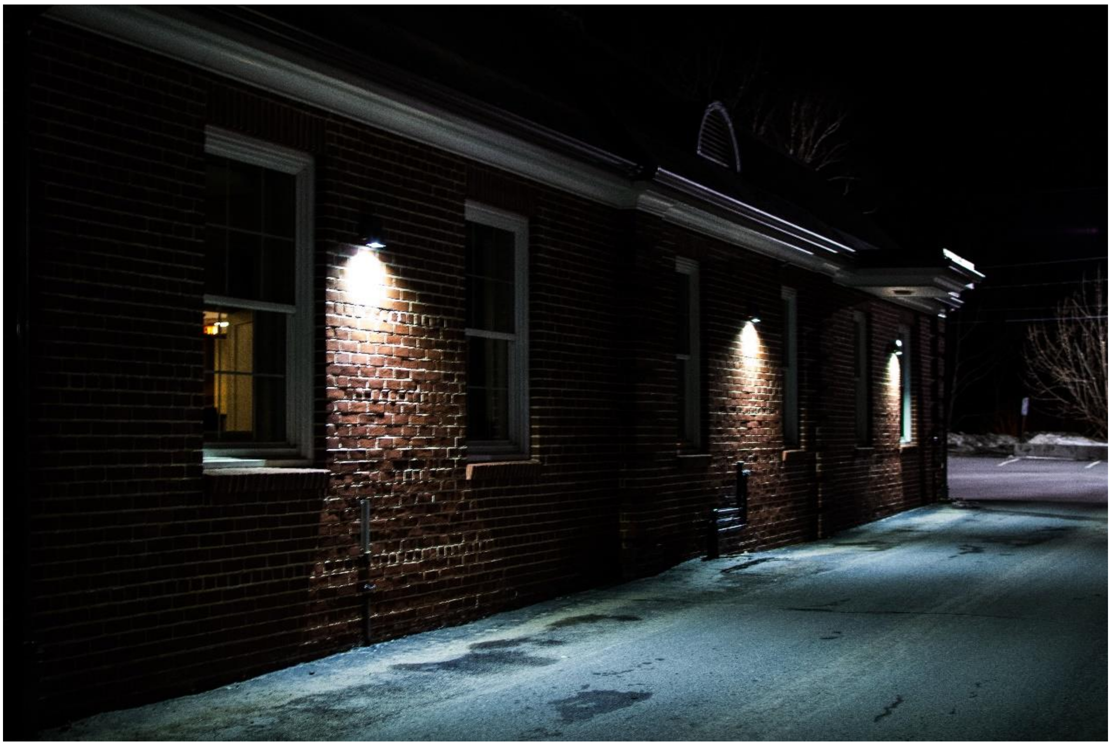
REPORT

COMPARATIVE LIFE CYCLE ANALYSIS (LCA)

LUMINAIRES FOR OUTDOOR LED LIGHTING



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PARTICIPANTS

Client:	Villaägarnas Riksförbund, Product Review
Contact:	Ulf Stenberg
Consultant:	Anna Pantze
Responsible for the assignment:	Jon Mellqvist
Quality reviewer:	Yannos Wikström and Ida Adolfsson
Third party reviewer:	Marcus Wendin, Miljögiraff

REVISIONS

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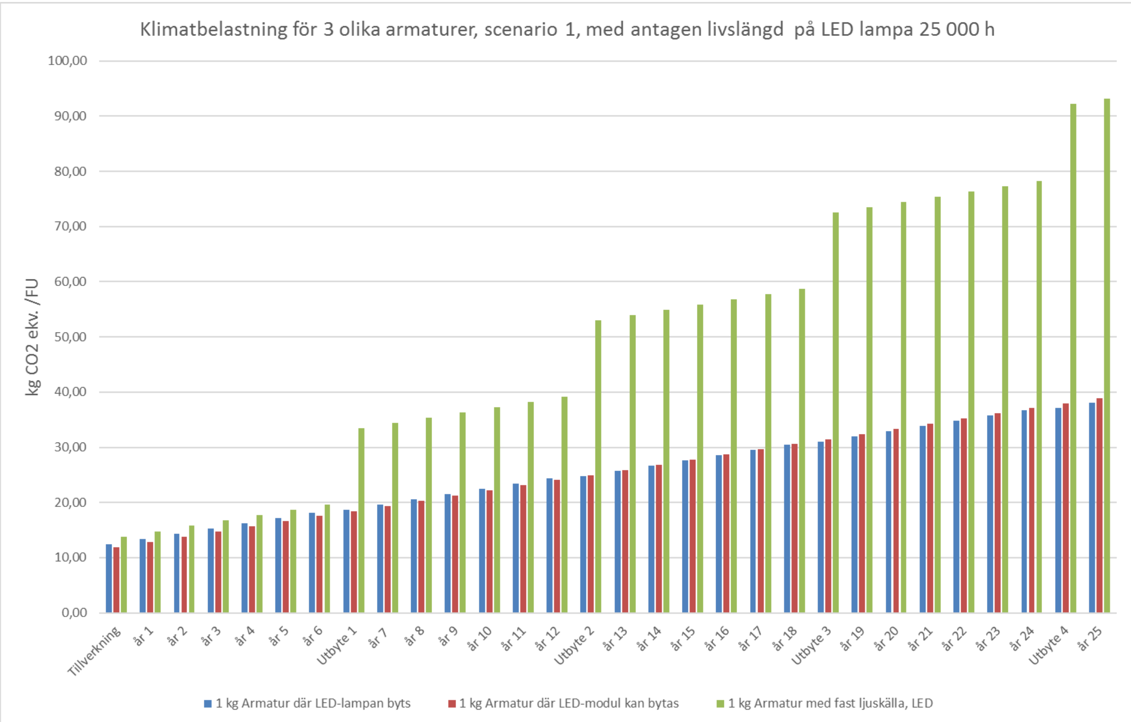
SUMMARY

Lighting is a very frequently used and often purchased product both in Sweden and internationally. When it comes to electricity consumption, for instance, lighting accounts for about 15% of the world's total electricity usage. The manufacturing of new lighting and the handling of obsolete lighting also require significant resources worldwide. How we buy and use lighting is therefore of great importance for the household economy as well as for economizing the earth's resources.

The comparisons in the report clearly show that aluminum luminaires for outdoor lighting (LEDs), but also those made of stainless steel with replaceable LED lamps/modules, have a potentially smaller environmental and climate impact over a 25-year period. The potential environmental impact of manufacturing, transport to the customer as well as operation and replacements can be three times as great for integrated LED luminaires that don’t have an interchangeable LED lamp/module.

How the climate impact measured in carbon dioxide equivalents[1] differs between the products is stated in the report.



Scenario 1 with a burning time of the LED lamp of 25,000 hours shows the potential climate impact over time for the different luminaires. The result is reported per functional unit, FU, Luminaire (1kg) with LED lighting of 20 W for a study period of 25 years.

1 Carbon dioxide equivalent (CO2 eq) is a measure of greenhouse gas emissions that takes into account that different gases contribute in different ways to the greenhouse effect and global warming. The total emissions of the greenhouse gases carbon dioxide, methane, nitrous oxide and fluorinated gases are reported on an annual basis to the UN Climate Convention and to the EU Commission in carbon dioxide equivalents.

Initially, the environmental impact is the same for the different luminaires, but over time, the integrated LED lighting has a greater environmental impact. The breaking point is the day that an LED lamp or whole luminaire needs to be replaced due to the burning time/service life of the LED lamp having reached its end. The breaking point comes after six years if the burning time is 25,000 hours, since the burning time for outdoor lighting with a twilight relay is about 4,000 hours a year (SABO 2013).

There is no significant difference to the environmental impact if the luminaires have a replaceable LED lamp or replaceable LED module, provided that luminaires with a replaceable LED module are handled in such a way that the module itself is replaced when the LED diode's service life is over.

The potential environmental impact is proportional to the weight of the outdoor lighting. Heavier outdoor lighting fixtures (LEDs) that need to be replaced and that, due to design, may weigh 4 kg instead of 1 kg increase the environmental impact. In such a case, the climate impact is up to four times greater for an integrated LED lighting without an interchangeable LED lamp/module than for a non-integrated LED lighting over a 25-year study period.

However, the lifecycle analysis does not take into account how the lighting fixtures with replaceable LED modules are handled by the end customer. A LED module is interchangeable, but you need to be an electrician or at least a professional with knowledge of your field to perform the replacement. There is a risk that lighting fixtures with interchangeable LED modules at the end customer will be treated as integrated LED lighting. This would mean that non-integrated lighting fixtures with interchangeable LED modules would have a higher environmental and climate impact and would not differ significantly from integrated units.

Another aspect that can have a negative impact on the integrated LED lighting is that when, sooner or later, it breaks, there is a risk that the same type of lighting will no longer be on the market. When the integrated LED lighting in for instance one of four façade lamps breaks, the integrated LED lighting may no longer be available. From one day to another you thus no longer have uniform lighting and are then faced with the choice to also replace the luminaires that still work. This aspect is not taken into account in the life cycle analysis.

INNEHÅLLSFÖRTECKNING

1 INTRODUCTION

The increased interest in sustainable development and reduced climate impact means that more and more life cycle analyses are being developed for different goods and products. Reliable information on the environmental impact is needed when developing business strategies, in product development, procurement and requirements, and can also serve as a basis for wise everyday decisions for individual consumers.

The international standardized method for gaining a holistic perspective on environmental impact and reliable and measurable results is life cycle analysis (LCA). Tyréns has many years of experience with LCA and works according to ISO 14040/14044.

1.1 BACKGROUND

Homeowners and other consumers in Sweden use and buy large amounts of lighting. The type of lighting they use affects the environment and climate differently.

