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Revision of the EU Green Public Procurement Criteria for Street Lighting and Traffic Signals

Preliminary report: Final version.

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Abstract
Lighting is used on more than 1.6 million km of roads in EU28 countries, accounting for some 35 TWh of electricity consumption (1.3% of total electricity consumption) and costing public authorities almost €4000 million each year. A broad review of relevant technical, policy, academic and legislative literature has been conducted. This report examines the current market situation and the potential for reducing environmental impacts and electricity costs by assessing the recent developments in road lighting technology, particularly LEDs. Particularly important areas identified relate to energy efficiency, light pollution, product durability and, specifically for longer lasting and rapidly evolving new LED technologies, reparability and upgradeability. The information in this report shall serve as a basis for discussion with stakeholders about the further development and revision of EU GPP criteria for street lighting and traffic signals.

Contents

Executive summary

Policy context

The environmental impacts of products throughout their lifecycle are highly variable from one product group to another and the range of environmental performance of products within a particular product group may be broad in some aspects and narrow in others. Consequently, it is extremely challenging to address or positively influence the environmental impact of different product groups with a single policy tool. For this reason, the Commission has developed an Integrated Product Policy (IPP) which comprises a number of different policy instruments to address the life cycle impacts of products from different angles.

As part of the Commission's IPP, Green Public Procurement (COM 2008/400) is a voluntary tool led by DG JRC on behalf of DG Environment of the European Commission. Other policy tools relevant to IPP include the EU Ecolabel (Regulation (EC) No 66/2010) Energy Labelling (Directive 2010/30/EU), Ecodesign for energy-related products (Directive 2009/125/EC), End-of-Waste criteria (related to the Waste Framework Directive 2008/98/EC) and the Industrial Emissions Directive (Directive 2010/75/EU).

The revision of EU GPP Criteria for all product groups is carried out on a periodic basis, prioritising product groups where criteria may have become outdated or are influenced by external factors such as innovation by industry, market changes and new minimum legal, technical or environmental requirements.

A close relationship between EU Ecolabel criteria and EU Green Public Procurement criteria in particular is desirable so that both policy tools can mutually support each other in order to increase awareness and market uptake of the EU GPP criteria.

Main findings

1 Only very recently (around 2015) has the cost of LED lighting become sufficiently low as to be considered competitive with more traditional road lighting lamp technology (High Intensity Discharge (HID) lamps). The last set of GPP criteria for road lighting (referred to as street lighting previously) was published in 2012. The 2012 criteria do not recognise LED technology and set a number of minimum energy efficiency and durability requirements that are totally unambitious if currently available LED technology is considered.

The scope of the criteria has been generally aligned with EN 13201 for road lighting and excludes certain niche applications such as tunnels, parking lots and sports installations which will all have their own particular performance requirements as set out by other standards. It is proposed to continue including traffic signals within the scope. Even though traffic signals do not perfectly fit in the scope and LED technology became mainstream several years before road lighting, unless there is a specific product group where it should be included (e.g. traffic management systems) then it should continue to be addressed together with road lighting.

In terms of market analysis, the EU28 countries contain an estimated 5.5 million km of roads, of which around 2.35 million km (43%) are lit. In the EU28 around 8 500km (12%) of motorways, 34 000km (12%) of main or national roads, 272 000km (18%) of secondary or regional roads and 1 350 000km (37%) of other roads, are lit. Energy consumption in European road lighting (EU25) in 2005 was of the order of 35 TWh, accounting for around 1.3% of total electricity consumption and costing the equivalent of €3850 million today.

In 2015, the dominant road lighting technology was High Pressure Sodium (HPS) lamps with 53% of market share while the emerging technology, LED, only accounted for 4% of market share. It is also worth pointing out that High Pressure Mercury (HPM) lamps, which are being phased out, accounted for 23% of the 2015 market share.

In terms of environmental impact, by far the dominant source of LCA impacts was the electricity consumption during the use phase. Even though LED technologies can reduce this impact significantly, it remains the main source of impacts due to the fact that the use phase is especially prolonged with LED technology. Relevant non-LCA impacts relate to light pollution, which has a number of specific aspects like sky glow, obtrusive light, glare and adverse effects on nocturnal species. These impacts can be addressed by requirements on the optics of the luminaire (e.g. upward light output ratio), lighting levels and the spectral power distribution of light sources used.

The emerging LED technology can offer significant advantages in terms of reduced energy consumption and longer lamp durations. Until recently a major barrier to the uptake of LED has been initial cost. For this reason, a number of financing mechanisms and business models have been developed that although investment decisions to be made based more on a life cycle cost basis. These include lighting contracting, light supply contracting and energy performance contracting.

Related and future JRC work

The EU GPP criteria for road lighting and traffic signals published in 2012 were very closely related to the requirements set out by Regulation (EC) No 245/2009 for fluorescent lamps, high intensity discharge lamps and related ballasts and luminaires. The current GPP criteria consider the ecodesign requirements from Regulation (EC) 245/2009 as a baseline for relevant criteria but also consider more recent related Regulations such as Regulation (EC) No 1194/2012 for LEDs. Another very closely related EU GPP product group is that of indoor lighting.

In 2018, when the revision process of the EU GPP criteria is expected to be finalised, a final Technical Report will be published containing all of the proposed EU GPP criteria together with relevant background research and supporting rationale. The criteria alone shall also be published as a standalone document and translated into all of the official languages of the European Union. It is also possible that a guidance document may be published for procurers that wish to know more about the different potential financial mechanisms and best practice in road lighting procurement worldwide.

Quick guide

This report presents a broad look at the road lighting sector from the following perspectives:

- Scope and definition.
- Relevant legislation.
- Market analysis.
- Technical analysis.
- Environmental analysis.

The findings presented here act as a basis for the ongoing EU GPP criteria revision process for the product group "Road lighting and traffic signals".

1 Introduction

Public procurement constitutes approximately 16% of overall GDP in Europe.[1] Therefore, considering the environmental performance of publicly procured products and services offers the chance to gain significant environmental improvements in the public sector.

To ensure a higher share of green public procurement (GPP) in Europe, it is important to identify and develop GPP criteria for products and services with a high degree of leverage in procurement decision-making combined with a significant improvement potential for environmental performance.

The development of GPP criteria for street lighting and traffic signals aims therefore at helping public authorities to supplement basic requirements and specifications with additional criteria either to ensure that street lighting and traffic signal projects are procured and implemented in an environmentally-friendly way or to give credit to innovative technical solutions that fulfil even stricter and additional environmental demands.

The development of criteria for a greener public procurement requires in-depth information about the technical and environmental performance of the product in question – in this case street lighting and traffic signals – as well as the procurement processes.

For this reason, the European Commission has developed a process which attempts to bring together both technical and procurement experts to develop a body of evidence which can be cross checked with real experience "in the field" and to develop in a consensus oriented manner a proposal for criteria which promise to deliver the optimum environmental improvements.

