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Life Cycle Assessment of a Circular Economic Model for Street Lighting

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Abstract— This work examines the transition to a circular economic model of public lighting through a new concept thinking lighting as a service. This completely changes the way street lighting is marketed today and is expected to lead industries towards a better manufacturing approach based on high efficiency and sustainability. In this context, it is possible to address elements such as contractual guarantees on product performance, service and maintenance models, as well as incentives to encourage sustainability and reuse of products. Industrialists must be then more committed to providing more sustainable maintenance to guarantee the best possible operation throughout the life cycle of the lighting system, which will give more value to the product not only through service sales but also through the guarantee of optimal operation. In this model, the manufacturer who provides this service must also be responsible for recycling the product in its end-of-life phase like the management of non-recyclable waste, etc.

To highlight the assessment of the environmental impact of this new model compared to the traditional street lighting ones, we used a life cycle assessment tool by integrating parameters on degradation, recycling, the economic model lighting as well as taking into account the energy mixes of different countries which concern the environmental impact. This study highlights the potential benefits of a transition towards circular business models in the lighting sector, while highlighting the challenges and opportunities for stakeholders in the street lighting sector.

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

I. INTRODUCTION

In a world where resources are finite and the waste treatment and recycling is very limited, the regular production model becomes more dangerous as natural resources become scarce and the search for an alternative model to preserve the resources and detract waste become an obligation [1].

As production and industrialization grow, the impact on the environment of linear economy grow and its limitation emerge such as high primary materials consumption and high waste at the end of the life of any product and in order to compromise between the industry ambitions and the environmental risk, the Circular Economy (CE) model has appeared [2].

Even though the CE model is not totally new, since it was proposed by Kenneth Bouldin's in 1996 as a closed system's idea to regenerate finite resource and then evolved by Rogge and Reichardt (2016) as a transition from ownership to service models [3].

The purpose of this paper is to study the CE model for public lighting and the benefits of transitioning from owning lighting product to renting them as a service, taking into consideration the benefits of this model but also the difficulty that opposes the adoption of CE. Also, a life cycle assessment using SimaPro and Ecoinvent will be used to compare the impact on environment due to changing in quality of Lamps in CE compared to the lamps usually used in linear model that usually sacrifice efficiency and reliability to much low budget, especially that the initial price for public lighting system may be relatively high, and the higher the efficiency and the quality of the luminaire the higher the initial investment would be.

II. CIRCULAR ECONOMY

A. Comparaison between CE and Linear Economy

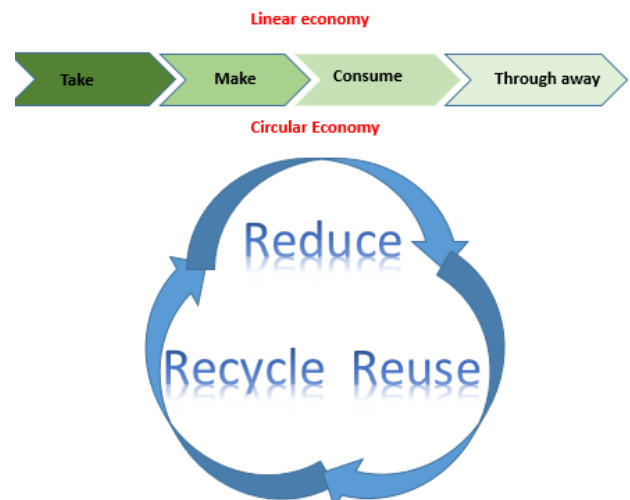


Fig1: Circular and Linear Economy

The circular economy reorients current ways and methods of production and consumption towards a

restorative and regenerative design. The circular economy considers opportunities to keep materials and resources in use for as long as possible, rather than following a linear "take, make, throw away" [4] economy model. Product design in CE, is made in such a way as to maximize the reuse and recycling of products, the 3R also called "Reduce, Reuse, Recycle" [5]. Therefore, this systemic approach, unlike the linear economy relying on limited resources and ravaging the environment in the process, certainly supports with resilience, the future growth.