The lighting itself accounts for about 15% of the world's total electricity consumption (2018 Borg & Co). Electricity use for lighting purposes, globally, is expected to decrease with the LED technology. New services and applications that haven't been thought through can increase the electricity consumption, or can decrease it but to a lesser extent than what is possible (2018 Borg & Co). LED stands for Light Emitting Diode and is an energy efficient diode that emits light.

Previous comparative life-cycle analyses focusing on the manufacture and use of various light sources, such as incandescent, low-energy and LED lamps, show that LED is the lighting solution with the lowest environmental impact (IEA 2014).

However, the service life of LED lighting is difficult to estimate: how it is used affects the service life and it is hard to judge user behavior. There are several reasons to replace a long-lived product before it reaches the end of its service life. Premises may need to be renovated or a product may become outdated or a new generation of products may be created giving greater energy savings. There is thus a significant risk of basing an LCA on an excessively long service life (IEA 2014).

1.2 AIM

Villaägarna wanted to investigate how different choices of luminaires with LED lighting, mainly outdoor lighting, affect the environment. Especially how luminaires with integrated LED lighting compare to luminaires that do not have integrated LED lighting. In non-integrated LED lighting, the LED lamp/module can be replaced when it reaches the end of its service life.

2 LIFE CYCLE ANALYSIS

A life cycle analysis (LCA) quantifies the potential environmental impact of a product or service over its entire life cycle and expresses the results in various environmental impact categories, such as global warming potential, eutrophication potential and acidification potential.

Figure 1 shows the working method used for LCA studies. The design was developed by the International Organization for Standardization. At the beginning of the life cycle analysis, a target definition was made and a functional unit was established together with system boundaries. The level of detail and delimitations should correspond to the objective and intended audience.

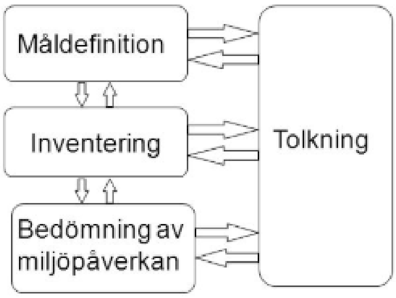


Figure 1. Framework for LCA according to the ISO 14040 standard

The depth and design of an LCA vary considerably depending on the objective of the analysis. Life cycle analyses can assess the environmental impact of existing product systems. LCA can also be more forward-looking (consequential LCA) and aim to describe the effects of potential changes within a system.
Examples of various life cycle analyses:

- Screening (LCA for a product or service at a general level);
- Complete (in-depth LCA),
- Scenario (modeling of different outcomes/scenarios),
- Organizational (LCA for an organization at the global level)

2.1 OBJECTIVES AND SCOPE

2.1.1 OBJECTIVES

The objective of the study was to answer the question of how the environmental impact for integrated and non-integrated LED luminaires differs in a life cycle analysis. The LCA report was communicated to Villaägarna and the results were communicated externally (Business to Consumer), wherefore the report also went through third-party review.

2.1.2 SCOPE

The life cycle analysis includes the extraction and manufacture of materials and components for outdoor LED lighting fixtures, transport to customers as well as operation, exchanges and final handling. Energy consumption and material waste from final assembly of the lighting fixtures are not included in the study.

The life cycle analysis is a snapshot of the manufacture and operation of three different luminaires with LED lighting. All three luminaires are made mainly of aluminum and the complete material content is taken from the Construction Products Assessment (2019). The scope is described in detail in section 5, Life Cycle Inventory (LCI).

2.2 DECLARED UNIT AND SCENARIOS

The functional unit should be consistent with the objectives and scope of the study.

The main purpose of a functional unit is to provide a reference to input data and results. In this case, the weight of the lighting fixtures ranged from 1 kg up to over 4 kg, wherefore the functional unit was the 1-kg LED luminaire of 20 W.

Declared unit: Luminaire (1kg) with LED lighting of 20 W

Function: Luminaire with LED outdoor lighting

Study period: 25 years

A LED lamp has a burning time of between 15,000 hours and up to 25,000 hours according to one source (2019, Lampinfo), whereas another source claims that the burning time is 50,000 hours (SABO, 2013). A third source shows that some manufacturers state a theoretical service life of 100,000 hours, but the service life is uncertain because the tests are unsure and follow-ups can only be done later (2014, IEA). The transformer also has a limited service life. The life of the LED diode and the transformer is uncertain and therefore two scenarios are used in the life cycle analysis.

Service life scenario 1: Service life for LED diode incl. transformer, 25,000 hours

Service life scenario 2: Service life for LED diode incl. transformer, 50,000 hours

2.3 SYSTEM BOUNDARIES

A schematic view of the system boundaries, i.e. what is included and what is not included in the life cycle analysis is shown in Table 1 below. Please note that a life cycle takes into account material consumption, energy, emissions, waste, etc. for the manufacture of all included materials for luminaires with LED lighting, but not the final assembly/manufacture and its energy consumption, material consumption for waste, scrap and other emissions.

Table 1. The table shows the system boundaries for the life cycle analysis of luminaires with LED lighting

Included	Excluded
Production and distribution • Raw material for the production of luminaires and integrated or non-integrated LED lighting • Energy and fuels • Transport of luminaire from factory to dealer	Production and distribution • Final assembly/manufacture of the luminaire is excluded. It is estimated to represent less than 5% of the total energy and material consumption. • No wiring to the fixture or procedures to be able to attach the outside lighting to a wall or the like are included
Operation and maintenance • Raw material for replacement of LED lamp or LED module for non-integrated LED lighting	Operation and maintenance • Transport of electricians when required for replacement is excluded. It is estimated to represent less than 1% of the total energy and material consumption.

• Transport of luminaire or LED lamp/module from factory to end customer • Raw material for replacement of the entire luminaire including LED module for integrated LED lighting • Energy and fuels	
Waste disposal • All final handling of worn out luminaires, lamps and modules is included.	Waste disposal -

2.4 CUT-OFF CRITERIA

In order to define cut-off criteria, a lower boundary is required. Flows under these criteria are considered negligible and can therefore be excluded. In this study, the cut-off criteria were set at 5 percent of the environmental impact. This means that if the data supply is insufficient or if there lack of data is dignificant, no more than 5% of the total energy consumption and 5% of the total material consumption can be excluded for each unit process.

Conservative assumptions for the interchangeable LED lamp and LED module in combination with reasonableness considerations have been used to meet these cut-off criteria. The input data collected for the luminaires from Construction Products Assessments means that 98 - 100% of all the included material is included. The focus is on material and energy flows that are known to have a major environmental impact.

2.5 ALLOCATION

When more than one product is produced within the same production system, the use of energy, materials and the potential environmental impact need to be allocated between different products.

2.5.1 ALLOCATION RULES

Allocation should be avoided as far as possible. In cases where allocation cannot be avoided, allocation of co-production and allocation for reuse and recycling have been applied.

All underlying processes that have been modeled follow the ISO standard and are called “cut-off” in Ecoinvent. The reason for allocation according to cut off is that the first primary product always carries the environmental impact for its entire production. If the product is later recycled, the first product cannot be accredited this in any way. Thus, recycled material will only carry the environmental impact of the recycling process itself.

3 DESCRIPTION OF OUTDOOR LED LUMINAIRES

The three different types of outdoor lighting fixtures that have been studied are described below.

Integrated LED lighting includes all electronics including custom-made LEDs in a single unit. The LED is not standard, and cannot be replaced. When the LED light reaches the end of its service life, one must replace the entire lighting fixture for the integrated LED lighting.

In non-integrated LED lighting with LED lamps, interchangeable lamps are manufactured according to international standards. When a non-integrated LED lamp reaches the end of its service life, it can be replaced with a new LED lamp and last many more years.

There are also non-integrated LED lights with interchangeable LED modules. A LED module is interchangeable, but you need to be a qualified and certified electrician or a professional with knowledge of your field to perform the replacement. The risk that lighting fixtures with interchangeable LED modules be treated as integrated LED lighting by the end customer is therefore great.

4 METHODS AND ENVIRONMENTAL IMPACT ASSESSMENT

4.1 SOFTWARE AND DATABASES

SimaPro software has been used in the life cycle analysis. SimaPro is specifically designed for LCA and is common in these contexts. For this project, SimaPro 8.5.2.0 was used. The library of generic LCI data (life cycle inventory data from databases) used in the analysis was EcoInvent v3.4. Econivent contains verified data that is constantly updated, thus the data is considered to be of good quality. Both averages and weighted averages for activities and products appear in Ecoinvent's database.

4.2 METHODS OF ENVIRONMENTAL IMPACT ASSESSMENT

The assessment method used was CML-IA baseline and CML-IA non baseline version 3.02 (updated in 2013). The method in Sima pro was EPD (2013) V1.04. and this is the same method that should be used when producing environmental product declarations (EPDs) for different products.

4.3 ENVIRONMENTAL IMPACT CATEGORIES

Emission data is sorted into so-called environmental impact categories that describe the type of environmental impact that the emissions give rise to, see Table 2. The chosen method, EPD (2013), includes the environmental impact categories global warming, thinning of the ozone layer, acidification, eutrophication, formation of ground-level ozone, abiotic depletion of non-fossil resources and abiotic depletion of fossil resources. The emissions are characterized according to the classification. Characterization means that the environmental impact of each emission is quantified within a specific environmental impact category, for example, all greenhouse gas emissions can be summed up to a measure of the greenhouse effect and all acidifying emissions to a measure of acidification.

Table 2. Description of environmental impact categories reported according to the functional unit.

