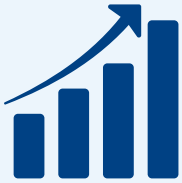
Key strategies to link economic development and smart urban lighting

Besides energy savings, smart lighting can support the transition towards long-term sustainable economic development of cities.

Three Economic Strategies

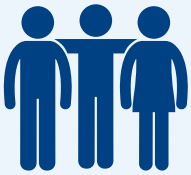


Sustain and grow the scale of smart urban lighting investments

There is a lot of unused potential for economic benefits and energy savings and the current low interest rate context is ideal to leverage your city's available capital.

Use smart urban lighting to put energy transition economics at the core of your city's climate action strategy.

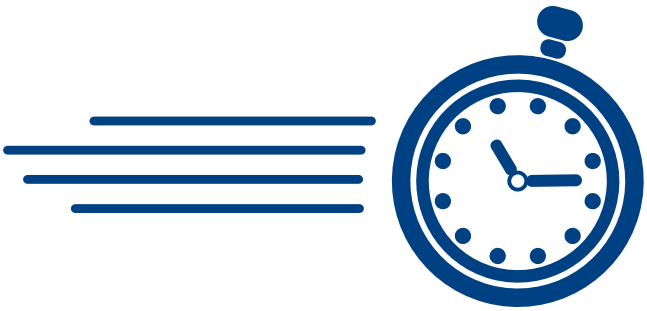
Smart urban lighting combines several key themes for the long-term sustainability success of your city: energy and digital transitions and climate action.



Double your city 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).[1]

There is an urgency to act, as investments in energy efficient technologies and adoption rates remain below the optimal level[2], preventing us from 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.



See next page for more information

Energy transition and the **rising price of electricity**

As the era of cheap energy is ending, the sustainability paradigm implies that more efforts from governments and society will be needed in relation to energy production and consumption, because we are transitioning to renewable energy sources that are less efficient.[3]

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Urban lighting: **energy and maintenance savings**

Street lighting typically accounts for more than half of a city's electricity bill, and savings from implementing full smart LED are considered to be 75–90% of baseline costs.[4] However, in mature markets such as Finland, cost savings from energy efficiency are taken for granted, and achieving savings in maintenance cost is the argument that is driving the implementation of smart lighting projects.

Decarbonization of lighting: **scenarios vs. roadmap**

One easy way to combine economic planning, carbon emission reduction objectives, and smart urban lighting goals is through creating economic plans for different adoption rates scenarios.

Yet, a better framing strategy might be to draw a roadmap towards rapid decarbonization, as it is argued that model-based and scenario assessments often fail to account for the non-linear change typical of innovative disruptions and human behaviour.[5]

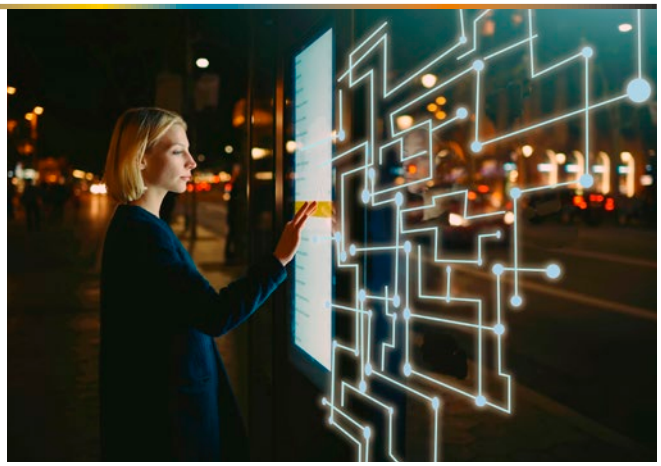

Photo: Shutterstock

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2 IEA, International Energy Agency 2014: Capturing the Multiple Benefits of Energy Efficiency and IEA 2013: Tracking Clean Energy Progress.

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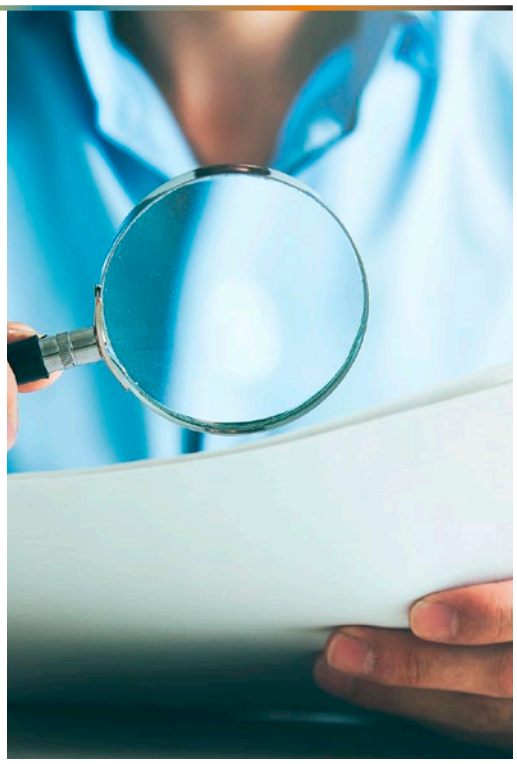
How to finance smart urban lighting investments

There are many options, but the most important strategy is to assess your 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

- **In-house procurement:**
  Complete control over the process, the city bears all risk.
- **Municipal Utility Companies (MUCO), relational contracts:**
  Partial of complete ownership over the third party, typically a municipal energy company, risk partially transferred.
- **Energy Utility Company (EUCO), long-term contract:**
  Ownership is exceptional, no performance targets.
- **Energy Service Companies (ESCO), long term performance contracts:**
  No municipal ownership; risk-sharing and responsibilities detailed in contract, guaranteed savings performance.



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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

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 NPV or low BCR, and still be informative for decision making.[1]

See next page for more information

How many of your city's **streetlights are metered?**

To measure and verify current situations and future projects, and fully use the argument of savings in economic planning, cities need a metered-consumption contract with their utilities company (instead of the traditional deemed-consumption or lump-sum payment).

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Systemic long-term risks of externalising basic urban infrastructure services to the technology industry

When considering your finance strategy for urban smart lighting, also remember that urban sustainability researchers have pointed out that if the only underlying principle in a smart city strategy is to expand the market for technology products and services, the results might actually leave parts of the city and its population unaccounted for, making the municipality less resilient in the face of future climate and social risks.[2]

Financing sustainable investments: **from more market-based procurement to re-municipalisation of energy services**

Recent research[3] and previous EU projects[4] argue that if a city lacks appropriate in-house governance capabilities to procure and implement large-scale innovative projects, market-based solutions can accelerate the diffusion of smart urban lighting. The most market-based option is a performance-based contract with a private energy service company, which finances the project. On the opposite side of the financial strategies spectrum, there is in-house capacity building and re-municipalisation of energy savings, as Hamburg, one of the LUCIA pilot cities, recently did.[5]

Photo © Christoph Hipp/Heike Bunte

References:

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2 Viitanen, Jenni and Richard Kingston. Smart cities and green growth: outsourcing democratic and environmental resilience to the global technology sector. Environment and Planning A 2014, vol. 46.

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4 EU Streetlight EPC (energy performance contracting) Project 2014–2017.

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See also: Revenues might come from solar energy production or fees from third parties using the smart network. About the real estate economics approach to decentralised photovoltaic energy and the argument for net metering, see Jussi Vimpari: Estimating the diffusion of rooftop PVs: A real estate economics perspective, Energy 172 (2019).