This process comprises the following steps:

Task 1: Stakeholder survey, scope and definition proposal, legal review

Task 2: Market analysis

Task 3: Technical analysis

This report is structured in the same way. Based on the tasks 1 to 3, the project team has prepared this preliminary report which is the basis for producing the Technical Report including draft criteria proposals. Both reports comprise the working documents for the 1st Ad Hoc Working group meeting which will be held on 22 November in Seville, Spain. The Technical Report including draft criteria proposal will be revised in light of the output of this meeting.

A questionnaire has been sent out in January 2016 to stakeholders to raise awareness and collect viewpoints related to the scope and definition of the products under study.

The internet page (http://susproc.jrc.ec.europa.eu/Street_lighting_and_Traffic_signs) with information related to the development of the GPP criteria is maintained by JRC to allow stakeholders to retrieve information about the project. It is also possible to register at this internet page to be involved in the consultation process.

[1] http://ec.europa.eu/trade/policy/accessing-markets/public-procurement/ (accessed 1 April 2016)

2 Scope, definition, legislation and standards

This chapter starts with the scope and definitions related to street lighting and traffic signals. Definitions of technical parameters can be found in chapter 3 and Annex 6.1. After introducing the scope and definitions, an overview is given of relevant European legislation and other initiatives related to street lighting and traffic signals. Before proposing a revised scope and definition, including outcomes of the questionnaire, the most relevant standards and guidelines are described in section 2.5.

2.1 Scope and definitions

This study concerns street lighting, also called road lighting in the EN 13201 standards, and traffic signals. Figure 1 and Figure 2 show illustrations about the scope of this study.

For the reader of the document it is important to understand that road lighting as defined in the EN 13201 standard series uses the concept of 'maintained' minimum lighting requirements. As a consequence maintenance schemes and factors such as lumen depreciation over lifetime need to be taken into account. This creates additional complexity in the design of lighting systems. Technical details and parameters are thoroughly explained in chapter 3. Those who are not familiar with this concept are invited to read freely available literature explaining how this standard and its approaches are applied, e.g. the references (Licht, 03) or (ZVEI, 2013).

Figure 1 Road lighting in a motorway

Figure 2 Traffic signal

2.1.1 Scope and definitions of the current GPP criteria for Street Lighting & Traffic Signals

The current set of GPP criteria for street lighting and traffic signals were released in 2012 (EC, 2012a), and the scope thereof is defined as follows:

- *Street Lighting is defined as "Fixed lighting installation intended to provide good visibility to users of outdoor public traffic areas during the hours of darkness to support traffic safety, traffic flow and public security."*

This is derived from the standard series EN 13201 and does therefore not include tunnel lighting, private car park lighting, commercial or industrial outdoor lighting, sports fields or installations for flood lighting (for example monument, building or tree lighting). It does include functional lighting of pedestrian and cycle paths as well as roadway lighting.

- *Traffic signals are defined as: "Red, yellow and green signal lights for road traffic with 200mm and 300mm roundels. Portable signal lights are specifically excluded."*

This is in accordance with EN 12368:2015 Traffic Control Equipment – Signal Heads.

A similar scope proposal can be found in section 2.6.

2.1.2 Road lighting classes

The technical report CEN/TR 13201-1:2014 gives guidelines on the selection of the most appropriate lighting class for a given situation. To do this, it includes a system to define appropriate lighting classes for different outdoor public areas in terms of parameters relevant to guarantee good visibility to users of outdoor public traffic areas during the hours of darkness, to support traffic safety, traffic flow and public security.

The decision on whether a road should be lit is defined in the national road lighting policy. This varies by country or municipality. Specific guidelines are usually available at national level for each country.

The European standard EN 13201-2:2016 contains performance requirements and includes the measurable quality parameters for road lighting.

2.1.2.1 Road lighting classes M, C and P

According to EN 13201-2:2016, there are three main classes (M, C, and P) and in each class several subclasses exists, e.g. M1 to M6.

The M classes are intended for drivers of motorized vehicles on traffic routes, and in some countries also residential roads, allowing medium to high driving speeds. The application of the subclasses depends on the geometry of the relevant area and on the traffic and time dependant circumstances. The appropriate lighting class has to be selected according to the function of the road, the design speed, the overall layout, the traffic volume, traffic composition, and the environmental conditions.

The lighting classes C are intended for use on conflict areas on traffic routes where the traffic composition is mainly motorised. Conflict areas occur wherever vehicle streams intersect each other or run into areas frequented by pedestrians, cyclists, or other road users. Areas showing a change in road geometry, such as a reduced number of lanes or a reduced lane or carriageway width, are also regarded as conflict areas. Their existence results in an increased potential for collisions between vehicles, between vehicles and pedestrians, cyclists and other road users, and/or between vehicles and fixed objects.

The lighting classes P are intended predominantly for pedestrian traffic and cyclists for use on footways and cycleways, and drivers of motorised vehicles at low speed on residential roads, shoulder or parking lanes, and other road areas lying separately or along a carriageway of a traffic route or a residential road, etc.

In standard EN 13201-2:2016 more classes are described (e.g. HS, EV, G, D, SC) and the technical report CEN/TR 13201-1:2014 gives guidelines on the selection of these lighting classes. G classes limit installed luminous intensity for the restriction of disability glare and control of obtrusive lighting, D classes are for the restriction of discomfort glare, and SC classes are based on semi-cylindrical illuminance for the purposes of improving facial recognition. EV classes are based on the vertical plane illuminance. The EV classes are intended as an additional class in situations where vertical surfaces need to be seen, e.g. at interchange areas. HS classes are an alternative to P classes and are based on hemispherical illuminance. The decision on whether these classes should be used for pedestrians and low speed areas is usually defined in the national road lighting policy, see section 2.1.3.

2.1.2.2 Road lighting for motorized traffic, classes M1 to M6

The M lighting classes are intended for drivers of motorized vehicles on traffic routes, and in some countries also on residential roads, allowing medium to high driving speeds. The lighting classes M1 to M6 are defined by the lighting criteria given for each class, with the highest luminance levels in class M1. The approach used is based on the so-called 'luminance concept' specifying minimum luminance levels (in Cd/m²). The use of the luminance concept requires the knowledge of the reflection properties of the road surface. They are taken into account either through the real properties (measurements) or through a reference r-table such as the C and R standards defined by the CIE (CIE 132:1999 and CIE 144:2001).

2.1.2.3 Road lighting of conflict areas, classes C0 to C5

The C classes are intended for so-called conflict areas. They occur whenever vehicle streams intersect each other or run into areas frequented by pedestrians, cyclists, or other road users, or when there is a change in road geometry, such as a reduced number of lanes or a reduced lane or carriageway width. Their existence results in an increased potential for collisions between vehicles, between vehicles and pedestrians, cyclists, or other road users, or between vehicles and fixed objects. Parking areas and toll-stations are also regarded as conflict areas. For conflict areas, luminance is the recommended design criterion. However, where viewing distances are short and other factors prevent the use of luminance criteria, illuminance may be used on part of the conflict area. Usually, the design of the lighting installation is based on the illuminance concept, hence putting minimum requirements on illuminance (in lux).