Impact Factor	**Abbreviation**	**Popular version and explanation of concepts**	**Unit**
Global warming potential	GWP-100 (fossil sources only)	Greenhouse effect. Emissions of gases from the combustion of fossil fuels that contribute to an increase of the earth's average temperature, calculated for a 100-year period.	kg CO_2 eq.
Depletion potential of stratospheric ozone layer	ODP	Ozone depletion. Emissions of ozone-depleting substances.	kg CFC-11 eq.
Acidification potential of soil and water	AP	Acidification. Emissions of substances that contribute to acidification, expressed as the sum of the acidification potential for soil and water.	kg SO_2 eq.
Eutrophication potential	EP	Eutrophication. Emissions of substances that contribute to oxygen deficiency in water.	kg $(PO_4)^{3-}$
Potential for the formation of tropospheric ozone photochemical oxidants	POCP	Formation of ground-level ozone. Emissions of substances that contribute to the formation of ground-level ozone.	kg C_2H_4 eq. (ethene eq.)
Abiotic depletion potential of non-fossil resources	ADPM	Depletion of resources by substances. The sum of substances that are extracted and thus contribute to the depletion of finite resources, such as e.g. iron, gold and phosphorus	kg Sb eq.
Abiotic depletion potential of fossil resources	ADPE	Depletion of fossil fuel resources. The sum of fossil fuels that are extracted and thus contribute to the depletion of finite resources, such as e.g. coal and oil	MJ

4.4 INTERPRETATION OF THE RESULTS

When the results are interpreted, the parts of the lifecycle analysis that contribute the most to each environmental impact category are identified. Thereafter, a sensitivity analysis is carried out and the environmental impact of the various alternatives is analyzed. Based on the results and the sensitivity analysis, it is possible to highlight the parts of the process that have the greatest environmental impact and the parts of the analysis that contain the greatest uncertainties.

4.5 ASSUMPTIONS

Major assumptions in the study:

- The assumed power was 20 W for all lamps.
- The approximate weight was 80 g for a replaceable LED lamp.
- A replaceable LED module was assumed to comprise a LED diode and a transformer.

- The non-integrated LED lighting with a replaceable LED module was assumed to have a slightly smaller transformer than the luminaire with the integrated LED lighting and the total reported material content was thus 99%.
- In the calculations, it was assumed that the end customer always replaces the interchangeable LED module or LED lamp when it stops working instead of discarding the entire luminaire in favor of a new one.
- The transport distance of the luminaires from factory to end customer was assumed to be 6,400 km by ship and 50 km by truck, which corresponds to a ship transport from the Mediterranean and truck transport to retailers. The same transport distance has been assumed for replaceable LED lamps and replaceable LED modules.

4.6 DELIMITATIONS

A life cycle analysis (LCA) is a simplified snapshot of a reality that is inherently more dynamic. This LCA focuses on some important environmental aspects but not all and does not take into account economic or social aspects. LCA contains assumptions and delimitations.

- Energy consumption and production of waste during final assembly of the luminaires in the factory are not included, as these specific data are not available.
- Transport of electricians when required for replacement is excluded since there is no access to relevant data. Transport is estimated to represent less than 1% of the total energy and material consumption.
- Handling of worn out luminaires, LED lamps and LED modules is not included in the life cycle analysis. Waste management is estimated to represent less than 5% of the total energy and material consumption.
- The study does not take into account whether you choose a luminaire of 1 kg or a luminaire of 4 kg, but a sensitivity analysis shows how the weight of the luminaire can affect the results.

The study is limited to three different luminaires sold on the Swedish market today. All three luminaires are made of mainly aluminum and are attached to the facade. There are also other types of luminaires for outdoor lighting in other materials or adapted for installation in the ground or on posts.

4.7 DATA QUALITY

When carrying out modeling in SimaPro, EcoInvent's database 3.4 (updated March 2018) is used as the selected generic database. The database is considered to be of high quality.

4.8 LACK OF DATA

The study is based on three luminaires with detailed descriptions of material content in the Construction Products Assessment. There are significantly more luminaires on the market and the study cannot be used to evaluate all outdoor luminaires with LEDs.

No information on energy use during factory assembly or waste during assembly is available and is therefore not included.

Regarding the non-integrated LED lighting with an interchangeable LED module, the declaration of contents in the Construction Products Assessment has 96% of all material content, but the transformer is missing. As the other two luminaires have a transformer in the interchangeable lamp or integrated in the luminaire and a transformer is needed, a transformer was assumed. The non-integrated LED lighting with a replaceable LED module was assumed to have a slightly smaller transformer than the luminaire with the integrated LED lighting and the total reported material content was thus 99%.

The integrated LED lighting had all material reported in < percentages, i.e. with a "less than" character in front of each percentage. This resulted in an overestimated declared material content of 116%. Therefore, the amounts were scaled down to 98%, by scaling away a little from each component.

4.9 THIRD PARTY REVIEW

A third party review is required according to ISO 14040-44 and was performed by LCA expert Marcus Wendin at Miljögiraff, see the attached review report.

5 LIFE CYCLE INVENTORY

The detailed declarations of content for the three different luminaires were taken from the Construction Products Assessment. These, together with an assumed weight of 80 g for a LED lamp, form the basis of the life cycle inventory. The three different luminaires were:

- Non-integrated LED lighting with an interchangeable LED lamp (100% of the material content was reported in the Construction Products Assessment and included in the life cycle analysis)
- Non-integrated LED lighting with an interchangeable LED module (96% of the material content is reported in the Construction Products Assessment. Here, a transformer has been added which means that 99% of the material content is included in the life cycle analysis, see more in section 4.8)
- Integrated LED lighting (116% material content according to the Construction Products Assessment since < characters were used, however, the amounts have been scaled down and 98% of the material content is included in the life cycle analysis, see more in section 4.8)

Input data is shown in Table 3 to 9. The tables also provide information on what input and processes from EcoInvent have been used during the modeling in SimaPro.

Table 3. Lifecycle inventory for non-integrated LED lighting with an interchangeable LED lamp and selected processes

	Contents	Amount	Unit	LCA process	LCA source
Non-integrated LED lighting with an interchangeable LED lamp	Aluminum	75	%	Aluminum, primary, ingot {IAI Area, EU27 EFTA}| production | Cut-off, U & Metal working, average for aluminum product manufacturing {GLO}| market for | Cut-off, U	Ecoinvent 3.4
	Stainless steel	4	%	Steel, chromium steel 18/8 {GLO}| market for | Cut-off, U Metal working, average for chromium steel product manufacturing {GLO}| market for | Cut-off, U	Ecoinvent 3.4
	Ceramics	4	%	Sanitary ceramics {GLO}| market for | Cut-off, U	Ecoinvent 3.4
	PMMA plastic	10	%	Polymethyl methacrylate (PMMA) beads, production mix, at plant RER Injection molding {RER}| processing | Cut-off, U	Ecoinvent 3.4
	ABS plastic	4	%	Acrylonitrile-butadiene-styrene copolymer {RER}| production | Cut-off, U Injection molding {RER}| processing | Cut-off, U	Ecoinvent 3.4
	PC plastic	<1	%	Polycarbonate {GLO}| market for | Cut-off, U Injection molding {RER}| processing | Cut-off, U	Ecoinvent 3.4
	PE plastic	1	%	Polyethylene, low density, granulate {GLO}| market for | Cut-off, U Injection molding {RER}| processing | Cut-off, U	Ecoinvent 3.4
	Cable	1	%	Cable, unspecified {GLO}| production | Cut-off, U	Ecoinvent 3.4
	Silicone	2	%	Silicone product {GLO}| market for | Cut-off, U	Ecoinvent 3.4
	LED lamp interchangeable incl. transformer	80	G	Interchangeable, Material see table 4	Ecoinvent 3.4

Table 4. Lifecycle inventory for interchangeable 80 gram LED lamp for non-integrated LED lighting, transport to customer and selected processes

	Contents	Amount	Unit	LCA process	LCA source
In replaceable LED lamp, weight 80 grams	Glass	20	Grams	Flat glass, coated {GLO}| market for | Cut-off, U Tempering, flat glass {RER}| processing | Cut-off, U	Ecoinvent 3.4
	Stainless steel	10	Grams	Steel, chromium steel 18/8 {GLO}| market for | Cut-off, U Metal working, average for chromium steel product manufacturing {GLO}| market for | Cut-off, U	Ecoinvent 3.4
	Plastic	20	Grams	Polypropylene, granulate {GLO}| market for | Cut-off, U Extrusion, plastic pipes {GLO}| market for | Cut-off, U	Ecoinvent 3.4
	LED diode	0.035	Grams	Light emitting diode {GLO}| market for | Cut-off, U	Ecoinvent 3.4
	LED module transformer	30	Grams	Transformer, low voltage use {GLO}| market for | Cut-off, U	Ecoinvent 3.4
	Transport to customer, truck	0.004	Tkm	Transport, freight, truck 16-32 metric ton, EURO6 {RER}| transport, freight, truck 16-32 metric ton, EURO6 | Cut-off, U	Ecoinvent 3.4
	Transport to customer, ship	0.516	Tkm	Transport, freight, sea, transoceanic ship {GLO}| market for | Cut-off, U	Ecoinvent 3.4

Table 5. Lifecycle inventory for non-integrated LED lighting with an interchangeable LED module and selected processes

