LUCIA

LIGHTING THE BALTIC SEA REGION

LUCIA COMPENDIUM vol. 1

Sustainable and Smart Urban Lighting

Interreg
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Sustainable and Smart Urban Lighting

LUCIA Consortium

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FOREWORD

The importance of city-to-city collaboration

Urban lighting, as a tool for social, cultural and economic development, contributes to building sustainable cities. For close to 20 years now within LUCI, the international network of cities on urban lighting, this has been widely acknowledged by more and more stakeholders across the world. Core functional lighting has progressively given way to a variety of lighting applications and we regularly find new perspectives on the use of lighting for public spaces, for social cohesion, for health and wellbeing, for art and culture in the city.

Much still needs to be explored to unleash the vast potential of urban lighting, as today there is yet again an extraordinary expansion of the urban lighting field with the development of smart lighting technologies. With ever-increasing rapid developments in the field, it is an immense challenge for cities to develop a strong vision of what is desirable and what is needed at a societal level.

City-to-city collaboration, cities working together with their partners on urban lighting, are the keys to a better understanding of urban lighting, and ultimately will contribute to solving one of the most pressing challenges of our time – the energy and climate crisis. In this regard, the improvements in efficiency, adaptability and connectivity of lighting are major breakthroughs, but they should not exclude a broad analysis of systemic impacts for cities and their citizens in terms of data management, privacy security, total cost of ownership, environmental negative externalities, etc.

The *Lighting the Baltic Sea Rwegion* project ("LUCIA") and this first volume of the Compendium are much needed for urban lighting stakeholders. We concretely see how city-to-city collaboration brings added value to a field of practice. With this very comprehensive set of information, practice-oriented examples, lessons learnt on a wide range of topics from urban lighting technologies to essential lighting economics and green procurement of smart lighting, going through environmental and societal impacts, this Compendium serves at least two important purposes.

First, it can be a quick introduction and guidebook with numerous further references, enabling a better understanding of urban lighting and its new developments. Second, it will help policy makers be inspired by what is possible, desirable and needed and will assist in the decision-making process in cities. This is of course true for cities in the Baltic Sea region, but also in the rest of Europe and the world.

In LUCI, we look forward to the further results of this project including the innovative solutions developed in pilot sites, their results and lessons learned.

As we work together in new projects and new collaborations, together we can help urban lighting reach its full potential, and ultimately help enhance quality of life for all.

Mr Hak Jin KIM
President of LUCI
Vice Mayor of Seoul

LUCI (Lighting Urban Community International) is the international network of cities on urban lighting. Created in 2002 at the initiative of the City of Lyon, today, LUCI is a non-profit organisation bringing together over 70 member towns and cities worldwide that use light as a tool for social, cultural and economic development. It also includes over 40 associated members from the lighting industry, design agencies and research institutes.

FOREWORD

Realising innovative ideas in European projects

Hamburg being a port and trade city has always been deeply marked by the positive results of international cooperation. We have learned over the centuries that international cooperation is often a significant source of inspiration. In the best sense of our Hanseatic tradesmen tradition we know that this exchange has clear and durable positive effects on us as well as on our partners. Therefore we appreciate to work closely together with European partners within European projects.

Even though Hamburg has no direct access to the Baltic Sea it has always felt closely linked to the region. Today, Hamburg project partners are participating in the Interreg Baltic Sea Region Programme with great success. Together with our European friends we are developing projects in order to realise innovative ideas. The LUCIA project demonstrates very clearly the success of bringing relevant actors together in order to achieve remarkable and locally visible results, creative and interdisciplinary.

I am very glad to see that LUCIA is absolutely in line with this approach. The solutions here and in all partner cities are not only technological but have achieved something special – as result of the European cooperation. The trustful interdisciplinary work was devoted to the topic of "public lighting" and demonstrated the fruitful effects of leaving and overcoming traditional perspectives and showing a comprehensive work.

Here in Hamburg at the local pilot area, Schroeder's Elbschloss-Tunnel, an almost forgotten infrastructure for many years, has been given a new life – and it looks great. For this I would like express my sincere gratitude to all those involved, the Borough of Hamburg Altona, our state companies and all partners involved in the LUCIA project.

I should like to encourage you to continue to initiate new European projects.

Yours,

Almut Möller
State Secretary, Free and Hanseatic City of Hamburg

FOREWORD

Inspire people…

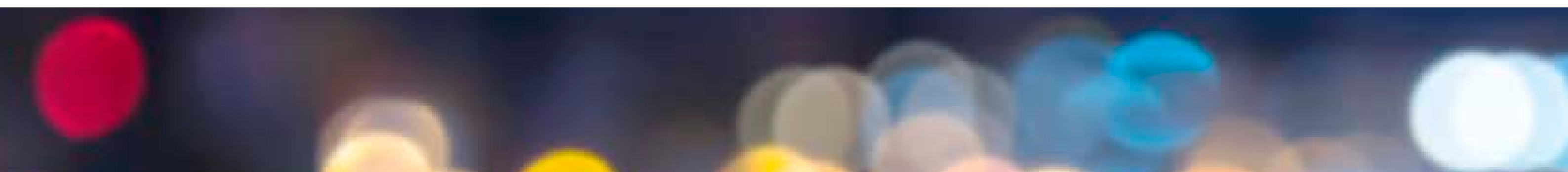
Public lighting is nowadays a complex issue and can't be simply reduced any more to "bulbs" and "cables". Many facets are responsible for much more than just putting a simple bright spot onto the ground. Currently the Borough of Altona leads four different EU projects, including LUCIA that contributes to the development of liveable places as well as bridging subjective/objective safety with a high demand to avoid light pollution at the same time. In other words like "two hearts beating as one".

Altona is well known for its diversity and richness of people and cultural life. We actively take responsibilities for our both citizens and the environment. At the same time overall global goals such as the UN-SDGs (Sustainable Development Goals) need to be kept uppermost in mind. In this sense a true but very simple sentence hasn't lost its general meaning: "Think global, act local". Because of this we, as a LUCIA Lead Partner, strongly support all activities to unleash fruitful knowledge which we can already explore in this Compendium.

The LUCIA project bridges expertise on latest technology of public lighting and focuses on smart urban daily life. We understand that the environmental and social justice reach out for global aspects and should be a core aspect of each modern public lighting system on local level for our municipalities. Fostering a new decade of a much broader understanding of public lighting contributes highly to reduce overall complexity. Accordingly we really need to inspire people to participate in their local community and to find the balance between taking care of the environment and the people.

Warm regards,

Dr. Stefanie von Berg
Mayor, Borough of Altona



Contents

Preface

Urban lighting (e.g. street and architectural lighting) plays a central role in the design of cities. Municipalities around the world are increasingly looking for new lighting solutions that can address opportunities such as increasing citizens' satisfaction (improved comfort, reduced road accidents, increased sense of safety), boosting city and regional attractiveness (more visitors and businesses), achieving energy savings, being a "smart city", etc. At the same time, municipalities must be aware of – and be prepared for – the related challenges and pitfalls such as selecting suitable technologies, light pollution, costs and economy, etc.

The Interreg project LUCIA *(Lighting the Baltic Sea Region – Cities accelerate the deployment of sustainable and smart urban lighting solutions)*[1] has been initiated in light of the above opportunities and challenges. The LUCIA project aims at helping municipalities (in the Baltic Sea region) to unlock the enormous potential of smart, energy efficient urban lighting solutions. The project provides decision makers and experts with state-of-the-art lighting knowledge, covering aspects of environment, technology, economy, social acceptance, urban planning and green public procurement.

This document is the first volume of the LUCIA Compendium; it focuses on sustainable and smart urban lighting, i.e. it introduces the findings, recommendations, and tools that have been identified or created during the first phase of the LUCIA project. Chapter 1 provides a motivation for deploying sustainable and smart urban lighting solutions, highlighting the benefits in terms of people satisfaction, energy savings, environmental protection, business development, etc. Chapter 2 focuses on what should be known about smart lighting technologies (e.g. control, metering, reliability, power quality, etc.), i.e. how they work, what is possible today, their advantages, drawbacks, and pitfalls to avoid. Chapter 3 covers the economic aspects such as economic strategic planning, finance and delivery models, life cycle assessment, multifunctionality and business models, and the economic calculation tool developed in the LUCIA project. Chapter 4 focuses on how to get lighting tendering processes more sustainable, in particular focusing on Green Public Procurement and how to raise awareness of this within municipalities. Afterwards, Chapter 5 looks at the societal acceptance aspects, including but not limited to lighting strategy[2], light pollution and biodiversity, darkness preservation, vandalism, and private sector cooperation. Chapter 6 serves as a "putting it together" recipe, i.e. how to integrate the above into an actionable plan, covering issues related to co-creation, cooperation structures, planning processes, etc. Finally, concluding remarks, references, and further readings end this first volume of the LUCIA Compendium.

The information provided in this Compendium is the result of the activities undertaken by the various organisations participating in the LUCIA project; may their respective individual contributors be warmly thanked.

1 https://www.lucia-project.eu/
2 See Chapter 5 for more details on lighting strategy vs. lighting master plan vs. lighting hierarchy

Chapter 1. Urban Lighting for Smart People

Is your city looking for solutions to increase comfort, reduce energy consumption, or improve the protection of the environment? If yes, let's consider how smart urban lighting can help achieving these goals and increase citizens' satisfaction.
Indeed the value of light to society is increasing, ranging from energy efficiency, sustainability, and wellbeing.

But what does this mean in practice?

Let's look at a few practical examples to get a better understanding.

Copenhagen in Denmark is a prime example of a smart and sustainable city. In order to achieve its goal of becoming carbon neutral by 2025, the city embarked on substantially reducing its energy consumption from street lighting. To do so, almost 20,000 street luminaires, mostly based on high-pressure sodium lamps, have been replaced by more energy-efficient LED-based luminaires (see Figure 1). In addition to improving energy efficiency, the city also wanted to exploit secure wireless lighting controls to further increase energy savings, enhance safety, and improve comfort and lighting quality.

A central management system has been created for managing and controlling street lighting. The road lighting is connected through a wireless control system allowing the functionalities of the luminaires to be used for smart lighting management, e.g. based on daylight levels, and in turn for energy efficient operation, holistic monitoring, and planned maintenance intervals. Another aspect for achieving smart lighting was the integration of lighting control with traffic density data so that lighting levels can be adapted to road use, i.e. adapt the illuminance depending on traffic density and road situation, all while meeting safety requirements. The addition of sensors and cameras could be integrated to detect cyclists and guide them onto the quietest or fastest route.

Switching to LED-based luminaires yielded an energy consumption reduction of almost 57%, not only decreasing the CO_2 footprint but also maintenance expenses [1]. In numbers this means saving 7.3 GWh per year, i.e. more than 12 million DKK (1,6 million Euro) [2].

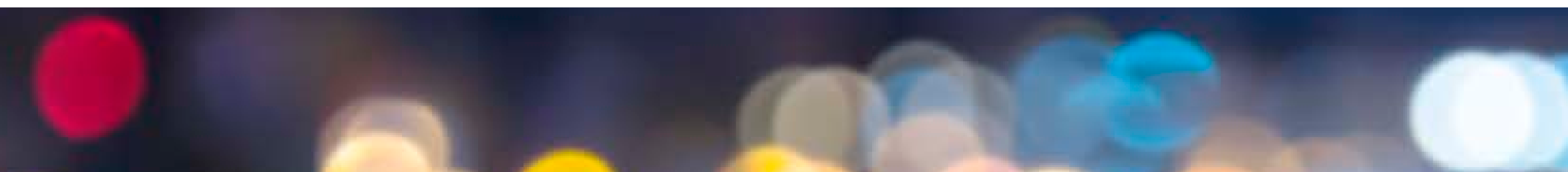


Figure 1. LED-based catenary luminaires in Copenhagen.

Consider another example: Župa Dubrovačka in Croatia. This municipality situated in the southeast of Croatia on the Mediterranean coast covers an area of approximately 23 km^2 and has a population of 6,663 people. In September 2014, the municipality introduced a sustainable energy action plan (SEAP) established as part of the Covenant of Mayors (COM) initiative. The SEAP provides the municipality with stronger leverage when they wish to implement a green public procurement (GPP) procedure.

By switching to an LED-based lighting solution, Župa Dubrovačka significantly reduced its energy consumption as compared to its previous street lighting system, where traditional high-pressure mercury lamps were used. The open tender was valued at ca. 180,000 Euro (excluding VAT). Using the GPP 2020 methodology, Župa Dubrovačka calculated the energy and CO_2 emissions savings, assuming a lifetime of 25 years. This calculation included the 686 newly installed LED lamps and showed that the new LED lighting solution only consumes 210,000 kWh and emits 64 tonnes of CO_2 per year, instead of 330,000 kWh and 100 tonnes of CO_2 per year previously. This corresponds to a reduction of CO_2 emissions from street lighting of 36%, i.e. saving an equivalent of 900 tonnes of CO_2 over a 25-year period. Not only this reduces the burden on the environment, but also yields savings of approximately 13,800 Euro per year at today's energy price (currently 0.115 Euro per kWh for street lighting); and this figure does not even include the savings made from the decreased servicing of the light fixtures. These key figures are illustrated in Figure 2. To balance comfort of the citizens and energy savings, the new LED-based solution is programmed in such a way that the lamps are switched on only when visibility reaches the legal minimum illumination level for street lighting; this is complemented by an automatic controller that regulates the power (wattage) and energy consumption in accordance with the intensity of natural lighting [3].

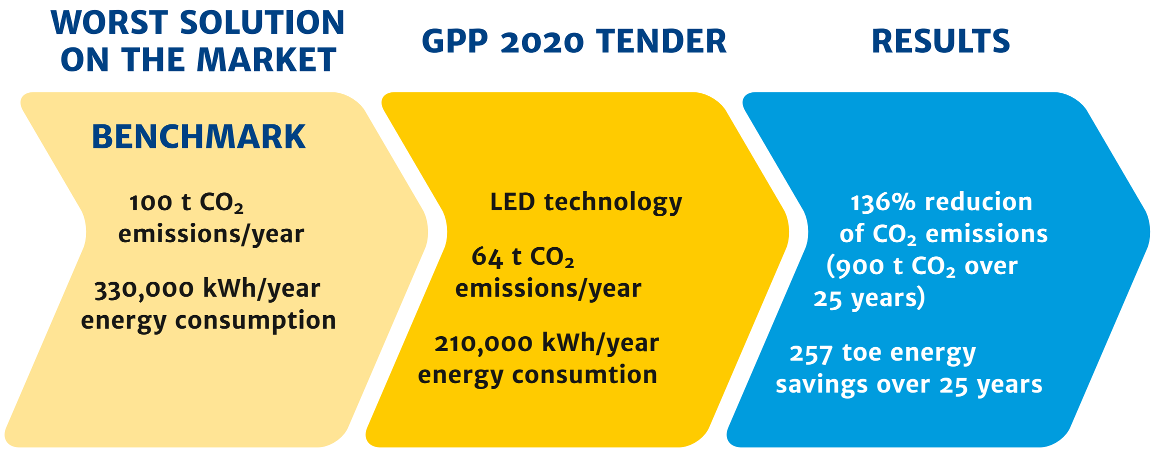


Figure 2. Key results of the LEDifcation process carried out in Župa Dubrovačka.[3]

On a larger scale, consider the city of Rotterdam (see Figure 3), the second largest city in the Netherlands with a population of ca. 610,000 inhabitants. Rotterdam's lighting plan has been in use since 2012. The main purpose of public lighting is to ensure traffic safety on the streets and community safety in the public domain. The city's lighting plan targets three specific ambitions of the municipal government policy:

1. to achieve a better design quality of both dayscape and nightscape in order to improve public space;
2. to achieve more efficient maintenance by introducing standardization in lighting equipment and poles;
3. to reduce energy levels and light pollution by applying technological innovations which contribute to sustainability on a citywide scale.

The city of Rotterdam issued a tender in 2012 to purchase standard lighting fixtures for the whole city, covering a period from 2013 to 2020. It is worth noting that the prices of the LED fixtures were almost identical to that paid previously for traditional light fittings but with significant advantages in terms of lighting, energy consumption, and social return. Energy savings depend on the deployment of the fixtures across the city; replacing existing sodium-based fixtures that have a higher energy consumption, the savings can be up to 35%. The contract value ranges between 8–10 million Euro, depending on the use of the fixtures and deployment. From 2012 (baseline year) to 2015, the street lighting's energy consumption decreased from 25.6 million kWh per year to 23.2 million kWh per year; this translates to a total saving of 1,262 tonnes of CO_2 [4].