B. LaaS: Lighting as a service

With rapidly evolving technologies and increasing pressure for sustainable practices, the concept of "Lighting as a Service" (LaaS) is emerging as an innovative and efficient solution. Traditionally, lighting has been viewed as an asset to be acquired, with very high initial investments for the purchase and installation of luminaires as well as maintenance costs, costly technology upgrades and energy inefficiency. LaaS stands out by offering an alternative based on the use of services rather than the possession of lighting system. In this model, users pay for the light provided rather than the lighting equipment itself. This approach is based on service contracts where lighting suppliers install, maintain and take care of the end of life of the luminaire. The result is a preference for efficiency and longer service life.

The idea of LaaS started rising lately due to various factors. One of them is that both companies and consumers become more aware of the environmental issues. Even though most companies will favorite making the most of money but having consumers that's think ecologically and cares about the environment pushes them to move towards more sustainable practices. Another factor is the quality of the lighting system provided by LaaS companies. The initial investment for high quality luminaires is expensive, particularly in the public lighting sectors, meaning that the high efficiency of these products will nevertheless offer both less environmental impacts and a significant energy reduction, which equates to a cost saving of use and overall cost for the complete life cycle of the lighting. Unfortunately, many consumers, like some town halls, perhaps do not have enough budget to start using these products that's why LaaS providers offer a financial flexibility by renting the luminaires and giving guaranties such as maintenance. The use of LaaS as a circular economy model promises economic, environmental and operational benefits, aligning performance and sustainability objectives.

C. Benefits of migrating towards LaaS

Migrating to LaaS offers many economic, environmental and operational benefits to modern businesses. Firstly, the initial cost is reduced due to a lower initial investment that would be required for purchasing lighting equipment. In addition, it becomes easy to maintain and save money in the long term, since the supplier is held responsible for maintaining and updating the systems, which contractually guarantees their optimal and uninterrupted operation.

The other benefit is increased energy efficiency, with LaaS providers more commonly using high-efficiency technologies to achieve features such as high-efficiency

LEDs, which save on energy consumption. Additionally, it will help reduce electricity utility bills. Such flexibility through LaaS will allow organizations to update their lighting solution as requirements and policies change without significant additional costs.

Migrating to LaaS is an interesting option for most companies to reduce their consumption, optimize their energy consumption and contribute positively to sustainability while obtaining high quality light in scenarios adaptable to their needs.

From an environmental point of view, LaaS can thus promote the use of sustainable lighting solutions that support the recycling and reuse of elements in order to reduce both waste and carbon footprint and the initial need for primary materials. Often, they combine advanced technologies to better control light consumption by using features such as motion sensors, lighting management systems and improving lighting comfort, which otherwise could waste energy and can consumes more energy than traditional lighting [7]. It's in the direct interest of the service provider.

Finally, LaaS contracts protect users thanks to elements mentioned and signed such as:

- Professional evaluation and design services to determine the most effective lighting solution according to the client's needs.
- Complete installation services, including removal of old fixtures and installation of new energy-efficient lighting systems.
- Flexible payment options, often structured as a subscription or rental model, to spread the cost over the term of the contract
- Ongoing maintenance and support services to ensure the lighting system operates efficiently and any issues are quickly resolved
- Periodic upgrades or replacements of lighting fixtures and components to ensure the system stays up to date with the latest technology and energy efficiency standards
- Assurances regarding lighting system performance, often including energy savings guarantees and performance measurements over the whole contract period.

D. Difficulty of migrating toward LaaS

The idea is that the company should no longer base its objectives on volumes, but on quality and the quest for smooth revenue streams [8]. Despite its many benefits, migrating to lighting as a service (LaaS) has its drawbacks, which a business must evaluate. The first is dependence on the service provider. By outsourcing lighting, businesses become dependent on the performance and reliability of the service provider. Any outage or service interruption can directly affect their operations.

The long-term cost could be higher. Even though the initial costs are low, the sum of the monthly payments for lighting services can, in the long run, exceed the purchase and support of traditional lighting systems. Therefore, the long-term financial implications of switching to LaaS

should be considered and well calculated by an expert if saving money comes first.

Sometimes LaaS offers intelligent lighting systems integrated into their solution which collect data on space usage and occupant behavior in certain cases. An issue that affects consumer privacy, and rental companies must ensure compliance with data privacy and security standards to protect consumer information.

In addition, in the event of an unforeseen breakdown, the service provider may not react quickly and may not respect the terms of its contracts and this may hamper the good work of consumers.