	Contents	Amount	Unit	LCA process	LCA source
Non-integrated LED lighting with an interchangeable LED module	Aluminum	72	%	Aluminum, primary, ingot {IAI Area, EU27 EFTA}| production | Cut-off, U & Metal working, average for aluminum product manufacturing {GLO}| market for | Cut-off, U	Ecoinvent 3.4
	Stainless steel	<1	%	Steel, chromium steel 18/8 {GLO}| market for | Cut-off, U Metal working, average for chromium steel product manufacturing {GLO}| market for | Cut-off, U	Ecoinvent 3.4
	PC plastic	15	%	Polycarbonate {GLO}| market for | Cut-off, U Injection molding {RER}| processing | Cut-off, U	Ecoinvent 3.4
	Cable	3	%	Cable, unspecified {GLO}| production | Cut-off, U	Ecoinvent 3.4
	Silicone	6	%	Silicone product {GLO}| market for | Cut-off, U	Ecoinvent 3.4
	Coating powder	<1		Coating powder {GLO}| market for | Cut-off, U	Ecoinvent 3.4
	LED diode Interchangeable	<1	%	Light emitting diode {GLO}| market for | Cut-off, U	Ecoinvent 3.4
	LED module transformer Interchangeable	3	%	Transformer, low voltage use {GLO}| market for | Cut-off, U	Ecoinvent 3.4

Table 6. Lifecycle inventory for interchangeable 53-gram LED module for non-integrated LED lighting, transport to customer and selected processes

	Contents	Amount	Unit	LCA process	LCA source
Interchangeable LED module, weight	LED diode	1.7	Grams	Light emitting diode {GLO}| market for | Cut-off, U	Ecoinvent 3.4
	LED module transformer	51	Grams	Transformer, low voltage use {GLO}| market for | Cut-off, U	Ecoinvent 3.4
	Transport to customer, truck	0.0025	Tkm	Transport, freight, truck 16-32 metric ton, EURO6 {RER}| transport, freight, truck 16-32 metric ton, EURO6 | Cut-off, U	Ecoinvent 3.4
	Transport to customer, ship	0.332	Tkm	Transport, freight, sea, transoceanic ship {GLO}| market for | Cut-off, U	Ecoinvent 3.4

Table 7. Lifecycle inventory for an integrated LED lighting and selected processes

	Contents	Amount	Unit	LCA process	LCA source
Integrated LED lighting, weight 1 kg	Aluminum	74	%	Aluminum, primary, ingot {IAI Area, EU27 EFTA}| production | Cut-off, U & Metal working, average for aluminum product manufacturing {GLO}| market for | Cut-off, U	Ecoinvent 3.4
	Stainless steel	1	%	Steel, chromium steel 18/8 {GLO}| market for | Cut-off, U Metal working, average for chromium steel product manufacturing {GLO}| market for | Cut-off, U	Ecoinvent 3.4
	Hot-dip galvanized steel	4	%	Steel, low-alloyed {GLO}| market for | Cut-off, U Zinc coat, pieces {RER}| zinc coating, pieces | Cut-off, U	Ecoinvent 3.4
	PC plastic	4	%	Polycarbonate {GLO}| market for | Cut-off, U Injection molding {RER}| processing | Cut-off, U	Ecoinvent 3.4
	ABS plastic	4	%	Acrylonitrile-butadiene-styrene copolymer {RER}| production | Cut-off, U Injection molding {RER}| processing | Cut-off, U	Ecoinvent 3.4
	PE plastic	5	%	Polyethylene, low density, granulate {GLO}| market for | Cut-off, U Injection molding {RER}| processing | Cut-off, U	Ecoinvent 3.4
	Cable	5	%	Cable, unspecified {GLO}| production | Cut-off, U	Ecoinvent 3.4
	Silicone	<1	%	Silicone product {GLO}| market for | Cut-off, U	Ecoinvent 3.4
	Printed circuit board, 99% glass fiber reinforced epoxy	1	%	Glass fiber reinforced plastic, epoxy resin, {RER}| production | Cut-off, U Modified process	Ecoinvent 3.4
	Electronics unspecified	1	%	Electronic component, passive, unspecified {GLO}| market for | Cut-off, U	Ecoinvent 3.4
	LED module LED diode	<1	%	Light emitting diode {GLO}| market for | Cut-off, U	Ecoinvent 3.4
	LED module transformer	3	%	Transformer, low voltage use {GLO}| market for | Cut-off, U	Ecoinvent 3.4

Table 8. Lifecycle inventory for the transport of 1 kg of luminaire that needs to be changed during the life cycle and the electricity consumed during the operating phase and selected processes.

	Contents	Amount	Unit	LCA process	LCA source
Transport	Transport to customer, truck	0.05	Tkm	Transport, freight, truck 16-32 metric ton, EURO6 {RER}| transport, freight, truck 16-32 metric ton, EURO6 | Cut-off, U	Ecoinvent 3.4
	Transport to customer, ship	6.5	Tkm	Transport, freight, sea, transoceanic ship {GLO}| market for | Cut-off, U	Ecoinvent 3.4
Electricity	Electricity consumption LED /year	80	kWh	Electricity, low voltage {SE}| market for | Cut-off, S	Ecoinvent 3.4

Table 9. Lifecycle inventory for final handling of luminaires, LED lamp and LED module

	Contents	Amount	Unit	LCA process	LCA source
Transport	Transport to waste center, truck	10	kgkm	Municipal waste collection service by 21 metric ton truck {CH}| market for municipal waste collection service by 21 metric ton truck | Cut-off, U	Ecoinvent 3.4
Waste scenario	LED luminaire recycling at recycling center	90	%	**LED luminaire recycling** Electronics scrap from control units {RER}| treatment of | Cut-off, U Aluminum (waste treatment) {GLO}| recycling of aluminum | Cut-off, U Remaining Waste (waste scenario) {NL}| treatment of waste | Cut-off, U	Ecoinvent 3.4
	10 % is assumed to end up in regular waste	10	%	Waste (waste scenario) {NL}| treatment of waste | Cut-off, U	Ecoinvent 3.4

5.1 CALCULATIONS

The service life is 25 years. The total electricity consumption during the operating phase and how often the LED lamp/module and the entire luminaire must be replaced are calculated as below.

The number of burning hours for outdoor lighting with twilight relays is approximately 4000 hours per year (2017, Statistics Sweden). The assumed power for all luminaires is 20 Watts.

Electricity consumption per year (20 Watt*4,000 h)	80kWh/year
Electricity consumption for 25 years	2,000 kWh/25 years
Scenario 1 LED service life (25,000 h/4,000 h)	6.3 years
Scenario 2 LED service life (50,000 h/4,000 h)	12.5 years

Scenario 1 involves 4 replacements of the LED lamp/module or the entire fixture during the 25-year study period. Scenario 2 involves 2 replacements of the LED lamp/module or the entire fixture.

6 RESULTS

Based on the selected assessment method, the potential environmental impact of different impact categories is calculated and reported. CML-IA baseline and CML-IA non baseline are scientifically based methods and generate a result with low uncertainty. The total environmental impact for the production of the three different luminaires is presented below, see Table 10.

6.1 RESULTS FOR ALL ENVIRONMENTAL IMPACT CATEGORIES - LED OUTDOOR LIGHTING

Tables 9 and 10 show the comparative life cycle analysis for three different LED outdoor luminaires. The potential environmental impact from manufacturing, transport to customer and operation and replacements are reported for the two different scenarios where the estimated burning time for LEDs is 25,000 and 50,000 hours respectively. The luminaire with the integrated LED lighting without the possibility of replacing the LED lamp/module has a greater potential environmental impact. The environmental impact is close to three times as great for all impact categories when the burning time for LEDs is 25,000 hours (scenario 1). Regarding the potential environmental impact, it is almost twice as large when the burning time for LEDs is 50,000 hours (scenario 2). There is no significant difference for the non-integrated LED luminaires whether they have a replaceable LED lamp or a replaceable LED module.

6.2 INTERPRETATION AND EVALUATION

Since climate impact is one of the greatest environmental issues of our time, it continues to receive special focus in interpretation and evaluation, but other environmental impact categories follow the same pattern.

Table 10. The result for environmental impact categories per functional unit, FU, Luminaire (1kg) with LED lighting of 20 W for a study period of 25 years. Scenario 1 with a burning time of 25,000 hours.

Impact Factor	**Unit**	**Non-integrated LED lighting with an interchangeable LED lamp**	**Non-integrated LED lighting with an interchangeable LED module**	**Integrated LED lighting**
Global warming potential	kg CO_2 eq.	38.2	38.9	93.2
Depletion potential of stratospheric ozone layer	kg CFC-11 eq.	0.000027	0.000027	0.000031
Acidification potential of soil and water	kg SO_2 eq.	0.23	0.24	0.61
Eutrophication potential	kg $(PO_4)^{3-}$ eq.	0.12	0.13	0.33

Potential for the formation of tropospheric ozone photochemical oxidants	kg C_2H_4 eq.	0.013	0.013	0.043
Abiotic depletion potential of non-fossil resources	kg Sb eq.	0.00047	0.00054	0.00545
Abiotic depletion potential of fossil resources	MJ	330	331	852

Table 11. The result for environmental impact categories per functional unit, FU, Luminaire (1kg) with LED lighting of 20 W for a study period of 25 years. Scenario 2 with a burning time of 50,000 hours.

