	2248	0	136	136
2208	0	0	0	2249	0	0	0
2209	0	0	0	2250	0	0	0
2210	0	27	27	2251	0	0	0
2211	0	280	280	2252	0	28	28
2212	0	0	0	2253	0	0	0
2213	0	682	682	2254	0	234	234
2214	0	4	4	2255	0	186	186
2215	0	0	0	2256	0	0	0
2216	0	0	0	2257	0	0	0
2217	0	584	584	2258	0	0	0
2218	0	84	84	2259	0	3	3
2219	0	0	0	2260	0	0	0
2220	0	29	29	2261	0	104	104
2221	0	3	3	2262	0	452	452
2222	0	0	0	2263	0	40	40
2223	0	0	0	2264	0	0	0
2224	0	399	399	2265	0	0	0

t [days]	failed after t days	suspended after t days	placed in operation t days ago
2266	0	6	6
2267	0	0	0
2268	0	0	0
2269	0	874	874
2270	0	183	183
2271	0	0	0
2272	0	0	0
2273	0	4	4
2274	0	125	125
2275	0	207	207
2276	0	716	716
2277	0	28	28
2278	0	0	0
2279	0	0	0
2280	0	9	9
2281	0	48	49
2282	0	2	2
2283	0	66	66
2284	0	0	0
2285	0	0	0
2286	0	0	0
2287	0	0	0
2288	0	10	10
2289	0	0	0
2290	0	414	414
2291	0	6	6
2292	0	0	0
2293	0	0	0
2294	0	0	0
2295	0	0	0
2296	0	0	0
2297	0	0	0
2298	0	0	0
2299	0	0	0
2300	0	0	0
2301	0	0	0
2302	0	3	3
2303	0	0	0
2304	0	0	0
2305	0	0	0
2306	0	0	0

t [days]	failed after t days	suspended after t days	placed in operation t days ago
2307	0	0	0
2308	0	0	0
2309	0	200	200
2310	0	0	0

Appendix B

Appendix B.1 Environmental impact for the LEDC, mechanics, optics parts and wiring for both Luminaire A1 and Luminaire B.

TableB 1 Environmental performance of LDC parts

	Luminaire A1				Luminaire B			
Impact Category	**Plastic ECG housing**	**Steel ECG housing**	**Circuit Board**	**Capacitors, Conductors, Varistor**	**Plastic ECG housing**	**Steel ECG housing**	**Circuit Board**	**Capacitors, Conductors, Varistor**
ADPe	3.49E-04	2.92E-06	1.40E-02	4.98E-02	3.49E-04	2.92E-06	1.40E-02	4.98E-02
ADPf	9.98E+01	6.81E+02	2.83E+03	5.07E+03	9.96E+01	6.81E+02	2.83E+03	5.06E+03
AP	1.48E-02	1.92E-01	1.18E+00	1.47E+00	1.48E-02	1.92E-01	1.18E+00	1.47E+00
EP	1.64E-03	1.81E-02	1.13E-01	9.92E-02	1.64E-03	1.81E-02	1.13E-01	9.93E-02
GWP	5.22E+00	7.91E+01	2.77E+02	3.46E+02	5.24E+00	7.91E+01	2.76E+02	3.46E+02
PE	1.15E+02	8.40E+02	3.71E+03	5.93E+03	1.15E+02	8.40E+02	3.71E+03	5.93E+03

TableB 2 Environmental performance of Mechanics parts

	Luminaire A1			Luminaire B			
Impact Category	**Metal Parts**	**Plastic Parts**	**Steel Gear Tray + trunking**	**Metal Parts**	**Plastic Parts**	**Screws**	**Steel Gear Tray + trunking**
ADPe	5.12E-06	1.50E-05	1.96E-02	3.22E-06	5.19E-05	2.80E-03	2.18E-02
ADPf	1.20E+03	6.75E+02	4.65E+03	7.50E+02	2.83E+03	6.46E+02	2.99E+04
AP	3.37E-01	5.71E-02	9.65E-01	2.11E-01	3.01E-01	2.89E-01	6.18E+00
EP	3.18E-02	1.09E-02	9.17E-02	2.00E-02	4.05E-02	1.75E-02	5.87E-01
GWP	1.39E+02	4.16E+01	4.40E+02	8.72E+01	1.44E+02	5.31E+01	2.84E+03
PE	1.47E+03	7.50E+02	5.26E+03	9.26E+02	3.15E+03	8.13E+02	3.31E+04