2.1.2.4 Road lighting for pedestrians, classes P1 to P6

These P classes are intended for pedestrian traffic or cyclists. The P classes (or HS classes) are intended for pedestrians and pedal cyclists on footways, cycleways, emergency lanes and other road areas lying separately or along the carriageway of a traffic route, and for residential roads, pedestrian streets, parking places, schoolyards, etc. The design of the lighting installation is also based on the illuminance concept similar to class C. However, the visual tasks and needs of pedestrians differ from those of drivers in many respects. Speed of movement is generally much lower and relevant objects to be seen are closer than those important for drivers of motorised vehicles. This is reflected in the parameters and associated options for the selection of a lighting class P for a pedestrian or low speed area.

Alternatively to the P classes, HS classes can be used and are based on the hemispherical illuminance. Hemispherical illuminance is mainly used in Denmark where low mounted road lighting is common. This way of lighting gives very low horizontal illuminance values between luminaires, but has been reported in Denmark to be satisfactory.

2.1.3 Country specific selection of road lighting classes

The selection of lighting classes is documented in technical report CEN/TR 13201-1:2014 and CIE 115:2010, but none of these documents are converted in a European standard due to country specific differences in road infrastructure. Therefore, countries still use their local standards or derivatives, e.g. FD EN 13201-1:2014 (FR), BS 5489-1:2003 (UK), UNI 11248:2007 (IT), NBN L 18-004 (B), ROVL-2011(NL) and DIN 13201-1(D). Table 1 also shows these differences based on the responses of an enquiry. Despite the different selection approaches the same definitions of lighting classes as defined in section 2.1.2 are used. So even if the same lighting classes are applied, the approach for selecting these lighting classes is different. These differences can be attributed to specific circumstances concerned with the road layout and use, and the national approaches which can be based on tradition, climate or other conditions.

Another example can be found in

. It shows different speed limits to define what speeds can be considered as very high, high, moderate or low. This may not correspond to specific country requirements. Even though Table 2 is an extract from EN 13201-1:2014, there is no consensus on its application amongst different countries.

Table 1. Example of country specific selection of road lighting classes (*based on replies to an enquiry done in 2015 by ÅF – Hansen & Henneberg (DK) as a subcontractor to DIN(D), the results are based only on replies and do not necessarily represent the detailed diversity amongst Europe.'*)

	Country	Configuration	Width of reference surface (m)	Lighting class	Road surface	Arrangement	Height (m)	Overhang (m)	Tilt (°)	Spacing (m)
Minor traffic road	NL	2 x 3,75m lane	15	ME4/ME5 + SR	C2, Q0=0,07	Single side	10 – 12	- 1,0	5	40 – 70
	B	2 x 2,5m lane + 2 x 1,8 parking strip + 2 x 2,7 pavement	14	ME3b + SR + CE/S overlapping *)	R3, Q0=0,08	Double sided Staggered	6	- 0,5	10	40
	CH	2 x 3m lane + 1,5m foot/bike lane	12	ME3b + S3 overlapping *)	R3, Q0=0,08	Single side	8	-1,5	5	35
	CZ	2 x 3m lane + 2 x 2m adjacent strip	12	ME5 + SR	R3, Q0=0,07	Single side	8	2	5	35
	FIN	2 x 3,5m lane + 6m side reserve + 3,5m foot/bike lane	17,5	MEW3 + SR + S4	R2, Q0=0,07	Single side	10	- 1,5	5	40
	N	2 x 3,5m lane + 1 x 3m adjacent strip + 3m foot/bike lane	16,5	MEW3 + SR + S2/S4 overlapping *)	C2, Q0=0,07 + W4	Single side	8	- 2,5	0	33
	DK	2 x 3,5m lane + 2 x 3,5m adjacent strip	14	MEW5 + A2/3	N2, Q0=0,09 + W4	Single side	8	- 2,0	0	35
	S	2 x 3,5m lane + 2 x 3,5m adjacent strip	14	MEW4 + SR	N2, Q0=0,09 + W3 (Q0=0,2)	Single side	7	-0,5	0	39
	I	2 x 3,5m lane + 2 x 1m footpath	14	ME4b + SR	C2, Q0=0,07	Single side	8	-0,5	0	25
	FR	2 x 3,5m lane + 2 x 1,5m	14	ME3a + SR	R2, Q0=0,07	Single side	8	0	5	28

*) "overlapping" indicates cases where an additional or adjacent traffic area has its own requirement and overlaps the strip for surround ratio, SR - when this requirement also applies.

Table 2. Speed parameters for the selection of lighting class M from EN 13201-1

Parameter	Options	Description
Design speed or speed limit	Very high	v ≥ 100 km/h
	High	70 < v < 100 km/h
	Moderate	40 < v < 70 km/h
	Low	V ≤ 40 km/h

2.1.4 Adaptive lighting classes or dimming of road lighting in EN 13201

Specific light points can be dimmed or selectively switched off. Since there is no harmonised standard related to dimming the original international standard CIE115:2010 needs to be consulted regarding dimming. Technical report CEN/TR 13201-1:2014 is derived from the international standard CIE 115:2010, but has not been transposed in a harmonized European standard. Dimming is included in Annex B of this technical report. Annex B is of assistance in choosing the correct lighting level when 'adaptive lighting' or dimming is used as it provides a more refined evaluation of the luminance or illuminance levels within the specific lighting class.

Standard CIE 115:2010 says that [*reducing the average level* (of e.g. illuminance) *by switching off some luminaires will not fulfil the quality requirements].* Switching off luminaires is not recommended as uniformity requirements are unlikely to be met when switching off part of the luminaires.

Standard CIE 115:2010 however introduces the concept of 'adaptive lighting' based on dimming. It says that:

"*The normal lighting class is selected using the most onerous parameter values, and the application of this class may not be justified throughout the hours of darkness (This might be under changing conditions e.g. weekends, different weather conditions). Temporal changes in the parameters under consideration when selecting the normal class could allow, or may require, an adaptation of the normal level of average luminance or illuminance, usually by reducing the level*. *The most important parameters in this respect are likely to be traffic volume and composition, and weather conditions, but ambient luminance can also have an influence."*

Local standards such as Richtlijn Openbare Verlichting (NL) (ROVL, 2011), BS 5489-1(UK) (BS, 2013) and UNI 11431:2011 (IT) implement dimming, but this adaptive lighting or dimming approach is not fully implemented in all EU 28 countries.

General dimming typically shifts road light classes with one or more levels upwards, i.e. to lower luminance levels. For example in certain time periods one could switch from road lighting class M3 to M6 on a motorway.