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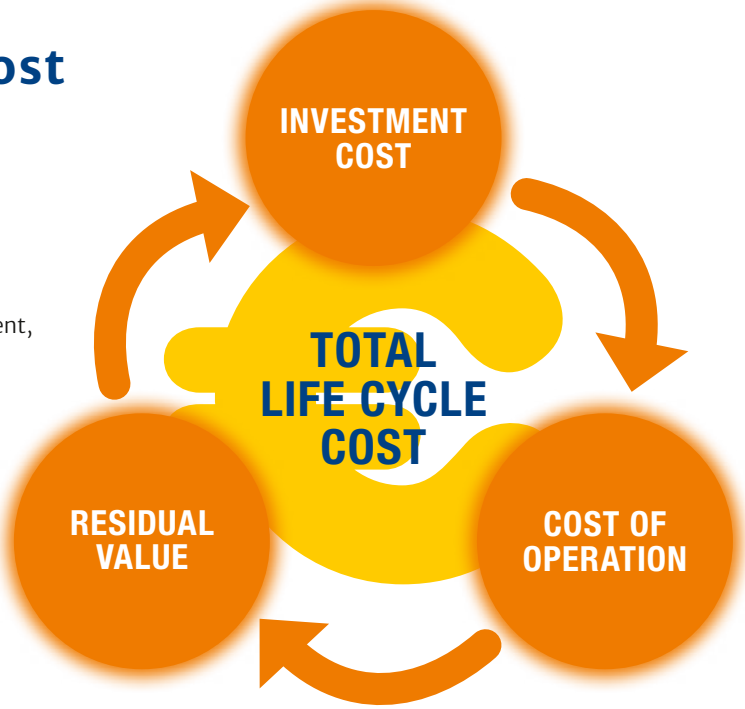
Applying a life-cycle approach to smart urban lighting investment decisions

Life cycle cost (LCC) analysis tries to define 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.[1]

Data input 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.

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

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 Internet of Things devices, uncertainty concerning the LED unit and the recycling options.

Life cycle cost 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. Demand product warranty or risk-sharing contracts to manage the long-term uncertainty.

See next page for more information

Achieving an overall life cycle assessment

To achieve an overall life cycle assessment, indirect economic impacts as well as the environment must be considered. An economic externality is the negative or positive impact (cost or benefit) resulting from a transaction, but not accounted for in its price, affecting third parties. The main direct externality of smart urban lighting project is light pollution, reducing dark night skies[2] and insect populations.[3]

Also, the LCC method should include the luminous properties and the light pollution externality to properly compare different options.[4] Smart lighting offers the potential to solve this issue, but this improvement will not appear in a straightforward matter without a clear strategy:

Include light pollution in your life cycle cost assessment and familiarise your organisation with this theme.

Photo: Shutterstock

Example of light pollution.

Photo: Topi Haapanen

Example of adequate lighting. Porvoo, Finland.

The rebound paradox

The rebound paradox is the well-documented phenomenon that energy-efficiency measures can result in smaller savings than expected, given an induced additional demand from the users. The size of this effect is difficult to measure, and existing research does not support the backfire hypothesis (more efficient technology leading to greater overall energy consumption).[5]

However, you should keep these issues in mind when designing your smart urban lighting project and try to minimise rebound risks.

Decision support under deep uncertainty

The combination of novel technology, evolving sustainability requirements, and climate change impact on our cities, produces a context of deep uncertainty over the decisions related to smart urban lighting investments. Deep uncertainty means that experts or decision makers cannot agree on the probabilities of important factors affecting the decision or its consequences.

In such cases, framing the decision correctly ("decision structuring") is more important than looking at any particular project assessment (such as LCA). "Deep uncertainty decision support" is a branch of applied research that municipalities can use to improve their operations.[6]

References:

1 The uncertainty comes mostly from lack of data quality and the most common method to address it is sensitivity analisys. See for example: Patrick Ilg et al. Uncertainty in life cycle costing for long-range infrastructure. Part I: leveling the playing field to address uncertainties. The International Journal of Life Cycle Assessment. February 2017, Volume 22.

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See also: www.darksky.org

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Economic benefits of multi-functional smart urban lighting

It is crucial to design a well-functioning economic, institutional and contractual framework, adapted to the local context.

Main upcoming smart functionalities	Framework design requirements
1 **Energy production** Such as decentralised wind,[1] solar[2] ...	**Electricity net metering model** ... answers to the challenges of costs, security of supply and CO_2 reduction.
2 **Network transmitters** The existing lampposts offer an ideal platform for ...	**Infrastructure marketplace management** ... a dense network of 5G antennas, or other smart devices requiring a physical support.[3]
3 **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.[4]

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

Photo: Shutterstock

See next page for more information

Economic framework design for the multifunctional lighting smart city

Only a properly designed economic local framework will support new business and revenue models that truly benefit the city's economy and the citizens' long-term well-being. The "smart city" paradigm requires new administrative strategies. For multifunctional lampposts consider at least:

Managing the relation with the power grid. A net metering legislation (NM) is recommended to support the diffusion of decentralised energy generation.[2] NM means that both self-consumed electricity and surplus electricity are valued at the same price (as opposed to net billing, where surplus electricity is valued at a lower price than if bought from the grid).

Managing the use of streetlamps as physical support to other physical devices, such as 5G antennas. The context determines the level of demand for access to the existing network of poles. A wrong framework might lead mobile network operators to over-compete and litigate against the municipality,[5] delaying the adoption of 5G. In low-demand situations, the municipality might have to support 5G adoption instead of charging fees for the installation of antennas.

Managing the data economy. Cities manage large amounts of data that could be used to create new services or improve existing ones. IoT (internet of things) sensors measuring for example air quality, parking pricing, or charging stations for EVs, will make internet-enabled lampposts a natural collecting point for this data economy. However, the local operator and the city administration should act as a "neutral host," allowing both cooperation and competition between service providers in the data platform.[4]

Creating additional business potential. The functions and IoT features connected with the lighting unit can provide new earning possibilities based on utilisation of commercial data of and for consumers and tourist (information to both directions).

Understanding new service value models: the business model canvas

To understand the new services enabled by your smart urban lighting project, it is useful to use the business model canvas (example to the right). You can fill in the canvas together with any stakeholder, such as technology providers, local entrepreneurs or the city energy company, to explicit changes and inform better policy decisions and support local economic development.

KEY PARTNERS	KEY ACTIVITIES	VALUE PROPOSITION	CUSTOMER RELATIONSHIPS	CUSTOMER SEGMENTS
Air quality company, transport company, local businesses	Negotiating incentives, marketing, managing fees.	Air quality monitoring and local shopping incentives for sustainable transport.	App with notifications, local vendors.	Citizens
	KEY RESOURCES Lampposts, app.		**CHANNELS** Public transport, businesses.	
COST STRUCTURE Additional budget for the managing city tourism office		**REVENUE STREAMS** Infrastructure use fees, percentage on shopping transactions.		

References:

1 For an example on the upcoming urban micro wind energy solutions, see the O-Wind Turbine, winner of the James Dyson Award 2018. (https://www.jamesdysonaward.org/2018/project/o-wind-turbine/).

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3 For an early example of infrastructure marketplace, see: https://smartlamppost.com (a joint venture between three of the most important players in Europe, in metal structures, Telecoms, Power and Smart Cities.

4 About the neutral host approach, see the Nokia BellLabs and City of Espoo consortium for 5G Lamposts, Luxturrim: https://www.luxturrim5g.com/new-blog/2019/11/4/nokia-driven-luxturrim5g-smart-city-ecosystem-extending.

5 For a short description of the 5G litigation problem in the UK, see: The Guardian 19 May 2010, "Revealed: 5G rollout is being stalled by rows over lampposts".

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Creating a "lighting hierarchy"

Wisely planned urban lighting reduces the negative effects of illumination and emphasizes the special features of the city.

What is a lighting hierarchy?

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.[1, 2]

A lighting hierarchy is about giving an importance to this special formation of the city. For instance, the Town Hall should be the brightest façade in the city, instead of a department store. High-traffic streets are brighter than streets with low traffic. 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 hierarchy makes it feasible to have darker areas with less light without losing safety.

A responsible lighting helps people to orient, adds safety to traffic, and prevents crimes. And, at the same time, lighting creates a beautiful city filled with lively energy.

Objectives of a lighting hierarchy

A lighting hierarchy – or a lighting master plan – develops a system for defining and meeting various societal needs.

- A good lighting concept gives structure and orientation.
- Lighting design makes the city unique.
- Lighting bridges main urban spaces.
- Light enhances neighbourhood characteristics.
- A lighting hierarchy preserves the darkness.
- A lighting master plan defines the city's overall appearance.

