HOW TO REDUCE THE GLOBAL WARMING IMPACT OF LUMINAIRES

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1. Introduction

The Intergovernmental Panel on Climate Change (IPCC) presented the Special Report on Global Warming of 1.5°C in 2018 (Masson-Delmotte, 2018). The report confirmed that climate change is already today affecting people and ecosystems all around the world. It also showed that limiting warming to 1.5°C is possible within the laws of chemistry and physics. However, without measures leading to a sharp decline in greenhouse gas emissions by 2030, global warming will surpass 1.5°C in the following decades. This would lead to irreversible loss of the most fragile ecosystems.

Lighting accounts for approximately 6% of global CO_2 emissions (en.lighten initiative, 2022). A drastic impact reduction of lighting is therefore an important contribution to limiting the global warming. With energy-efficient LED technology and modern Light Management Systems (LMS), the lighting industry has powerful tools to reduce the emissions. However, a complete view on lighting products is necessary to understand the impact of the different lifecycle phases. How important are the Manufacturing and Distribution phases in relation to the Use phase? What is the benefit of circular luminaires designed for repair and reuse with regards to global warming?

In this report, we analyze lifecycle assessment (LCA) data for luminaires published in Environmental Product Declarations (EPDs) using the LCA rules defined by the program operator PEP Ecopassport. Special attention is given to the Global Warming Potential (GWP) – the indicator that measures how strongly a product contributes to global warming. With these results, we analyze what measures are most efficient to reduce the global warming impact of LEDVANCE products. Finally, the role of Circular Economy and the ROHS-banning of fluorescent tubes are discussed.

2. LCA as a tool to quantify environmental impact

A lifecycle assessment is a valuable method to comprehensively and systematically assess the environmental impact of a product. It covers the whole lifecycle of the product, from the raw material extraction, manufacturing, distribution, use and end-of-life. Standardized environmental impact categories with corresponding indicators help to understand how the product influences the environment over the lifecycle. The Global Warming Potential (GWP), expressed in the unit "kg CO_2 equivalent" is the indicator for climate change impact. Other important categories are ozone depletion, acidification, eutrophication of water and soil, water use and the depletion of abiotic resources. There is no importance ranking of the impact categories in the LCA.

Conducting a LCA of a luminaire is a time-consuming task, considering the high number of components in a luminaire. Assumptions need to be made and boundary conditions need to be defined to complete a LCA. Standardization of the LCA method and data quality requirements are extremely important to make sure that the results from two different LCAs can be compared. The LCA method is standardized in ISO14040 and ISO14044 and the reporting in terms of type III environmental declarations (EPD) is defined in ISO14025[1]. Further details relevant to the EEE industry is defined in EN50693. Finally, program operators such as the PEP Ecopassport organization defines Product Category Rules (PCR) and even more detailed Product Specific Rules (PSR).

PSR0014 (PEP Ecopassport PSR0014, 2018) is the PSR for Luminaires based on the PCR of the PEP Ecopassport organization. The first edition was published in 2018. Lighting Europe – representing the lighting industry in Europe – has joined the PEP Ecopassport organization to share their lighting expertise and help to improve the PSR for luminaires. As a Lighting Europe member, LEDVANCE is actively contributing to the PSR revision. With an improved PSR for luminaires in sight, jointly backed by the European Lighting industry, LEDVANCE is currently working on its first verified PEPs for professional products.

One of many important details defined in the PSR0014 is the definition of the functional unit. In PSR0014 the functional unit for Luminaires is "Provide lighting that delivers an outgoing artificial luminous flux of 1000 lumens during a reference lifetime of 35000 hours". The environmental impact is evaluated for the functional unit and allows a fair comparison between luminaires with high and low luminous flux and varying lifetime.

3. Meta-analysis of luminaire EPDs based on the PEP Ecopassport PSR0014

In parallel to our own LCA analysis, we are analyzing the PEPs already published for luminaires using PSR0014 (PEP Ecopassport, 2022)[2]. This gives us a more solid dataset to identify the biggest improvement potentials. The questions we want to have answered are:

- With highly efficient LED luminaires as starting point, what phase of the lifecycle is contributing the most to global warming?
- How are all the environmental impacts correlating to each other?

Table 1 shows some of the environmental impacts and the average (over all published PEPs using PSR0014) relative impact in the different use phases. The products for which the PEPs have been made are very different. Some are heavy, high lumen outdoor luminaires; others are just providing a few hundred lumen.