3 Based on https://gpp2020.eu/fileadmin/files/Webinars/GPP_2020_webinar_street_lighting_-_UNDP_Croatia.pdf

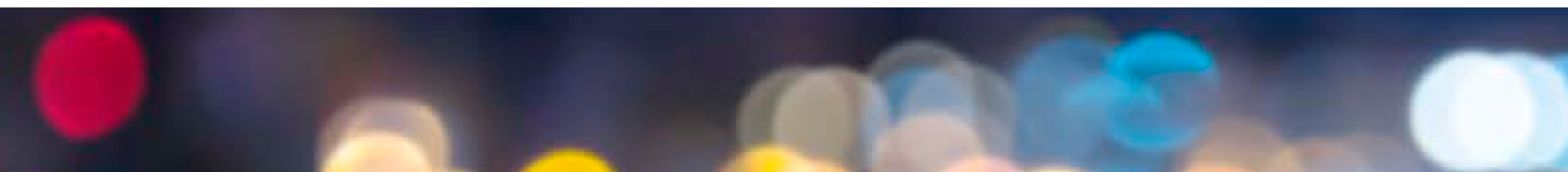


Figure 3. The city of Rotterdam at night.

As shown in the above examples, smart urban lighting offers tremendous opportunities in terms of people's satisfaction, energy savings, environment protection, etc. Implementing energy efficient lighting is also an essential element for cities to contribute to the Sustainable Development Goals (SDG).

At the same time, going from a strategic vision to action and ultimately to implementation raises many questions. For example, what do we need to know about the technology? Or about social acceptance? How to approach the economic planning? Moreover, reaching these goals requires urban planners not only to be well informed but also to work in the interdisciplinary field of urban development, i.e. remove the silos between different sectors and have a holistic mindset.

WHERE TO FIND ANSWERS TO SUCH QUESTIONS

Let's look no further than the next chapters of this LUCIA Compendium. One of the goals of the LUCIA project is to inspire and encourage urban and lighting planners and decision-makers to evaluate, adopt, and deploy smart urban lighting solutions in their municipalities. In order to make informed decisions, the remainder of this LUCIA Compendium provides knowledge, directions, and inspiration about smart lighting technologies, the economic aspects, how to make lighting tendering processes more sustainable, how to raise awareness of this within municipalities, social acceptance aspects, and "how to put it all together".

Chapter 2. Enabling Technologies for Smart Urban Lighting

While there is no universal definition of smart lighting, the Interreg North-West Europe SMART-SPACE project highlights some of its key elements [5]: i.e. enabling people to use and enjoy public space, providing the right light at the right moment, the right place, and with the right atmosphere, realising a higher level of wellbeing, integrating sensors and software controls, adjusting to the actual local needs, realising efficiency energy consumption.

As much as smart urban lighting is multidisciplinary in essence and focused on people, it would not be as smart and efficient as it is today without technological advances.

The primary goal of this chapter is to provide the essential knowledge to be taken into account when working towards sustainable and smart urban lighting.

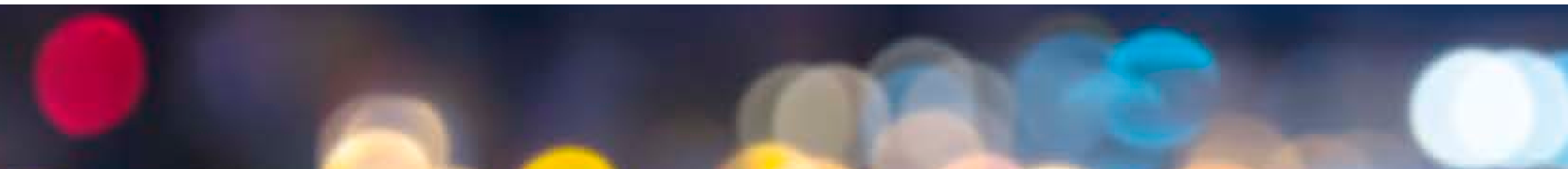
The selection of information presented in this chapter is partly based on the answers provided by the pilot municipalities[4] to a questionnaire prepared by the LUCIA project. The questionnaire dealt both with state-of-the-art technologies and GPP requirements. The analysis of the answers identified the need for more information about supporting technologies, reliability and failures, savings potential in terms of energy and CO_2 reduction, reduction of operation and maintenance costs, energy consumption indicators, free and pre-programming of dimming levels, metering issues, measurements for verification, and power quality issues.

Furthermore, an open online survey directed to municipal lighting planners and managers in municipalities of the Baltic Sea region was carried out in February and March 2020. It was answered by 84 respondents, representing mainly smaller (up to 20,000 inhabitants) and medium-sized (20,000–100,000 inhabitants) municipalities in Estonia, Finland, Latvia, Germany, Poland and Sweden. 85% of the respondents indicated that their municipality has converted less than half of its public lighting to LED technology (and only 5% indicated a convertion rate higher than half). In terms of energy savings, 80% of the respondents indicated that their municipality has installed energy-saving dimming systems during the last 3–5 years. Moreover, 57% of the respondents indicated that their municipality already uses, or plans to use, integrated and supporting technologies such as smart lamp posts and Internet of Things (IoT)-enabled smart sensors in the next 3–5 years. The survey respondents also assume that integrated and supporting multifunctional technologies require less maintenance, that reliability of the components is high, and that (long-term) contracts with technology providers cause less costs.

Information about these essential technological aspects has been compiled in the LUCIA state of the art report [6] and a collection of six technology factsheets [7] which are referred to in this chapter.

The chapter introduces the technological state-of-the-art, illustrating what is possible today, what are the advantages and drawbacks of various solutions, and what the common pitfalls are. The chapter includes a concise description of the evolution of electric urban lighting technology, some details about LED technology and available LED-based luminaires, smart control mechanisms, installation, maintenance, power quality and supporting technologies.

4 https://www.lucia-project.eu/pilot-sites/



2.1 A brief history of electric urban lighting technologies

While street lighting can be traced back to ancient times (e.g. oil lamp, torches) and has evolved over time (e.g. gas lighting), this section only covers the evolution of electric lighting solutions. The remainder of this section is partly based on [8].

It is generally agreed that the first electric streetlights were based on arc lamps also known as **Yablochkov candles**. Theses were first used in the second half of the 1870s in Paris, and then in London. Although improved differential arc lamp had been developed by Friederich von Hefner-Alteneck, arc lamps still suffered from several drawbacks, i.e. their strong and harsh light, limited lifespan, low energy efficiency; thus, they offered poor value for money as compared to gas lighting.

Next, in the early 20th century, the work of Thomas Edison's made that electric lights began to be competitive. Electrification of major cities took place whereby **incandescent lamps** progressively replaced gas lanterns.

Discharge lamps used in street lighting appeared the 1930s. They were composed of a tube and two electrodes. The tube contained mercury gas and was internally covered with a fluorescent powder; they also became known as **fluorescent tubes** and their wider adoption started in 1945.

In parallel, the first **sodium vapour lamp** appeared in 1932. Composed of a long light bulb, the passing of an electric arc in a medium rich in sodium emitted a yellow-orange light.

Fluorescence and sodium technologies had their pros and cons. Fluorescent tubes' colour rendering index was higher than that of sodium lamps, making it easier to perceive colours in a street at night, as compared to the monochromatic light of sodium lamps. On the other hand, sodium lamps were more energy efficient than the fluorescent ones, i.e. they provided more visible light for the same electric consumption. Moreover, their monochromatic light is much less dispersive in case of humidity and fog.

Next, the first metal halide lamps appeared on the USA market in the early 1960s. They used a combination of mercury and iodides of sodium. However, they produced a white light with pink hue; they were improved in the mid 1960s, emitting a bluish-white light. Metal halide lamps became widely used in public lighting from the 1990s, offering a range of possible shades of whites (cool white, neutral white, warm white) and increased lifespan thanks to ceramic burners.

Finally, we entered the age of **LED lighting**. Although the first mentions of LED can be traced back to the 1920s, the first commercially available LED appeared in 1962 (non-visible infrared light) and the mass production of visible light LEDs started in the late 1960s. After the development of red, yellow, red-orange LEDs, two major further advances were made: the high-efficiency blue LED and subsequently the key enabler for urban street lighting, namely the white LED. Although the first white LEDs were expensive and inefficient, their price has dropped sharply and their light output increased exponentially. Similarly, the quality of the light has improved over time; thus, the recent development of white LEDs gave them public visibility and they are now widely accepted as a replacement for other sources of white light.

2.2 LED technology and LED-based lighting

LEDs emit mostly monochromatic light. In order to use them a white light source, white LEDs are needed. This can be achieved in several ways, either by combining LEDs of different colours, or by using phosphors, as illustrated in Figure 4 [9].

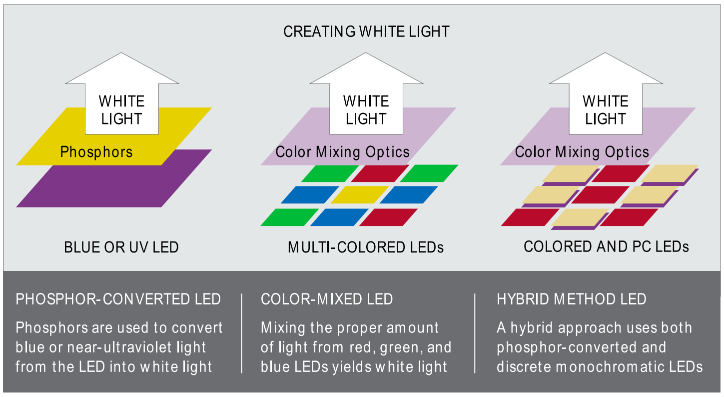


Figure 4. Creating white light with LEDs [9].

Compared to most other lighting technologies, LEDs have very high-energy efficiency levels, as shown in Table 1, where efficacy (an element of efficiency) is expressed as lumen per watt of power (lm/W) and life time in hours (h).

LEDs are highly energy efficient when measuring light output per watts of electricity input. The most efficacious LED lamps available on today's market operate at up to 150 lm/W. Since they use less power over the year, their operation is more eco-friendly than other solutions and thus contribute to reducing CO_2 emissions.

Not only LED lighting solutions require up to ca. 85% less energy than other options, their potential lifetime is also longer than that of other solutions. Lasting up to 5 times longer than other options, they do not need to be replaced as often.

LAMP TYPE	EFFICACY (LM/W)	LIFETIME (H)
Mercury vapour	13–48	12,000–24,000
Metal halide	60–100	10,000–15,000
High pressure sodium (HPS)	45–130	12,000–24,000
LED	70–150	25,000–60,000

Table 1. Comparison of efficacy levels and lifetime of the most common urban light sources, highlighting the competitive advantage of LEDs. Based on [10] and [11].

Nowadays, a significant percentage of HPS lamps, typically installed in the mid-1980s, have reached their end of life and must be replaced. LED-based lighting is more energy efficient and has longer lifetime as compared to its HPS (sodium-vapor) luminaire predecessor. LEDs also provide increased service reliability and lower maintenance costs, which translates into lower maintenance costs and fewer service vehicle trips, and in turn reduced carbon emissions [12].

Altogether, it is expected that the annual global electricity savings for lighting will reach 640 TWh in 2030, as illustrated in Figure 5 ([13], adapted from [9]).

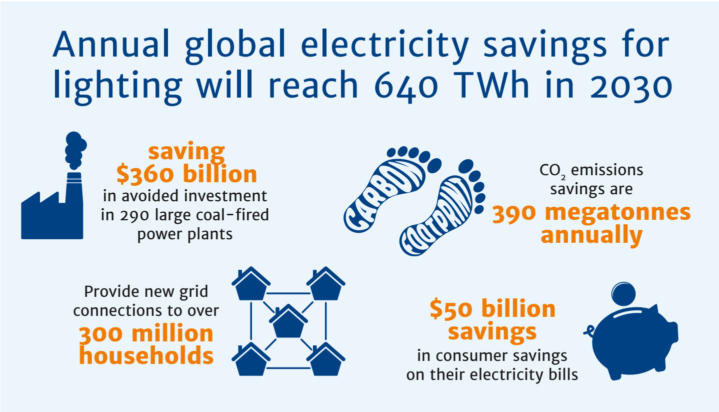


Figure 5. Annual global electricity savings from lighting will reach 640 TWh in 2030 [13] (adapted from [9]).

Given its many advantages, many municipalities around the world are converting to LED-based lighting (a process known as LEDification), both for economic and environmental reasons. However, LEDification has its own challenges. Among others, rapid innovation may lead to a vast product offerings and shortened product lifecycles, which not only increases natural resources consumption but also affects maintenance (e.g. reduced availability of spare parts due to phasing out earlier products). LED lighting promises long lifetime and lower costs assuming service and spare parts are available throughout the product's lifetime; if this is not the case, then the total cost of ownership starts to increase (see Table 2 for an overview of the pros and cons of LED lighting).

ADVANTAGES OF LED LIGHTING	DISADVANTAGES OF LED LIGHTING
Highest efficiency light Lowest running costs	Control gear (driver) required for operation
Long operating life – typically more than 20,000 hours High flux in a small package, good for optical control offering excellent colour rendering	Higher relative first costs (but competition is driving prices down)
Instant on, instant restrike, dimmable Contains no mercury	Needs good thermal design because waste heat is conducted, not projected

Table 2. Advantages and disadvantages of LED lighting (based on [6]).

Measuring energy efficiency

The key parameters for measuring energy efficiency according to EN13201-5 are:

- The luminous efficacy, expressed in lm/W;
- The power density indicator (PDI), expressed in $W/(lx \cdot m^2)$;
- The annual energy consumption indicator (AECI), expressed in $kWh/(m^2 \cdot y)$;
- The operational profile, hours the lighting installation is switched on for each day and at what percentage of full power it will operate at for each hour;
- The road profile.

Main requirements for tenderering

The EU GPP criteria can be found online ([14], see “Road lighting and traffic signals”). When preparing a tender, it is advised to provide a standard photometric file that is compatible with common light planning software and that contains technical specifications on the light output and energy consumption of the luminaire, measured by using reliable, accurate, reproducible and state of-the-art measurement methods relevant to international standards.

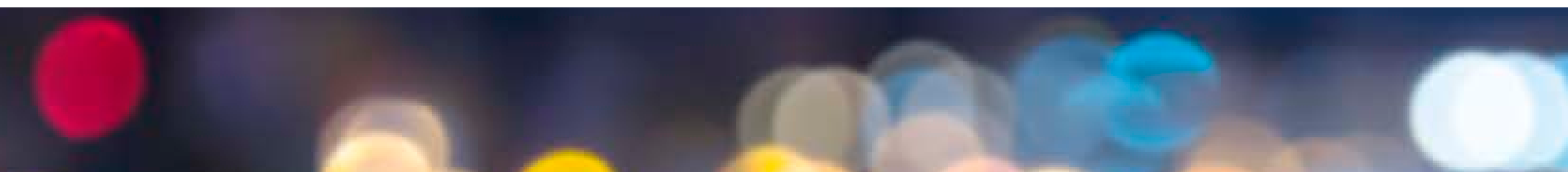
It is also required to provide a clear calculation, where the values for the luminaire efficacy, maintenance factor and utilance factor[5] of their proposed design are visible. The calculation results must include the measurement grid and calculated illuminance/luminance values.

Moreover, it is also required to provide the technical specifications of the metering and measurement system and to provide clear instructions for system operations and maintenance (O&M) of the system. A calibration certificate compliant with Measuring Instruments Directive 2004/22/EC shall be provided for each control zone.

Possible pitfalls of LED lighting

There can be negative consequences when using the most efficient, higher colour temperature LEDs. Cities that have used 4,000K or even 5,000K streetlights have faced important backlash from citizens (e.g. Seattle, Montreal) as the light is too white and harsh. Warmer 3,000K LEDs are considered as better options.

5 In this context, the utilance factor means the light utilization factor



Key takeaways related to LED lighting[6, 7]

- LEDs reduce energy consumption for street lighting by up to 60% as compared to conventional lamps.
- Dimmed LED lighting can reduce energy consumption by up to 85% as compared to other solutions.

2.3 Lighting control mechanisms

What to consider when designing a lighting control system?

Different control types and strategies must be considered case by case to ensure energy and cost saving of the street lighting systems.