Impact Factor	**Unit**	**Non-integrated LED lighting with an interchangeable LED lamp**	**Non-integrated LED lighting with an interchangeable LED module**	**Integrated LED lighting**
Global warming potential	kg CO_2 eq.	37.3	37.4	65.5
Depletion potential of stratospheric ozone layer	kg CFC-11 eq.	0.000027	0.000027	0.000029
Acidification potential of soil and water	kg SO_2 eq.	0.22	0.22	0.42
Eutrophication potential	kg $(PO_4)^{3-}$ eq.	0.11	0.12	0.23
Potential for the formation of tropospheric ozone photochemical oxidants	kg C_2H_4 eq.	0.012	0.012	0.028
Abiotic depletion potential of non-fossil resources	kg Sb eq.	0.00043	0.00047	0.00339
Abiotic depletion potential of fossil resources	MJ	320	315	587

6.2.1 CLIMATE EFFECTS FROM THE LUMINAIRE'S LIFE CYCLE PARTS

Figures 2 and 3 show the two scenarios for the three luminaires examined. Here, the entire life cycle is divided into the manufacture of the luminaires including LED lamps, transport to the customer and the operating phase with electricity consumption and replacement. Replacement involves the new manufacture of LED lamps/modules (non-integrated luminaires) or new manufacture of the entire luminaire (integrated luminaire). The exchange also includes final handling of the luminaire, both luminaires and interchangeable parts. It is clear that the new manufacture of the luminaire for the integrated LED lighting has a higher climate impact. A shorter burning time for the LED diode causes a greater difference in climate impact between integrated LED lighting and non-integrated LED lighting.

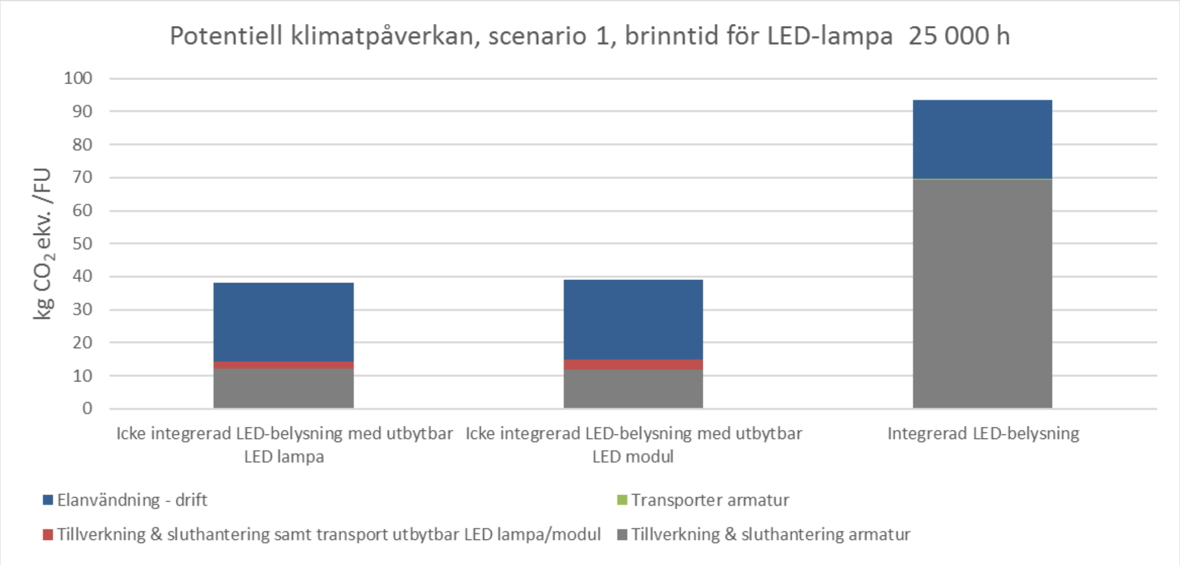


Figure 2. Scenario 1 with a burning time of the LED lamp of 25,000 hours shows the distribution of the potential climate impact from different parts of the life cycle of the different luminaires. The result is reported per functional unit, FU, Luminaire (1kg) with LED lighting of 20 W for a service life of 25 years.

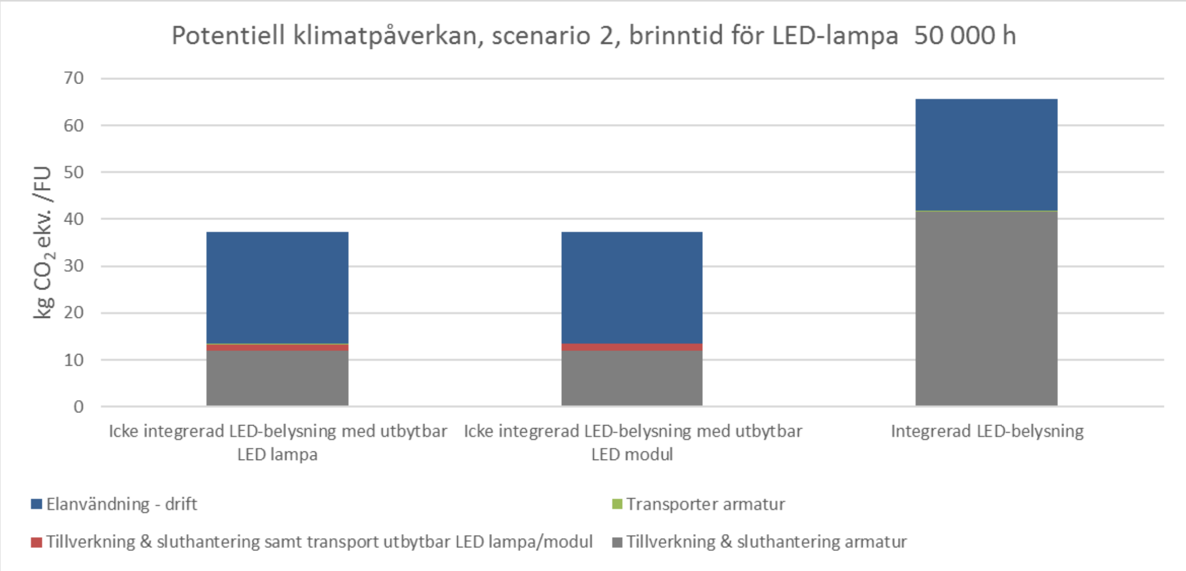


Figure 3. Scenario 2 with a burning time of the LED lamp of 50,000 hours shows the distribution of the potential climate impact from different parts of the life cycle of the different luminaires. The result is reported per functional unit, FU, Luminaire (1kg) with LED lighting of 20 W for a study period of 25 years.

6.2.2 CLIMATE EFFECTS OF THE LUMINAIRES OVER TIME

It is important to understand how the environmental impact/climate impact presents itself over time, since the difference between an integrated or non-integrated LED luminaire is affected by how long the lighting will be used. Figure 4 illustrates the potential climate impact over time for Scenario 1. When the service life of the LED is 25,000 hours, a difference in climate impact occurs only after six years. This is when the LED lamp/module is replaced the first time in the non-integrated LED lighting and the entire luminaire needs to be replaced for the integrated LED lighting.

In scenario 2, the climate impact is basically the same for all three luminaires during the first twelve years, when the service life of the LED lamp/module of 50,000 hours is over and the first replacement needs to be carried out, see figure 5.

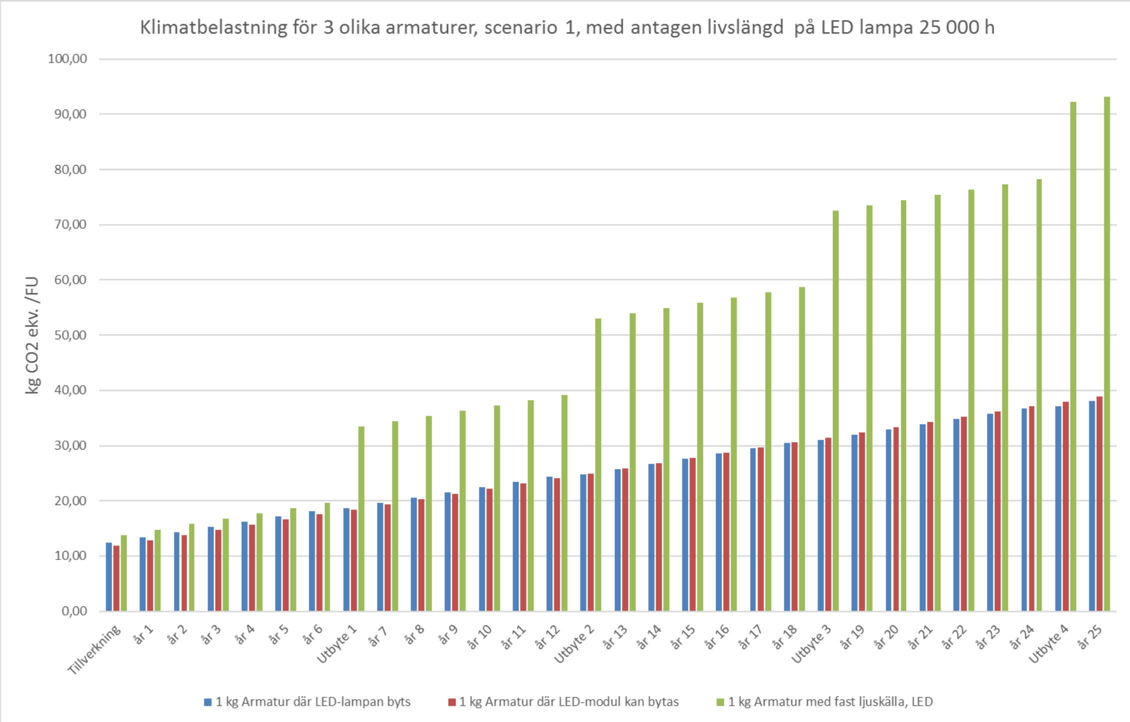


Figure 4. Scenario 1 with a burning time of the LED lamp of 25,000 hours shows the potential climate impact over time for the different luminaires. The result is reported per functional unit, FU, Luminaire (1kg) with LED lighting of 20 W for a study period of 25 years.