2.1.5 Road classes defined in Eurostat and other European road statistics

In the study for the Revision of Green Public Procurement Criteria for Roads[2] a review of the main definitions used by relevant institutions was performed in order to set a unified definition for "roads". In line with the common definitions used by the OECD and Eurostat, it is proposed to define "road" by: *"Line of communication (travelled way) open to public traffic, primarily for the use of road motor vehicles, using a stabilized base other than rails or air strips"* (Eurostat, 2009).

Eurostat provides a classification of roads to develop its statistics figures and roads are categorised according to three internationally comparable types:

a) Motorway

b) Road inside a built-up area

c) Other road (outside built-up area).

The International Road Federation (ERF, 2013) builds its statistics upon a slightly different classification:

Motorways: Kilometre length of roads, specifically designed and built for motor traffic, which does not serve properties bordering on it, and which:

[2] http://susproc.jrc.ec.europa.eu/road/docs/2AHWG_GPP_road_draftTechnicalReport_v2.pdf

a) *is provided, except at special points or temporarily, with separate carriageways for the two directions of traffic, separated from each other, either by a dividing strip not intended for traffic, or exceptionally by other means;*

b) *does not cross at level with any road, railway or tramway track, or footpath;*

c) *is especially sign-posted as a motorway and is reserved for specific categories of road motor vehicles.*

Highways, main or national roads: Kilometre length of A-level roads. A-level roads are roads outside urban areas that are not motorways but belong to the top-level road network. A-level roads are characterized by a comparatively high quality standard, either non divided roads with oncoming traffic or similar to motorways. In most countries, these roads are financed by the federal or national government.

Secondary or regional roads: Kilometre length of roads that are the main feeder routes into, and provide the main links among highways, main roads, or national roads.

Other roads - Urban: Length of roads within the boundaries of a built-up area, which is an area with entries and exits specially identified by signposts as such. Urban roads often have a maximum speed limit of around 50 km/h. Excluded are motorways and other roads of higher speed traversing the built-up area, if not sign-posted as built-up roads. Streets are included.

Other roads - Rural: Length of all remaining roads in a country not included in above mentioned categories.

Paved roads: Length of all roads that are surfaced with crushed stone (macadam) with hydrocarbon binder or bituminized agents, with concrete or with cobblestone.

Note that 'Other roads' (rural and urban) are merged in the statistical data provided by the International Road Federation IRF.

The correspondence between Eurostat, IRF classifications and typical road lighting classes in EN 13201-2:2016 are shown in Table 3.

Table 3. Comparison of Eurostat and IRF classification with typical road lighting classes in EN13201-2

Eurostat	IRF	Typical road lighting class in EN13201-2
Motorway / freeway	Motorways	M
Express road	Highways, main or national roads	M
Road outside a built-up area	Secondary or regional roads	C
	Other roads - Rural	C or P
Road inside a built-up area: urban road	Other roads - Urban	C or P

2.1.6 Street Lighting Components

2.1.6.1 Definition of luminaires, lamps and light sources

The distinction between 'Luminaires', 'Lamps' and 'Light sources' can be made based on recent European Regulations (EC) 874/2012 on energy labelling of electrical lamps and luminaires and 1194/2012 on ecodesign requirements for directional lamps, light emitting diode lamps and related equipment.

Herein 'Luminaire' means an apparatus which distributes, filters or transforms the light transmitted from one or more lamps and which includes all the parts necessary for supporting, fixing and protecting the lamps and, where necessary, circuit auxiliaries together with the means for connecting them to the electric supply.

A 'Lamp' is defined as a unit whose performance can be assessed independently and which consists of one or more light sources. Therefore it may include additional components necessary for starting, power supply or stable operation of the unit or for distributing, filtering or transforming the optical radiation, in cases where those components cannot be removed without permanently damaging the unit.

A 'Light source' means a surface or object designed to emit mainly visible optical radiation produced by a transformation of energy. The term 'visible' refers to a wavelength of 380 - 780 nm.

In this definition a 'luminaire' can accommodate one or more 'lamps' while a 'lamp' can consist of one or more 'light sources'. As a consequence a 'luminaire' is the largest object and 'light source' the smallest one.

2.1.6.2 Lamps (including LED modules) used in road lighting

High-intensity discharge lamps (HID) are the most used lamps in road lighting, even though LED street luminaires are currently on the market. Examples of lamps used in street lighting are:

- High-pressure sodium lamps (HPS) (see Figure 3)
- Metal halide lamps with quartz arc tube (Q-MH)
- Metal halide lamps with ceramic arc tube (C-MH)
- Low-pressure sodium lamps (LPS)
- High-pressure mercury lamps (HPM) (note: will be phased out by regulation 245/2009)
- Compact fluorescent lamps with non-integrated ballast and linear fluorescent lamps (CFLni, LFL)
- Gas lamps for street lighting (still in use in some cities, e.g. Berlin[3])

HPS and MH lamps are generally referred to as High Intensity Discharge (HID) lamps. Criteria for these lamps were included in the GPP criteria that were released in 2012.

The mercury and sodium variants of HID lamps are the most common in road lighting, although mercury lamps are generally less efficient in their energy use than sodium lamps. Both metal halide (MH) and high-pressure sodium (HPS) lamps are used in street lighting for different kinds of applications, each with its own advantages. For example, metal halide lamps are best suited for clear white illumination, for example in city centre streets, where the light gives the true colours of the illuminated objects. High-pressure sodium lamps are well suited for general street lighting, including in residential areas. They attract for example fewer insects because of their yellow colour and thereby require less maintenance and cleaning. HPS lamps have longer lifetimes than MH lamps.

Fluorescent lamps are not so often used because they are temperature sensitive and it is more difficult to fit with compact and precise optics for street lighting.

More recently, for projects where new luminaires are installed, LED luminaires are dominating the market. The directional nature of LEDs means that LED luminaires are generally more efficient and can in principle direct the light very precisely to where it is required. Retrofit LED street lighting solutions replacing HID lamps already exist on the market, but in many cases they can still not provide equivalent lumen output and optics when compared to high wattage HPS and MH lamps. LED luminaires can also be dimmed without losing efficacy while dimming possibilities are limited for HPS and MH lamps.

The following LED-related definitions have been used in Regulations 874/2012 and 1194/2012:

[3] http://www.stadtentwicklung.berlin.de/bauen/beleuchtung/de/gaslicht/

- 'Light emitting diode (LED)' means a light source, which consists of a solid-state device embodying a p-n junction of inorganic material. The junction emits optical radiation when excited by an electric current.
- 'LED package' means an assembly having one or more LED(s). The assembly may include an optical element and thermal, mechanical and electrical interfaces.
- 'LED module' means an assembly having no cap and incorporating one or more LED packages on a printed circuit board. The assembly may have electrical, optical, mechanical and thermal components, interfaces and control gear.
- 'LED lamp' means a lamp incorporating one or more LED modules. The lamp may be equipped with a cap.