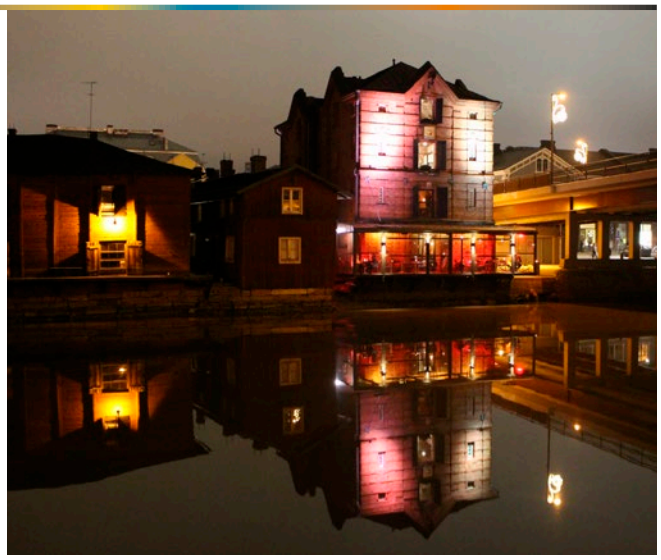

Photo: Topi Haapanen

How to create a lighting hierarchy

- Define objectives for the lighting hierarchy.
- Develop lighting categories for the different types of urban spaces.
- Integrate existing lighting concepts.
- Understand spatial relationships between various neighbourhoods.
- Accentuate the city's prominent architecture.

A lighting hierarchy – or a lighting master plan – allows the city to be more environmentally sustainable. A lighting hierarchy helps to avoid problems associated with a harmful lighting (e.g. light pollution).

See next page for more information

What is special about the city?[2,3]

With a lighting hierarchy, the public can better understand important places and buildings around the city. Lighting visualises skylines and essential structures, highlighting unique features of the chosen space. A well-developed lighting hierarchy assists the citizens by giving a visual guidance for spatial identification.

Example: *Lake Binnenalster, in the inner city of Hamburg, is a lake in darkness. The surrounding façades are illuminated with warm white light. The Town Hall in the background, with historical and political importance, is brighter than the office buildings and department stores. Through the lighting contrast from the dark lake, the lighting hierarchy can be achieved with only a small amount of lighting and energy consumption.*

A lighting hierarchy **reduces overall brightness and light pollution**

A lighting hierarchy defines the maximum luminance for the city's important places and buildings, and subsequently, the appropriate brightness level for less important façades around the city. Following the same principle, private lighting should always be less bright than lighting for priority features. In the overall lighting scheme, it is also important to consider the surrounding brightness. Using a lighting hierarchy, the city should limit the maximum luminance and the surrounding brightness through a policy for the use of individual lighting in shop-windows, windows, walls, and roofs.

Example: *The luminance of the façade of the Town Hall in Hamburg is pretty low; it is about 3–4 Candela per square meter.*

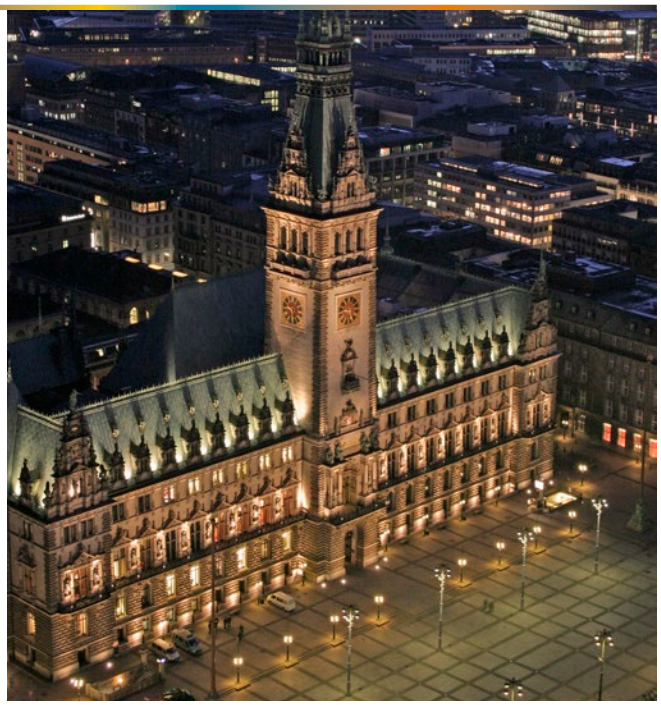

Photo: Brandi Lichtdesign

A lighting hierarchy creates a **safer environment around the city**

A lighting hierarchy also includes considerations for the street lights. By defining a hierarchy based on the typology of streets or paths, traffic intensity, environment, and road safety, the city can achieve lower brightness for the overall city without necessarily compromising the public's safety.

Human eyes adapt to brightness. Therefore, it is critical to provide a low brightness-contrast for the surroundings to prevent glare, while maintaining regularity of the luminance level for the streets. It is also important to take into account the overall illuminance for the public areas.

Example: *Illumination for the paths in a park. It is safer for the public to illuminate a single path with the highest traffic, than to illuminate multiple paths and scattering the traffic flow.*

References:

1 Oldenziel, Ruth et al: (2016): Cycling Cities: The European Experience. Hundred years of Policy and Practice. Eindhoven/Munich.

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Light pollution affects biodiversity

It is important to protect the environment from the harmful effects of lighting. Our welfare relies on the pollination of animals.

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 street light kills about 6.8 million insects every night in the summer. Birds, fish and amphibians also become confused by the presence of artificial light, which results in death due to exhaustion or 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.

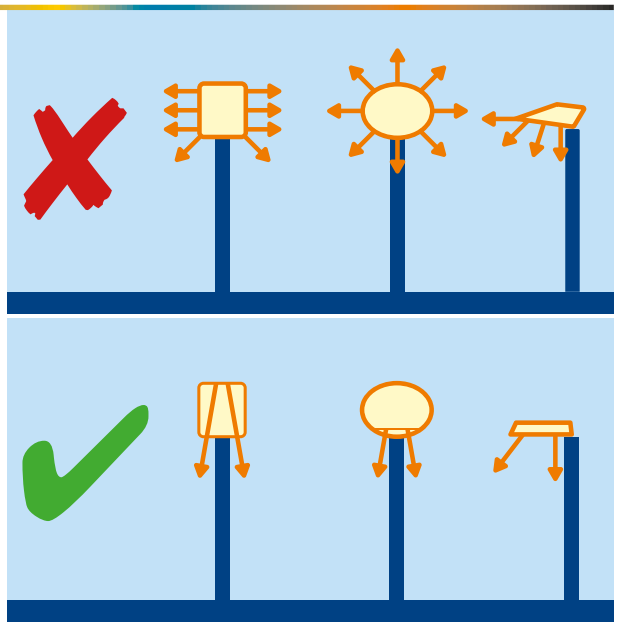
For plants, artificial light extends the growth period and causes early leaf out, impacting the wider composition of the floral community.[1]

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.

How to protect biodiversity from light pollution[2,3,4]

- Reduce the overall light output.
- Use luminaires with direct light distribution (full cut off lighting).
- Choose warm white light colour for public lighting.
- Provide regulations for the maximum luminance level, size, and placement for advertising panels.
- Restrict sky beamer light shows (or limit to minimum periods).
- Install insect-tight luminaires.
- Reduce illumination in areas close to nature and parks.
- Use light control systems to lower the illumination level during the times of low traffic.



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Consequences of growing brightness (luminosity)

More and more cities are transforming public spaces into places of residence , resulting in a growing usage of artificial light for night time visibility. Over the past decades, the brightness level of major cities has increased tremendously. Higher brightness levels create a positive image, and people tend to equate brightness to safety. However, the nature suffers with a huge loss of biodiversity.

In an urban environment, insects actively congregate around the light sources and die of exhaustion, become an easy catch, starve to death, or burn inside a luminaire. Hence, light pollution harm insects by reducing their total biomass and population size, and by changing the relative composition of the population, all of which can extend the negative influence further up the food chain.

Furthermore, migratory fish and birds can become confused by artificial lighting, resulting in excessive loss of energy and spatial impediments to migration, resulting in reduced migratory success. Daytime feeders extend their activity under illumination, putting an increased predation pressure on nocturnal species.

Humans are not an exception when it comes to suffering from light pollution. Artificial light at night affects our melatonin production and can lead to symptoms like insomnia.

Photo: Shutterstock

Where, when, and how much light?

It is important to develop lighting concepts with a consideration of biodiversity to avoid harmful lighting concepts (e.g. sky and façade lighting) that can harm the surrounding nature. The amount of light depends on the urban environment.

In designing lighting for festivities and advertising placards with LED, be careful in making decisions about the place and time of the light shows, in order to not disturb nearby living organisms.