TableB 3 Environmental performance of Optics parts and wiring

	Luminaire A1		Luminaire B		
	Optics	**Wiring**	**Optics**		**Wiring**
Impact Category	**PMMA Optical Element**	**Wiring**	**PMMA Optical Element**	**PET End Piece Optics**	**Wiring**
ADPe	1.34E-04	3.85E-02	2.07E-04	4.32E-07	3.85E-02
ADPf	1.20E+04	6.94E+02	1.86E+04	7.38E+01	6.94E+02
AP	1.27E+00	8.13E-01	1.96E+00	3.89E-03	8.13E-01
EP	1.30E-01	2.10E-02	2.01E-01	5.00E-04	2.10E-02
GWP	6.29E+02	5.99E+01	9.70E+02	3.03E+00	5.99E+01
PE	1.37E+04	8.59E+02	2.12E+04	8.36E+01	8.59E+02

Appendix B.2 Environmental impact for the installation, use phase and end-of-life of the Luminaire A1 and Luminaire B

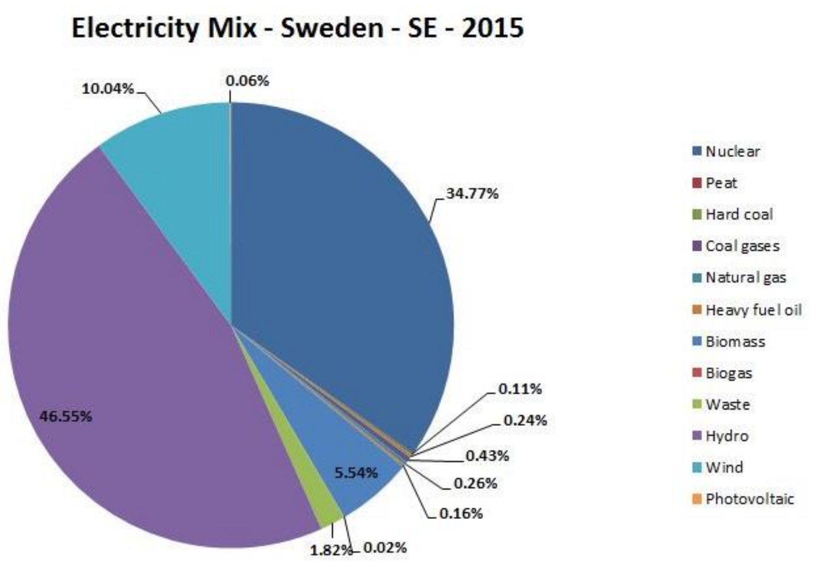
TableB 4 Environmental performance for the installation, use phase and end-of-life of Luminaires A1 and Luminaire B

	Luminaire A1				Luminaire B		
Impact Category	**Installation**	**Use phase***	**Use phase****	**End-of-life**	**Installation**	**Use phase**	**End-of-life**
ADPe	2.02E-07	1.14E-01	1.37E-01	1.11E-05	2.36E-07	1.55E-01	2.51E-05
ADPf	7.18E+01	3.83E+06	4.62E+06	5.79E+02	8.39E+01	5.22E+06	1.02E+03
AP	2.22E-02	1.01E+03	1.22E+03	1.54E-01	2.59E-02	1.38E+03	3.03E-01
EP	5.16E-03	9.48E+01	1.14E+02	2.61E-02	6.03E-03	1.29E+02	6.44E-02
GWP	5.13E+00	3.58E+05	4.32E+05	3.26E+02	6.00E+00	4.88E+05	4.36E+02
PE	7.25E+01	9.05E+06	1.09E+07	8.78E+02	8.47E+01	1.23E+07	1.43E+03