Currently, it is more common to install LED luminaires. For some HID lamps LED retrofit lamps or kits exists. The retrofit options differ in their 'ease-of-use'. Some are plug-and-play solutions, requiring only substitution of the lamp itself, while others require the existing ballast to be replaced or removed/by-passed. Retrofit kits are available only for low wattage HPM, HPS and MH lamps. The luminaires for HID lamps are usually not designed for LED light sources in the sense of optical and thermal conditions.

In all retrofit options attention is required to make sure that the lamps fit in the space available in the luminaire, that thermal management conditions are met, and that the amount and distribution of the light is satisfactory (new lighting calculations may be necessary to ensure that street lighting requirements are still met). Some of the available LED retrofit kits are specific for a certain HID-lamp type and/or for a specific type of luminaire. Due to the differences in control gear and the need for rewiring this might change the safety-responsibility from the original luminaire manufacturer to the retrofit installer. As a consequence it might require that the full CE marking procedure for the luminaire needs to be redone by the installer. This requires additional safety investigation and administrative work.

Figure 3 Typical street lighting lamps (HPS)

2.1.6.3 Ballasts and control gear

Standard EN 12665:2011 provides the following definitions for ballast and control gear.

A 'Ballast' means a device connected between the supply and one or more discharge lamps whose main purpose is to limit the current of the lamp(s) to the required value;

'Control gear' means components required to control the electrical operation of the lamp(s). Control gear may also include means for transforming the supply voltage, correcting the power factor and, either alone or in combination with a starting device, providing the necessary conditions for starting the lamp(s).

From this definition a unit inserted between the electrical supply system and one or more LED package(s) or LED module(s) which serves to supply the LED package(s) or LED module(s) with its (their) rated voltage or rated current is a LED control gear.

2.1.6.4 Street lighting Luminaires

A ″luminaire″ is defined in EN 12665:2011 as an "apparatus which distributes, filters or transforms the light transmitted from one or more light sources. A luminaire with integral non-replaceable lamps is regarded as a luminaire, except that the tests are not applied to the integral lamp or integral self-ballasted lamp. A luminaire can contain several parts such as a lamp and ballast/control gear.

Illustrations for road lighting luminaires can be found in Figure 4.

Figure 4 Typical road lighting luminaire

2.1.7 Traffic Signal Components

The main component of traffic signals is the 'head', which contains the lamps. Traditionally these have been 50W incandescent (or tungsten halogen) lamps. Additionally to the head there needs to be the support arms and poles to hold it all up as well as the electric controller, which may receive input from a range of controls like traffic sensors or timers.

Other lighting technologies are nowadays used in traffic signals, namely light emitting diode (LED) lamps. These lamps have lower energy consumptions and longer lifetimes compared to incandescent or halogen lamps for all the colours used in traffic signals (UK, 2006). As well as saving on direct energy costs by using LEDs instead of conventional lamps one also saves on less frequent maintenance operations for lamp replacement. LEDs can also have better light output than incandescent lamps providing a better contrast with the surrounding daylight and thus clearer visibility of the signals for road users. A LED signal consists of an array of LED sources, so if one LED fails the rest remain lit, ensuring that the signal continues to operate.

A number of definitions in relation to traffic signals are available through the standards that exist. The European Standard EN 12368:2006 for 'Traffic Control Equipment – Signal Heads' describes its scope as follows:

"This European Standard only applies to red, yellow and green signal lights for road traffic with 200mm and 300mm roundels. It defines the requirements for the visual, structural, environmental performances and testing of signal heads for pedestrian and road traffic use. Portable signal lights are specifically excluded from the scope of this European Standard."

The standard defines a signal head as:

"a device which comprises one or more optical units, including the housing(s), together with all the mounting brackets, fixings, hoods, visors, cowls and background screens, whose task is to convey a visual message to vehicle and pedestrian traffic".

This EN standard provides limited environmental requirements, but includes the specification that signal heads should comply with one of the following classes for operational temperature ranges, indicating the variety of climatic conditions traffic signals may operate under.

- Class A: +60°C to -15°C
- Class B: +55°C to -25°C
- Class C: +40°C to -40°C

The current GPP criteria focus on traffic signals as defined by the EN standard above. Portable traffic signals are excluded as these will not necessarily be of the same standard as fixed traffic signal installations.

2.1.8 Construction components related to street and traffic lighting

For both street lighting and traffic signals the 'street lighting components' as discussed in section 2.1.6 and 2.1.7 will be automatically considered in the scope of this study. Poles, building mounts, catenary wire systems or any other type of support and the required fixing mounts are considered as a separate product group and referred to as 'related construction components'. The revision of the scope (section 2.6) deals with the inclusion and/or exclusion of these secondary materials for the scope of this study and revised GPP criteria.

2.2 Procurement process

The purchase process of 'public street lighting products' is controlled by public authorities and is therefore a 'Business to Government' (B2G) market (see also chapter 2). Exploitation can be done by the authorities themselves or can be subcontracted to Energy Services Companies (ESCOs). In general the market is a so called 'specifiers market' and uses public tenders. For luminaire replacement or new road lighting projects local authorities will specify the road lighting requirements in accordance with classes defined in EN 13201-2:2016 together with some additional infrastructural requirements such as pole distance, maximum pole height, design style (functional, decorative), etc. In many cases public tenders also require a second source supplier for repair components, especially for replacement lamps and/or control gear to safeguard long term operation. Afterwards, usually the lowest cost bid that satisfies the tender requirements is selected. Environmental aspects can be included either as a minimum requirement or as reward criteria.

In road lighting there are few possibilities to use more efficient light sources or lamps in existing luminaires, because of the so-called lock-in effect caused by the needed lamp control gear and optical compatibility (see section 4.4.2). Therefore such a tender often simply requires identical replacement lamps, with potentially some improvement options on lifetime and lumen maintenance (EC, 2012a).

When a luminaire has to be procured with more ambitious requirements the most obvious options are:

- Specify compliance with existing GPP criteria;
- Specify compliance with the indicative benchmark in Ecodesign Regulation 245/2009.

It is also possible that a mix of the above options is used in the actual tender for green public procurement. Further, it should be noted that it is possible to procure public and street lighting as a service. In that case street lighting can be part of an Energy Performance Contract (EPC) and the responsibility for reducing electricity consumption shifts to the service provider of the EPC. EPC contracts are further discussed in section 3.5.5.

2.3 Relevant European Legislation and initiatives

2.3.1 Directives on public procurement

The public procurement directives 2014/24/EC and 2014/25/EC set requirements for the manner in which certain public contracts above specified value thresholds must be awarded. The essential requirement is the use of a competitive procedure (tendering) with conditions and processes that are non-discriminatory, proportionate, transparent, verifiable, and applied in a consistent manner. The directives allow the use of various tender procedures ranging from an open procedure to competitive dialogue which may be used in the case of particularly complex contracts. For the public sector, use of the negotiated procedure is only possible in exceptional circumstances, whereas in the utility sector the negotiated procedure may be used more freely.