- Only provide the needed amount of artificial light, in accordance with the surrounding and the vulnerability of living organisms nearby.
- Use shielded luminaires.
- Provide temporary lighting by precisely controlling where and when the light is needed.
- Switch off the artificial lights at times of low traffic and during critical periods for light-sensitive organisms (e.g. migration or hunting time).

References:

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Preserving darkness in the city

Dark sky preservation raises awareness of city lighting concept as a whole. Avoiding over lighting reveals darkness as a part of the natural environment.

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 "light-domes" above our cities have grown more than 5% each year. And today, we can no longer see the stars of the night sky.[1]

The stars or the Milky Way are not visible at night due to the light-domes. 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.

Photo: Shutterstock

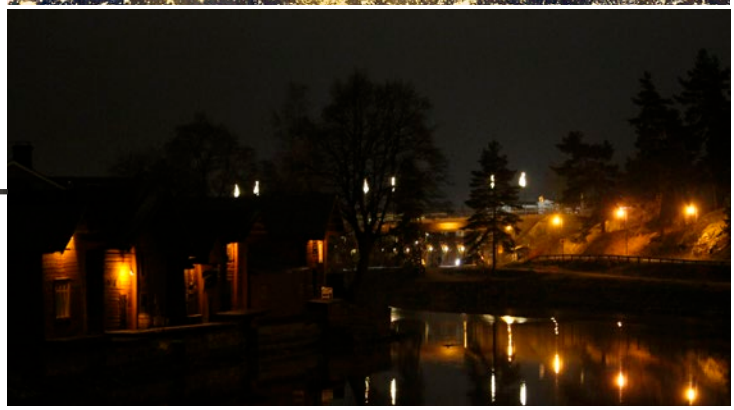


Photo: Topi Haapanen

Example of maintaining the dark sky. Porvoo, Finland.

Ways to protect dark sky in an urban environment

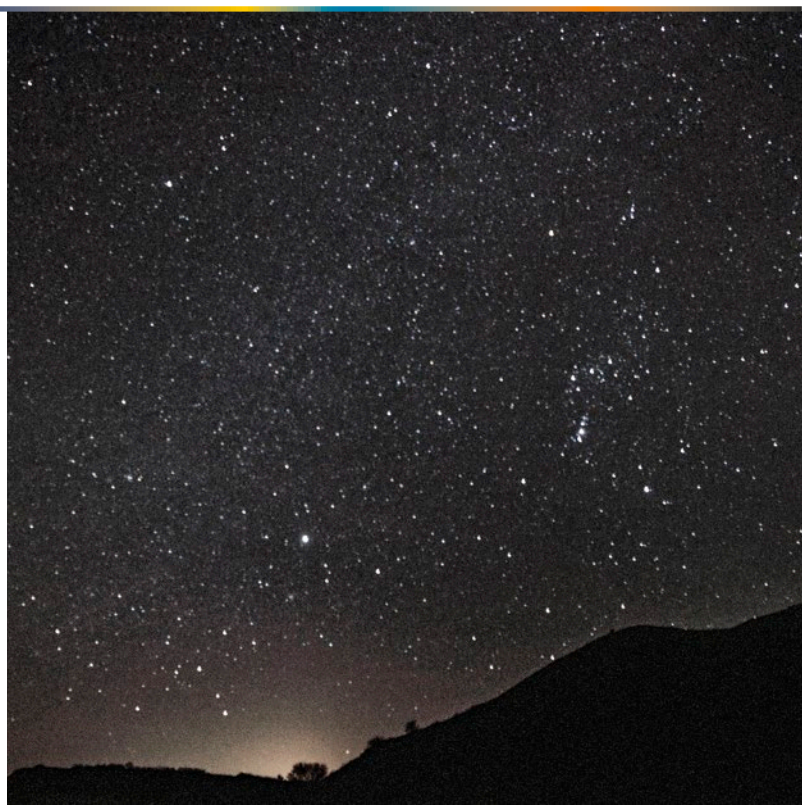
- Integrate the field of astronomy to education curriculum in public schools.
- Raise awareness for problems associated with the use of artificial lights through public workshops and discussion forums. For instance, organise city-wide "dark walks" for the general public.
- Protect darkness for areas around the observatories through policy regulations to allow for sensual experiences.
- Develop and adopt a lighting masterplan that incorporates sustainable design and environmentally friendly technology to a city-wide lighting regulation.

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.

See next page for more information

Reducing light pollution[2,3,4]

- Reduce the overall light output in the city.
- Use luminaires with direct light distribution (full cut off lighting).
- Choose warm white light colour for the public lighting.
- Provide regulations for the maximum luminance level, size, and placement for advertising panels.
- Restrict (or limit to minimum periods) sky beamer light shows.
- Create dark areas with a comfortable and welcoming atmosphere, to invite citizens to adjust to darkness and observe stars at night.
- Use light control systems to lower the illumination level during times of low traffic.
- Implement an environmentally friendly lighting design.



Kragemosen is one of several areas where there is close to zero light pollution on the Danish island of Samsø.

Precedents for "dark sky parks" and "dark sky communities" in cities

There are several areas in Europe that are officially designated as "dark sky parks" or "dark sky reserves". A dark sky park aims to provide darkness by lowering the usage of artificial light, to protect natural habitats and the view of the night sky. This provides important cultural, educational, and scenic values for the citizens. A dark sky reserve offers additional features for science and discoveries. In these parks, one can see the moon, bright stars, sometimes the brightest planets or even the Milky Way with the naked eye.

Additionally, "dark sky communities" use high quality luminaires to foster public engagement. All of these communities as a whole can bring additional economic benefits to cities as well as tourist attractions.

Examples in Germany: *Westhavelland (dark sky reserve), Rhön (dark sky reserve), Fulda (dark sky community).*[5]

References:

1 Fisher, Luci (2016): Understanding light pollution. In: Cities and lighting. The LUCI network magazine. No. 8-2016; pp 14-19.

2 Corten, Isabelle (2016): Participative light planning. In: The LUCI network magazine. No. 8-2016; pp 28-29.

3 Held, Martin/ Hölker, Franz: (2013): Ökologie der Zeit und künstliche Beleuchtung in der Nacht. In: Held, Martin/Hölker, Franz/Jessel, Beate (Edit.). Schutz der Nacht – Lichtverschmutzung, Biodiversität und Nachtlandschaft. Bundesamt für Naturschutz. Bonn.

4 Gouvernement du Grand-Duché de Luxembourg (2018): Mouvement écologique (Leitfaden „Gutes Licht" im Außenraum für das Großherzogtum Luxemburg. Wirkung nächtlicher, künstlicher Beleuchtung auf Fauna und Flora). Luxembourg. www.emwelt.lu

5 https://www.darksky.org/our-work/conservation/idsp/communities/
https://www.darksky.org/our-work/conservation/idsp/communities/fulda-germany/
https://www.darksky.org/our-work/conservation/idsp/reserves/rhon/
https://www.darksky.org/our-work/conservation/idsp/reserves/westhavelland/

See also: www.darksky.org

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Can lighting reduce vandalism? Protecting public property from damage

There are different types of environments in the city. Identifying places where vandalism occurs more often has an effect on how to organize the urban lighting.

Photo: Shutterstock

Vandalism: *the act of intentionally damaging property belonging to other people – "physical damage," "intentionality," "owned by someone else."*

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 safety of our daily life. It is required to prevent crime and identify potential risks. For many years, public utilities and municipalities have been using luminaires to help eliminate the problems of vandalism.

However, brighter does not mean safer. A lit-up ground does not necessarily mean a bright sky. Smart lighting that directs light where 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 impacting negatively on road traffic collisions and crime.

BRIGHTER DOES NOT MEAN SAFER

According to a study of London Street lighting and crime in 2011[1], 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[2] showed a correlation between brightly-lit alleys and increased crime.

Key factors for responsible lighting: **eliminate the cover of darkness**

Site and building considerations to minimise crime:

- **Lighting at valuable points:** If total lighting around entire building, 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.
- **Security lighting around buildings:** lighting should be provided all around the buildings – a well-lighted building prevents attempts at unlawful activities
- **Lighting for parking bus stations, bicycle and car parkings:** establishing a good lighting layout allows light to be well-spread throughout public lots, protecting public property from vandalism/damage and making users feel safe.

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 within your city with high rate of damage and identify problems. Integrate and encourage public participation and sensitise the inhabitants for their areas' safety concerns.