Life Cycle Phase	Manufacturing	Distribution	Installation	Use	End of life
Impact Category					
Global Warming Potential	3%	0.6%	0.1%	96%	0.2%
Ozone Depletion	24%	0.5%	0.1%	75%	0.1%
Acidification	4%	0.7%	0.1%	96%	0.1%
Water Eutrophication	12%	0.6%	0.1%	87%	0.2%
Photochemical Ozone Formation	5%	1.2%	0.1%	93%	0.1%
Depletion of Abiotic Resources - Elements	75%	1.7%	0.3%	23%	0.3%

Table 1: Relative environmental impact of luminaires for some important impact categories distributed over the different phases of the LCA. Average values from published PEP Ecopassport for luminaires.

[1] There are three types of environmental declarations. ISO14024 defines the requirements for voluntary (Type I) environmental labelling schemes like FSC (forestry products), "Blauer Engel" and "Nordic Swan". ISO 14021 specifies requirements for any self-declared environmental claims and statements (Type II declarations). The Type III environmental declaration (ISO14025) is based on a full LCA and the data must be independently verified.

[2] In total 8 PEPs for luminaire (families) based on PSR0014 have been published (status 2022-07-22)

- On average for the analyzed luminaires, 96% (range 89%-99%) of the Global Warming Potential is caused in the Use Phase. The emission from electricity generation to operate the luminaires is causing the high GWP impact of this phase. This result is quite remarkable, considering the great improvement of luminous efficacy and resulting improvement of power consumption achieved by introducing the LED technology.
- Most other impact categories like ozone depletion, acidification, water eutrophication and photochemical ozone formation are also dominated by the Use Phase. Just like for the GWP, it is the emissions from electricity generation that is causing this.
- Although being the second most contributing phase, Manufacturing including any intercontinental transport to the local distribution center in Europe plays a minor role for the GWP (3% share). The long lifetime of LED luminaires is the most important explanation for this result. The relative impact of the Manufacturing Phase for other impact categories is more substantial (4%-24%) and especially when it comes to the depletion of abiotic resources – elements, the importance of the Manufacturing phase (75% share) becomes obvious.

The Installation, Distribution and End-of-life phases can be practically neglected in this comparison.

4. How to reduce the global warming impact of luminaires

The meta-analysis of existing luminaire PEPs reveals that the optimization of the Use Phase is the key to reducing the Global Warming Potential of luminaires. With the exception for replacement of light sources, the use phase environmental impact is caused by the electrical power consumption. 1kWh electricity produced in the EU (EU-27) causes a GWP of 0.261 kg CO_2 eq. (Our World In Data, reference year 2021).

Figure 1 shows the GWP from the Use Phase as a function of the luminous efficacy for more than one thousand luminaire products from LEDVANCE. The definition of functional unit from PSR0014 have been followed for this calculation. For a given luminous flux emitted from the luminaire, the power consumption is inversely proportional to the luminous efficacy (lm/W) of the luminaire. It is worth noting that the relatively big difference between the most effective luminaires (up to 160 lm/W) and the least effective luminaires (below 100 lm/W) are related to application specific requirements. A high lumen, high CRI, narrow-beam spotlight restricted in size has a much lower efficacy than a ceiling luminaire without challenging requirements on lumen, size or beam angle.