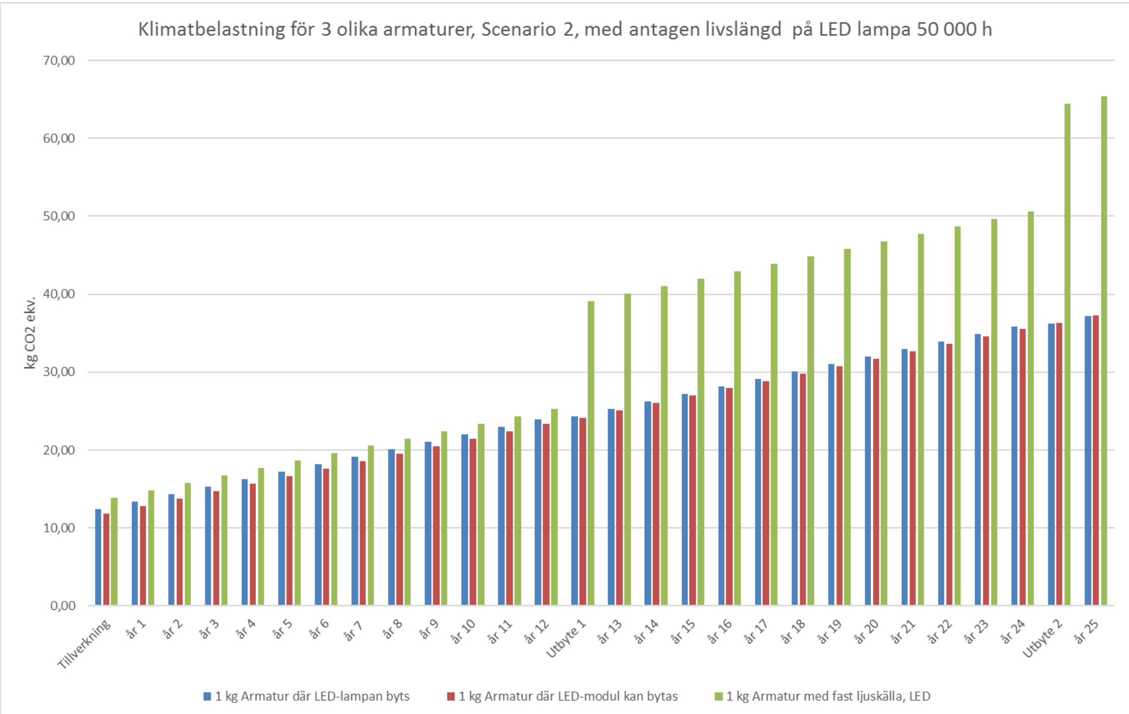
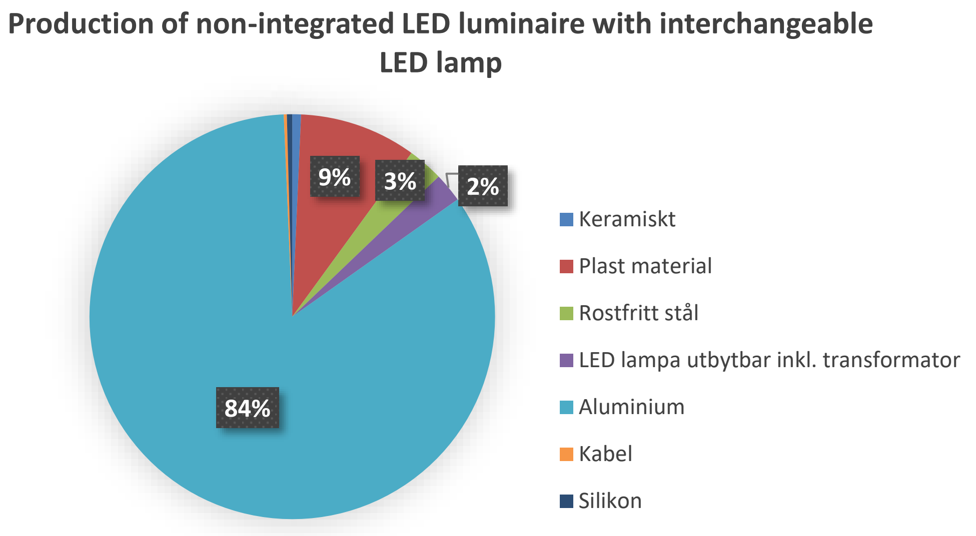
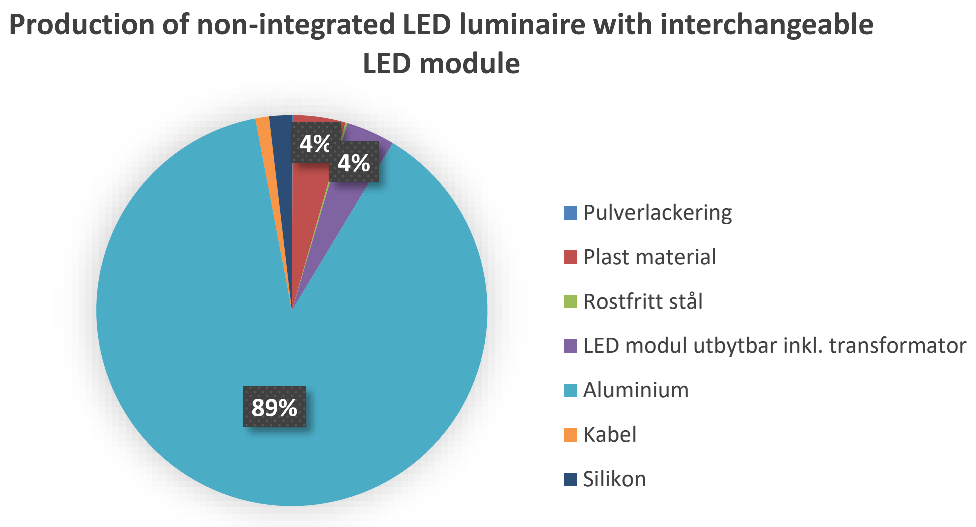


Figure 5. Scenario 2 with a burning time of the LED lamp of 50,000 hours shows the potential climate impact over time for the different luminaires. The results are reported per functional unit, FU, Luminaire (1kg) with LED lighting of 20 W for a study period of 25 years.

6.2.3 CLIMATE IMPACT FROM MANUFACTURE OF MATERIALS TO LUMINAIRES

In the manufacture of materials for the various outdoor lighting fixtures, it is primarily the aluminum that accounts for most of the climate impact. Figure 6 illustrates the climate impact of different parts of the production of the three luminaires in the form of a pie chart. In the various outdoor lighting fixtures, made primarily of aluminum, more than 70% of the potential climate impact comes from the production and processing of aluminum.





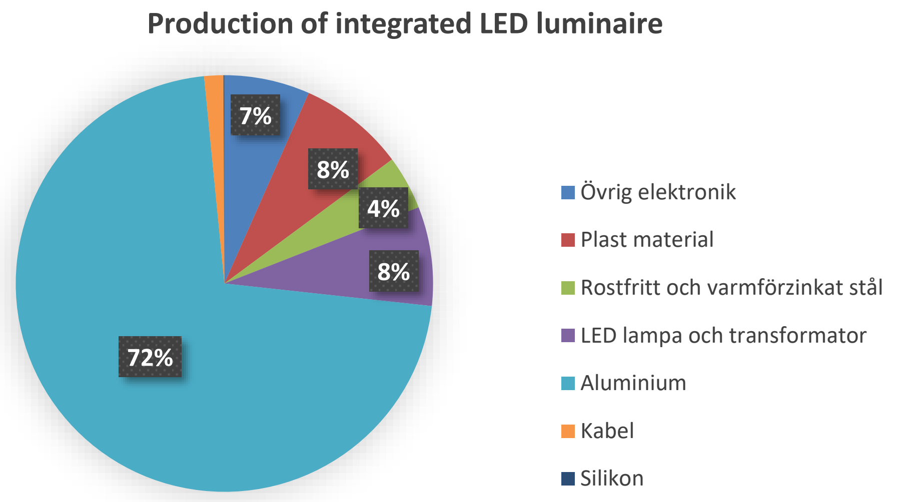


Figure 6. Distribution of the potential climate impact from different parts of the production for luminaires

7 VALIDATION

7.1 IMPACT ANALYSIS

The modeling and methodology are consistent throughout the process. The report and the results correspond to the set objectives and scope and no deviations have been made.

7.2 UNCERTAINTY ANALYSIS

The environmental impact is reported in several different impact categories. The generic data from EcoInvent used in this study contains uncertainty data.

The standard deviation, with 95% confidence intervals, for the different environmental impact categories has a coefficient of variation of between ± 0.01 and 0.014%, which indicates a low uncertainty in the basic data. The fossil climate impact has little uncertainty as the standard deviation with a 95% confidence interval has a coefficient of variation of 0.09%.

Another consequence that is raised during the discussion is whether the end customer will replace the interchangeable LED module when it stops working or the entire luminaire.

7.3 SENSITIVITY ANALYSIS

The burning time/service life of the LED is a controlling factor to why two different scenarios were set up and the difference of 25,000 hours and 50,000 hours is important. Also, the factor contributes to an average burning time for LED lamps of 4,000 hours per year, but that assumption feels reasonable and well supported and a variation here is smaller in magnitude than the two scenarios for different burning time.

For a burning time of 50,000 hours, the potential environmental and climate impact does not differ significantly between the non-integrated and the integrated luminaire until after 12 years, when the first replacement occurs, see Figure 5. The two scenarios provide a good sensitivity analysis of burning time and service life.