See next page for more information

Solutions for public places often affected by damage

Different public services require different solutions. Examples of this are public elevators, toilets, public transport, public tunnels, parks, narrow pathways, etc.

- Place lights in strategic locations around the property, to lower the chance of criminal activity in an area and serve as a deterrent with the implementation of automated motion sensors.
- Install LED based white-light illuminators to deliver perfect light for use with colour cameras. LED white-light simulates daylight unlike most standard incandescent sources and will illuminate images, brightening chosen areas.
- Use taller light poles to avoid damage to the luminaires.

Example: *In Hamburg, the minimum of 2 m height is required for the light-pole. Knee-high luminaires are not suitable to use in Hamburg due to the high probability of damage.*

Photo: Michael Zapf

Photo: Göteborgs Stad

Top: Alter Elbtunnel, Hamburg, Germany. Public historical tunnel for cyclists and pedestrians under river Elbe.
Bottom: Public transport hub Gamlestads Torg, Göteborg, Sweden.

Choosing durable luminaires

- Check how producers "test" their lights.
- Check the "safety class" of lamps which might indicate "sustainability".
- Anti-vandal luminaires: vandal-resistant luminaires have mechanical properties that allow it to be protected against break-in (e.g. anti-tearing, difficulty to disassembly, specially shaped screws, strong mechanical resistance) – intended for specific applications such as public passages or penitentiaries.
- Lighting for "high vandal risk" areas (e.g. subways, waiting areas, parking garages etc.) typically have features like: stainless steel or aluminium housing, impact resistant covers and secure locks, fast and easy installation (adjustable cable channels that can be fitted to any architectural environment).

References:

1 Steinbach, Rebecca; Perkins, Chloe et al. (2015): London Street Lighting: https://jech.bmj.com/content/jech/69/11/1118.full.pdf

2 Morrow, Erica N.; Hutton, Shawn A. et al. (2000): Chicago Alley lighting Project: https://www.csu.edu/cerc/researchreports/documents/ChicagoAlleyLightingProject2000_000.pdf

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The role of the private sector in public lighting planning

Enhancing co-operation between public and private sector in lighting planning engages different stakeholders in improving city development.

Benefits of including the private sector in lighting planning[1, 2]

Due to urbanisation, cities are growing intensively with a rapid growth of population. This leads to an expansion of industrial and shopping areas. Concentrated energy use leads to greater light pollution with significant impact on human health and surrounding ecology.

Cities should identify specific target groups such as industry, retail, 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.

Photo: Brandi Lichtdesign

Photo: Shutterstock

Heading towards more liveable and sustainable cities requires involving target groups – industry, retailers, etc.[3]

- The UN defined the SDGs (Sustainable Development Goals) to provide guidelines for building sustainable societies around the globe. The goals include "decent work and economic growth" (SDG 8) and "sustainable cities and communities" (SDG 11).
- Industrial areas are mostly located far away from the city centre, close to urban green spaces near. 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 architectonical concepts and choice of lighting that best-suit 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.

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

See next page for more information

Identify target group-specific technical and communication concepts

- Build an open platform for discussion between civil society, retailers, industries, experts, and policy makers.
- A wide range of disciplines need to be engaged and communicated.
- Both private and public sectors need to benefit from the decision being made; hence prior research is necessary to create questions based on the needs of all the stakeholders.

Methods and tools to involve target groups in lighting planning:

- "Round table" – regular public discussion forums.
- An integrated database with information from all sectors involved.
- Workshops and presentations to share expert knowledge.
- Excursions arranged by experts, to visit remote regions and share their insights.

"Experts to Experts"

- Professional lighting experts can plan the lighting, also for private industrial buildings and retail shops.
- To bring different experts together, cities need to invest in prior research and prepare critical, yet innovative, questions.
- Bringing experts together could mean finding a middle ground for different interests (e.g. environmental protection from light pollution vs. economic prosperity and marketing efficiency).
- Addition of new third-party input can be helpful to enrich the discussion.
- The forum should incorporate an interdisciplinary framework to openly share different perspectives (e.g. urban planners vs. ecologists).
- Industries and retail businesses need to understand economic profits that can be obtained from installing sustainable lighting.

Establish public-private partnerships

- The target group suggests the topic (e.g. industrial lighting, shop window lighting, etc.).
- Each target group prepare precise and specific questions for lighting design.
- Cities need to prepare answers and appropriate actions by involving a number of departments within their administration.
- Provide case studies for the target groups specific to the topic of discussion.

References:

1 Hänel, Andreas (2019): Light pollution in cities – challenges between marketing, public safety and environment. (Unpublished) Presentation 07.11.2019 – Workshop-Economy of Public Lighting. Hamburg.

2 Gouvernement du Grand-Duché de Luxembourg (2018): Mouvement écologique (Leitfaden „Gutes Licht" im Außenraum für das Großherzogtum Luxemburg. Wirkung nächtlicher, künstlicher Beleuchtung auf Fauna und Flora). Luxembourg. www.emwelt.lu

3 UN-SDG: https://www.un.org/sustainabledevelopment/cities/, https://www.unenvironment.org/regions/asia-and-pacific/regional-initiatives/supporting-resource-efficiency/sustainable-cities

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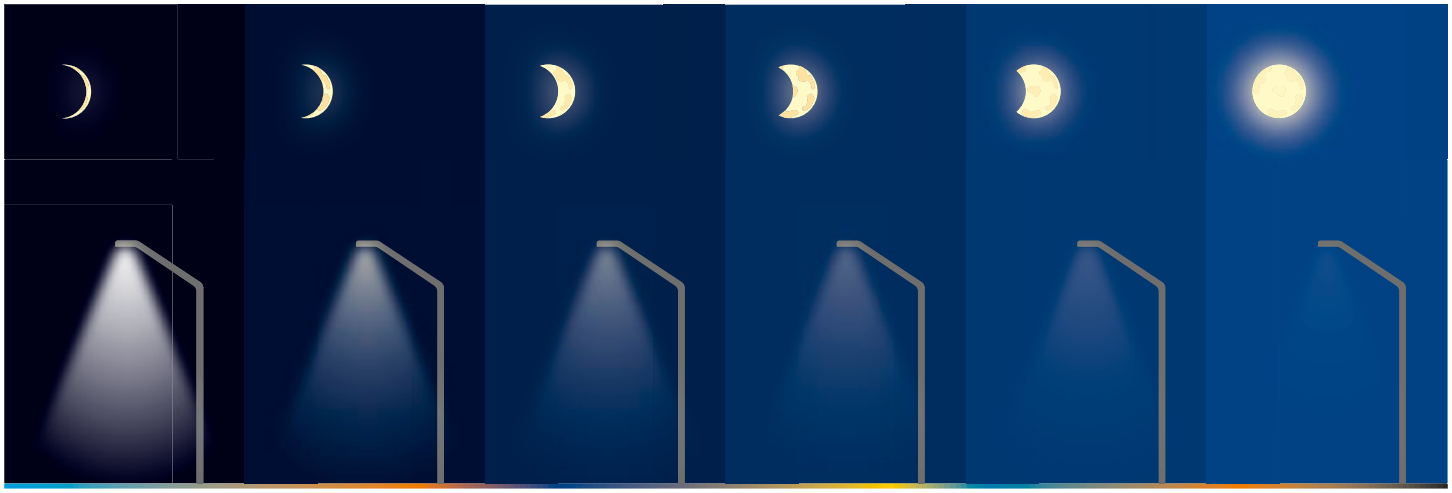
What to consider in designing a lighting control system

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

Based on the type of control system, there are three types of lighting control systems:[1]

- **Autonomous control (calendar)** – The luminaires are pre-programmed with fixed periods for operation. This is by far the simplest and cheapest solution.
- **Centralised control** – 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.
- **Dynamic control** – 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.



Advantages of investing in a lighting control system

- Increase energy savings.
- Increase operational savings and better customer satisfaction.
- Achieve additional smart city applications.

ACTIVE CONTROL allows for significant energy savings, but it must be weighed against added complexity and cost.

DYNAMIC CONTROL is up to 34% more efficient than calendar control.

