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► To cite this version:

Mohamed Ridha Kouki, Laurent Canale, Kévin Bertin, Zouhour Araoud, Marc Mequignon, et al.. The Environmental Impact of Sensors in Smart Lighting Systems: Enhancing the Lighting as a Service (LaaS) Model. IEEE Sustainable Smart Lighting World Conference (LS:24), IEEE Smart Cities Technical Community & Technical University of Eindhoven, Nov 2024, Eindhoven, Netherlands. 4 p. hal-04874210

HAL Id: hal-04874210

<https://hal.science/hal-04874210v1>

Submitted on 8 Jan 2025

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The Environmental Impact of Sensors in Smart Lighting Systems: Enhancing the Lighting as a Service (LaaS) Model

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Abstract—*The transition to a circular economy aims to minimize waste and preserve resources. Lighting as a Service (LaaS) is a model that aligns with the principles of circularity, by providing lighting solutions that may reduce environmental impact and promote sustainability. As lighting technologies have become more sophisticated, LaaS Models have developed smart lighting systems using motion sensors and hubs which, by reducing the duration of use, result in lower energy consumption. Studies carried out a few years ago indicated that although sensors and hubs were capable of saving energy, their standby consumption resulted in higher consumptions. Recently, new generation sensors and hubs with low standby consumption emerged. Thanks to this, the environmental performance of smart lighting systems is improved, according to new measurements, guaranteeing a comfortable user experience.*

Keywords— *smart lamps, life cycle assessment, LED, digital sobriety.*

I. INTRODUCTION

The circular economy concept and Lighting as a Service (LaaS) are coinciding to improve the lighting industry, taking it from a product-based model to a comprehensive service solution that minimizes waste and preserve resources [1]. LaaS embodies circularity principles by focusing on energy-efficient technologies, modular designs, and responsible end-of-life management. At The core of this advancement are smart lighting systems heavily reliant on advanced sensor technologies, which optimize energy use. These sensors play an essential role in enhancing user experience, driving energy efficiency, and extending product lifespans. By concentrating on providing services instead of owning products [2], LaaS has the potential to help reduce environmental impact and manage resources more responsibly, while also paving the way for a new era of intelligent and adaptive lighting solutions that align with the broader goals of a circular economy while meeting the evolving needs of users and businesses alike [3].

The evolution of sensor technology in smart lighting systems marks a significant turning point in the

environmental impact of “Lighting as a Service” (LaaS) solutions. Studies carried out a few years ago showed that the promise of energy efficiency through intelligent lighting control was partially undermined by the high-power consumption of old sensor technologies. These old generation sensors, if taking into consideration both the energy and raw materials their production required and their consumption of energy in stand-by mode, often consumed substantial amounts of energy, sometimes leading to a paradoxical situation where smart lighting systems had a higher overall environmental footprint than traditional lighting systems [4].

However, recent advancements have altered this landscape. Modern sensors now boast remarkably low standby power consumption, often using one in ten thousand of a watt when inactive. This significant reduction in sensor energy consumption has turned the table in favor of smart lighting systems. The energy saved thanks to the intelligent control system such as occupancy-based lighting and daylight harvesting, now outweighs the minimal power draw of the sensors in standby mode, especially that the initial price for lighting system may be relatively high, and the higher the efficiency and the quality of the luminaire the higher the initial investment would be.

In order be able to judge the real environmental impacts due to both using old and entry-budget sensors compared to new ultra-low standby consumption sensors, a Life Cycle Analysis (LCA) need to be conducted.

II. LAAS TECHNOLOGY AND LCA

A. Smart LEDs Lighting

As an improvement for traditional lighting system, the smart ones come with functionalities and features that integrated into the LED lights in order to help improve the experience of the user, provide more comfort and also better lighting services.

Smart lighting system provide features such as remote controlling the color temperature or to program sessions for

luminosity and color change to mimic the natural solar cycle. The integration of movement and presence sensors in lighting control system help using the new features through smartphone via either Wi-Fi or Bluetooth and also improves lighting experience through lighting when needed and where needed.