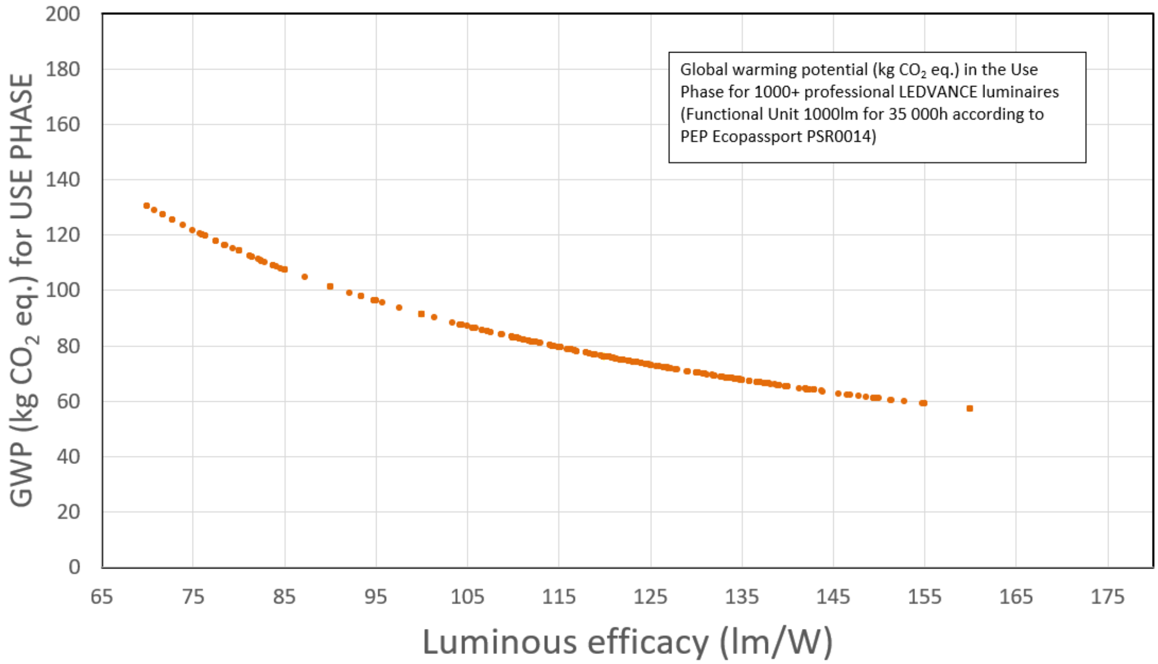

Figure 1 Global Warming Potential in units of kg CO_2 equivalent from the Use Phase for LEDVANCE luminaires with different luminous efficacy. The evaluation is made for the functional unit (1000 lm for 35000h) from PEP Ecopassport PSR0014.

The trivial answer to the question how to reduce the Global Warming Potential of Luminaires would therefore be to increase the luminous efficacy. LEDVANCE strives to offer luminaires with market-leading efficacy for all applications. The potential for further improvement is however limited. With one and a half decade of breathtaking LED efficacy improvement behind us, physical limits are being approached. Optimization of the secondary optical elements, the driver electronics and the system design including the thermal design can all help to achieve further marginal improvements. However, a marginal improvement is not what we are looking for!

5. The benefit of sensor-controlled lighting

The biggest remaining potential lies in the intelligent control of the luminaires. The best luminaire with the lowest GWP in a rarely used room is the one that automatically switches off the light when the room is empty! The best luminaire in a room flooded with light on a sunny winter day is the one that dims the light – thus realizing the required illuminance level with an optimized power consumption. This is often referred to as daylight harvesting. Intelligent luminaires, controlled by sensors detecting the presence of people and the illumination level in the room, minimizes the energy used while ensuring the comfort of good illumination. The energy saving potential highly depends on the actual conditions in the room. PSR0014 is generalizing the potential by introducing energy saving coefficients for light control based on presence detection (-25%) and daylight sensing (-25%) or the combination thereof (-45%).

Figure 2 shows the GWP according to PSR0014 in the use phase of LEDVANCE luminaires – now including luminaires with presence and/or daylight sensing. The improvement is significant! It should be noted that these savings can be realized either by integrating these functionalities in the luminaire or by integrating the luminaire in a light-management system (LMS). The latter is the better choice in many cases, since it enables a few sensors to control a bigger number of luminaires. Furthermore, luminaires in a LMS will change the light setting uniformly as a group.