There exist three types of lighting control systems [15], allowing adapting lighting intensity as needed (see Figure 6).

1. Autonomous control (calendar) in which the luminaires are pre-programmed with fixed periods for operation. This is by far the simplest and cheapest solution.
2. Centralised control where a central system sends the control signal to all luminaires within a group. The information flow is in one direction only. While the central node can determine the status of the groups of lamps, it does not receive information about their individual status or any other local conditions.
3. Dynamic control which enables a greater extent of control. Lamps can be controlled in groups or on an individual basis. The central control server can collect information on their status depending on the options installed.

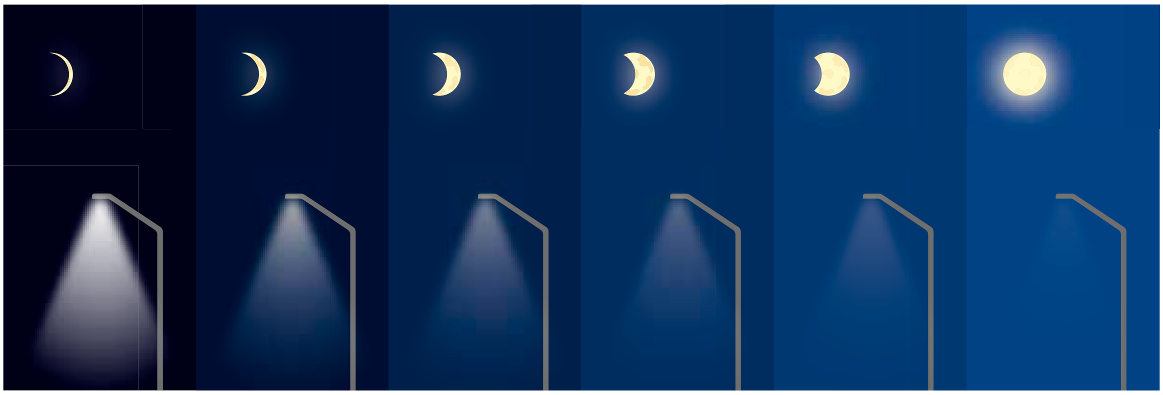


Figure 6. A lighting control system allows adapting lighting intensity as needed [16].

6 https://doi.org/10.3390/su10113925
7 http://www.premiumlightpro.eu/

Advantages of investing in a lighting control system

Investing in a lighting control system brings several benefits such as:

- increased energy savings;
- increased operational savings and better customer satisfaction;
- achieve additional smart city applications.

Possible pitfall in lighting control

Active control allows for significant energy savings, but this must be weighed against added complexity and cost. Calculated from several sources ([17], [18], [19]), the average dynamic control is up to 34% more efficient than calendar control.

2.4 Installation and maintenance

Improving the reliability of lighting systems

Lighting system reliability is the product of all the individual reliability considerations, like LEDs, optical systems, PCBs, mechanical components; the thermal reliability of an LED luminaire life is also a function of the power supply, operating temperatures, thermal management, materials, and electrical and material interfaces.

The most influencing factors on reliability and lifetime

The most important physical influencing factors on the reliability and lifetime of LED light sources include humidity, temperature, current and voltage, mechanical forces, chemicals and light radiation, which could lead to a total failure or influence the aging characteristics in the long term [20]; see also Figure 7 [21].

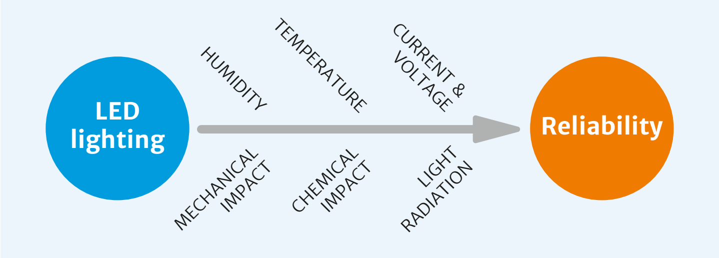


Figure 7. The most influencing factors on lighting system reliability [21].

Better planning of lighting systems

It is essential to carefully plan lighting systems. Many considerations, factors and parameters should be kept in mind [22], [23], such as:

- Planning and using high-quality LEDs from manufacturers who publish reliability data.
- Asking for luminaire warranty from manufacturer, at least comparable to traditional luminaires used for the application under consideration.
- Asking for photometric reports for luminaires, based on LM-79-08 test procedure, from an independent testing laboratory.
- Integrating remote monitoring of light points, to save operational costs and prevent issues before they happen.
- Ensuring modularity and emphasise recyclability, by requiring more efficient and longer use of components.
- Taking seriously into account temperature data for the LED and information about how the measured temperature relates to expected life of the system, when operated in the luminaire in the intended application.
- Asking for test data about long-term performance of the LED luminaire.

!

Possible pitfall in terms of reliability

More than 60% of lighting system failures are related to the lamp driver. Advantages of longer life may not be realised if the expected use cycle is less than the lifetime.

2.5 The importance of power quality

LED lights are non-linear loads that produce harmonic distortion in power grids. Increased harmonics distortions cause higher operation and maintenance costs of the lighting systems.

What is power quality (PQ) about?

Power quality is defined as the power grid's ability to supply a clean and stable power flow, as a constantly available power supply. The power flow should have a pure sinusoidal waveform; it should remain within specified voltage, and frequency tolerances. An adequate PQ guarantees the necessary compatibility between all equipment connected to the grid. It is an important issue for efficient operation of power grids. The main reason to improve PQ is economic value for utilities, their customers, and suppliers of load equipment.

Figure 8 illustrates how the power signal can be affected by common power quality problems (spike, harmonic sag, notch, swell, noise).

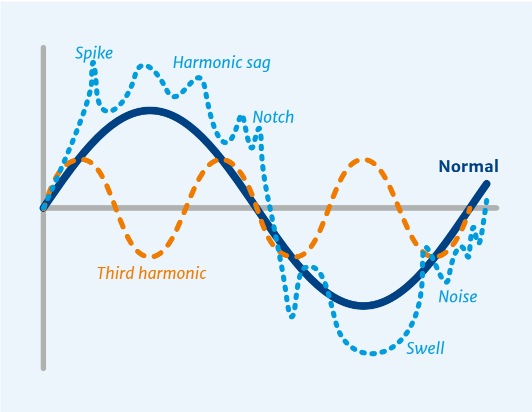


Figure 8. Illustration of the common power quality problems. The bold curve shows thenormal (ideal) voltage signal, the dashed orange curve shows the third harmonic, and the blue dashed curve shows how various power quality problems affect the power signal [24].

Dealing with PQ problems

Dealing with PQ problems is essential for ensuring the proper operation of both the LED luminaires and other equipment connected to the grid. Factors and parameters to be considered include:

- Power factor correction with compensators.
- Reduction of harmonics with harmonic filters or reactors.
- Optimisation of voltage with voltage stabilising units.
- Lighting and surge protection devices against overvoltage and voltage spikes.

Possible pitfalls and preventing PQ problems

It is encouraged to procure and install components (i.e. luminaires) with power factor ≥0.95.

It is recommended to perform regular power quality monitoring for timely maintenance of filter, harmonics suppressions.

2.6 Supporting technologies – The key to smart lighting

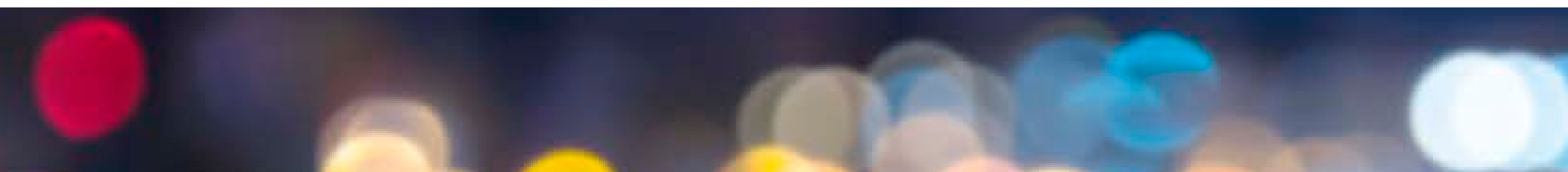
The smart street lighting infrastructure acts as a service gateway for other street level devices and is seen by some as the backbone of the smart cities.

The smart city starts with smart lighting

Smart lighting's integrated control and communication infrastructure enable to connect major elements of city infrastructure at every level at which utilities have control, and new areas of potential growth.

Smart lighting also gives the flexibility to add new applications like EV charging stations, sensors to assess air quality, public WiFi or smart parking. It provides the ability to add smart sensors that help monitor everything from the weather and air quality to traffic. The availability of new data enables to provide new services for citizens and increase their safety.

Finally, integrated renewables enable to implement nearly zero-energy and environmentally friendly solutions.



Main supporting technologies

The availability of renewable sources, like solar or wind power, mean that lighting systems can be entirely self-powered, and even send excess power back to the utility, helping balance demand and make the grid more resilient.

IoT-enabled smart sensors on the streetlights allow the monitoring of city environmental data, like air or noise pollution, weather, seismic activity, and other conditions.

Cameras integrated to streetlight system could improve public safety, reduce vandalism and enable to develop novel image processing applications.

A prime example of a smart lighting technology is the smart lamp post that features various types of sensors, a WiFi hotspot, cameras, energy saving lighting control, etc., as conceptually illustrated in Figure 9. Two real-life examples can be seen in Figure 10, including one in the Baltic Sea region (Espoo, Finland).

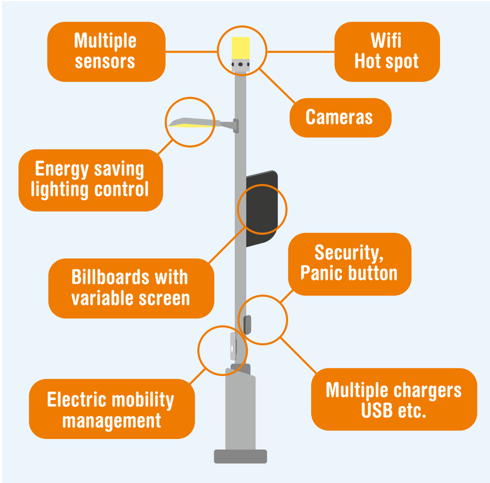


Figure 9. Illustration of the many features potentially supported by a smart lamp post [27].

Figure 10. Real-life examples of smart lighting poles. Left: Energy-saving lamp post powered by solar cells. Right: example in the Baltic Sea region (Espoo, Finland): LuxTurrim5G Smart Pole[8] configured for traffic monitoring and public safety services: speed radar, 3D laser scanner, communication public address (PA) system and pole integrated information display.

Key takeaway about supporting technologies

The IoT relies on the fact that communication technologies enable all electronic devices to have data exchange with other assets, or utility or municipal management and take actions without human interactions.

8 https://www.luxturrim5g.com/new-blog/2020/5/28/a-unique-smart-city-pilot-goes-live-in-espoo-finland

2.7 The need for lighting system system verification measurements

Verification measurements are part of the planning, implementation, and evaluation processes of street lighting systems to ensure a safe and sustainable environment.

Why we need verification measurements

To succeed in implementing a new lighting system, there are several reasons for performing verification measurements of the system:

- To get an overview of the compliance of the installation, the energy consumption and the energy efficiency of the lighting control, and the condition of the luminaires;
- To guarantee road safety and a safe traffic environment;
- To get input data for prospective street lighting improvements, from a technical and economical point of view.

When to carry out control measurements?

The measurements should be performed at several points during the decision and implementation process (see Figure 11 for an illustration):

- Before a new lighting system design (in the case of an object to be renovated).
- After completion of new lighting system.
- Before warranty expiration of the outdoor lighting system.
- Regular evaluation of the lighting system.

Figure 11. Illustration of a lighting system verification measurement [26].

Key takeaways related to verification measurements

Verification measurements are performed by a licensed energy service company or organization responsible for the project and may also be commissioned by a certified measurement laboratory.

WHERE TO FIND MORE INFORMATION ABOUT ENABLING TECHNOLOGIES FOR SMART URBAN LIGHTING

The state-of-the-art about modern, multi-functional LED lighting systems with a special focus on energy saving can be found in the LUCIA Technology State of the Art Report [6].

LEDification: LUCIA Technology Factsheet #2 [13] focuses on energy efficiency and luminous efficacy which have the highest Impact on increasing environmental friendliness of lighting systems.

Control of lighting systems: LUCIA Technology Factsheet #1 [16] focuses on street lighting control strategies (e.g. astronomical timer, daylight harvesting, traffic detection), dimming (in combination with timers, daylight haversting, and traffic detection), and the benefits of dimming, and a comparison of the energy consumption reduction obtained by switching to LED lighting and further gains when applying dimming.

Installation and maintenance of lighting systems: LUCIA Technology Factsheet #3 [21] focuses on the different types of failure categories (power supply, control circuit, housing integrity, LED packages, electrical contact), the main technical requirements for new LED-based light sources (rated life, control gear failure rate, warranty, reparability), and requirements for tenderer (test data, technical manual, technical specifications, declaration of compliance).

Importance of power quality: LUCIA Technology Factsheet #4 [24] focuses on how LEDfication affects PQ (non-linear nature of the load, conversion of AC to DC power, triplen Harmonics, low power factor of LED driver, inrush current) and how PQ affects lighting systems costs (increased installation costs, increased O&M costs).

Supporting technologies: LUCIA Technology Factsheet #5 [27] focuses on the pros and cons of self-powering with renewable sources (applications, advantages, disadvantages), and the benefits of networked lighting controls (NLC) (peak energy management, lifetime energy savings, etc.)

Lighting system verification measurement: LUCIA Technology Factsheet #6 [26] focuses on the purpose of measurements after object completion (e.g. compliance with EN13201-4: 2015 and EN 12464-2: 2014, assessing the expected energy savings, etc.), the purpose of measurements before warranty expiration (e.g. obtain a warranty evaluation, check lighting installations for compliance with CEN/TR 13201-1; EN 13201 2-4, etc.), the most important measurable parameters (e.g. Illuminance/luminosity, luminance/brightness, etc.) and the aims of measurements based on standard EN 13201-4:2015 (measurements at the final testing phase, measurements during the road lighting lifetime, measurements for adaptive road lighting, measurements for investigation of discrepancies).

Chapter 3.
Essentials of Economics for Smart Urban Lighting

While the technologies presented in the previous chapter are essential to the realization of smart urban lighting solutions, the economic aspects are equally important and must be addressed carefully. This chapter gives an overview on key issues such as economic strategic planning, financing, delivery models, life cycle assessment, multifunctionality and business models, this chapter also introduces a practical economic calculation tool developed as part of the LUCIA project.

Furthermore, the answers to the first LUCIA survey, also energy price is linked to issues such as stock prices, green energy, overall picture, pilot area energy consumption; measuring is mostly concerned with energy meters and network power; good practices on sustainable and smart lighting is available (e.g. via the LUCI Association[9]); and that city budgeting depends on budget strategies, promotion of the benefits, prioritising, and energy consumption evaluation.

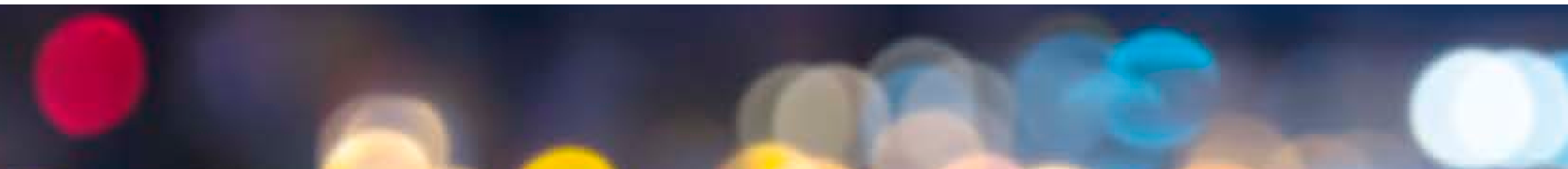
Additionally, the answers also emphasised that in terms of energy savings, there exist specific mechanisms and methods (which do not have direct economic motivation) for promoting energy savings among stakeholders and that comparisons between older and newer technology is important. Multifunctionality was also highlighted as critical, for example 5G, gaming, AR/VR, tourist guiding, activating inhabitants, best practice analysis of innovation solutions, legal issues, lamp post using as a charger.