The scope of the directives is limited to contracts above certain values because it is assumed to be particularly relevant in the context of economic activities between EU Member States. Concession agreements and other forms of public-private partnership are also not subject to the full application of the directives.

This broader application means in practice that the EU procurement rules must be considered for all types of public contracts for the realisation of street lighting. Such contracts are subject to competitive procedures based on EU legal principles of equal treatment and transparency. The requirements relate to the advertising of contracts as well as to the way in which the competition is structured and the formulation of technical specifications, selection and award criteria. The directives explicitly allow environmental considerations to be included at different stages in the procedure and they explicitly refer to the requirements under EU environmental arrangements such as environmental management schemes and eco-labels. To ensure transparency and equal treatment, products that fulfil the requirements under the eco-label without having the label must also be accepted under specific circumstances.

2.3.2 Communication on GPP

In 2008, the European Commission adopted a Communication on GPP (COM400, 2008), which, as part of the Sustainable Production and Consumption Action Plan, introduced a number of measures aimed at supporting GPP implementation across the EU. Its key features are:

EU GPP criteria

To assist contracting authorities in identifying and procuring greener products, services and works, environmental procurement criteria have been developed for 19 product and service groups, which can be directly inserted into tender documents. These GPP criteria are regularly reviewed and updated to take into account the latest scientific product data, new technologies, market developments and changes in legislation.

Helpdesk

The European Commission established a Helpdesk to disseminate information about GPP and to provide answers to stakeholders' enquiries. Contact details are available on the GPP website at: http://ec.europa.eu/environment/gpp/helpdesk.htm

Monitoring

The European Commission has commissioned several studies aimed at monitoring the implementation of GPP at all governmental levels. The most recent study was published in 2011, and the results can be found on the GPP website: http://ec.europa.eu/environment/gpp/studies_en.htm

Information

The GPP website is a central point for information on the practical and policy aspects of GPP implementation. It provides links to a wide range of resources related to environmental issues as well as local, national and international GPP information. This includes a News-Alert featuring the most recent news and events on GPP, a list of responses to Frequently Asked Questions (FAQs), a glossary of key terms and concepts, studies and training materials. All are available for download from the website:

http://ec.europa.eu/environment/gpp/index_en.htm

Legislative principles

GPP criteria must take into consideration the specific principles of EU environmental policies, namely the precautionary principle, the principle of preventive action, the principle of rectification at source, and the polluter pays principle.

2.3.3 European Green Paper COM (2011) 889

In December 2011 the European commission published a Green Paper (COM 889, 2011) called 'Lighting the Future: Accelerating the deployment of innovative lighting technologies'. Based on this green paper a public consultation was launched (EC CONNECT, 2012) and a report was produced (EC CONNECT, 2013). From the public consultation the top 3 concerns that emerged are quality, performance and standardisation (see Table 4).

Table 4. List of the most quoted topics by the respondents on the public consultation of the green paper (COM 889, 2011). The list is established according to the number of references made to these topics in the replies.

Key word	Meaning specifically or making reference to	Number of references made within the replies	In percent of total contributions
Quality	SSL product quality	265	26%
Performance	Performance of SSL products	261	25%
Standards	Standardisation for high quality SSL products	241	23%
Cost	Initial cost of purchase	194	19%
Information	Information and awareness	178	17%
Surveillance	Market surveillance	123	12%
Education	Education of consumers and vendors	116	11%
Value chain	Value chain of SSL industry	116	11%
Awareness	Awareness on SSL options	111	11%
Health	Health and wellbeing issues	98	9%
Best practice	Best practice of SSL applications	85	8%
Intelligent	Intelligent high quality lighting solutions	78	8%
Compliance	Compliance to product standards	64	6%
Compatibility	Compatibility of light sources and appliances	50	5%
Risk	Potential adverse effects and health risks	46	4%
Certification	Certification of product performance	42	4%
Confidence	Consumer confidence in technology	37	4%
Jobs	Securing of European jobs	33	3%
Pollution	Abundant use of light, "light pollution"	30	3%
Roadmap	EU level roadmap to increase SSL use	28	3%
National policy	National policy frameworks	20	2%
Recycling	Recycling of SSL lamps	16	2%

2.3.4 Ecodesign Regulation

Three principal ecodesign regulations and two amendments related to lighting are in place today, all having a different specific scope. Regulations (EC) No 245/2009, 347/2010 and 1194/2012 are under revision and a preparatory study for this has been completed[4].

- **Commission Regulation (EC) No 245/2009 of 18 March 2009** implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to ecodesign requirements for fluorescent lamps without integrated ballast, for high intensity discharge lamps, and for ballasts and luminaires able to operate such lamps, and repealing Directive 2000/55/EC of the European Parliament and of the Council.

  Article 3 and Annex III of this regulation sets ecodesign requirements in three stages and an additional intermediate stage. The possible phasing out of specific lamps is based upon achieving performance criteria like colour rendering (Ra), efficacy (lm/W), lamp lumen maintenance factor and lamp survival factor. For HID lamps, only the lamps that have an E27, E40 or PGZ12 cap are within the scope of the regulation.

In the first stage (2010):

- Halophosphate Fluorescent Lamps (T8 linear, U shaped, T9 circular, T4 linear) were phased out
- Standby losses less or equal to 1 W per ballast
- Fluorescent ballasts for current lamps in the market shall fulfil at least EEI = B2
- The term ballast efficiency was introduced
- Several information requirements were introduced such as fluorescent lamp rated lamp efficacy at 25°C and 35°C (T5) at 50 Hz (where applicable) and High Frequency
- Extract on lamp efficacy req.: LFL T8-36 W requires 93 lm/W (25°C)
LFL T5-28 W requires 93 lm/W (25°C)
LFL T5-39 W requires 73 lm/W (25°C)
- Extract on fluorescent ballast efficiency req.: T8-36W class B2 ≥79.3%
T8-36 W class A2 ≥ 88.9 %
- On ballasts for fluorescent lamps the regulation contains rated/typical wattage for 50 Hz and HF operation. This also reflects the typical efficacy gain found for HF operation compared to 50 Hz

***In the second stage (2012)**:*

- Halophosphate Fluorescent Lamps (T10, T12) were phased out
- For High Pressure Sodium and HPS / Metal Halide MH Lamps (E27/E40/PGZ12):
  - Set up established performance criteria for MH E27/E40/PGZ12 lamps
  - Standard HPS E27/E40/PGZ12 were phased out, this means that HPS lamps need an enhanced Xenon
- Extract on lamp efficacy requirement: - HPS 70 W clear ≥ 90 lm/W
- HPS 70 W not clear lamp ≥ 80 lm/W
- MH 70 W clear ≥ 75 lm/W
- MH 70 W not clear lamp ≥ 70 lm/W
- Standby losses less or equal to 0.5 W per fluorescent ballast
- Minimum efficiency for HID ballast, e.g. a 70 W HID lamp requires 75 % efficiency