7.3.1 COMPARISON WITH STAINLESS STEEL LUMINAIRES

No comparisons with other LCA studies have been made, but the study also examined how the life cycle analysis would look if the luminaires were made primarily of stainless steel instead of aluminum. The proportion of aluminum in the various luminaires was replaced with stainless steel and the results were equivalent. However, stainless steel has a slightly lower climate impact than aluminum, so the difference between the non-integrated and the integrated unit was smaller, see Figure 7. For a burning time of 25,000 hours (scenario 1), the potential environmental impact was twofold when the luminaire was made of stainless steel. This can be compared to close to threefold when the luminaires were made of aluminum.

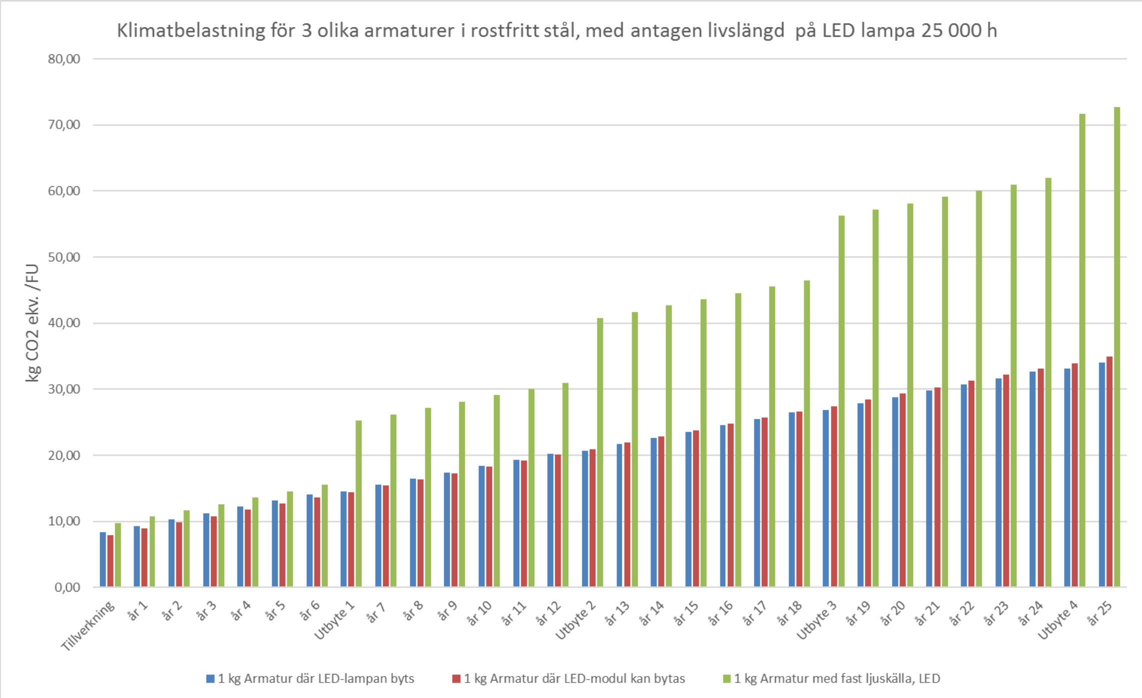


Figure 7. Sensitivity analysis according to scenario 1 where luminaires were made of stainless steel instead of aluminum with a burning time for the LED lamp of 25,000 hours. The potential climate impact is shown over time for the various luminaires. The results are reported per functional unit, FU, Luminaire (1kg) with LED lighting of 20 W for a study period of 25 years.

7.3.2 SENSITIVITY ANALYSIS OF DIFFERENT WEIGHTS FOR THE LUMINAIRES

In reality, the various luminaires that were compared weighed between 1-4 kg. An integrated outdoor lighting fixture (LED) that needs to be replaced and that, due to design, may weigh 4 kg instead of 1 kg increases the environmental impact. This is because more material, i.e. more aluminum (or stainless steel) needs to be manufactured. For an aluminum luminaire weighing 4 kg, the climate impact can be up to four times higher for an integrated LED lighting without the possibility of changing the LED lamp/module as compared to a non-integrated LED luminaire, see Figure 8.

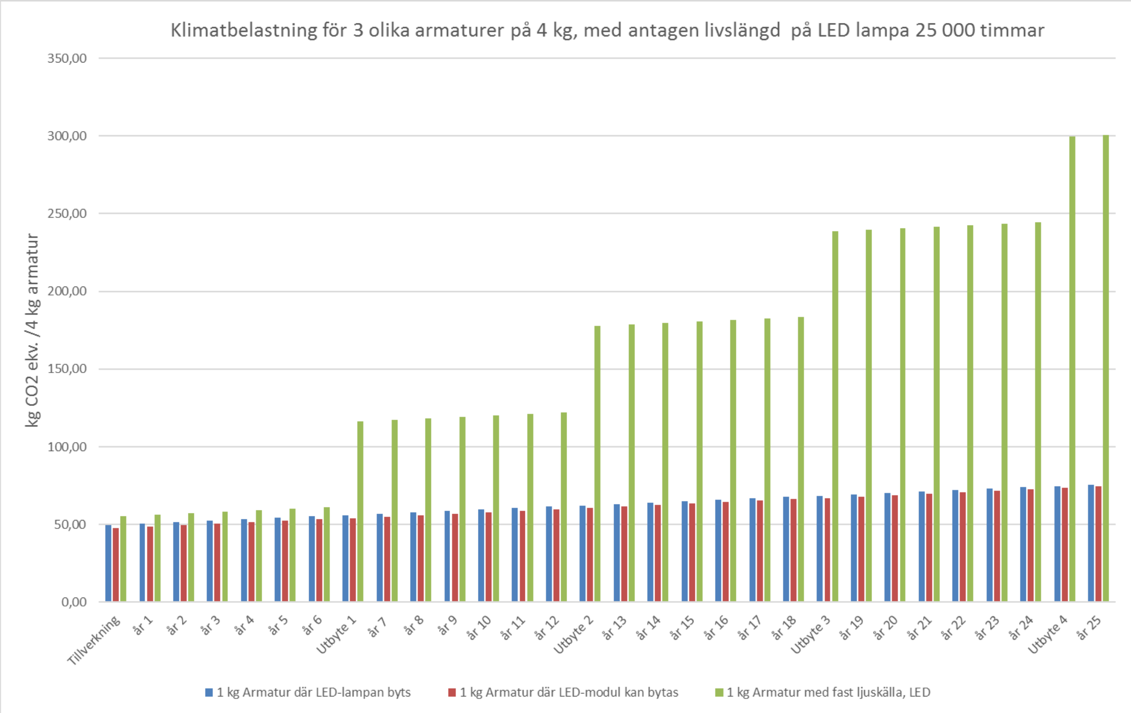


Figure 8. Sensitivity analysis according to scenario 1 where the luminaires were assumed to weigh 4 kg instead of 1 kg with a burning time of the LED lamp of 25,000 hours. The potential climate impact over time is displayed for the different luminaires. The result is reported per luminaire of 4 kg with LED lighting of 20 W for a study period of 25 years.

8 DISCUSSION

The comparisons clearly show that aluminum outdoor lighting luminaires (LEDs) have a potentially smaller environmental and climate impact over a 25-year period. Initially, the environmental impact is the same but over time, more specifically from the day a LED lamp (or a whole fixture) needs to be replaced because the LED's burning time/service life has reached its end, the integrated LED lighting has a greater environmental impact.

It is important to understand how the environmental impact/climate impact presents itself over time, since the difference between an integrated or non-integrated LED luminaire is affected by how long the lighting will be used.

When the LED diode's service life is 25,000 hours, there is a difference in climate impact after six years when the LED lamp/module is replaced the first time in the non-integrated LED lighting and the entire luminaire needs to be replaced for the integrated LED lighting. When the service life of the LED is 50,000 hours, a difference in climate impact occurs only after twelve years.

Another important aspect when it comes to choosing outdoor lighting fixtures (LEDs) is which material makes up the majority of the luminaire. This study shows that outdoor lighting fixtures where the proportion of aluminum is replaced by stainless steel gives a slightly lower climate impact, while the total weight of the luminaire naturally has an influence. Obviously, heavier luminaires will have an increased environmental impact. In the study, all input data was normalized to the functional unit. In reality, the various luminaires that were compared weighed between 1-4 kg.

CONCLUSIONS

The comparisons clearly show that aluminum outdoor lighting luminaires (LEDs), but also those of stainless steel, with an interchangeable LED lamp/module have a potentially smaller environmental and climate impact over a 25-year period. The potential environmental impact of manufacturing, transport to the customer as well as operation and replacements can be up to three times as great for integrated LED luminaires with no possibility of replacing the LED lamp/module.

Initially, the environmental impact for the different luminaires is the same but over time, more specifically from the day a luminaire needs to be replaced because the LED's burning time/service life has reached its end, the integrated LED lighting has a greater environmental impact.

There is no significant difference of the environmental impact if the luminaires have a replaceable LED lamp or replaceable LED module, provided that luminaires with a replaceable LED module are handled in such a way that the module itself is replaced when the LED diode's service life is over.

The potential environmental impact is proportional to the weight of the outdoor lighting. Heavier outdoor lighting fixtures (LEDs) that need to be replaced and that, due to design, may weigh 4 kg instead of 1 kg increase the environmental impact. In such a case, the climate impact is up to four times higher for an integrated LED lighting, in which the LED lamp/module cannot be replaced, than for a non-integrated LED lighting over a 25-year study period.