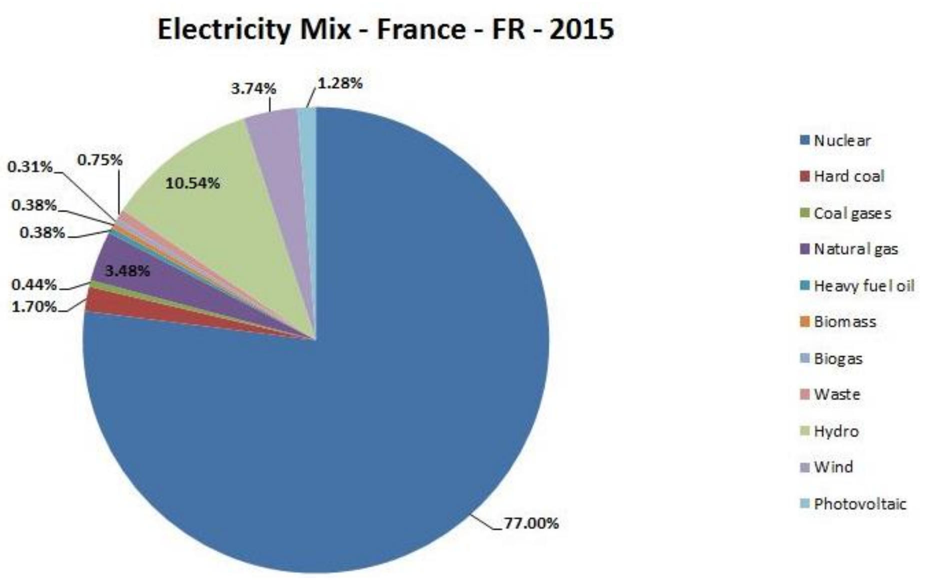
(*) With dimming, (**) without dimming

Appendix C

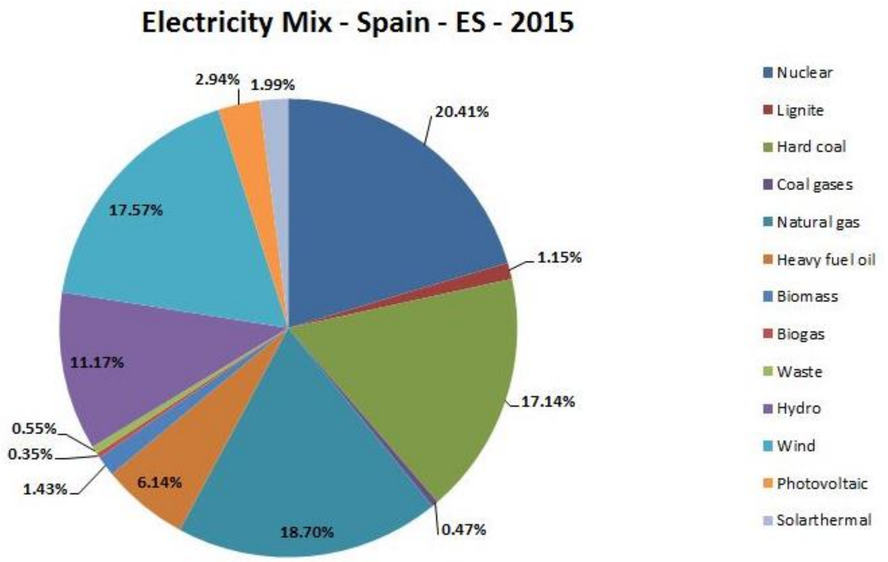
Appendix C.1 Electricity mix grid of Sweden, France, Spain and Italy.



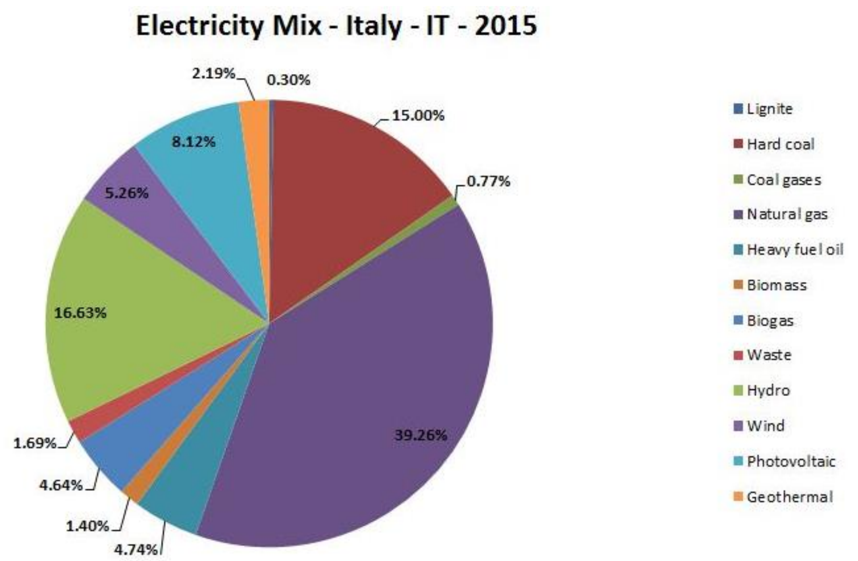
Source: GaBi ts dataset



Source: GaBi ts dataset



Source: GaBi ts dataset



Source: GaBi ts dataset

Appendix C.2 Environmental impacts values to produce 1MJ from different electricity generation sources

TableC 1 Environmental impacts values to produce 1MJ from electricity mixes. Source: GaBi ts dataset (2015)

Impact Category	E28	Sweden	Spain	Italy	France
ADPe	1.33E-07	5.73E-08	1.24E-07	2.17E-07	7.55E-08
ADPf	4.47E+00	2.21E-01	4.74E+00	5.57E+00	7.38E-01
AP	1.18E-03	1.32E-04	1.11E-03	9.74E-04	1.96E-04
EP	1.11E-04	2.49E-05	1.23E-04	1.12E-04	2.60E-05
GWP	4.18E-01	3.69E-02	4.15E-01	4.43E-01	6.39E-02
PE	1.06E+01	7.18E+00	1.12E+01	1.09E+01	1.03E+01

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