[4] http://ecodesign-lightsources.eu/

- Introduction of minimum HID ballast efficiency and the obligation to make them available

In an intermediate stage (2015) the following lamps:

- High pressure mercury lamps are expected to be phased out
- High pressure Sodium-Plug-in/Retrofit lamps (HPM replacement) expected phase out
- Extract on lamp efficacy requirement: other HID 50 W ≥ 50 lm/W [5]

In the third stage (2017):

- Low performing MH E27/E40/PGZ12 lamps are phased out; in practice, this means that 'quartz' MH lamps are phased out in favour of 'ceramic' discharge tube MH lamps
- Compact Fluorescent Lamps with 2 pin caps and integrated starter switch (Reason: these lamps are phased out in stage 3 as they in practice do not operate on A2 class ballasts)
- Ballasts for fluorescent lamps without integrated ballast shall have the efficiency: ηballast ≥ EBbFL, where EBbFL = Plamp/(2*sqrt(Plamp/36)+38/36*Plamp +1) for 5 < Plamp < 100 Watt

For example: a 36W T8 lamp ballast should have ηballast ≥ 87.8%. This is far above the minimum class B1 requirement from stage 1 and is likely to commercially phase out magnetic ballasts in low cost applications. A side effect of phasing out magnetic fluorescent ballasts is an increase in efficacy gain for those lamps on HF operation. More efficient magnetic ballasts require more copper and are expected to become too expensive for the market.

- More strict minimum efficiency for HID ballast, e.g. a 70W HID lamp requires 85% efficiency.

Commission Regulation (EU) No 347/2010 of 21 April 2010 amending Commission Regulation (EC) No 245/2009 as regards the ecodesign requirements for fluorescent lamps without integrated ballast, for high intensity discharge lamps, and for ballasts and luminaires able to operate such lamps.

This Regulation is amending Commission Regulation (EC) No 245/2009, 'in order to avoid unintended impacts on the availability and performance of the products covered by that Regulation'. The amendments also intend to 'improve coherence, as regards the requirements on product information between Regulations 244/2009 and 245/2009'. Regulation 347/2010 introduces some changes in the exemptions and a large number of changes to the tables in Annex III of 245/2009 on minimum CFLni lamp efficacy and lamp lumen maintenance and survival factors (FLLM, FLS) for HPS lamps for stage 2 in 2012.

- **Commission Regulation (EC) No 1194/2012 of 12 December 2012** implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to ecodesign requirements for directional lamps, for light emitting diode lamps and related equipment.

[5] Note: Regulation 244/2009 on household lamps is much stronger for CFLi lamps, e.g. a 50 W requires about 64 lm/W and CRI≥80 in Regulation 244/2009, while Regulation 245/2009 requires only 50 lm/W for other 50 W HID.

This regulation sets minimum functional requirements for directional and non-directional LED light sources. From the 1st of September 2013, minimum requirements apply for:

- the number of switches before failure (half the product life in hours, with a maximum of 15 000 switches)
- starting time (< 0.5s)
- lamp warm-up time (<2s to reach 95% Φ), premature failure rate (≤ 5.0 % at 1 000 h)
- colour rendering (Ra ≥ 80 for general purpose or ≥ 65 if the lamp is intended for outdoor or industrial applications)
- colour consistency (maximum variation of chromaticity coordinates within a six-step MacAdam ellipse[6] or less)
- lamp power factor (PF) for lamps with integrated control gear (P ≤ 2W: no requirement; 2W < P ≤ 5W: PF > 0.4; 5W < P ≤ 25W: PF > 0.5 ;P > 25W: PF > 0.9)

From the 1st of March 2014 additional minimum requirements apply on

- the lamp survival rate (>90% at 6000h[7]);
- lumen maintenance (>80% at 6000h).

▪ **Commission Regulation (EC) No 244/2009 of 18 March 2009** implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to ecodesign requirements for non-directional household lamps.

  These requirements are not relevant for road or traffic lighting.

▪ **Commission Regulation (EC) No 859/2009 of 18 September 2009** amending Regulation (EC) No 244/2009 as regards the ecodesign requirements on ultraviolet radiation of non-directional household lamps.

  These requirements are not relevant for road or traffic lighting.

2.3.5 Energy labelling

Also an energy labelling regulation regarding lighting is in place:

▪ **Commission Delegated Regulation (EU) No 874/2012 of 12 July 2012** supplementing Directive 2010/30/EU of European Parliament and of the Council with regard to energy labelling of electrical lamps and luminaires.

  This regulation requires energy labelling for lamps. It should be noted that there are differences in tolerance requirements on lumen output data between Regulation (EC) 874/2012 versus Regulations (EC) 244/2009 or 245/2009. As a consequence, calculating the label according to formulas from (EC) 874/2012 with information required under (EC) 244/2009 or 245/2009 could produce in some cases different results.

  Note that the EC is reviewing the current energy labelling directive.

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[6] Ellipse-shaped colour region in a chromaticity diagram where the human eye cannot see the difference with respect of the colour at the centre of the ellipse. MacAdam ellipses are used e.g. in standards for describing acceptable colour deviation between LED lamps/luminaires of the same model (1 step = 1 ellipse area; 2 step = 2 concatenated ellipse areas, etc.)

[7] The intention is to ascertain a minimum product life (lumen maintenance >70%) of around 20 000 h. The period of 6 000 h at the mentioned parameters values was defined to limit costs for compliance testing.

2.3.6 RoHS 2 – Directive on the Restrictions of Hazardous Substances in Electrical and Electronic Equipment (2011/65/EU)

The RoHS Directive restricts the use of lead (Pb), mercury (Hg), cadmium (Cd), hexavalent chromium (Cr6+), polybrominated biphenyls (PBB) and polybrominated diphenyl ether (PBDE) in manufacturing of certain electrical and electronic equipment (EEE) sold in the European Union.

The new RoHS Directive 2011/65/EU, also known as RoHS 2, introduces new CE marking and declaration of conformity requirements. Before placing an EEE on the market, a manufacturer / importer / distributor must ensure that the appropriate conformity assessment procedure has been implemented and the CE marking affixed on the finished product. Since January 2013, electronic products bearing the CE mark must meet the requirements of this new directive.

Impacts of RoHS 2 on street and traffic lighting

RoHS 2 is important for the components of the system, such as lamps and controls.

RoHS 2 Annex I explicitly mentions 'lighting' as an electrical and electronic equipment (EEE) category covered by the Directive.

According to RoHS 2 Annex II the limited substances are: lead, mercury, cadmium, hexavalent chromium, PBB and PBDE. The maximum allowed concentration by weight in homogeneous materials is 0.1% (for cadmium 0.01%). Article 4 specifies that Member States shall ensure that EEE’s placed on the market do not contain more than the specified maximum concentrations of these substances.