B. *LaaS: definition and key components*

LaaS is a subscription-based model which changes the way that lighting system are delivered, maintained and also optimized. Users practically pay for the services of lighting such as installation, maintenance, upgrade and energy management instead of only purchasing lighting system. These services are appealing not only for those who aim to reduce upfront capital cost but also for those who prefer to focus on both sustainability and efficiency.

The key components of this model include:

- **Sensors:** these are essential for real-time data tracking and monitoring such as occupancy, ambient light level and usage reason. They help adapt and control lighting.
- **LED:** LED fixtures are the backbone of any LaaS solution due to their high energy efficacy and durability.
- **IoT Connectivity:** Hubs and gateway systems allow the centralization of data analytics, control and integration with all the management systems of a smart building.
- **Energy Management Software:** this analyzes the data coming from the sensors in order to either provide insights or to automate lighting services.

Based on these 4 pillars of smart lighting systems, LaaS model aims for saving cost through reducing energy consumption. It also tries to reduce environmental impacts, however in order to achieve this some critical requirement need to be present such as a high efficacy LED [5], a hub with both low power and the maximum number of ports to connect lighting devices, and sensors with low consumption power in both active and stand-by mode.

C. *lighting systems LCA*

LCA is the most widely used methodology to analyze and assess the environmental impact of any system, including lighting systems. In recent years, many LCAs have been published to compare and study different cases of lighting technologies [6]. All research has recognized that LEDs have the least impact on the environment due to their low energy consumption. However, opinions still diverge when it comes to comparing smart lighting systems and traditional systems. This difference comes from the variety of parameters and usage scenarios [7] that must be taken into account when performing an LCA, such as the country of use, the type of use, and the quality of the different components of the system, both in terms of lifetime and consumption. For example, the standby consumption of sensors in lighting systems or in other sectors is rarely considered. However, it has been shown that this consumption greatly affects the environmental footprint of the entire system [4]. For example, in the EU it has already been proven through LCA for a study case of a residential

use that systems that integrate sensors with a standby consumption higher than 1W, needs an unrealistic reduction in usage time to achieve an environmental impact equivalent to that of a traditional LED luminaire.

D. *Sensors in smart lighting systems:*

Thanks to the integration of multiple sensor technologies, lighting systems have undergone a transformative evolution. These sensors are the backbone of intelligent lighting fixtures. Passive infrared (PIR) occupancy sensors have a critical role in detecting human presence and enabling the automation of on/off switching to avoid unnecessary lighting for unoccupied spaces [8]. Photometric sensors measure existing light levels in order to provide intelligent dimming and color temperature adjustments for optimal visual comfort [9]. Spectral sensors have the capacity to detect color temperature to allow adaptive lighting that mimics natural circadian rhythms in order to improve physiological and psychological well-being [10].

III. LIFE CYCLE ASSESSMENT:

An environmental impact assessment was performed to compare the difference between ultra-low standby power sensors in LaaS and normal budget sensors for three different smart system configurations.

The first one is a hub with two detectors per 8 lamps. This setup provides a centralized control system that is easily integrable with the smart home environment. It allows remote access and firmware updates for the system to keep up with the latest features, offering flexible expansion options, which is good for future scalability. However, this configuration has a number of drawbacks: it consumes the most standby power and is the most expensive compared to other setups. The hub is a single point of failure that may cause the whole system to malfunction in case of its failure. Besides, it requires a stable network infrastructure to function efficiently.

The second configuration have two non-included sensors for each 8 lamps. This setup is designed to be energy-efficient, with very low power consumption when not in use. It's easy to set up and works without relying on any network infrastructure, making it an affordable choice. Since it doesn't require a central hub, it's also more reliable as there's no single point of failure. However, it does have some drawbacks. It lacks advanced smart features and remote access, which may limit its integration with modern smart home systems. Additionally, its limited customization options and the need for manual programming can make it less intuitive and more time-consuming to use.

The third configuration require one included sensor for every lamp. This setup is an excellent choice for energy efficiency, as it uses the least amount of standby power. With simplified wiring and the fact that the sensors are built directly into the lamp, it's both reliable and cost-effective. However, it does have some limitations. Without centralized control or smart features, it doesn't offer the flexibility of more advanced systems. The detection patterns are fixed, meaning you can't easily adjust them to suit your needs. Additionally, because the sensors are integrated

during manufacturing, upgrading or retrofitting the system later on can be tricky.