Finally, in terms of business models, the answers showed that when in case of municipality ownership, lighting is a service already provided by lighting companies.

Key findings from a wider survey that had been shared with a larger network of municipalities in the Baltic Sea region (84 municipalities) included the fact that 66% of the respondents indicated that the average costs for public lighting in their municipality are below 50 Euro per year and citizen. Additionally, 57% of the respondents whose municipality plan to invest in energy efficient lighting also plan to invest in multifunctional technologies. Another striking finding was that on average, respondents estimate that their municipalities expect to save 30% compared to the current costs by using more energy efficient lighting solutions.

Clearly, the economics of smart lighting are very important for municipalities. Information about these essential economics aspects has been compiled in the LUCIA report *Assessment of Economic Aspects of Smart Lighting Systems in Selected Pilot Areas around the Baltic Sea* [28] and the collection of four economy factsheets [68] which are referred to in this chapter.

9 https://www.luciassociation.org/



3.1 Key strategies to link economic development and smart urban lighting

Besides energy savings, smart lighting can support the transition towards long-term sustainable economic development of cities. For this, three economic strategies are possible, as shown in Figure 12 and presented below.

Three Economic Strategies

Sustaining and growing the scale of smart urban lighting investments is essential; indeed, there is a significant unused potential for economic benefits and energy savings; moreover, the current low interest rate context is ideal to leverage a city's available capital.

It is recommended to use smart urban lighting to put energy transition economics at the core of cities climate action strategy: smart urban lighting combines several key themes for the long-term sustainability success of cities: energy and digital transitions and climate action.

Moreover, it is encouraged to double cities' efforts towards empowering citizens and building new collaboration structures: the urban digital revolution enables data and government transparency as new tools to improve the city economy (e.g. municipal services), but the city economic strategy must actively put these goals at the centre of management and define best practices (e.g. citizen data sovereignty) [29].

Figure 12. Three Economic Strategies for linking economic development and smart urban lighting [30].

Key takeaways related to strategies

There is an urgency to act, as investments in energy efficient technologies and adoption rates remain below the necessary level [31], which prevents achieving the EU commitment of zero net carbon emissions by 2040. Improving energy efficiency is considered the most cost-efficient way to face rising economic risks, such as energy price and security.

3.2 How to finance smart urban lighting investments

There are many options for financing smart urban lighting investments, but the most important strategy is to assess the city's procuring capabilities and break free from budget deficit inaction and siloed administration approaches.

Models of governance for the municipal procurement of innovative energy demand reduction technologies

Several models of governance can be used, as summarised below.

- With an in-house procurement, there is complete control over the process, but the city bears all risk.
- Via a Municipal Utility Company (MUCO) and relational contracts, there is partial or complete ownership over the third party, typically a municipal energy company, in which case the risk is partly transferred.
- Using an Energy Utility Company (EUCO) and a long-term contract, ownership is exceptional and there are no performance targets.
- Finally, with an Energy Service Company (ESCO) and long-term performance contracts, there is no municipal ownership; risk-sharing and responsibilities are detailed in the contracts and there is a guaranteed savings performance.

The essential performance measures related to financing smart urban lighting projects are illustrated in Figure 13.

Key performance indicators of smart urban lighting project finance

1 **PAYBACK TIME**
(investment / yearly savings in energy and maintenance)

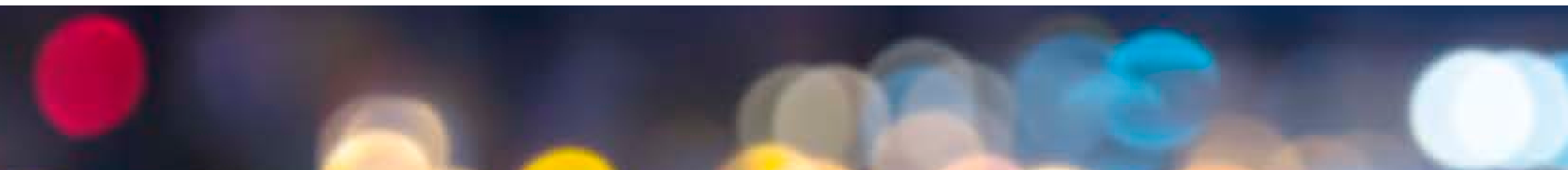
2 **NET PRESENT VALUE**
(NPV = discounted value of all project cashflows)

3 **BENEFIT COST RATIO**
(BCR = total discounted benefits / total discounted costs), for judging the cost-effectiveness

Figure 13. Key performance indicators of smart urban lighting project finance [32].

Takeaway / possible pitfalls related to financing

The economic evaluation of sustainability investments under deep uncertainty strongly depends on the real policy options and their implementation order. Under evolving requirements to mitigate climate change and adapt our cities to it, most transition paths could still result in negative net present value (NPV) or low benefit-cost ratio (BCR), and still be informative for decision making [33].



3.3 Applying a life-cycle approach to smart urban lighting investment decisions

A key issue to consider when making smart urban lighting investment decisions is the so-called life cycle cost analysis (LCC, see Figure 14). The LCC is a tool that aims at defining the long-term economic costs of an investment. The use of LCC analysis for an urban smart lighting case is challenging, given the high level of uncertainty.

For using LCC, different types of data are needed to calculate the life-cycle cost of smart urban lighting projects

The life cycle cost is the present value of a system's required investments in all its phases, namely:

1. Investment cost. Procurement, design, project management, purchase of products, etc.
2. Operation costs. Energy, maintenance, insurance, administration.
3. Residual value. In case it can be sold after its demise, but it might be negative value: e.g. removal and recycling costs.

Expected characteristics and risks in smart urban lighting projects

The typically expected characteristics and risks in urban lighting projects include:

1. Procurement costs might rise with level of innovation because of lack of in-house know-how.
2. Maintenance costs expected to be lower, good risk management of expected energy price increase.
3. High expected real estate value of distributed urban infrastructure for IoT devices, uncertainty concerning the LED unit and the recycling options.

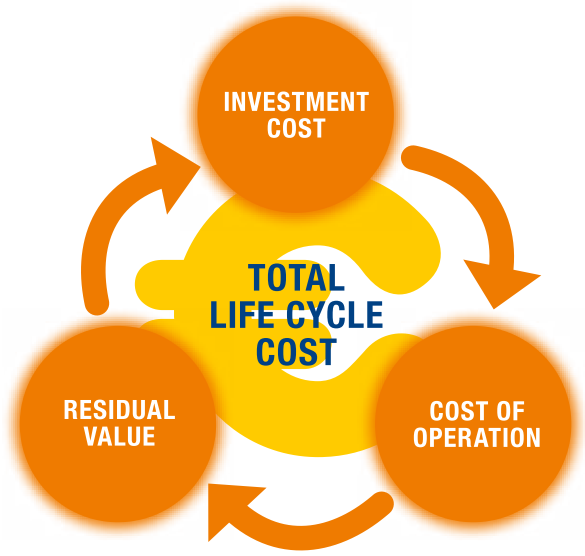


Figure 14. Total life cycle cost for smart urban lighting investment decisions [34].

Key takeaways / possible pitfalls related to lifecycle

Lifecycle costs include investments, but it is a wider assessment than only procurement costs. In smart urban lighting LCC, the technology lifespan is a key driver of overall costs. Municipalities should demand product warranty or risk-sharing contracts to manage the long-term uncertainty.

3.4 Economic benefits from multifunctional smart urban lighting

It is crucial to design a well-functioning economic, institutional and contractual framework, adapted to the local context. Key considerations for this are listed in Table 3.

MAIN UPCOMING SMART FUNCTIONALITIES	FRAMEWORK DESIGN REQUIREMENTS
Energy production Such as decentralised wind, solar …	**Electricity net metering model** … answers to the challenges of costs, security of supply and CO_2 reduction.
Network transmitters The existing lamp posts offer an ideal platform for …	**Infrastructure marketplace management** … a dense network of 5G antennas, or other smart devices requiring a physical support.
Sensor-based services The development of Internet-of-things business models …	**Neutral host operating model** … needs an open environment for operators, avoiding vendor lock-in.

Table 3. Mapping upcoming smart functionalities onto framework design requirements (based on [35]).

Key takeaways related to multifunctionality

LED lamps for outdoor lighting is a fast-developing technology. The upcoming smart urban lighting innovations revolve around Internet-of-things applications, enabled by 5G networks. Cities acting as early adopters will have a better chance to succeed, by building up knowledge and attracting investments to their local innovation ecosystems.

WHERE TO FIND MORE INFORMATION ABOUT THE ECONOMICS FOR SMART URBAN LIGHTING

The overall analysis of existing knowledge, process for compiling the most relevant information into factsheets, workshops in the pilot cities and the development of an assessment and calculation tool can be found in the LUCIA report *Assessment of Economic Aspects of Smart Lighting Systems in Selected Pilot Areas around the Baltic Sea* [28].

Key strategies to link economic development and smart urban lighting: LUCIA Economy Factsheet #1 [30] focuses on the energy transition and the rising price of electricity, energy and maintenance savings in urban lighting, and decarbonization of lighting in terms of scenarios vs. roadmap.

How to finance smart urban lighting investments: LUCIA Economy Factsheet #2 [32] focuses on how much a city's streetlights are metered, systemic long-term risks of externalising basic urban infrastructure services to the technology industry, and financing sustainable investments: from more market-based procurement to re-municipalisation of energy services.

Applying a life-cycle approach to smart urban lighting investment decisions: LUCIA Economy Factsheet #3 [34] focuses on achieving an overall life cycle assessment, the≈rebound paradox, and decision support under deep uncertainty.

Economic benefits from multifunctional smart urban lighting: LUCIA Economy Factsheet #4 [35] focuses on the economic framework design for the multifunctional lighting smart city (managing the relation with the power grid, managing the use of streetlamps as physical support to other physical devices, managing the data economy, creating additional business potential), as well as understanding new service value models: the business model canvas (key partners, key activities, value proposition, customer relationships, customer segments, key resources, channels, cost structure, revenue streams).

3.5 What experts and practitioners say

As part of the LUCIA project, a series of local expert workshops have been organised. These workshops explored the economic aspects of energy efficient urban lighting and provided participants up-to-date information about the topic. Interactive sessions were organised during October–November 2019 in five pilot cities of the project: Porvoo, (Finland), Tallinn (Estonia), Jūrmala (Latvia), St. Petersburg (Russia), and Hamburg (Germany).

The output of the workshops shall support the realisation of LUCIA project pilots, which are roughly divided into two types: park area lighting (Tallinn and St. Petersburg), and lighting of pedestrian and cycling routes (Porvoo, Jūrmala and Hamburg).

Additionally, a specific LUCIA pilot project is implemented in Albertslund in the DOLL (Danish Outdoor Lighting Lab) living lab. This lab has been developed during the past years in close cooperation with technology providers as a testing area for new lighting solutions such as movement sensors, control of traffic signals as well as a presentation platform for integration of lighting solutions.

While the economic aspects were the main focus in each city, specific points of interest varied depending on the character of the pilot location. Porvoo is mostly focused on investing in new infrastructure, Tallinn on creating appealing public space lighting, Jūrmala on creating of an attractive tourism area, St. Petersburg on new technologies in smart urban lighting investments, and Hamburg on economy of the city lighting – environmental opportunities and challenges.

In each pilot city, the participants of the local expert workshops consisted of urban and infrastructure planners, local energy/electricity company representatives, other stakeholders, and hosts and project experts. The total number of participants reached 57 persons dealing with lighting.

What follows presents key takeaways expressed by experts and practitioners during those workshops. A more comprehensive overview of the workshops and details thereof can be found in the LUCIA report Summary Report: *Local Expert Workshops – Economic Aspects of Smart Urban Lighting* [36].

The starting points of the pilot cities fall into two groups: four cities own the electric energy company (Porvoo, Jūrmala, Hamburg, St. Petersburg), whereas one city does not own it (Tallinn). When it comes to the roles of the electric energy company and municipality, two important questions that the expert highlighted are 1) are there incentives between them? and 2) who benefits from the cost savings?

For Porvoo, the experts and practitioners highlighted issues such as the cases of tourism, art, and their indirect effects; how long it takes to implement and benefit from new technologies; and that taking ecologic aspects (e.g. bats) into consideration is essential.

Tallinn's experts and practitioners emphasised that lighting is more than light, i.e. light is a feeling with a strong impact on people's satisfaction. Moreover, they pointed out that while new technologies are ready, suitable business models are still lacking.

For Jūrmala, the experts and practitioners raised the issue of privacy, i.e. are the safety and surveillance features of smart lighting technologies a way to spy on citizens? They also highlighted the issue of aligning smart lighting with Sustainable Development Goals.

For Saint Petersburg, the experts and practitioners expressed concerns about how to deal with the technology risks associated to e.g. networks in smart lighting systems. It is also worth noting that they already have concrete plans to reach full LED-based lighting by 2032.

The experts and practitioners from Hamburg reminded that adaptive lighting and avoiding light pollution are crucial; moreover, efficiency gains alone are not enough and there is a need for truly innovating in order to fully exploit smart lighting technologies.

It is also worth noting that the following issues were agreed upon by the workshops' participants:

- It is important and rewarding to find, understand and analyse, from the point of view of economics, the knowledge on smart urban lighting from implemented projects, previous programmes and research.
- When thinking about the idea of supporting LUCIA pilots, they realise that the LUCIA pilots themselves are interesting cases and represent novel thinking, if compared with most of the cities and regions benchmarked.
- Projects are owned by one actor, but they affect many. The multi-stakeholder context is common to every pilot (energy company / lighting company / different city departments) and finding new cooperative ways to organise a project holds the key to win-win, larger economic benefits (and diverse financial delivery models).
- Big cities like St. Petersburg have existing plans for full LED transition with good adoption rate and availability of necessary funding.

All in all, in order to support a wider adoption of smart urban lighting in the Baltic Sea region, the workshop participants identified the necessity to start with the LUCIA project pilot cities by scaling up and applying the lessons learnt from the pilot to the whole city level (see the upcoming LUCIA Compendium Volume 2).

Finally, the experts and practitioners also highlighted the following points when it comes to smart lighting investment decision making:

- Investments have a cost, but they also increase market value.
- Quality and social impacts are as important as the economic ones.
- Even if there is money available for good ideas, the projects are quite low budgeted and having an economic assessment tool might help in rising their volumes.
- Sustainable Development Goals could help in showcasing non-numeric indicators.
- The focus should be on numbers + GIS tool for urban/light planners.
- In one case, the pilot owners are not currently measuring how much energy goes into outdoor lightning (vs. indoor lightning or other electricity consumption), although this type of information is known at the city level and even maybe at the district level.
- It would be interesting to calculate the economic benefits from cooperating in new ways.
- Forecasting or measuring this project impact will not necessarily help with the next project budget.
- Beyond calculations, we can change rules, make new legal instruments.

3.6 A tool for the municipalities: the economic assessment tool

As part of the LUCIA project, and given the key findings presented in the previous sections, an economic assessment tool has been developed. The purpose of the LUCIA economic assement tool is to help municipalities in indicative assessment of economic and environmental impacts related to investments in public outdoor lighting. Notably, the impacts of a transition from sodium or hallide based luminaires to smart Light Emitting Diode (LED) luminaires can be studied. The tool helps assessing electricity consumption before and after the investment. Furthermore, the tool also gives information about carbon dioxide (CO_2) emissions.

Use of the tool is recommended for municipalities where investments in public outdoor lighting are ongoing or planned cases. The tool provides visual charts and diagrams that help understanding the potential benefits of the investment. The report can be printed out as a paper copy or PDF for dissemination or further use.

The principle of the LUCIA economic assesment tool is shown in Figure 15.