See next page for more information

Street lighting control strategies[2]

- **Astronomical timer** – using precise information about sunrise and sunset times for any given geographical position. Doesn't consider weather conditions.
- **Daylight harvesting** – using photo sensors to detect the ambient light and adjust the artificial lighting if the ambient light levels fall or increase beyond certain threshold values. Doesn't consider traffic.
- **Traffic detection** – using motion sensors to make lighting dynamic and responsive to human presence, e.g. traffic may be consistently low, especially late at night.
- **Dimming** – depending on traffic, weather, and ambient lighting conditions it may not be necessary to operate lamps at full power throughout the night. By combining proper astronomical timers, daylight harvesting, and traffic detection schemes with dimming, huge energy savings can be attained. In some projects, up to 85–90% savings were achieved.

Benefits of Dimming[3]

- **Less electricity consumption** (easy to reduce electricity costs by 25-60%, reduced environmental impacts associated with electricity production).
- **Less light pollution** (less sky glow, less glare, less intrusive light, less effect on nocturnal species).
- **Lower risk of overheating** (and thus premature failure) – LED lifetime may be extended even beyond normal manufacturer claims.
- **Increased security**.

Consumption of LED solutions compared to high pressure sodium (HPS) lamps[4]

TYPE OF LIGHTING SETUP	ENERGY CONSUMPTION COMPARED
HPS – before retrofit	100%
LED – after lamp changing	59%
LED – dimmed with luminous flux tuning	50%
LED – dimmed with dynamic control	36%

See also:

1 LED Street Lighting Procurement & Design Guidelines, Ref. Ares (2017) 5874064 - 30/11/2017

2 http://www.premiumlightpro.eu/ and https://www.tvilight.com/

3 https://ec.europa.eu/environment/gpp/eu_gpp_criteria_en.htm

4 https://doi.org/10.3390/su10113925

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Energy efficiency and luminous efficacy of LEDification

Energy efficiency and luminous efficacy have the highest impact on increasing environmental friendliness of lighting systems.

Energy Efficiency

The goal to reduce the amount of energy required to provide products and services.

Efficacy

The amount of visible light emitted for a given amount of power used.

Payback time of LEDification

Varies from less than a year (for direct retrofit of a light source) to 2-3 years for a complete lighting system.

Efficacy levels and lifetime of typical streetlighting lamps[1]

LAMP TYPE	EFFICACY lm/W	LIFE TIME hours
Mercury vapour	13-48	12-24 K
Metal halide	60-100	10-15 K
High pressure sodium	45-130	12-24 K
LED	70-150	25-60 K

COMPARED TO MOST OTHER TECHNOLOGIES, LEDs REACH VERY HIGH-ENERGY EFFICIENCY LEVELS (lumen per watt of power)

Annual global electricity savings for lighting will reach 640 TWh in 2030

saving $360 billion in avoided investment in 290 large coal-fired power plants

CO_2 emissions savings are **390 megatonnes annually**

Provide new grid connections to over **300 million households**

$50 billion savings in consumer savings on their electricity bills

LEDs reduce energy consumption for street lighting up to 60% compared to conventional lamps.

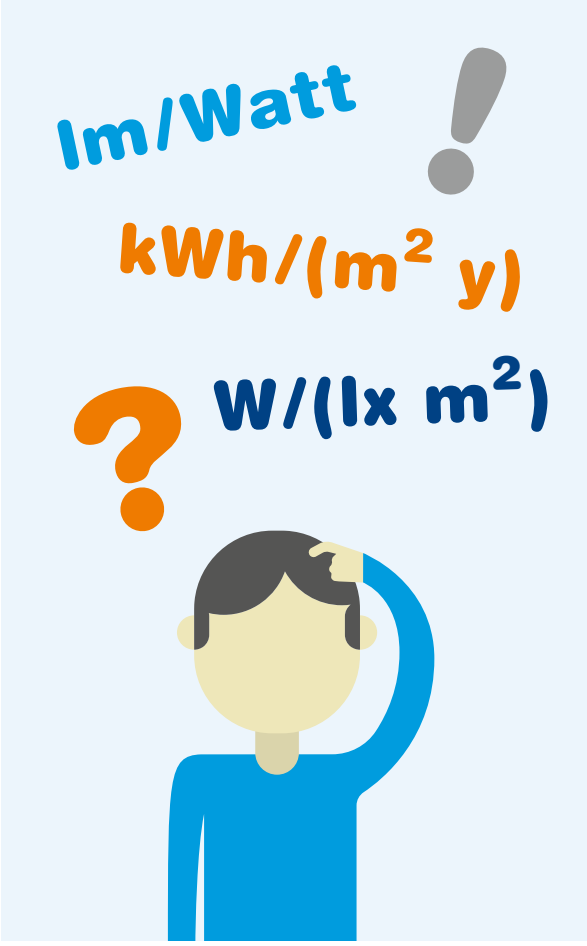
Dimmed LED lighting can reduce energy consumption up to 85% compared to conventional solutions.[2]

See next page for more information

Measuring energy efficiency

Overview of key terms for measuring energy efficiency according to EN13201-5

- **Luminous efficacy**, (lm/W).
- **Power density indicator (PDI)**, W/(lx m^2).
- **Annual energy consumption indicator** (AECI), kWh/(m^2 y).
- **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.
- **Road profile**.



Lowest luminaire efficacy of prospective lighting systems[3]

YEAR OF TENDERING	EFFICACY, lm/W
2018–2019	130
2020–2021	147
2022–2023	165

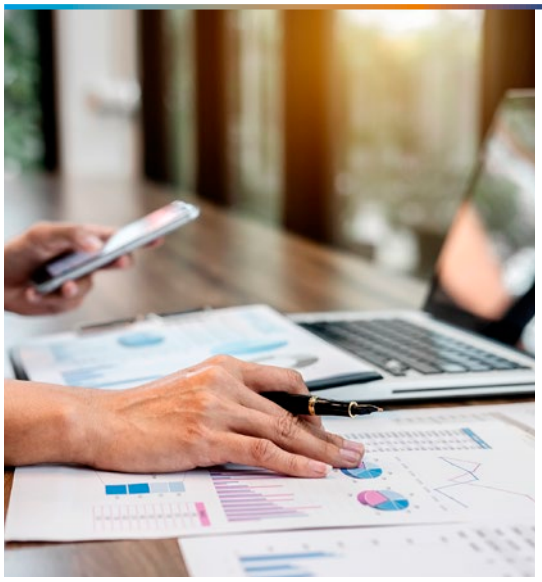


Photo: Shutterstock

Main requirements for tenderer[3]

- 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.
- Provide a clear calculation, where the values for the luminaire efficacy, maintenance factor and utilance factor of their proposed design are visible. The calculation results must include the measurement grid and calculated illuminance/luminance values.
- Provision the technical specifications of the metering and measurement system and provide clear instructions for O&M of system. A calibration certificate compliant with Measuring Instruments Directive 2004/22/EC shall be provided for each control zone.

See also:

1 https://doi.org/10.1016/j.crhy.2017.10.013 and https://doi.org/10.3390/su10113925
2 https://doi.org/10.3390/su10113925 and http://www.premiumlightpro.eu/
3 https://ec.europa.eu/environment/gpp/eu_gpp_criteria_en.htm

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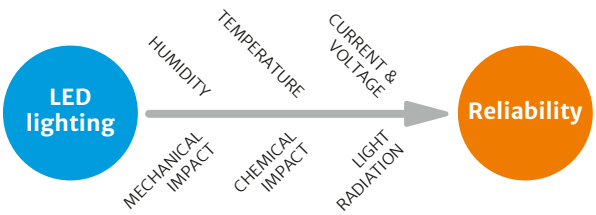
Improving the reliability of lighting systems

Lighting system reliability is the product of all of the individual reliability considerations, like LEDs, optical systems, printed circuit boards, mechanical components, thermal reliability of 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[1]

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.