III. LIFE CYCLE ASSESSMENT (ISO 14044)¹:

An environmental impact assessment was done to compare the difference between high quality lamps used in LAAS Model and the traditional lighting Lamps. The different Data for the lamps are presented in Table I.

TABLE I. CHARACTERISTIC OF LAMPS USED

	Lampe N1 (LaaS)	Lampe N2 (Normale)
Reliability	0.98	0.90
Efficiency	0.95	0.85
Lifespan (hours)	60000 h	60000 h

The results are done using as a functional unit megalumen hour and France energy mix with nearly 63 % nuclear energy and 11 % hydraulic energy. With wind and solar energy, France has a total of 86.5 % non-carbon energy production [6].

Even though this parameter is very significant in life cycle analysis [7], the purpose of the paper is to compare the impact of the quality of lamp independent of the country.

A. Impact of improving reliability

The impact of increasing the reliability will affect only the materials, packaging, transport and end of life treatment but it will not impact the usage part of the life cycle.

In Fig. 2 it's shown that an impact of almost 6% over almost the 18 indicator is decreased due to the reliability improvement, however this only apply for phases other than usage which does not have that much of an impact on the overall cycle assessment since the majority of LED impact come from energy usage [9].

The Fig. 3 shows the impact of reliability in the hole life cycle including the using phase, the impact of the three lamps become pretty equal since the biggest percentage of led impact come from the usage phase.

We can stay that increasing the reliability may have small impact but depending on the cost of this optimization it may not be the best thing to do from the perspective of the industry providing the LaaS service.

B. Impact of improving efficiency

It should be noted, however, that the life cycle associated with system reliability is not mentioned in ISO 14044, although it is in the experimental standard XP X30-901: Circular economy - Circular economy project

management system. Plot in Fig. 4 shows the variation of single score impact of the LED while increasing the efficiency of the lamp used in the LaaS. In the figure 4 LaaS lamp was taken as a reference that's why it does not variate with increasing efficiency while the traditional lamp increases its impact due to the functional unit used. Even through the efficiency impact only the usage phase, we can see from figure 4 how the overall impact gape between LED using LaaS method and improving efficiency and traditional LED.

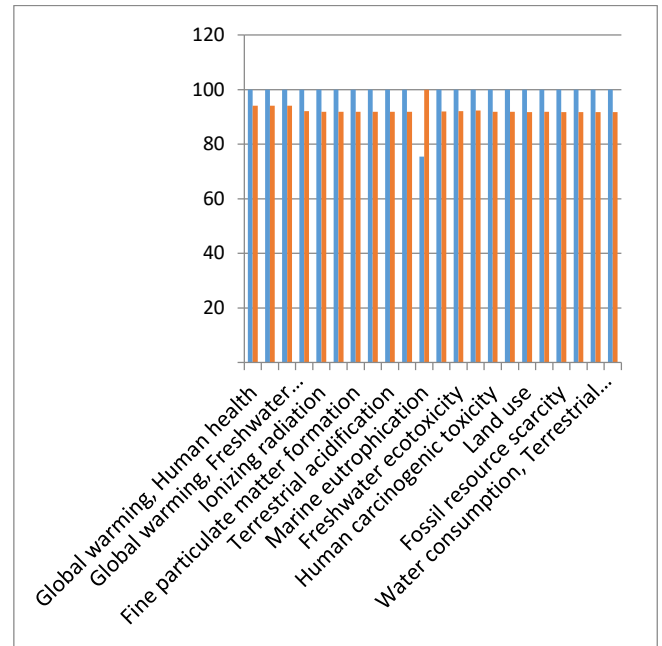


Fig 2. Environnemental potential impact using Endpoint characterisation method for France (In Blue, no LaaS LED, in orange, with LaaS LED).

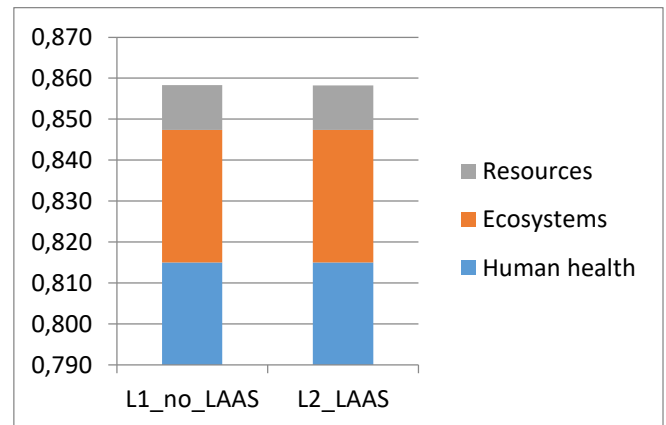


Fig 3. Environnemental potential impact using Endpoint single score method for France