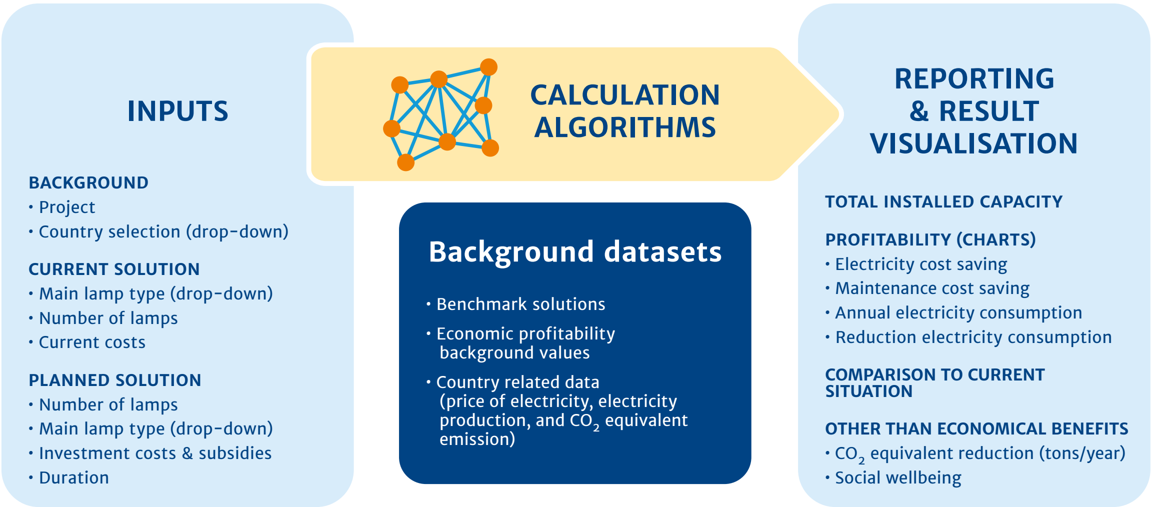


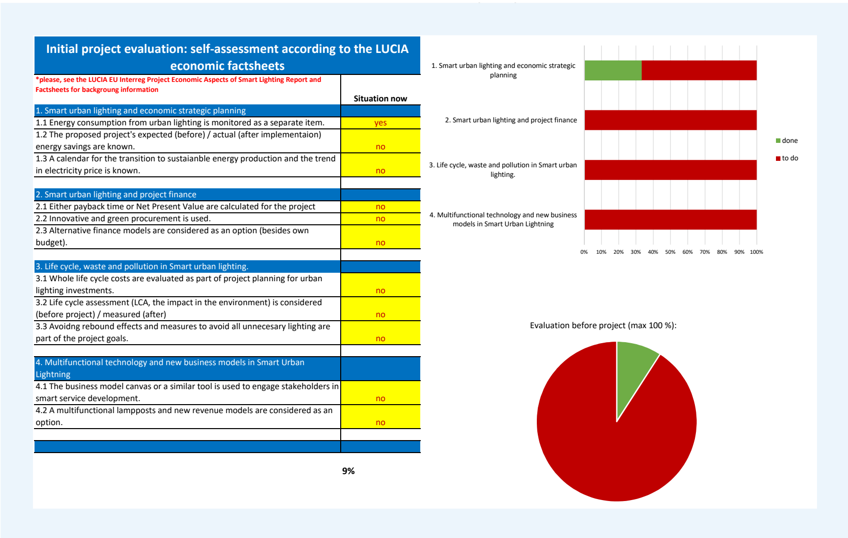
Figure 15. Principle of LUCIA economic assessment tool.

The tool contains evaluation sheets for before and after switching to smart lighting, i.e. they provide an overview of the state-of-the-art situation of the organization in respect to lighting investments.

The evaluation sheets address four distinct themes:

1. Smart urban lighting and economic strategic planning.
2. Smart urban lighting and project finance.
3. Life cycle, waste and pollution in smart urban lighting.
4. Multifunctional technology and new business models in smart urban lighting.

Figure 16 illustrates the tool at work for the Borough of Altona in Hamburg, Germany. Additional screenshots are available in the Appendix. The tool is available for evaluation on the LUCIA project website.[10]



Initial project evaluation: self-assessment according to the LUCIA economic factsheets	
*please, see the LUCIA EU Interreg Project Economic Aspects of Smart Lighting Report and Factsheets for backgroung information	Situation now
1. Smart urban lighting and economic strategic planning	
1.1 Energy consumption from urban lighting is monitored as a separate item.	yes
1.2 The proposed project's expected (before) / actual (after implementaion) energy savings are known.	no
1.3 A calendar for the transition to sustaianble energy production and the trend in electricity price is known.	no
2. Smart urban lighting and project finance	
2.1 Either payback time or Net Present Value are calculated for the project	no
2.2 Innovative and green procurement is used.	no
2.3 Alternative finance models are considered as an option (besides own budget).	no
3. Life cycle, waste and pollution in Smart urban lighting.	
3.1 Whole life cycle costs are evaluated as part of project planning for urban lighting investments.	no
3.2 Life cycle assessment (LCA, the impact in the environment) is considered (before project) / measured (after)	no
3.3 Avoidng rebound effects and measures to avoid all unnecesary lighting are part of the project goals.	no
4. Multifunctional technology and new business models in Smart Urban Lightning	
4.1 The business model canvas or a similar tool is used to engage stakeholders in smart service development.	no
4.2 A multifunctional lampposts and new revenue models are considered as an option.	no
	9%

Figure 16. "Before" sheet for Altona district in Hamburg, Germany.

10 https://www.lucia-project.eu/resources-for-you/

Chapter 4.
Green Public Procurement

The EU has defined various sets of Green Public Procurement (GPP) criteria to help including green requirements in public tender documents. The EU GPP criteria seek to balance issues and factors such as environmental performance, cost, market availability, verification, etc. It is worth noting that organizations launching procurements can include all or only some of the EU GPP requirements, depending on their needs and ambition level.

This chapter presents the EU GPP criteria and related key processes that are useful in the context of sustainable and smart urban lighting.

4.1 The EU GPP Criteria and pre-tender considerations

GPP criteria

The EU published updated criteria for Green Public Procurement (GPP) on road lighting in December 2018. GPP is a voluntary instrument, but it plays a key role in the EU's efforts to become a more resource-efficient economy. In that way, the criteria can give directions for decisions on a new lighting system for cities.

The GPP criteria do not set up a definition on when the city has used enough criteria for their procurement to be considered "green". By adhering to the mindset of the GPP and having active considerations on each criterion, the municipality will most likely make a green public procurement.

GPP criteria for road lighting are not new. The first version was published in 2012. In 2018, more criteria have been added, such as glare. Moreover, the fast increase in LED quality, efficiency, and lifetime expectancy as well as dimming and management systems, required more ambitious criteria.

The purpose of the EU GPP is to provide updated, clear, and ambitious environmental criteria, based on a lifecycle approach and a scientific evidence base.

Before a tender

The first step is to have access to valid data on the current installation (age, type, lighting profile, optics, coordinates, luminaires, management, lamp posts, installation, cabling, turn lockers etc.) and then compare the existing technical performance and cost factors with products available on the market.

The second step is to decide whether a new installation is needed or if other options such as retrofit and redesign of an installation, simple retrofit of an installation, retrofit of controls only, or like-for-like relamping are preferable. During that process it is essential to look into the potential for major savings in energy/maintenance costs. As a decision tool, the lifecycle estimate and the LUCIA economic assessment tool (see Chapter 3 in this LUCIA Compendium) can provide valuable guidance.

4.2 Key aspects in the tendering phase

Innovation before tendering

In some cases, products and solutions available on the market do not meet the goals or expected development. If there exists a wish to conduct innovation work, explore solutions, and be more prepared in future procurements, special attention should be given to this before starting the tender, as illustrated in Figure 17. Cooperation between companies and public actors on e.g. test and prototypes holds a risk of disqualifying the private company in a tender. If this is the case, the procurement-free public private innovation (PPI) agreement should be taken into account before starting the tender.

More information can be found in the upcoming LUCIA Planning and Procurement Factsheet #1 on Public-Private Infrastructure (PPI) contract.

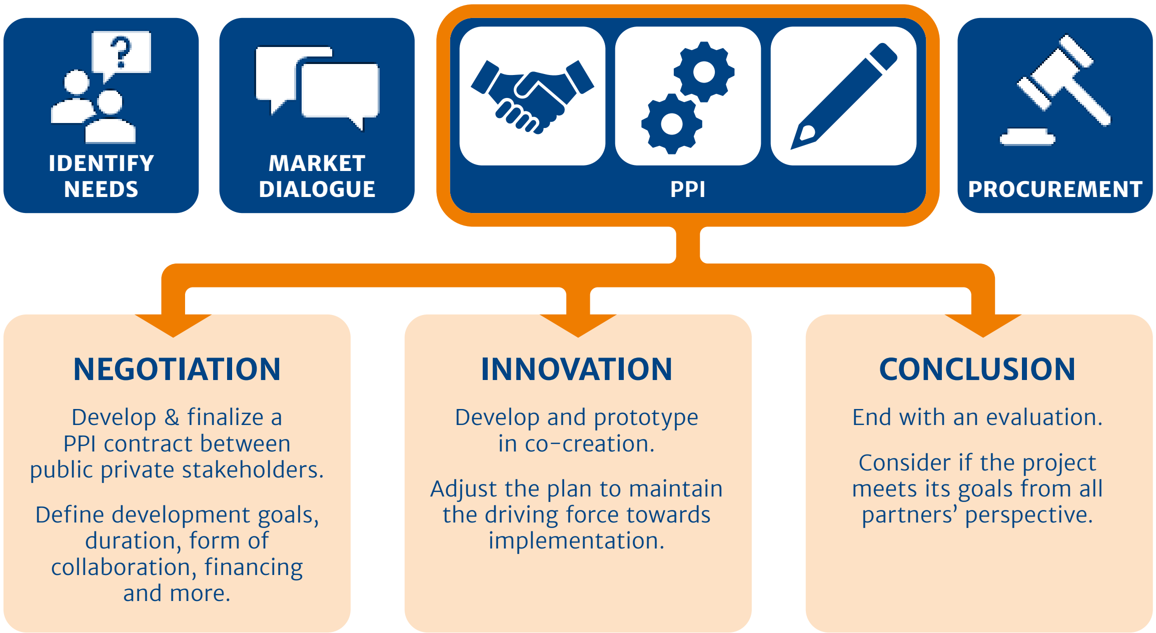


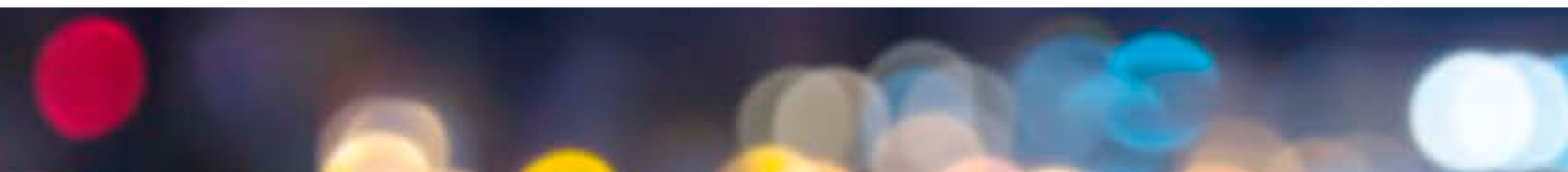
Figure 17. PPI in the tendering process.

Type of tender

It is necessary to consider the type of tender and contract that must be prepared and the goals and lighting improvements that must be achieved.

GPP can be implemented in all types of tendering: competitive dialogue, restricted procedure, open procedure, competitive procedure with negotiation, etc. However, the bigger the changes and investment, the more relevant it is to carefully consider the EU GPP criteria.

Even though lighting is part of EU rules, regulations, and guidelines, these are not implemented in national regulations and recommendations in the same way. Therefore, the GPP criteria cannot be used directly as demands or requirements in the local tender document, and it is thus needed to compare them with national regulations and recommendations.



A holistic approach

Already in the tendering process, the benefits of pursuing a holistic approach helps building a green procurement. A holistic approach can be, for example:

- Tendering a whole lighting system instead of luminaires, management system and construction as separate deliveries.
- Using goals for the lighting system as criteria as well:
  - On the larger scale, this helps increasing safety and low-energy use, as well as protecting flora and fauna.
  - On a practical scale, this fosters circularity, quality of light, type of management, ownership of data, design, energy efficiency, lighting profile, etc.
- Compromising and prioritising between energy efficiency, cost, quality, maintenance, etc.; for example, the lowest energy consuming luminaires have visible LED panels and a higher risk of glare.

Many of the GPP criteria are technical demands; the city can ask a lighting company or a consultant to suggest the criteria, but always with an explanation of what the result will be.

Criteria for public lighting

The GPP criteria are prepared for keeping the pace with the fast development in lighting. This is done by introducing two levels of criteria.

The core criteria are designed for easy application of the GPP, focusing on the key area(s) of environmental performance of a product and aimed at keeping administrative costs for companies at a minimum.

On the other hand, *the comprehensive criteria* take into account more aspects or higher levels of environmental performance; these can be used by any authority that wants to go further in supporting environmental and innovation goals.

Figure 18 gives an overview of the key technical specifications for green public procurement in lighting.

GREEN PUBLIC PROCUREMENT, TECHNICAL SPECIFICATIONS:

- Luminaire efficacy
- Dimming control compatibility
- Minimum dimming performance
- Annual Energy Consumption Indicator (AECI)
- Metering
- Power factor

- Ratio of Upward Light Output (RULO) and obtrusive light
- Annoyance
- Ecological light pollution and star visibility

- Provision of instructions
- Waste recovery
- Product lifetime, spare parts and warranty
- Repairability
- Ingress Protection (IP) rating
- Labelling of LED luminaires

Figure 18. List of key technical specifications for green public procurement in lighting.

Taking the GPP into account in the tendering process the rule of thumb seen from the efficacy criteria, could give an indication on the possibilities. The rule of thumb is that asking for the core criteria will lead to match around 50% of the market and with the comprehensive criteria around 25% of the market [37], [38], [39].

For each criterion there are predefined standards for verification; by including verification in the tender, the municipalities are better ensured to actually obtain what is promised as well as having the possibility to adjust in the process.

Experiences from measurements on luminaires in independent laboratories show that the energy consumption is not always as promised in the technical specifications (datasheets) of the luminaire. If more public builders include demands about verification in independent laboratories as part of the bid and sampling of the delivery as the project starts, that situation can be improved.

More information about the EU GPP criteria

The overall procurement practice guidance document (in English) titled: "A guide to the green public procurement of road lighting" was published in December 2018; it is available online in [37] and has been revised in [40].

The document provides guidance to the holistic approach as well as to the detailed criteria. It is available, together with other supporting documents, in the EU official languages online under the link "Road lighting and traffic signals" in [14].

Circular economy

To be able to reach the goal on climate neutrality by 2050, circular economy is an approach that needs to be considered in future public procurements. By setting the demand from the public sector in front of the change to more circularity, it can influence the design of products, production processed, reduce the use of new materials and yield a higher degree of reuse. In that way, less waste is produced and better value from the parts that become waste is generated, i.e. getting the waste back into circulation, as illustrated in Figure 19. This goes along with asking for circular business models.

As a start, it is a good idea to include requirements about the possibility to disassemble luminaires with regular tools, except when it comes to bollarts and luminaires in tunnels, due to security and to avoid vandalism. Some manufacturers have introduced a circular business model, by making service agreements that secure their products to be returned and repaired or reused, and not discarded upon failure. Another aspect is to make sure the manufacturer is part of the national system set in place as per the European waste electrical & electronic equipment (WEEE) directive. The directive is implemented in national laws and aims to limit the electrical and electronic waste. It gives a responsibility to the manufacturers to aim for the production of environmentally friendly products and increase reuse, recycling, and other forms of recovery. The GPP document also covers some of these aspects and can also be used for inspiration regarding specific criteria to be included in the tender.

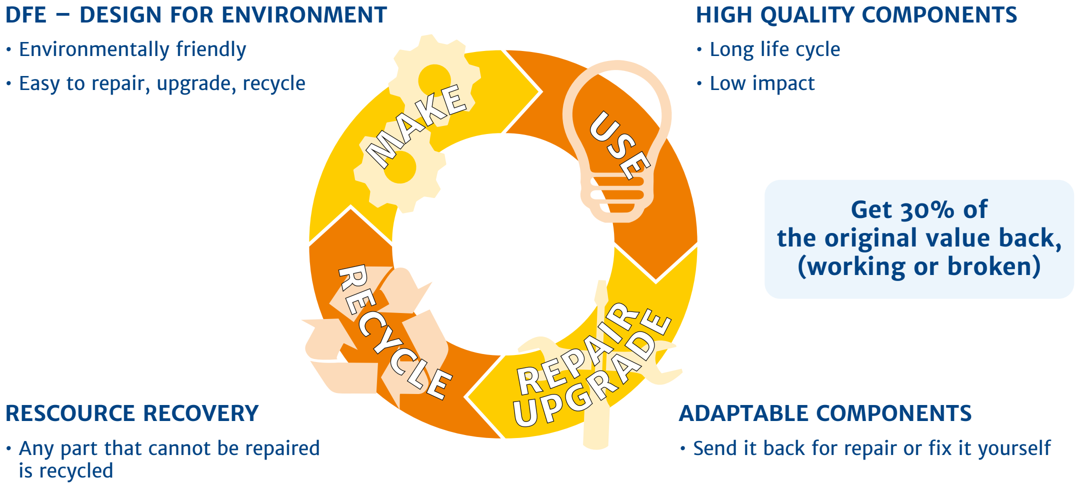


Figure 19. Illustration of the circular economy concept.