A. Configuration 1:

The consumption for the ultra-low stand-by sensor is $1 \mu\text{W}$ compared to 0.5 W for the normal budget sensor and the consumption for a high-quality Hub is a 1.5 W with 50 ports compared to 1.5 W for only 10 ports.

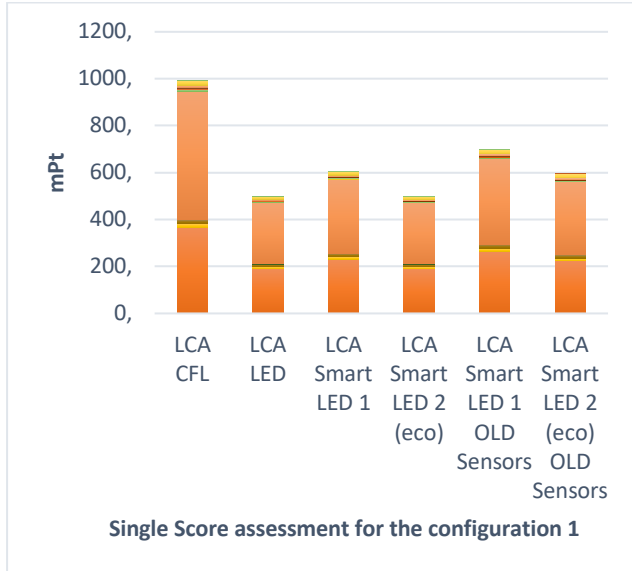


Fig. 1: Single Score assessment for the configuration 1

Fig. 1 shows that with an acceptable reduction in usage time, this configuration still achieves a slightly lower environmental impact than traditional LEDs, while retaining all the benefits of smart features, such as remote access capability, easy integration with smart home systems, and centralized control. However, the integration of old or entry budget sensors will give a higher environmental impact than the traditional LED fixture.

B. Configuration 2:

The consumption for the ultra-low stand-by sensors for this configuration is also $1 \mu\text{W}$ compared to 0.5 W for the old sensors and there is no hub integrated.

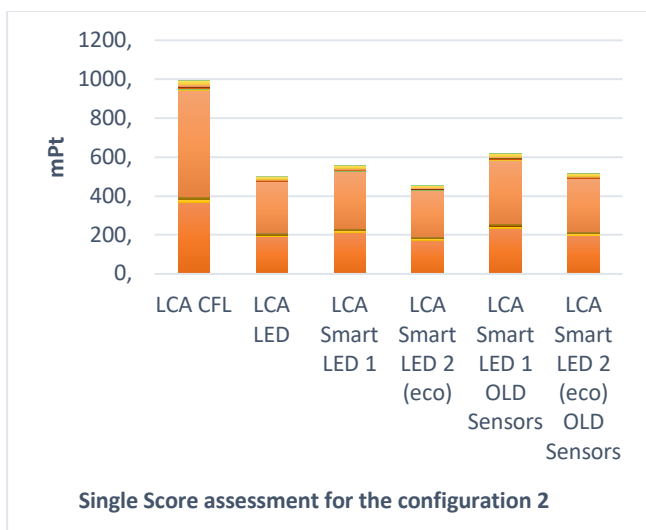


Fig. 2: Single Score assessment for the configuration 2

The Fig. 2 shows that using non included sensors of an ultra-low stand-by consumption will keep the overall environmental footprint lower than traditional LEDs. However, with reasonable reduction in usage time, old sensors will still keep the full system impact higher than a traditional LED.

C. Configuration 3:

There is only one sensor included in the lamp with $1 \mu\text{W}$ for the new sensors compared to 0.5 W in stand-by mode for the old ones.