¹ ISO 14044 :2006 Environmental management – Life Cycle Assesment

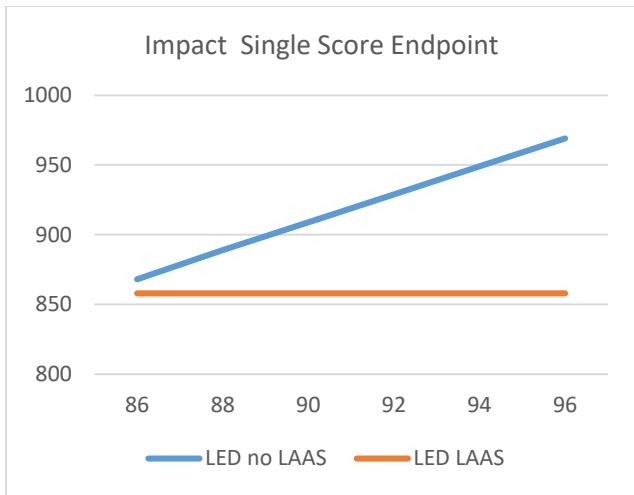


Fig .4: Impact of LED in function of Efficiency using Endpoint Single Score

Figure 5 shows the 18 indicators impacts for both lamps when the efficiency of LaaS LED is at 96% and the efficiency of traditional LED is at 85%. There is a difference of almost 14% over all the impact.

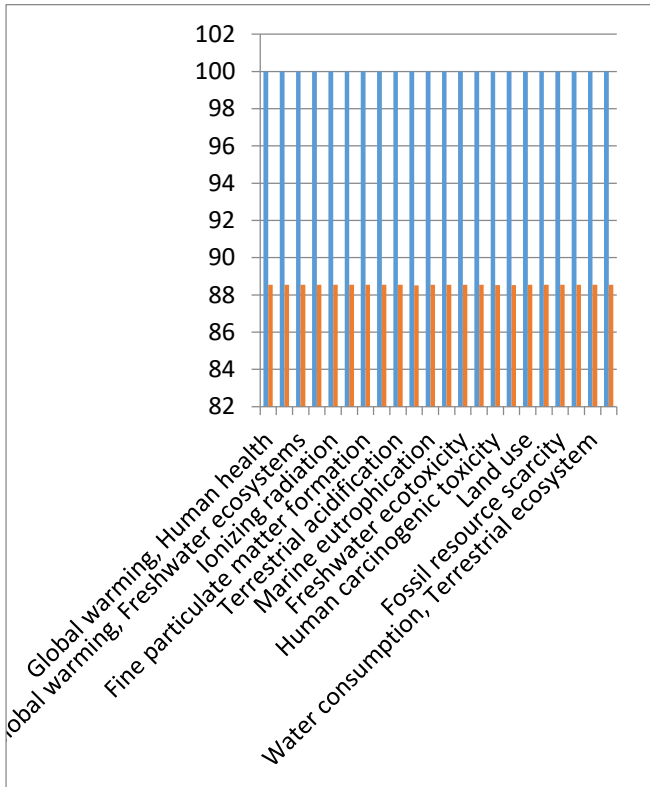


Fig .5 Comparaison of environnemental impact for both led using ENDpoint characterisation (Blue, no LaaS LED ; Orange, LaaS LED)

Having this much difference in environmental impact when improving efficiency is both interesting for the provider of the LaaS service and the user since the percentage difference is clearly worth the investments from an ecological perspective.

C. Impact of country's energy mix

For this part we will study the impact of traditional lamps and LaaS lamps taking into account the difference between the French energy mix based on the production of nuclear energy and renewable energies and the American energy mix which is based on 33% gas natural, 36% oil, 10% coils, 13% renewable energy and only 8% nuclear energy [10].