In March 2020, the European Commission adopted a new Circular Economy Action Plan.[11] The plan presents a set of interrelated initiatives to establish a strong and coherent product policy framework that will make sustainable products, services and business models the norm and transform consumption patterns so that no waste is produced in the first place. We can expect a wide number of new regulations and initiatives which will make it easier for public buyers to demand circularity in the procurement process.

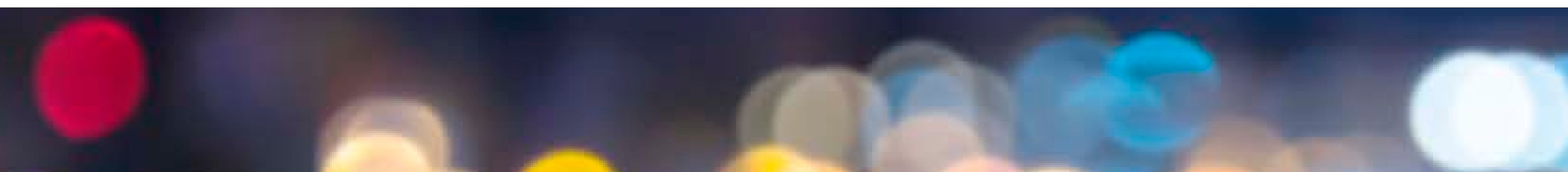
11 https://ec.europa.eu/commission/presscorner/detail/en/ip_20_420

Chapter 5.
The People, the Environment, and the Light

Smart lighting technologies are at the heart of an ecosystem that includes the people and the environment. It is essential to take this multi-faceted system into account when planning and evaluating smart lighting systems.

A first questionnaire shared at the beginning of the project among the LUCIA partner municipalities revealed a number of points and issues:

- A majority of the partner municipalities do not have standard procedures/best practices to integrate automatical dimming or switching off programmes in residential areas. In one case though, there are guidelines to promote such integration and two partner municipalities do have such procedures in place;
- Blue light annoyance has been reported by a few of the partners municipalities; none of the partner municipalities have official measurement procedures towards light pollution and harm of insects/pollinators, etc.; only one partner municipality has official rules for dimming (blue) lights in parks and gardens;
- Only one partner municipality has official rules to evaluate vandalism towards public lighting on a regular basis; only one partner municipality has official rules to prioritise damage among main/side roads/residential areas and public spaces; all partner municipalities reported that significant amounts of vandalism towards public lighting are not correlated to the distance from city centres; on the other hand, only half of the partner municipalities indicated that vandalism towards public lighting occurs in specific areas;
- Another key finding was that none but one partner municipality has procedures to evaluate the satisfaction of the public with lighting in general; none of them have such a procedure in place for specific areas;
- None of the partner municipalities have procedures for evaluating how elderly suffer from the side effects of blue light and only half of them have procedures to evaluate the impact of lighting on health in general;
- None of the partner municipalities have procedures to evaluate gender aspects related to e.g. safety feeling and lighting;
- All partner municipalities use light as a tool to additionally stimulate art and culture, one major concern being additional costs (e.g. for electricity and sustainable light installations);
- One partner municipality has systematic structures for public participation towards establishment of public lighting; however, half of them reported using other formats/actions for public participation.



A wider, not representative, open online survey[12] answered by representatives of 84 mainly smaller and medium-sized municipalties across Baltic Sea region municipalities highlighted that:

- 55% of the respondents indicate that their municipalities have binding rules for conservation and protection of species;
- Vandalism towards public lighting is mostly reported either immediately after the incident or on a regular basis (more than twice per year);
- In decreasing order, regular vandalism to public lighting is mostly observed in city centres, then in no specific area, followed by pedestrian/cyclists tunnels, socially disadvantages areas, residential areas, etc.
- In decreasing order, the main arguments used to promote sustainable and smart lighting is that new technologies foster energy savings, lower the maintenance costs, help reducing and controlling light pollution, are sustainable investments in city planning, increase subjective and objective safety, fulfil GPP criteria, foster positive public reputation among citizens;
- 48% of the respondents indicate that they receive positive or very positive feedback when raising awareness of light pollution;
- Citizens' satisfaction with public lighting is mostly evaluated once a year (33%), never (28%), or every 3–5 years (22%), the rest being other/unknown;
- Citizens' perceived safety with regards to public lighting in public spaces among certain target groups is either never evaluated (47%), once a year (25%), occasionally or every 3–5 years (20%), the rest being unknown.

Clearly, the social dimension of smart lighting plays a critical role for municipalities. Information about these essential social aspects has been compiled in the collection of five social acceptance factsheets [41] which are referred to in this chapter.

5.1 What is a "lighting strategy"?

Why creating a lighting strategy?

Every city has its own type of urban environment: important buildings or monuments with historical or cultural background, public areas with a certain atmosphere, unique landscapes, commercial centres, and residential spaces [42] [43]. A lighting strategy is about giving an importance to this specific urban landscape. For instance, the town hall could be the brightest façade in the city, instead of a department store. Highly trafficked streets including modes of active mobility could be brighter than side streets with a smaller number of different traffic modes. Moreover, smart cities should be barrier-free cities. Lighting can act as a guide for people to navigate around the parks. In a dim environment, we need less light to give a spatial accent compared to brighter surroundings. The lighting strategy makes

LIGHTING: STRATEGY, MASTER PLAN, AND HIERARCHY

The terms lighting strategy, lighting master plan, and lighting hierarchy may have different meanings depending on national or cultural contexts. In general, a lighting master plan is seen as a tool for documenting a vision and for implementing strategies focused on light. One of the key aspects of a lighting master plan is the lighting hierarchy, i.e. defining zones with different lighting levels, properties, etc.

Lyon (France) is a pioneer city in the field, see [63] for its latest lighting master plan. Other examples include, among others, that of Rotterdam (the Netherlands) [66], Zürich (Switzerland) [65], Dresden [67], and Jyväskylä (Finland) [64].

12 See https://www.lucia-project.eu/baltic-sea-region-municipalities-on-the-move-towards-smart-public-lighting/ for a summary article including a downloadable presentation with a more detailed summary of the results.

it feasible to have darker areas with less light without compromising safety. A responsible lighting helps people to orient, adds safety to traffic and citizens, and prevents crimes. And, at the same time, lighting creates a beautiful city filled with livelable spaces, a key feature of the cities of tomorrow. An example of a lighting master plan map is shown in Figure 20 (here Lyon's "nouveau Plan Lumière").

The objectives of a lighting strategy are multifold

A lighting strategy – or a lighting master plan – develops a system for defining and meeting various social needs. Furthermore, a good lighting concept gives structure and orientation; lighting design makes the city unique. Lighting bridges and main urban spaces enhances neighbourhood characteristics.

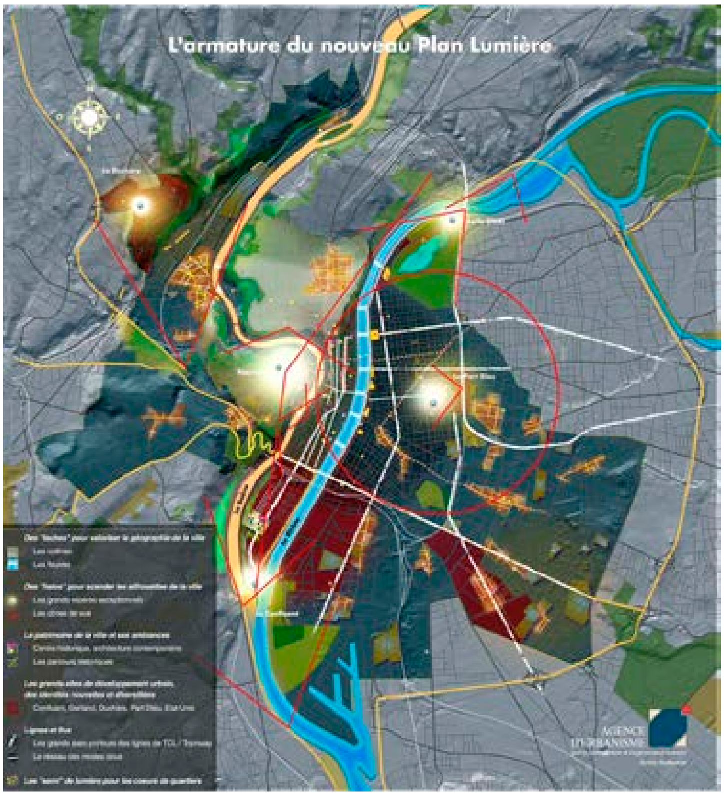


Figure 20. Lyon's lighting master plan "nouveau Plan Lumière".

At the same time, a lighting strategy should aim at preserving the darkness.

Figure 21 shows how a "lighting hierarchy"[13] is applied in practice, i.e. the luminance of the façade of the Town Hall in Hamburg (Germany) is quite low (about 3–4 Candela per square meter). A lighting strategy or master plan defines the city's overall appearance.

13 In some countries such as Germany, a "lighting strategy" has a stronger meaning and is sometimes equivalent to a lighting strategy or lighting master plan.

Figure 21. Illustration of a lighting strategy in action, wherein different zones are lightened as per different needs and purposes. Hamburg, Germany.
PHOTO: ULRIKE BRANDI LICHT

How to create a lighting strategy?

A number of steps have to be taken in order to create a lighting strategy:

1. Define objectives for the lighting strategy.
2. Develop lighting categories for the different types of urban spaces.
3. Integrate existing lighting concepts while involving additional stakeholders e.g. experts, citizens, legislators is also important.
4. Understand spatial relationships between various neighbourhoods.
5. Accentuate the city's significant architecture and spaces.

Key takeaways related to lighting strategy

A lighting strategy – or a lighting master plan – allows the city to be more environmentally sustainable. A lighting master plan can be the backbone and strategic planning instrument and fosters on additional social-economic cohesion building processes[14]. Additionally, a lighting master plan contributes to a systematic and integrated development of new innovations and concepts within the city. A useful simple list of the advantages of an integrated public lighting strategy supported by a master plan is available on Page 3 of the LUCI Charter on Urban Lighting [44].

14 https://www.luciassociation.org/magazine/Cities-Lighting-003/

5.2 Light pollution affects biodiversity

More than 75% of global food crop types, including fruits and vegetables, and some of the most important cash crops, such as coffee, cocoa and almonds, rely on animal pollination. Since artificial light interfers with nocturnal pollination, which in turn reduces the number of fruits produced by the plants, it is essential to consider recommendations to protect biodiversity from light pollution.

Impact of light pollution on biodiversity

Many organisms, including humans, have evolved molecular circadian rhythms controlled by natural day-night cycles, which play key roles in metabolism, growth, and behaviour. A substantial proportion of global biodiversity is nocturnal (30% of all vertebrates and more than 60% of all invertebrates).

Artificial light threatens biodiversity by changing the night behaviour of organisms, e.g. insects getting attracted to street luminaires. In Germany, each streetlight kills about 6.8 million insects every night in the summer [45]. Birds, fishes, and amphibians also become confused by the presence of artificial light, which results in death due to exhaustion or for example, collision with other birds. In addition, light pollution restricts the population of night predators, as they can only hunt in the darkness of a natural setting. For plants, artificial light extends the growth period and causes early leaf out, impacting the wider composition of the floral community [45].

How to protect biodiversity from light pollution

Protecting biodiversity from light pollution is a rich topic [46], [47], [48], [49], [50]. Several recommendations have to be taken into account to protect biodiversity from light pollution, as listed below and illustrated in Figure 22:

- Reducing the overall light output;
- Using luminaires with direct light distribution (full cut off lighting);
- Choosing warm white light colour for public lighting;
- Providing regulations for the maximum luminance level, size, and placement for advertising panels;
- Restricting (or limiting to minimum periods) sky beamer light shows;
- Installing insect-tight luminaires;
- Reducing illumination in areas close to nature and parks;
- Using light control systems to lower the illumination level during the times of low traffic.

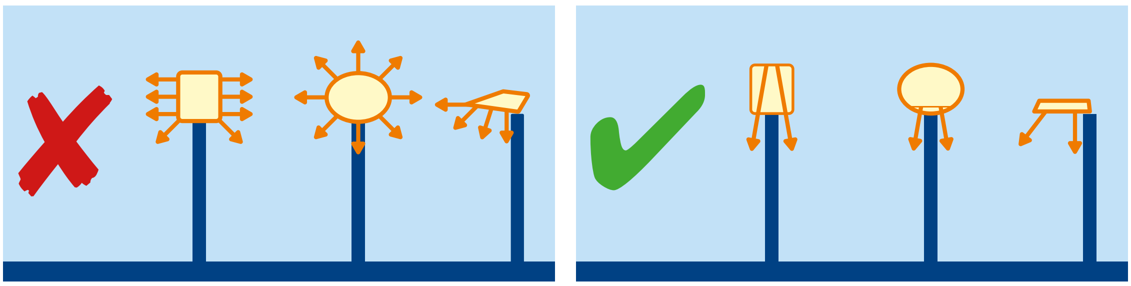
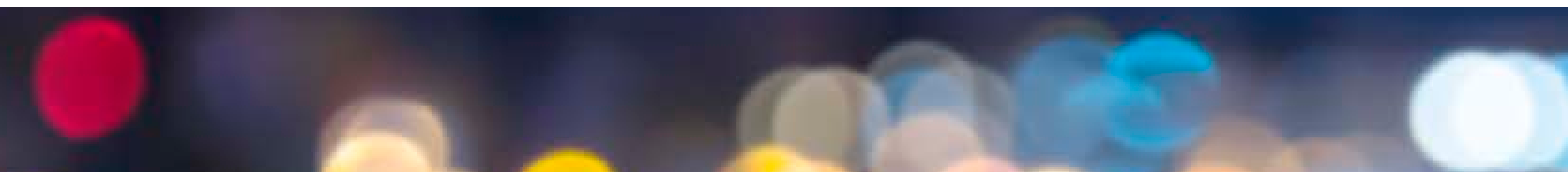


Figure 22. Illustration of dos and don'ts to protect biodiversity against light pollution [58].



Key takeaways related to light pollution

Natural light controls circadian rhythms of living organisms and also influences seasonal processes. Unnecessary artificial light causes serious malfunctions in these biological natures. Light pollution causes many organisms to die, and humans also can suffer from health issues. About 50% of all known animal species are insects that are essential for pollination. They are extremely sensitive to light. Ensure that all requirements are met for nature protection in city lighting design.

5.3 Preserving darkness in the city

Where is the dark sky?

Brightness is often related to positive feelings. Light represents the modern age and economic prosperity. With a rapid industrial development, the amount of light in the cities has increased tremendously. A large amount of both direct and reflected artificial light gets diffused through airborne particles in an urban environment. As a result, the skyglow "lightdomes" above our cities have grown by more than 5% each year; and today, we can no longer see the stars of the night sky [47].

As stated by the authors of the world atlas of artificial night sky brightness [51]: "This atlas shows that more than 80% of the world and more than 99% of the U.S. and European populations live under light-polluted skies. The Milky Way is hidden from more than one-third of humanity, including 60% of Europeans and nearly 80% of North Americans." City children can no longer experience the virtue of history and culture of seeing stars at night. Scientists have to relocate their observatories to remote suburban areas, outside the city environment; and with the diminishing number of available observatory spaces, the field of astronomic research is getting limited.

Ways to protect the dark sky in an urban environment

A number of measures can be taken to protect the dark sky in an urban environment:

- Integrating the field of astronomy to education curriculum in public schools;
- Raising awareness for problems associated with the use of artificial lights through public workshops and discussion forums. For instance, organise city-wide "dark walks" for the general public;
- Protecting darkness for areas around the observatories through policy regulations to allow for sensual experiences;
- Developing and adopting a lighting master plan that incorporates sustainable design and environmentally friendly technology to a city-wide lighting regulation;
- Encourgaging turning off or dimming public lighting, e.g. in the middle of the night;
- Collaborating with private sectors (shops & companies) to encourage them to turn off their lit advertising boards.