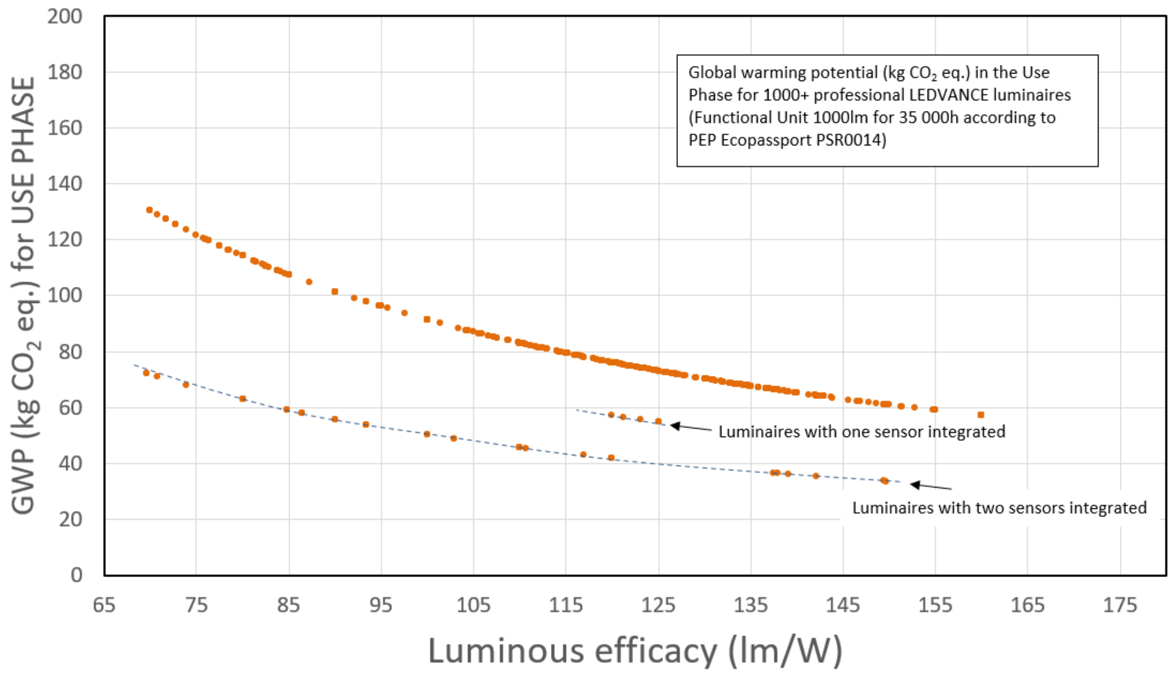

Figure 2 Global Warming Potential in units of kg CO_2 equivalent from the Use Phase for LEDVANCE luminaires with different luminous efficacy – including also luminaires with lighting control based on presence detection, daylight sensing or the combination thereof. The evaluation is made for the functional unit (1000 lm for 35000h) from PEP Ecopassport PSR0014.

VIVARES is the future proof IoT light management system from LEDVANCE. VIVARES makes it easy to produce optimum lighting conditions while implementing energy saving presence detection and daylight harvesting. With the VIVARES cloud service offering, the energy consumption can be monitored and optimized in real time – thus further reducing the climate impact of the lighting installation.

6. The benefit of circular luminaire designs

The concept of circular economy is to re-use and repair products as much as possible to save natural resources and reduce the amount of waste generated. For luminaires, special attention is paid to the light source and the driver of the luminaire, since these two parts have a limited lifetime. By designing the luminaire in such a way that the light source and driver can be replaced, the lifetime of the luminaire can be extended. A longer lifetime means smaller footprint from the Manufacturing Phase for the functional unit. The PEP analysis raises some interesting questions about the role of circular economy luminaire design for the GWP. Let us have a look at three use case examples. In all examples, we assume that the luminaire is limited to 100 years of use. To keep it simple, we further assume that manufacturing and distribution environmental impact of replacement light sources and drivers can be neglected compared to the impact of the whole luminaire[3]. The baseline proportion of the use phases are taken from Table 1.

[3] These assumptions are of course not correct. Buildings are generally renovated (including the electrical installation) long before 100 years of use and the LED light source and driver contain components requiring high energy use for its manufacturing. But we are looking for a best-case benefit of circular designs here.

Example 1: Luminaire with long lifetime components and low annual use

A non-circular luminaire with 100.000h lifetime used in an office environment (2000h annually) will reach the end of life after 50 years of use! With a circular design, the light source and the driver can be replaced once until the 100 years of use have been reached, thus enabling another 50 years of use. What is the GWP impact? With the assumptions made, the Manufacturing Phase impact in the LCA would be reduced by 50%. But since the Manufacturing Phase is just causing approximately 3% of the total impact from the beginning, the total impact reduction is just 50% of the 3%. Less than two percent total reduction is indeed not very much.

Example 2: Luminaire with moderate lifetime components and 24/7 operation

A somewhat more rewarding scenario would be an application with 24/7 use of artificial light (8760h per year) and a light source and driver with more moderate 50.000h lifetime. In this case, the parts need to be replaced every 5.7 years and in total seventeen times until the luminaire has been used for 100 years. The impact of the manufacturing phase could be reduced by 94%! But considering the whole lifecycle, the GWP reduction with the circular luminaire design is still less than 3%.