CALCULATIONS AND UNCERTAINTIES

One uncertainty and limitation is that the final assembly/production and its energy and material consumption for waste and other scrap etc. are not included. The final assembly/production is estimated to represent less than 5% of the total energy and material consumption. However, there is great uncertainty regarding the increased material supply for the waste that will be associated with the final assembly in the production. Manufacture of more material (that is scrapped during manufacturing) can be higher than 5%. The differences in environmental impact between outdoor lighting fixtures (LED) with an interchangeable LED lamp/module and outdoor lighting fixtures with integrated LED are expected to increase if the final assembly/production is also included.

The lifecycle analysis does not take into account how the lighting fixtures with replaceable LED modules are handled by the end customer. A LED module is interchangeable, but you need to be an electrician or at least a professional with knowledge of your field. There is a risk that lighting fixtures with interchangeable LED modules at the end customer will be treated as integrated LED lighting. In this case, this would mean that the non-integrated lighting fixtures with interchangeable LED modules would have a higher environmental and climate impact and would not differ significantly from integrated units.

Another aspect that can have a negative impact on the integrated LED lighting is that when it sooner or later breaks, there is a risk that the same type of lighting will no longer be on the market. When the integrated LED lighting in for instance one of four façade lamps breaks, the integrated LED lighting may no longer be available. From one day to another you thus no longer have uniform lighting and are then faced with the choice to also replace the three luminaires that still work. This aspect is not taken into account in the life cycle analysis.

The service life of the LED diode including the transformer is estimated to be from 15,000 hours up to 100,000 hours and the service life has a major impact on the result. It is therefore important that the results are reported for the two different scenarios, 25,000 hours and 50,000 hours.

RECOMMENDATIONS

Extending the study to include the final assembly/production and its energy and material consumption would reduce the uncertainty. Especially waste during manufacturing can lead to major differences on the environmental impact.

It would also be interesting to compare stand-alone outdoor lighting fixtures with solar cells against fixtures with a fixed installation and cables and also include the installation in the life cycle analysis.

9 REFERENCES

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Lampinfo (2019) Facts about LED lamps, (http://lampinfo.se/fakta-om-led-lampor/ Retrieved 2019-05-07)

Life Cycle Assessment Review Report By Miljögiraff

Commissioner: Anna Pantze, Tyréns AB
Reviewer: Marcus Wendin, Miljögiraff AB
Date: 2019-09-19

PEACE LOVE AND GIRAFFES

1 Background and objectives

In an assignment for Villaägarna, Tyréns carried out a life cycle assessment of a general exterior lamp with LED. They want to use the results in external communication. Also, they want to say how much better a lamp is if the led can be replaced.

For that comparison they will relate to a period of 50 years. The LCA was carried out according to the standards ISO 14040-44. In this context, the customer would like to launch an external critical review according to the standard ISO 14040 of this study. This critical review shall turn around points defined by the standard ISO (objectives and scope, analysis of the inventory, the evaluation of the impacts and the interpretation).

For this LCA one LCA expert should review the LCA for compliance to:

- ISO standard 14040:2006 – Life Cycle Assessment Principles and Framework
- ISO standard 14044:2006 – Life Cycle Assessment Requirements and Guidelines

1.1 Description of the work to be reviewed

The International Organization for Standardization (ISO) (2006a:6.3) states the following concerning the procedure for the review of a comparative study planned to be published:
"A critical review may be carried out as a review by interested parties. In such a case, an external independent expert should be selected by the original study commissioner to act as chairperson of a review panel of at least three members. Based on the goal and scope of the study, the chairperson should select other independent qualified reviewers. This panel may include other interested parties affected by the conclusions drawn from the LCA, such as government agencies, non-governmental groups, competitors and affected industries."

This is a public study with comparative assertions. Therefore, a review panel would be recommended according to ISO 14040 if it should be published. For the moment it is agreed that the review is conducted only by one person.

Key characteristics for this review are summarized in Table 1 below.

Table 1 Key characteristics of the work to be reviewed

Title	LCA rapport_tredjepartsgranskad och justerad [294537]
Commissioner	Tyréns
Main author	Anna Pantze
Coaching for the study	Yes, regarding disposal scenario
Products and variants investigated	Exterior lamp with and without replaceable LED.
Scope	Cradle to gate and usage in 25 years
Standard to be applied	ISO/TS 14040 and 14044
Comparative study	Yes
Publication foreseen	Yes
Size of documentation provided for review	26 pages report
Software for background calculations	SimaPro 8.5.2
Background database	Ecoinvent 3.4
Foreground data	Examples from Byggvarubedömningen
Provision of LCI data for review	Documented in report
Life cycle impact assessment	CML IA baseline (EPD 2013 in SimaPro)
Date for submission of draft 1 report	20190605
Date for submission of draft 2 report	20190905
Stages of the review	One stage for review of the full LCA
Planned finalization of the study	20190930
Meetings in person	None
Reviewer	Marcus Wendin, Miljögiraff, SE

2 Standards and reviewcriteria

The critical review will be carried out according to the International Standards ISO 14040 and 14044 (International Organization for Standardization (ISO) 2006a, b). The LCA will be reviewed according to the following five aspects outlined in ISO 14040. It is assessed if:

- *"the methods used to carry out the LCA are consistent with this International Standard*
- *the methods used to carry out the LCA are scientifically and technically valid*
- *the data used are appropriate and reasonable in relation to the goal of the study*
- *the interpretations reflect the limitations identified and the goal of the study, and*
- *the study report is transparent and consistent."*

2.1 Tasks of the reviewer

The tasks of the reviewers are to review the provided documentation according to Table 1 including the four LCA phases, namely

- Goal and scope definition
- Inventory analysis
- Impact assessment, and
- Interpretation

The critical review was carried out by Marcus Wendin at Miljögiraff.
The following interactions between the practitioner and the reviewer took place:

- Provision of draft LCA report dated 2019-06-05, 26 pages in PDF-format, including a full description of the study.
- Submission of detailed review comments by the reviewer, 2019-06-07
- Provision of a revised LCA report with track-changes dated 2019-06-08, 26 pages PDF-format,
- including all stages of the LCA. Abstract with two pages. Detailed answer to first review comments by the author.
- No further comments
- Submission of the review statement, dated 2019-06-14
- The LCA was extended to include disposal scenario. And an updated version was sent 2019-09-05 for review.
- Submission of the review statement, dated 2019-09-19

3 Critical review report

All questions of the reviewer were answered sufficiently. Upon reviewer's request revisions were made concerning allocation, credits and description of results. The critical review process took place in an open and constructive atmosphere. The final study report includes all the comments of the reviewer given in the earlier stages of the review process.

The present final version of the review report considers the revisions made by the practitioner after submitting the feedback on the pre-final report.

The goal of the study as such was not reviewed as this lies in the responsibility of the commissioner. However, it was reviewed whether or not the goal is stated explicitly and transparently. The definition of the scope was part of the critical review, in particular the definition of the functional unit, the system definition and its boundaries and the allocation approaches.

The review of the inventory analysis includes the inventory raw data in SimaPro format (input data), the modelling approaches and selected inventory results.
The review of the impact assessment includes the impact indicator results.

Within the interpretation phase, the consistency of the modelling, the data used, and the conclusions are reviewed and checked whether it is in line with the goal and scope definition. Data quality aspects, significance and sensitivity analyses as well as completeness checks are subject to the critical review too.

In general, the inventory models established are scientifically and technically valid.

All foreground data, including the whole modelling and calculations were presented to the reviewer in SimaPro format and are documented in the report. This facilitated the review considerable and is highly acknowledged.

The data used in the foreground and the background are appropriate and reasonable, given the goal and scope of the study. Nevertheless, it is not possible to fully ensure the correctness and validity of all calculations within such a review process.

The results presented in the report are well justified. The interpretation also considers the limitations due to the goal and scope of this study.

All relevant information could be found in the report. With extensive information, the report is acknowledged as transparent and consistent.

3.1 Self-declaration of reviewer independence & competencies

(According to ISO/PDTS 14071, Annex B)
I Marcus Wendin, hereby declare that:

- I am not a full- or part-time employee of the study's commissioner or practitioner.
- I have not been involved in scoping or carrying out any of the work to conduct the LCA study at hand, i.e. I have not been part of the commissioner's or practitioner's project team(s).
- I do not have vested financial, political, or other interests in the outcome of the study.
- My competencies relevant to the Critical Review at hand include knowledge of and proficiency in:
  ISO 14040 and ISO 14044.
  LCA methodology and practice, particularly in the context of LCI, (including data set generation
  and data set review, if applicable).
  Critical Review practice.
  The scientific disciplines relevant to the important impact categories of the study.
  Environmental, technical, and other relevant performance aspects of the product system(s) assessed.
  Language used for the study.
- A short CV and a list of relevant references is part of the review report.
- I assure that the above statements are truthful and complete.

3.2 Conclusions

The reviewed LCA study and abstract complies with the requirements of the ISO standards 14040 and 14044. The goal and scope are appropriately defined. The methods used are scientifically and technically valid. The data used are appropriate and reasonable in view of the goal and scope of the study. The report is complete, clearly structured and well-readable.

Conclusions and recommendations are based on the results of the analyses, respecting the limitations described in the report.

I recommend submitting the entire LCA report including this review report to the commissioner.

Marcus Wendin 2019-09-19 Styrsö

4 Referenser

ISO. (2006a). *Environmental Management – Life cycle assessment – Principles and framework. 14040:2006.* Geneva, Switzerland: International Organization for Standardization.

ISO. (2006b). *Environmental Management – Life cycle assessment – Requirements and guidelines ISO 14044:2006.* Geneva, Switzerland: International Organization for Standardization.

ISO. (2006c). *Environmental labels and declarations—type III environmental declarations—principles and procedures. ISO 14025:2006.* Geneva, Switzerland: International Organization for Standardization.