See Figure 23 for an example of light pollution and ways to improve the situation.

Figure 23. Examples of light pollution (very bad and bad) and ways to improve the situation (better and best)".

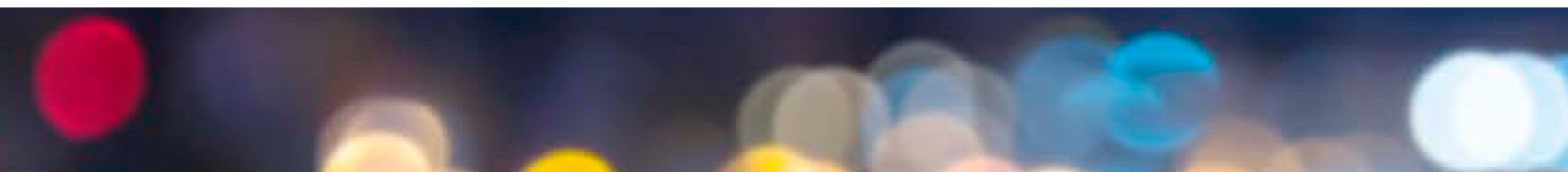
Key takeaways related to darkness

Identifying dark zones can bring back the tradition of sensual experiences related to seeing stars at night. Taking actions to preserve "dark sky" in an urban environment can lead to overall increase in energy efficiency and sustainability for the city. The identification of dark zones in the city does not compromise security and the feeling of safety for the public.

5.4 Can lighting reduce vandalism?

Public lighting and vandalism

Municipalities are confronted with material damage on public properties. Damages are caused not only towards public luminaires but also to "city furniture" and private property, at train and bus stations, in pedestrian/cyclist tunnels and fountains (with luminaires), etc. Lighting is a key factor for the subjective safety of our daily life. It is required to deter crime and identify potential risks. For many years, public utilities and municipalities have been using public lighting to help eliminate the problems of vandalism. However, brighter streets do not mean safer streets. A lit-up ground does not necessarily mean a bright sky. Smart lighting that directs light where it is needed, and provides light when it is needed, creates a balance between safety and starlight. When risks are carefully considered, local authorities can safely reduce street lighting, saving both economic costs and energy without necessarily negatively impacting road traffic safety and crime.



Key factors for responsible lighting, consider the following for site and buildings to minimise crime:

- Lighting for parking lots: establishing a good lighting layout that allows the light to be well-spread throughout the lot, can discourage parking in dark areas;
- Security lighting around buildings: lighting should be provided all around the buildings – a well-lighted building prevents attempts at unlawful activities;
- Lighting at key points: If total lighting around entire buildings, stations, or tunnels is not affordable, lighting can be concentrated around exterior openings, such as entry doors, ticket booths, intersections, windows, intake/exhaust louvres, grills, panels, ladders, etc.

Key takeaways related to vandalism

Damage on public property has several causes, e.g. general spatial planning – monotone housing areas; “dark” corners, huge shopping malls in peri-urban areas, etc. Check areas with high rate of damage and identify problems. Integrate and encourage public participation and sensitise the inhabitants for their areas’ safety concerns.

Possible pitfall related to vandalism: Brighter does not mean safer

According to a study of London street lighting and crime in 2011 [52], there is no evidence that increased lighting reduces total crime. Bad outdoor lighting can, in fact, decrease safety by making victims and property easier to see. Similarly, the Chicago Alley Lighting Project [53] showed a correlation between brightly lit alleys and increased crime.

5.5 The role of the private sector in public lighting planning

There are many benefits stemming from including the private sector in lighting planning

Due to urbanisation, cities are growing intensively with a rapid densification of population. This leads to an expansion of industrial and shopping areas where there is an important use of commercial and advertising lighting. Concentrated energy use leads to greater light pollution with significant impact on human health and surrounding ecology. In this context, it is highly recommended to include the private sector in public lighting planning [45], [54].

Cities should identify specific target groups such as industry, retail (see Figure 24 for an example in Hamburg), and sports clubs, and empower them to use and understand sustainable lighting concepts. By creating private-public partnerships, cities can provide more holistic and comprehensive lighting master plans to reduce the overall brightness of the urban environment and the wider impacts of light pollution. Incorporation of private sectors is a key element in successful urban planning.

Figure 24. Lighting and retail, Hamburg.
PHOTO: ULRIKE BRANDI LICHT

Heading towards more liveable and sustainable cities requires involving target groups – industry, retailers, etc.

The UN defined the SDGs (Sustainable Development Goals) to provide guidelines for building sustainable cities around the globe [55], [56]. The goals include "full productive employment and decent work" and "economic growth."

Industrial areas are mostly located far away from the city centre. These places often threaten ecosystems with an inefficient, unappealing, or unnecessary use of artificial lights with a lack of understanding for sustainable lighting concepts. The cities should include these industrial areas in their lighting investments by advising their architectonic concepts and choice of lighting that best suits their needs.

Light pollution can also be caused by window lighting in retail areas around the inner cities. Therefore, it is necessary to empower retailers to invest in sustainable lighting concepts for shop windows, especially when the shops are closed at night.

Key takeaways related to private sector in public lighting planning

Incorporate private sectors (e.g. shop retailers, industries, sports clubs, etc.) into public lighting plans, also when lighting regulations are already in place.

WHERE TO FIND MORE INFORMATION ABOUT THE PEOPLE, THE ENVIRONMENT, AND THE LIGHT

Lighting strategy: LUCIA Social Acceptance Factsheet #1 [57] focuses on how a lighting strategy can help the public better understand important places and buildings around the city, how a lighting strategy reduces overall brightness and light pollution, and how a lighting strategy creates a safer environment around the city.

Light pollution and biodiversity: LUCIA Social Acceptance Factsheet #2 [58] focuses on the consequences of growing brightness (luminosity) and where, when, and how much light to use.

Darkness in the city: LUCIA Social Acceptance Factsheet #3 [59] focuses on how to reduce light pollution and precedents for “dark sky parks” and “dark sky communities” in cities.

Vandalism and light: LUCIA Social Acceptance Factsheet #4 [60] focuses on solutions for public places often affected by damage and choosing durable luminaires.

Private sector cooperation: LUCIA Social Acceptance Factsheet #5 [25] focuses on how to identify target group-specific technical and communication concepts, methods and tools to involve target groups in lighting planning, Experts to Experts tips, and establishing public to private partnerships.

Chapter 6.
The City and the Light

Public lighting plays a central role in the urban life and infrastructure. Besides energy savings, lighting comes with other great impacts: a safer city, increased quality of lighting, and lighting as a basis for improving the image of the city for all citizens, making the city more vibrant and liveable. Lighting will be running in a modern sustainable city, so why not use the already existing infrastructure to make the city smarter and more sustainable? This chapter aims to inspire urban and lighting planners on the process of a strategic implementation of new lighting, with early decisions and holistic approach, including issues such as knowledge uptake, strategies, citizen involvement, etc.

6.1 Knowledge and strategies

Uptake of knowledge

Implementing a smart lighting system and taking steps into the smart city requires many professions and complex knowledge. The uptake of the knowledge in the earlier chapters will often stay with the technical experts, both in the municipality and the lighting companies, and those working together with the consultants and construction companies.

This chapter recommends taking the first early steps on the strategic level and include urban planners and citizens in the process in an early phase for considering new lighting. Instead of jumping directly to financing, national regulations, and guidelines, technical aspects and the tendering process, it is recommended to start with the development of the city in cooperation with other professions.

Strategy and municipal plan

To implement a new strategy on lighting for the city, it can be an advantage to see lighting from a holistic view and include lighting in the strategy and the municipal plan (Figure 25). By doing so, lighting becomes an integrated element of the city development and the goals tend to shift from pure savings on cost, energy, and service to how the new lighting should benefit the citizens and the city. When taking decisions on smart city in this early phase, the possibilities in the development increases and gives directions on investments.

Figure 25. Lighting in an essential part of the strategy and municipal plan.

Lighting can be used to reach a goal or be the actual goal. Some examples of the types of goals that can be reached by modern lighting include:

- Increase safety and traffic security;
- Increase accessibility, strengthen connections and environmentally friendly mobility;
- Increase lighting quality and reduce nuisance for people and ecosystems;
- Savings on energy consumption and operations;
- Minimising the environmental footprint and promote circular investment and business models;
- Implementing green lighting technology and promote the smart city;
- Create attractive urban environments for all citizens with equal and free access to urban lighting;
- Avoid light pollution and keep dark areas.

Lighting strategy and plan

Another approach is to start by making a sector strategy or plan on lighting. This gives the opportunity to describe the type of lighting that should be selected for each part of the city, the approach for lighting on urban spaces, the goals, the design and lighting quality, the energy use and organization, etc.

In many ways the lighting plan can aim for the same purpose as the strategic and municipal plan and will often be more detailed. But it can also tend to be very technical and detailed.

When using the lighting strategy and plan as a planning document, it is often observed that it is anchored only in the municipal infrastructure. Working on getting the plan to be an integral part of the planning hierarchy with political commitment will strengthen the holistic approach and make the consequences for other sectors and the city more visible.

6.2 Cooperation, people, and the city

Beyond silos – cooperation matters

When it comes to new construction projects and renewal of existing lighting, as well as maintenance and service, there are signficant differences when it comes to how the responsibilities for public lighting are organised in cities, as well as whether the municipality owns the lighting or not.

Whether the municipality has a large or a smaller influence on the lighting system holds important considerations for both the political level and for the urban and lighting planners to invest in a new or renovated lighting system.

Case studies show that cooperation between departments and between lighting company and municipality improves the results of the new lighting. Even though it might seem to take a lot of time, aiming for the cooperation has proven value. Both politicians and citizens express more satisfaction with the result. More information about this can be found in the upcoming LUCIA report "Lighting in Urban Development".

The more knowledge and complexity the task contains, the more important it is to cooperate. The number of competencies in the field of lighting has been analyzed to help the lighting education to meet future demands. A study [61] has identified 111 different competencies related to lighting (both indoor and outdoor) as demand from employers across sectors. The competencies lay in categories of light and experience; light, health and wellbeing; light and technology; light and energy; light and planning; daylight; digitalised light; light characteristics and measurements. Including lighting designers in municipal or consultancy teams is often limited by cost saving or cut downs, but they are a group with many of the competencies.

Involving the citizens

Before changing lighting in a neighborhood, it is rewarding to involve the citizens, both when it comes to changing the street lighting and organising more artistic or urban space projects. Methods vary due to different cultural and planning traditions. The citizens tend to show most interest in areas close to their home or along their work commuting route. Since lighting is difficult to discuss due to many technical terms and knowledge, the process can start by exploring different lighting solutions together and getting a common language to use in discussions via e.g. lighting workshops.[15, 16]

The field of citizen engagement is evolving, also when it comes to developing lighting projects. Both lighting designers and municipal planners are working on ways to improve this area. A wide range of tools can be used in such a process, for example different types of co-creation methods, workshops, focus groups, discussions with lighting ambassadors, sandbox with luminaries to choose from etc. In any situation, it is essential to always go for case- and site-specific approaches.

The smart city

Before moving on with the change of lighting systems, it is also important to consider the transition towards the smart city. The city infrastructure with roads, lighting, electricity, waterpipes, sewage etc. are the fundamental elements; by moving towards the smart city, the next layer is added. Indeed, the smart city is based on a digital infrastructure, which leads to the interconnection between the elements

15 https://www.lucia-project.eu/lucia-light-installation-in-hamburg-pedestrian-tunnel-in-a-new-light/
16 https://www.lucia-project.eu/playing-with-the-power-of-light-in-tallinns-guerilla-lighting-workshop/

and then applications (Figure 26). Together, this creates a better service system with the benefit of behavioural change and supporting the citizens.

Lighting is the most mature sector in the smart city and often delivers a good business case, if taking steps for communication systems and optic fiber installation at the same time. While there is no need for optic fiber connectivity in each lamp post nor a need for the same communication network for everything, optic fiber accessibility throughout the city makes communication networks for sensors and applications easier.

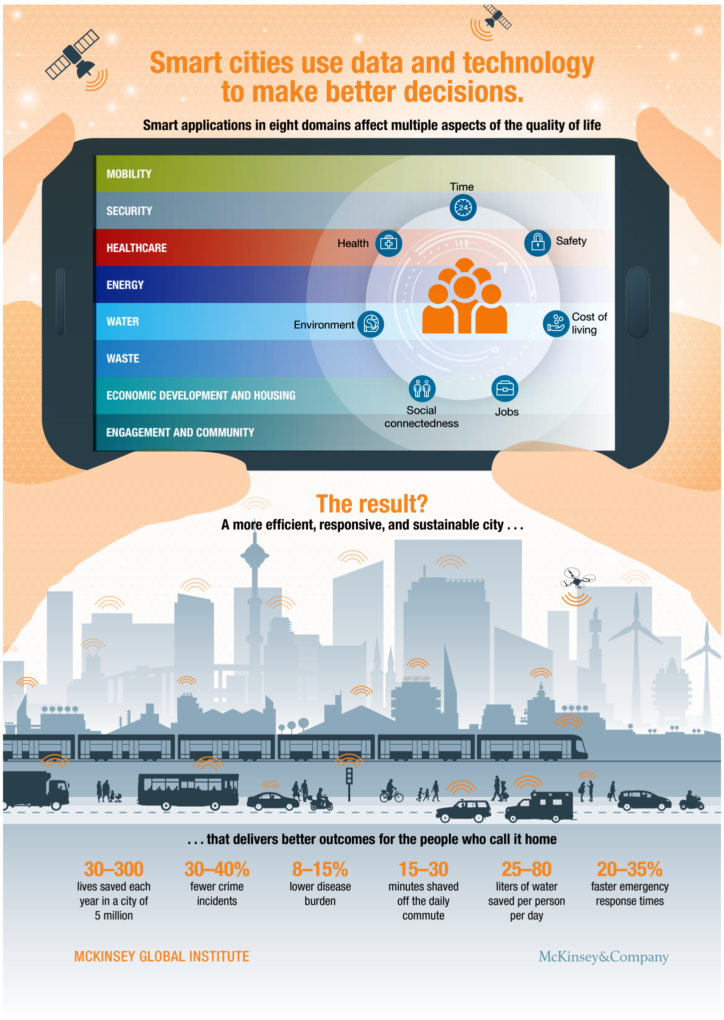


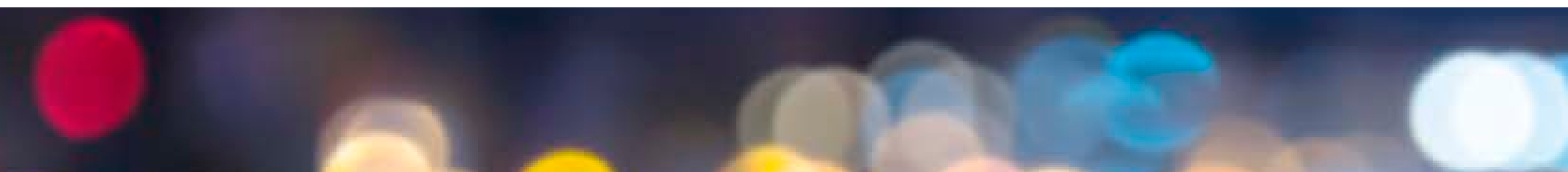
Figure 26. Smart applications create a better service system, improving the quality of life.
IMAGE: MCKINSEY GLOBAL INSTITUTE

Implementing the digital infrastructure as the next layer in the city along with lighting is a unique opportunity. Since construction work is expensive, the strategy of installing fiber in the ground along with such work is used in many cities. Some choose to at least install pipes for future fiber optics. The fiber optics as the backbone in the digital infrastructure makes it possible to use different communication systems and choose the one that meets the specific solution from case to case, as well as support large amounts of data traffic. 5G is also in rapid development and is being implemented in central parts of cities. How to use 5G as communication network for the smart city is still under development. For example, DOLL Living Lab will carry out some use-cases on 5G that will be presented in the second volume of the LUCIA Compendium (expected in 2021).

When choosing the specific sensor solution for a specific smart city use case, e.g. parking or waste, it is worth to demand solutions with a low energy use. Solutions built upon on narrowband technologies are often more energy efficient.