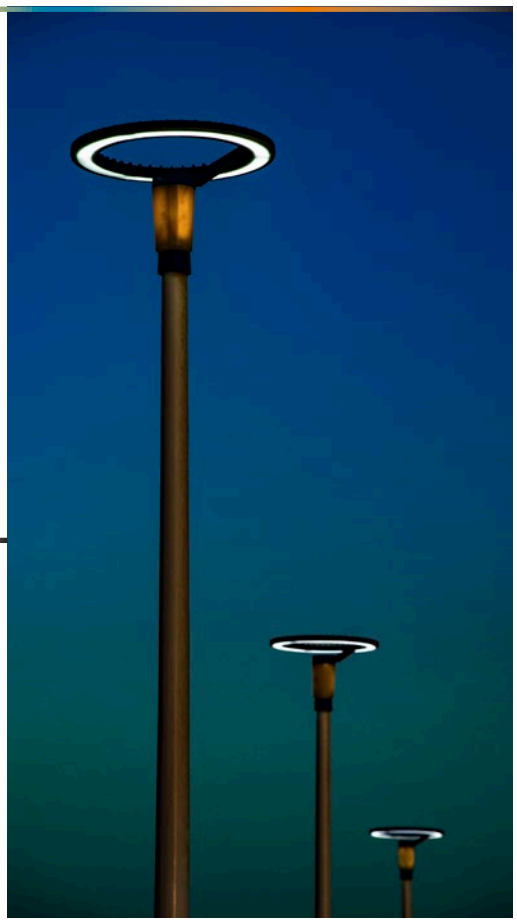


Photo: Shutterstock

Better planning of lighting systems[2]

- Plan and use high-quality LEDs from manufacturers who publish reliability data.
- Ask for luminaire warranty from manufacturer, at least comparable to traditional luminaires used for the application under consideration.
- Ask for photometric reports for luminaires, based on LM-79-08 test procedure, from an independent testing laboratory.
- Integrate remote monitoring of light points, to save on operational costs and prevent issues before they happen.
- Ensure modularity and emphasise recyclability, by enabling more efficient and longer use of components.
- Take 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.
- Ask for test data about long-term performance of the LED luminaire.

More than 60% of lighting system failures are related to the driver.

Advantages of longer life may not be realised if the expected use cycle is less than the lifetime.

See next page for more information

Classification of failure categories[3]

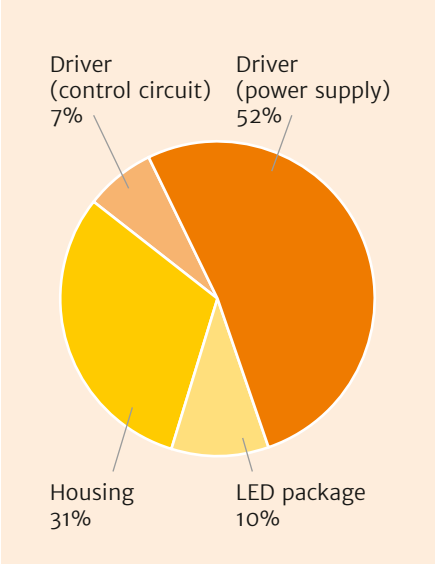
DRIVER (POWER SUPPLY) includes power supplies and contains all failures related to the power supply or its inability to perform as specified by the luminaire manufacturer.

DRIVER (CONTROL CIRCUIT) includes control board(s) or other control devices, if they are separate and unique from the power supply, including controls that monitor and/or manage the luminaire's operational state.

HOUSING INTEGRITY includes failures from loss of housing integrity, resulting in moisture ingress, debris accumulation, structural failures, etc.

LED PACKAGES includes traditional end-of-life lumen degradation, chip package failures, significant color shifts, etc.

ELECTRICAL CONTACT includes wiring and connector failures and any general connectivity issues resulting in failure or faulty functioning of the luminaire.



Main technical requirements[4]

- New LED-based light sources shall have a rated life at 25°C of:
  - L96 at 6,000 hours,
  - L70 at 50,000 hours (projected),
  - C0 at 3,000 hours or C10 at 6,000 hours,
  - C50 at 50,000 hours (projected).
- The specified control gear failure rate shall be lower than 0.2% per 1,000 h and be covered by an 8-year warranty for control gear.
- The repair or provision of relevant replacement parts of LED modules suffering abrupt failure shall be covered by a warranty for a period of 5 years (GPP core criteria) from the date of installation.
- Components must be identifiable, accessible and removable without damaging the component or the luminaire.

Requirements for tenderer[4]

- The repair or provision of relevant replacement parts of LED modules suffering abrupt failure shall be covered by a warranty for a period of 7 (GPP comprehensive criteria) years from the date of installation.
- Test data regarding the maintained lumen output of the light sources shall be provided by an International Laboratory Accreditation Cooperation-accredited laboratory that meets IES LM-80* for actual data and IES TM-21* for projected data.
- To provide a technical manual, which shall include an exploded diagram of the luminaire illustrating the parts that can be accessed and replaced. The parts covered by service agreements under the warranty must also be indicated.
- To provide the technical specifications, demonstrating that ingress protection rating criterion has been met according to IEC 60598-1 clause 9.
- To provide a declaration of compliance with the above failure rate for any control gear it intends to supply. The declaration shall be supported by relevant industry-standard testing procedures.

See also:

1 www.midstreamlighting.com
2 www.brandon-lighting.com and www.solarlighting.com
3 www.nglia.org
4 https://ec.europa.eu/environment/gpp/index_en.htm

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The importance of power quality

LED lights are non-linear loads producing harmonic distortion in power grid. Increased harmonics distortions causes higher operation and maintenance costs of the lighting systems.

Photo: Shutterstock

What is power quality about?

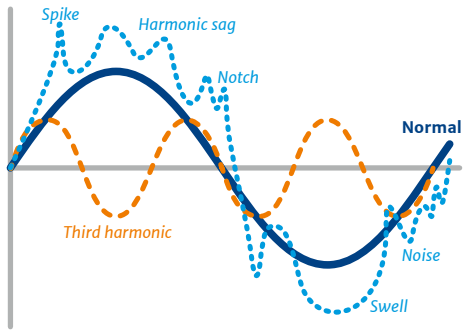
Power quality is defined as the power grid's ability to supply a clean and stable power flow, as a constantly available power supply.

The power flow should have a pure sinusoidal waveform; it should remain within specified voltage, and frequency tolerances.

An adequate power quality 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 power quality is economic value for utilities, their customers, and suppliers of load equipment.

Common power quality problems



PREVENTING PQ PROBLEMS:

Procure and install components (i.e. luminaires) with power factor ≥0.95.

Perform regular power quality monitoring for timely maintenance of filter, harmonics suppressions.

Dealing with power quality problems

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

See next page for more information

Photo: Shutterstock

How LEDfication affects power quality[1]

Non-linear nature of the load
Harmonic, especially third harmonic, is generated due to low voltage network as LEDs are non-linear loads.

Conversion of AC to DC
LED Drivers convert AC power into DC power that is appropriate to light a bulb. During this conversion, high frequency current is generated which is the root cause of Harmonics.

Triplen Harmonics
LED lights can cause triplen harmonics and they have to be considered separately as system response to triplen harmonics is different than other harmonics.

Low power factor of LED driver
LED drivers with a low power factor reflect harmonics back to the mains. Increasing number of high-power LED lights increases a risk of electrical pollution across the mains.

Inrush Current
LED lighting with compensated power factor can cause high inrush current. This can cause damage and malfunction of equipment.

How PQ affects lighting systems costs

Increased installation costs

Driven by demand for over-dimensioning of electrical installation, caused by increased energy use and energy losses in system.

Increased O&M costs

Driven by increased energy consumption, lighting system instability and failure rates.

- Higher voltage is harmful to lighting system performance and longevity.
- Lower voltage can cause brown outs and reduced lighting quality.

See also:

1 www.apqi.org

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Supporting technologies – the key to smart lighting

Smart street lighting infrastructure acting as service gateway for other street level devices is the backbone of the smart cities.

The smart city starts with smart lighting

- **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.
- **Flexibility to add new applications** like electrical vehicle charging stations, sensors to assess air quality, public Wi-Fi or smart parking.
- **Ability to add smart sensors** helps monitor everything from the weather and air quality to traffic.
- **Availability of new data** enables to provide new services for citizens and increase their safety.
- **Integrated renewables** enable to implement zero-energy and environmentally friendly solutions.