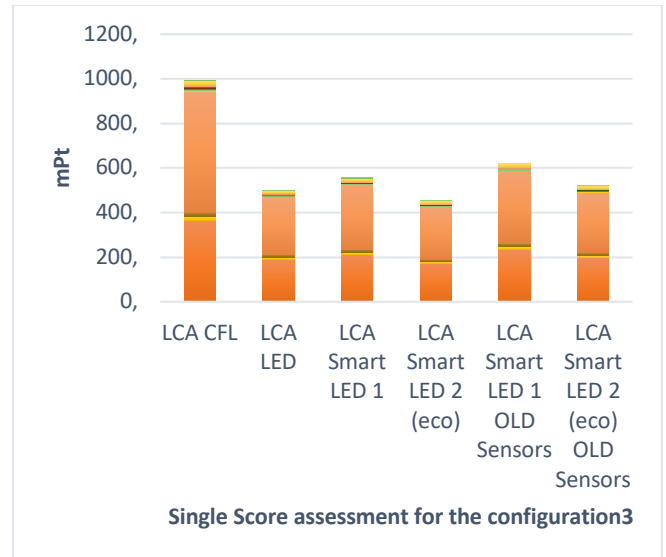


Fig. 3: Single Score assessment for the configuration 3

Fig. 3 shows that even for the configuration where sensors are included in the fixtures which usually are the less impacting, old sensors system still slightly higher than traditional LED system while the ultra-low stand-by consumption sensors keep the system at the lowest environmental impacts.

D. Reduction in usage time:

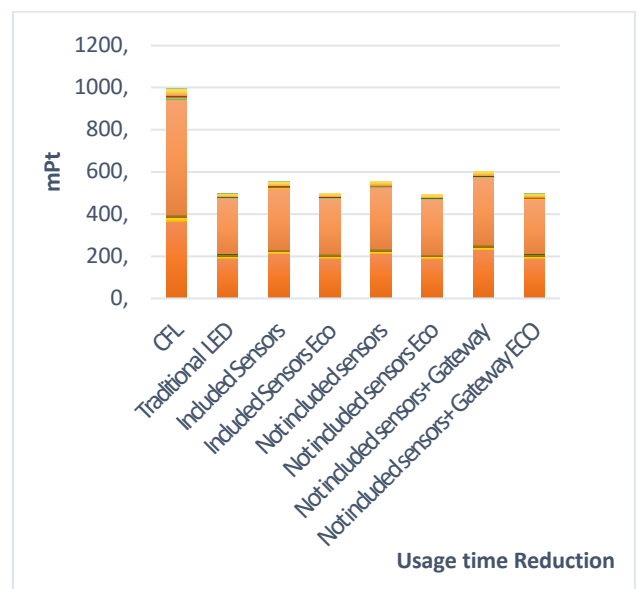


Fig. 4: Usage time Reduction

Fig. 4 shows the reduction time needed in order to get similar impact to a traditional LED system. In general, the usage time for a traditional LED in a residential case is about 2.7 hours. The reduction time needed for included sensors configuration is about 0.25 hours. The reduction time needed for non-included sensors in configuration 2 is about only 0.3 hours to get similar environmental impact. The reduction time needed for the configuration 1 with the hub and the 2 non-included sensors needs 0.5 hours reduction time in daily usage to reach the same impact as a traditional LED which is reasonable and can be reach.

IV. CONCLUSION

To conclude, the impact of LaaS largely depends on the quality and efficiency of its components. From an environmental impact perspective, the quality of the sensors is as important as the LED itself.

The impact of sensors, especially the impact of sleep mode, is generally overlooked in most fields, especially in the building sector. However, it has been proven that it can significantly increase the environmental impact of the sensor system if not carefully chosen and evaluated.

In the context of lighting, it is very important to consider a reasonable reduction time of use to be able to evaluate the correct impact of the sleep mode of the sensors

The LaaS model offers the possibility to invest in high-quality sensors and LEDs through a monthly payment instead of paying the full cost of the infrastructure up front. The impact of the smart lighting system is thus lower than that of the traditional lighting system.

The environmental impact of the configuration with sensors included and the configuration with sensors not included are quite close. However, the configuration with a gateway and sensors not included has a higher impact but offers more comfort to the user thanks to different lighting services.

In case high quality components are used, the impact of the traditional lighting system is the worst, which means that the environmental cost of the comfort offered by the first configuration can be evaluated by comparison with other configurations of intelligent systems.

The life cycle analysis of the lighting system also depends heavily on the case study. The usage time and the different scenarios differ between public lighting, residential lighting and tertiary lighting

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