It is also essential to make sure that the municipality has the necessary rights to the data from the smart solutions in the city. That also means having full access to the communication network and making it possible to integrate the data and integrate them with the whole municipal digital infrastructure.

Finally, it is also essential to keep in mind that in smart cities, the issues of privacy and cyber security play a crucial role to be able to maintain accessibility, integrity, and trust from the citizens. Essentially, it must be recognised that there are no 100% secure systems. Efforts on security in smart city solutions must therefore concentrate on keeping the risks at an acceptable level. This means to implement systems with a security level so high, and potential damage effects so small, that municipalities and other actors are not prevented from reaping the many benefits of successful digitization: better service to citizens, lower climate footprint of activities, abolition of redundant workflows, etc. [62].



Concluding remarks

This first volume of the LUCIA Compendium has introduced the findings, recommendations, and tools that have been identified or created during the first phase of the LUCIA project in terms of key issues related to the technological, economic, and societal aspects of smart urban lighting.

The knowledge gained during the first phase of the LUCIA project will be put into practice by means of six pilot sites in the cities of Albertslund (Denmark), Hamburg (Germany), Jūrmala (Latvia), Porvoo (Finland), Saint Petersburg (Russia), and Tallinn (Estonia) and their replication potential will be evaluated by their respective metropolitan regions. These outputs will be presented in the second volume of the LUCIA Compendium.

LUCIA
Interreg Baltic Sea Region
EUROPEAN UNION
EUROPEAN REGIONAL DEVELOPMENT FUND

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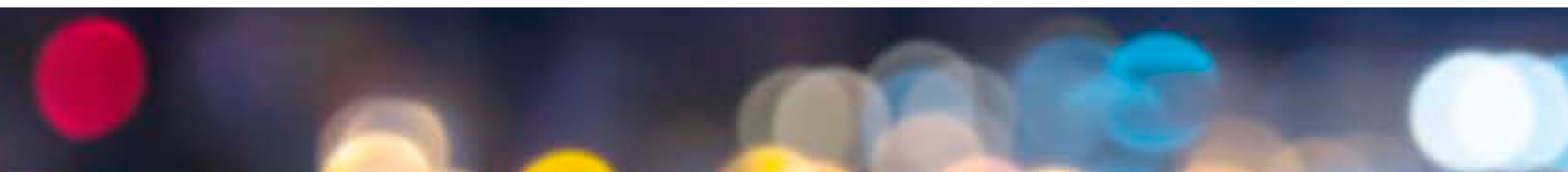

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Glossary

AECI Annual energy consumption indicator (AECI) is the total electricity consumed by a lighting installation day and night throughout a specific year in proportion to the total area to be illuminated by the lighting installation. Its unit is $kWh/(m^2 \cdot y)$

BEI Baseline Emissions Inventory. Is used to quantify the amount of CO_2 emitted due to energy consumption in the territory of the Covenant of Mayors signatory in the baseline year.

BCR Benefit Cost Ratio is an indicator, used in cost–benefit analysis, that reflects the overall value for money of a project or proposal.

BSR Baltic Sea region includes the countries located in the area surrounding the Baltic Sea in Northern Europe.

CO_2 Carbon dioxide is a colourless gas composed of a carbon atom and two oxygen atoms. While it is formed naturally when e.g. people or animals breathe out, it is also formed when burning e.g. fossil fuels, solid waste, trees and other biological materials. Carbon dioxide is the main long-lived greenhouse gas in the atmosphere stemming from human activities.

COM Convenant of Mayors. This is the mainstream European movement involving local and regional authorities, voluntarily committing to increasing energy efficiency and use of renewable energy sources within their territories. By their commitment, Covenant signatories aim to meet and exceed the European Union 20% CO_2 reduction objective by 2020.

EC European Commission.

EROI Energy Return on Investment, also known as Energy Returned on Energy Invested (EROEI or ERoEI), is defined as the ratio between the amount of usable energy delivered by a given energy resource and the amount of energy required to deliver that energy.

ESCO Energy Service Company.

EUCO Energy Utility Company.

HPS lamps High Pressure Sodium lamps are made of a narrow arc tube containing sodium, mercury or xenon, under a high pressure for higher efficiency.

GIS Geographic Information Systems are conceptualised frameworks for capturing and analyzing spatial and geographic data.

GPP Green Public Procurement. The EC's GPP guidelines are meant to "help public authorities buy goods and services with a lower environmental impact. It is also a useful reference for policy makers and companies responding to green tenders".

Interreg European Territorial Cooperation is one of the European Union's key instruments for supporting cooperation across borders. Interreg programmes are funded by the European Regional Development Fund (ERDF).

IoT Internet of Things refer to systems of interconnected computing, mechanical, and digital devices characterised by their ability to transfer data over wireless or wired networks with no human-to-human or human-to-computer intervention.

LED Light Emitting Diode. An LED is a semiconductor light source. Light is emitted when an electric current circulates through it (electrons recombine with electron holes, which releases energy in the form of photons, i.e. light).

LCC Life Cycle Cost and the associated Life Cycle Cost Analysis (LCCA) is a tool for finding out the most cost-effective option when purchasing, owning, operating, maintaining, and disposing of an asset or process.

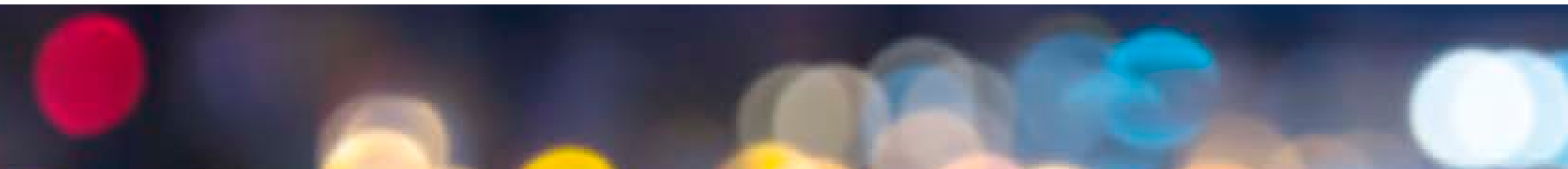
Lumen The Lumen is SI derived unit that represent a luminous flux; it is a measure of the total quantity of visible light emitted by a source per unit of time.

MUCO Municipal Utility Company.

NLC Networked Lighting Controls systems include individually addressable luminaires and control devices that enable multiple control strategies, programmability, and monitoring at the levels of e.g. building, enterprise and zones.

NPV Net Present Value or Net Present Worth (NPW) helps evaluate and compare capital projects or financial products with cash flows spread over time for example in investments.

O&M Operation & Maintenance



PDI Power Density Indicator is the value of the system power divided by the value of the product of the surface area to be lit and the calculated maintained average illuminance value on this area according to EN 13201-3. Its unit is $W \cdot lx^{-1} \cdot m^{-2}$ (i.e. $W/(lx \cdot m^2)$).

PPI Public-Private Infrastructure

PQ Power Quality refers to the electric power quality, including how its characteristics in terms of voltage, frequency, and waveform comply with their prescribed range.

ROI Return On Investment is defined as the ratio between a net profit (for a given time period) and the cost of investment (of resources at a given point in time) required to generate that profit.

SDG Sustainable Development Goals are a key element of the 2030 Agenda for Sustainable Development adopted by all United Nations Member States in 2015 and include tackling climate change.

SEAP Sustainable Energy Action Plan. This is a document that shows how a local authority / municipality aims to reach EU and national 2020 energy targets, through a range of cross-sectoral energy actions. A SEAP covers the entire geographical area of a local authority and uses the results of a Baseline Emissions Inventory (BEI) to identify the best areas of action and opportunity for reaching the local authority's CO_2 reduction target.

SI The International System of Units (SI, from Système international (d'unités)) is the modern form of the metric system. It is the only system of measurement with an official status in nearly every country in the world.

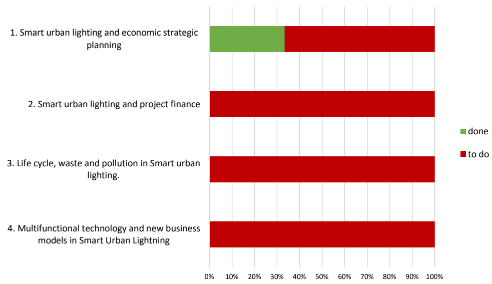
SSL Solid State Lighting. Lighting based on LED, organic light-emitting diodes (OLED), or polymer light-emitting diodes (PLED) as illumination source instead of electrical filaments, plasma, or gas.

WEEE European waste electrical & electronic equipment (WEEE) directive.

Appendix

Figure 27, Figure 28, and Figure 29 illustrate some of the key features of the economic assessment tool for the specific case of Altona district in Hamburg, Germany.

Initial project evaluation: self-assessment according to the LUCIA economic factsheets	
*please, see the LUCIA EU Interreg Project Economic Aspects of Smart Lighting Report and Factsheets for backgroung information	Situation now
1. Smart urban lighting and economic strategic planning	
1.1 Energy consumption from urban lighting is monitored as a separate item.	yes
1.2 The proposed project's expected (before) / actual (after implementaion) energy savings are known.	no
1.3 A calendar for the transition to sustaianble energy production and the trend in electricity price is known.	no
2. Smart urban lighting and project finance	
2.1 Either payback time or Net Present Value are calculated for the project	no
2.2 Innovative and green procurement is used.	no
2.3 Alternative finance models are considered as an option (besides own budget).	no
3. Life cycle, waste and pollution in Smart urban lighting.	
3.1 Whole life cycle costs are evaluated as part of project planning for urban lighting investments.	no
3.2 Life cycle assessment (LCA, the impact in the environment) is considered (before project) / measured (after)	no
3.3 Avoidng rebound effects and measures to avoid all unnecesary lighting are part of the project goals.	no
4. Multifunctional technology and new business models in Smart Urban Lightning	
4.1 The business model canvas or a similar tool is used to engage stakeholders in smart service development.	no
4.2 A multifunctional lampposts and new revenue models are considered as an option.	no
	9%



Evaluation before project (max 100 %):

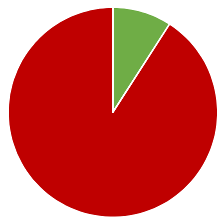
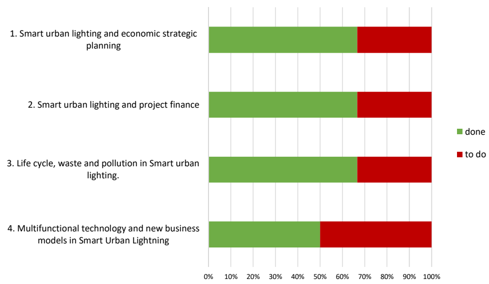


Figure 27. "Before" sheet for Altona district in Hamburg, Germany

Project evaluation: self-assessment according to the LUCIA economic factsheets	
*please, see the LUCIA EU Interreg Project Economic Aspects of Smart Lighting Report and Factsheets for backgroung information	Situation after
1. Smart urban lighting and economic strategic planning	
1.1 Energy consumption from urban lighting is monitored as a separate item.	yes
1.2 The proposed project's expected (before) / actual (after implementaion) energy savings are known.	yes
1.3 A calendar for the transition to sustaianble energy production and the trend in electricity price is known.	no
2. Smart urban lighting and project finance	
2.1 Either payback time or Net Present Value are calculated for the project	no
2.2 Innovative and green procurement is used.	yes
2.3 Alternative finance models are considered as an option (besides own budget).	yes
3. Life cycle, waste and pollution in Smart urban lighting.	
3.1 Whole life cycle costs are evaluated as part of project planning for urban lighting investments.	yes
3.2 Life cycle assessment (LCA, the impact in the environment) is considered (before project) / measured (after)	yes
3.3 Avoidng rebound effects and measures to avoid all unnecesary lighting are part of the project goals.	no
4. Multifunctional technology and new business models in Smart Urban Lightning	
4.1 The business model canvas or a similar tool is used to engage stakeholders in smart service development.	no
4.2 A multifunctional lampposts and new revenue models are considered as an option.	yes
	64%



Evaluation after project (max 100 %):

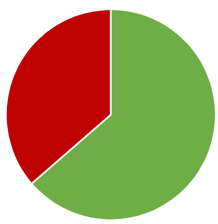


Figure 28. "After" sheet for Altona district in Hamburg, Germany

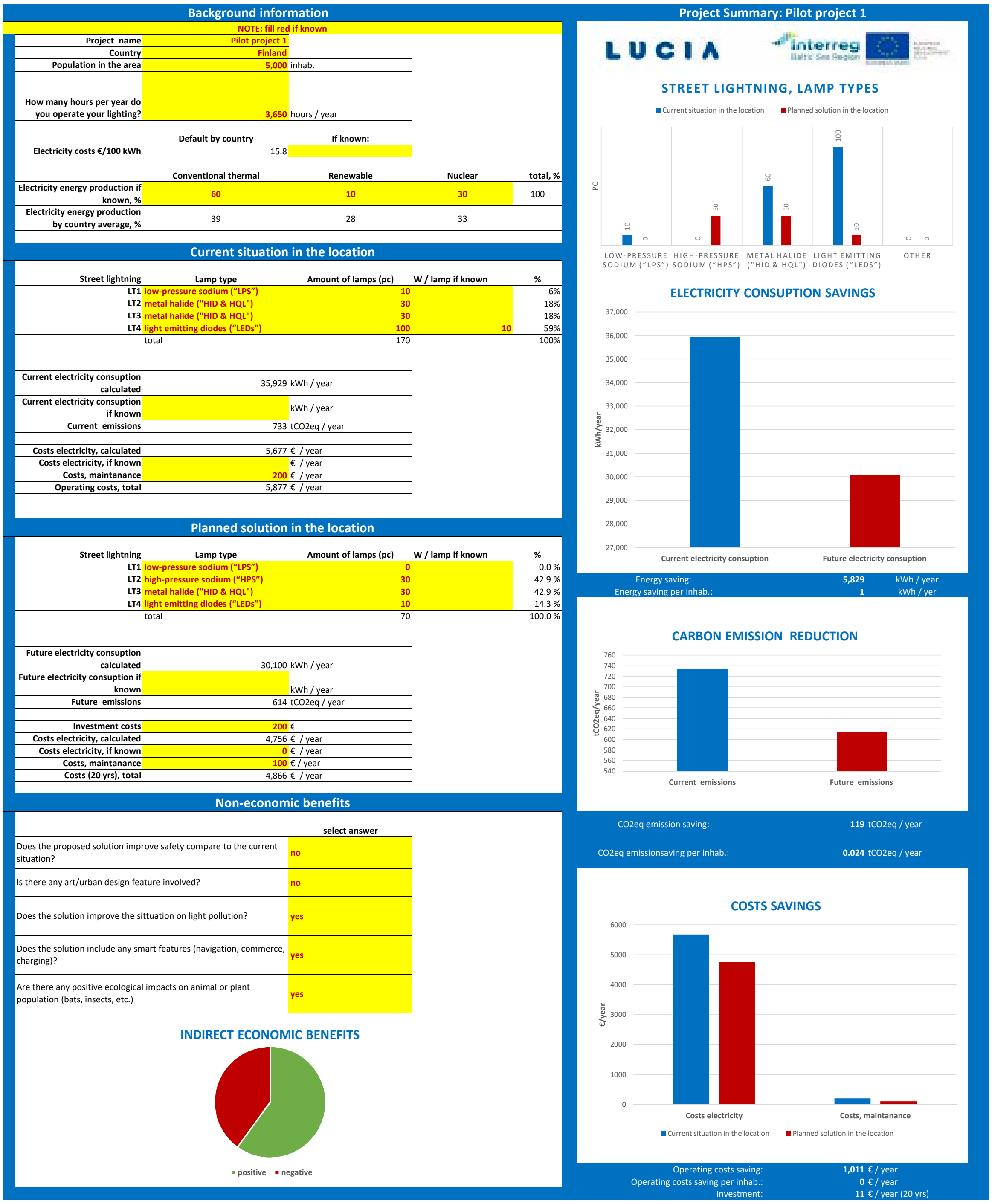


Figure 29. "Calculation" sheet for Altona district in Hamburg, Germany

The LUCIA project provides municipalities with up-to-date knowledge of energy efficient urban lighting, covering aspects of environment, technology, economy and social acceptance. To provide a tangible experience of its potential, innovative and energy efficient lighting solutions are installed in six cities across the Baltic Sea region.

Project budget: € 3.12 million
Project lifetime: 2019–2021

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Interreg Baltic Sea Region

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