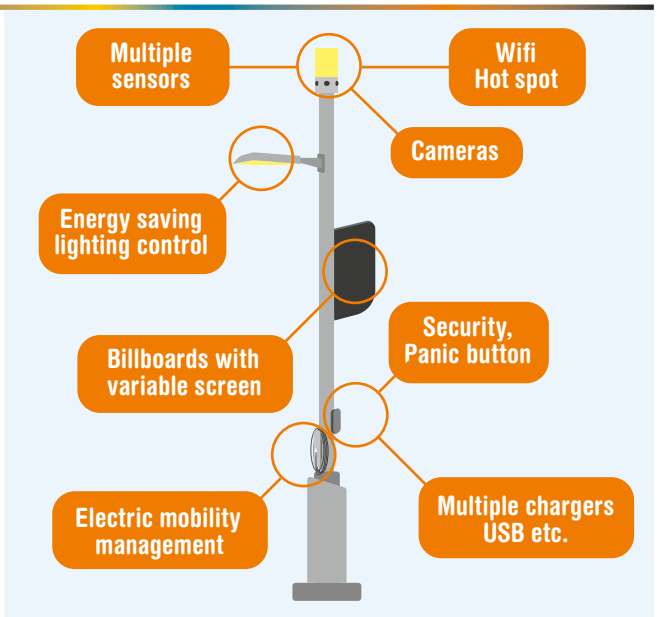


Photo: Shutterstock

Main supporting technologies

- **Renewable sources**, like solar or wind power, meaning Lighting system 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.

The internet of things (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.

See next page for more information

Pros & Cons of self-powering with renewable sources

Applications

- Locations with higher electricity costs.
- Locations with costly investment.
- Eco-sensitive landscapes.
- Temporary or emergency installations.

ADVANTAGES

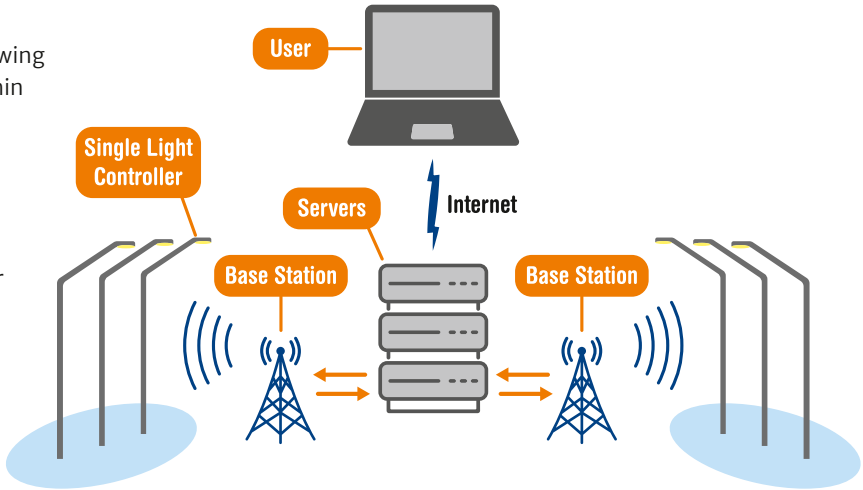
- Lower operation/maintenance costs because of no wiring between lighting points/grid, long life components, and no connection fees.
- Reduced planning and installation costs, when used on remote/rural/off-grid areas.
- Reduced carbon footprint compared to conventional lighting systems.
- Reduced probability of overheating.

DISADVANTAGES

- Higher investment costs.
- Higher risk for theft.
- Risk of Cyber-attacks and data security.
- Extreme weather conditions stop or reduce the energy production.

Benefits of networked lighting controls (NLC)

- Peak energy management.
- An additional 22% lifetime energy savings on average.
- NLCs can boost the energy efficiency of stand-alone LED commercial lighting projects by up to 47%.
- Improved public safety, based on research showing that 50% of automobile accidents happen within a 3 hour time period at dusk.
- Energy optimisation, allowing cities to add more lights at the same energy consumption.
- Street NLC can control advertising panels, parking spot availability notification, and other new city services.
- Electric vehicle charging can be incorporated into NLC, making the charging process more convenient.



See also:

1 New Report: Potential for Energy Efficiency Programs to Deliver More Savings by Properly Valuing Lighting Systems. DesignLights Consortium. Nov 5th, 2019. LEDs Magazine.

2 www.ase.org/lighting-savings-report

3 www.echelon.co

The need for lighting system verification measurement

Verification measurements are part of planning, implementation and evaluation process of streetlighting systems to ensure safe and sustainable environment.

Why we need verification measurements

To succeed in implementing a new lighting system, there are a number of reasons for performing verification measuremenst 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.

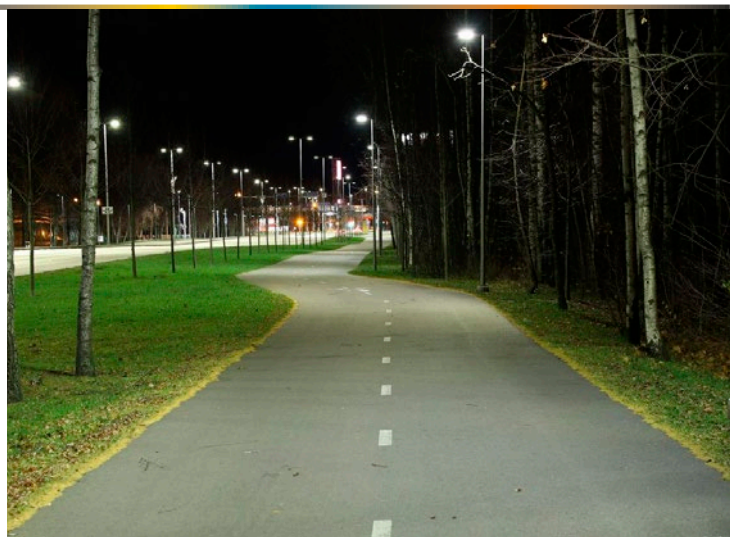


Photo: Toivo Varjas

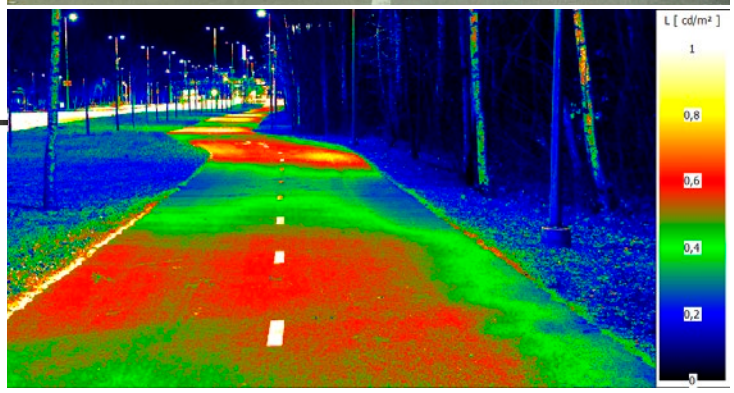


Photo: Toivo Varjas

Verification measurement on pedestrian street in Tallinn, Estonia

When to carry out control measurements

The measurements should be performed at several points during the decision and implementation process:

- 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.

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.

See next page for more information

The purpose of measurements after object completion

- Compliance with EN13201-4: 2015 and EN 12464-2: 2014.
- Assessing the expected energy savings.
- Checking compliance with warranty claims.
- Improving control system and maintenance practices.
- Road safety inspections.

The purpose of measurements before warranty expiration

- Obtain a warranty evaluation.
- Check lighting installations for compliance with CEN/TR 13201-1; EN 13201 2-4.
- Assess changes in luminaire energy efficiency.
- Road safety inspections.

The most important measurable parameters

- Illuminance (luminosity) - to provide adequate lighting for light and pedestrian crossings.
- Luminance (brightness) - to provide proper roadway lighting and a safe traffic environment for vehicle drivers.
- Uniformity to ensure a safe traffic environment with good visibility and contrast detectability.
- Glare to minimise light pollution, less risk of glare and safety in illuminated environments.

Photo: Toivo Varjas

Aims of measurements based on standard EN 13201-4:2015

Measurements at the final testing phase
Measurements carried out during the final testing/ commissioning phase of the road lighting installation, to verify the compliance with standard requirements and/or with design expectations. These results can be used for the road lighting installations formal approval.

Measurements during the road lighting lifetime
Measurements carried out at pre-determined intervals during the road lighting lifetime, to quantify the degradation of the lighting performance and to define the need for maintenance or to verify the compliance of the road lighting installation with the standard requirements or design expectations, generally based on maintained values.

Measurements for adaptive road lighting
Measurements carried out continuously or at pre-determined intervals to control the luminous flux of luminaires in adaptive road lighting, where the installations performance is kept at the given value within a given tolerance.

Measurements for investigation of discrepancies
Measurements carried out as and when required to investigate discrepancies between measures and design expectations or environment influence.

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