Example 3: Luminaire with moderate lifetime components and 24/7 operation - upgradable

Let us re-use example 2 (50.000h lifetime of driver and light source, 24/7 use) but now consider upgrades of the luminaire. At the first light source replacement after 5.7 years, we assume that the new light source has 10% higher luminaire efficacy than the original one. At the second replacement, the efficacy is improved by another 10%. After that, the light source efficacy is assumed to remain constant until the luminaire has reached the end-of-life. At the first replacement cycle, the luminaire is also upgraded to be controlled by a presence sensor (25% lower energy consumption) and this functionality remains until the end-of-life. With these assumptions, the use phase GWP impact is reduced by 37% compared to a non-circular luminaire and since the use phase makes up 96% of the total impact, the reduction on lifecycle level is 35%. As seen in example 2, a small further improvement (less than 3%) is achieved in the Manufacturing Phase. In total, the GWP reduction for a circular upgradable design approaches 40%! Please note that this benefit of an upgradable design cannot be considered in EPDs like PEPs.

In conclusion, circular luminaire design has a marginal effect on the GWP evaluated over the lifecycle, assuming that the replacement parts have the same performance as the original parts. In contrast, a circular luminaire designed for upgrades of the light source and integration of LMS functionality can greatly reduce the GWP seen over the lifecycle.

7. RoHS-banning of low-pressure discharge lamps and its impact on GWP

The use of mercury in lighting products is generally prohibited by the RoHS Directive and with the amendment of currently valid exemptions, T5 and T8 fluorescent lamps will be banned in the European Union from August 25, 2023.

Fluorescent tubes used to be the symbol for energy efficient lighting in the 20th and early 21st century. Do we risk a backlash in carbon emissions with the banning of the fluorescent tubes? On the contrary! Fluorescent tubes can now be phased out and replaced by tubes with LED technology (SubstiTUBE) in many general lighting applications. SubstiTUBE T8 Pro has approximately the double efficacy (up to 175 lm/W) and four times longer lifetime (75.000h) than its fluorescent predecessor! Further reduction of the environmental footprint is realized with sensor functionality integrated in the tube (SubstiTUBE Motion Sensor) or in a wireless light management system with sensors (SubstiTUBE T8 Connected for parking garages). Even the more modern T5 fluorescent tubes cannot compete regarding efficacy and lifetime with the alternative T5 SubstiTUBEs with LED technology.

For a light source, being the part of a luminaire consuming the most power, the Use Phase will dominate the lifecycle regarding global warming potential. Therefore, the reduction of energy consumption during the Use Phase can roughly be translated to the same number for GWP reduction for the whole lifecycle. This means that the GWP of LED tubes are approximately 25% - 50% lower (or even less for types with LMS functionality) than their fluorescent ancestors. As a matter of fact, the transition from fluorescent to LED-based tubes is the perfect example of the benefit of circular luminaire design that allows for upgrades!

8. Conclusion

Lifecycle assessment is a valuable method to systematically assess the environmental impact of a product. We have analyzed the LCA results of luminaires that have been published as PEP Ecopassports to identify the biggest contributing phases to the Global Warming Potential (GWP) for this product group. Based on this analysis, we have identified the measures that result in the highest reduction of GWP.

- Despite the introduction of the highly efficient LED technology, the Use Phase is dominating the GWP impact of modern luminaires. On average, 96% of the total GWP is generated during the Use Phase, caused by the emissions from electricity generation needed to operate the luminaires.
- The biggest improvement potential in the dominating Use Phase is the intelligent control of the luminaires based on presence detection and daylight sensing. Generalized, 25% reduction of the Use Phase GWP is possible with one of these energy saving functions and 45% for the combination thereof. These functionalities are usually realized with a modern light management system (LMS).
- Luminaires with circular design – allowing the replacement of driver and light source – extends the lifetime of the luminaire. With the global warming aspect in focus, the biggest benefit of circular design is the possibility to upgrade the luminaire with more efficient light sources and sensor-assisted light management functions.
- The major transition from T5 and T8 fluorescent tubes to LED-based SubstiTUBEs due to the RoHS-banning will have a sizeable effect to limit global warming.

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