Figure 6 shows that even for the US mix, the LaaS lamp remains less impactful than the traditional lamp. However, by also analyzing the environmental indicators between the American and French mixes, the use of LEDs both traditional and in LaaS has a strong impact on global warming. The use of LEDs in the French mix also seems to have a significant impact on the scarcity of mineral resources and ionizing radiation. Using the SimaPro process contribution section, these two high impact indicators are caused by uranium production as well as uranium mining.

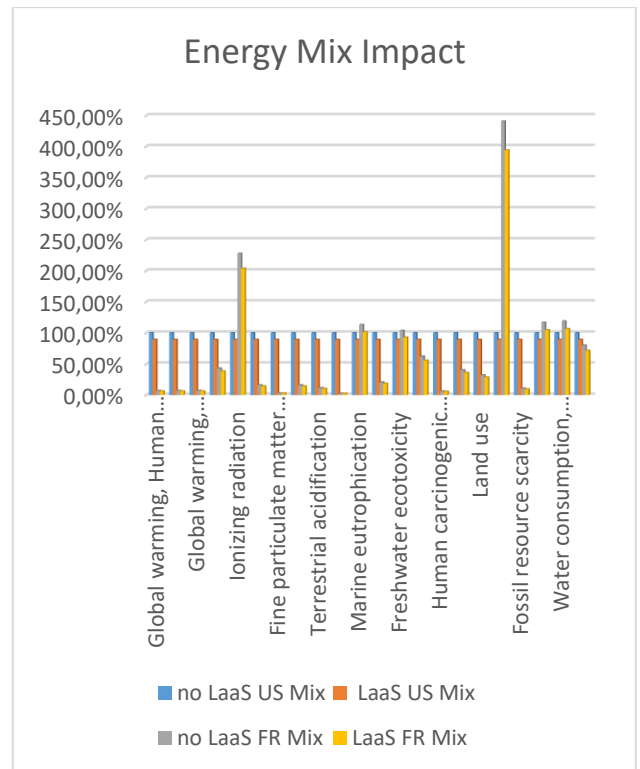


Fig .6 Comparaison of environnemental impact of energy mix in US and French on both LaaS and traditional lamp for

IV. CONCLUSION

To conclude, improving the quality of luminaires provided by LaaS is very important. The full impact of lighting, at every stage of the system's lifecycle, is borne by the supplier. The lessor of the service only bears responsibility for consumption. The supplier has an interest in low LCA impacts associated with a long service life that minimizes costly exchanges. The principle is to integrate constraints into the design specifications upstream of the lighting project. As a reminder, Eco-design is a key approach to a company-wide circular economy strategy, based on the identification of significant environmental

impacts. It aims to generate new concepts and develop low-impact product-service systems, designed with a view to their recyclability, repairability or durability. Even though as shown above increasing reliability may not be very impacting in term of environmental impact but it's still necessary for two principal reason, the first one would be that for one indicator which is the marine eutrophication is very impacted by production which means, less reliability equal higher marine eutrophication impact, and the second reason is that having less reliability can causes more cost for the providers of LaaS which can lead to either projects failures or to more fees for the consumers and also it causes higher probability for breakdowns that both causes maintenances fees and perturbation for the consumers and their non-satisfactions.

As for the efficiency, it is for sure a very important factor to improve and to consider when both providing or subscribing for a LaaS model, since high efficiency luminaires have a lot less environmental impact over the hole life cycle of the lighting system but it also provides economic benefits such reducing the cost of electricity bill.

Still a deep study is needed before switching to LaaS depending on both the needs and also the service provided and the terms of contracts. In the case of using some intelligent layers such as sensors and motion sensors this may cause both extra environmental impacts both in production and usage phase such as hidden electricity usage in Standby mode.

Consumers need to ensure that the LaaS providers respects the efficiency of their lighting system, declare it in the contract and then monitor and make a follow-up from time to time throughout the duration of the contract.

These primary factors studied looks in favor of moving to LaaS model however it's very important to study other factors such as country electricity mix which may affect the LCA results, also the waste treatment and the recycling processes for the country where the transition to LaaS model may happen since these two processes are pillars of the 3R in circular economy.

The purpose of this paper is not to confirm the transition toward LaaS model or to refuse it, but to point to the benefits and the disadvantages offered by this model and also the impacts on environment due to quality improvements in LaaS process in a case study while also mentioning what other condition may affect the results such as the added layers in some intelligent system or the additional cost that may be applicable, the country energy mix, the other characteristics of the luminaires and the dependency to the provided.

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