RoHS 2 Annex III lists applications that are exempted from the restriction in Article 4(1). For all street lighting products this includes:

(i) For mercury in single capped (compact) fluorescent lamps (maximum per burner):

- for general lighting purposes < 30 W: 2.5 mg (from 31 Dec 2012)
- for general lighting purposes ≥ 30 W and < 50 W: 3.5 mg (from 31 Dec 2011)
- for general lighting purposes ≥ 50 W and < 150 W: 5 mg
- for general lighting purposes ≥ 150 W: 15 mg
- for general lighting purposes with circular or square structural shape and tube diameter ≤ 17 mm: 7 mg (from 31 Dec 2011)
- for special purposes: 5 mg
- for general lighting purposes < 30 W with a lifetime equal or above 20 000 h: 3.5 mg (until 31 Dec 2017)[8]

(ii) For mercury in double capped linear fluorescent lamps for general lighting purposes (maximum per lamp):

- Tri-band phosphor with normal lifetime and a tube diameter < 9 mm (e.g. T2): 4 mg (from 31 Dec 2011)
- Tri-band phosphor with normal lifetime and a tube diameter ≥ 9 mm and ≤ 17 mm (e.g. T5): 3 mg (from 31 Dec 2011)
- Tri-band phosphor with normal lifetime and a tube diameter > 17 mm and ≤ 28 mm (e.g. T8): 3.5 mg (from 31 Dec 2011)
- Tri-band phosphor with normal lifetime and a tube diameter > 28 mm (e.g. T12): 3.5 mg (from 31 Dec 2012)

[8] This addition is introduced in Commission Delegated Directive 2014/14/EU of 18 October 2013, OJ L4/71 of 9 January 2014, http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=OJ:L:2014:004:FULL&from=EN

-Tri-band phosphor with long lifetime (≥ 25 000 h): 5 mg (from 31 Dec 2011)

(iii) For mercury in other fluorescent lamps (maximum per lamp):

- Linear halophosphate lamps with tube > 28 mm (e.g. T10 and T12): 0 mg (from 13 Apr 2012)
- Non-Linear halophosphate lamps (all diameters): 15 mg (until 13 Apr 2016)
- Non-linear tri-band phosphor lamps with tube diameter > 17 mm (e.g. T9): 15 mg (from 31 Dec 2011)
- Lamps for other general lighting and special purpose (e.g. induction lamps): 15 mg (from 31 Dec 2011)

(iv) For mercury in discharge lamps:

- Other low-pressure discharge lamps (max per lamp): 15 mg (from 31 Dec 2011)
- High Pressure Sodium (vapour) lamps for general lighting purposes in lamps with improved colour rendering index Ra > 60 (max per burner)
  - P ≤ 155W: 30 mg (from 31 Dec 2011)
  - 155W < P ≤ 405W: 40 mg (from 31 Dec 2011)
  - P > 405W::40 mg (from 31 Dec 2011)
- Other High Pressure Sodium (vapour) lamps for general lighting purposes (max per burner)
  - P ≤ 155W: 25 mg (from 31 Dec 2011)
  - 155W < P ≤ 405W: 30 mg (from 31 Dec 2011)
  - P > 405W:40 mg (from 31 Dec 2011)
- High Pressure Mercury (vapour) lamps (HPMV): no limit (until 13 Apr 2015)
- Metal Halide lamps (MH): no limits are set.

In addition to the above exemptions for mercury, the annex also contains some exemptions on lead, cadmium and hexavalent chromium contained in components of lamps such as the glass and ceramic parts, soldering materials, electrical contacts, fluorescent coatings, etc. Some of these exemptions have been added in a series of 2014 Directives[9] amending Directive 2011/65/EU.

2.3.7 Waste Electrical & Electronic Equipment Directive (WEEE) (2012/19/EU)

Directive 2012/19/EU (WEEE)[10] was issued in July 2012 as a recast of Directive 2002/96/EC, which is repealed with effect from 15 February 2014.

The aim of this directive is expressed, for example, by its article 1: "*This Directive lays down measures to protect the environment and human health by preventing or reducing the adverse impacts of the generation and management of waste from electrical and electronic equipment (WEEE) and by reducing overall impacts of resource use and improving the efficiency of such use*."

[9] Directives 2014/1/EU through 2014/16/EU of 18 October 2013, OJ L4/45 through 75, 9 January 2014, amending Directive 2011/65/EU. http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=OJ:L:2014:004:FULL&from=EN

[10] Directive 2012/19/EU of the European Parliament and of the Council of 4 July 2012 on waste electrical and electronic equipment (WEEE), OJ L197/38, 24.7.2012, repealing directive 2002/96/EC with effect from 15 Feb. 2014, http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2012:197:0038:0071:en:PDF

The directive puts the responsibility for handling of WEEE on the producers of such equipment. They shall finance the collection and treatment of their WEEE in a harmonised way that avoids false competition. Producers will shift payments to the consumers under the principle that the '*polluter pays*', avoiding costs for the general tax payer[11].

In a transitional period (from August 2012 to August 2018) the directive applies to the EEE categories and equipment indicated in Annex I and II of the directive. After August 2018, the directive applies to all EEE (indicated in Annex III and IV). Article 2.3 and 2.4 specify equipment to which the directive does not apply.

Article 11 in this Directive sets minimum recovery targets regarding all WEEE that requires separate collection in accordance with Article 5 and sent for treatment in accordance with Articles 8, 9 and 10. Member States shall ensure that producers meet the minimum targets set out in Annex V.

Impacts of the WEEE Directive on street and traffic lighting

Article 2.3(c) clearly excludes '*filament bulbs*' from the scope of the directive.

Article 5 explicitly mentions '*fluorescent lamps containing mercury*' as items for separate collection but also refers to category 5 and 6 of Annex III that also includes small luminaires with no external dimension more than 50 cm. There is no reference to separate collection for HID lamps containing mercury.

Article 11 in this Directive sets minimum recovery targets regarding all WEEE that requires separate collection according to Article 5, hence to fluorescent lamps containing mercury and small luminaires. For these lamps Member States shall ensure that producers meet the minimum targets set out in Annex V.

Annex I distinguishes '*lighting equipment*' as an EEE category to which the directive applies also in the transitional period. Annex II gives examples of EEE falling into this category: LFL, CFL, HID (HPS, MH), LPS, "luminaires for fluorescent lamps with the exception of luminaires in households", "other lighting or equipment for the purpose of spreading or controlling light with the exception of filament bulbs".

Annex III distinguishes '*lamps*' as an EEE-category. The examples given in Annex IV are more or less the same as those from Annex II but additionally 'LEDs' are mentioned explicitly.

Annex V specifies minimum recovery targets for lighting products as follows:

- From 13/8/2012 to 14/8/2015 : 70% recovered; 50% prepared for re-use and recycled; 80% recycled for gas discharge lamps
- From 15/8/2015 to 14/8/2018 : 75% recovered; 55% prepared for re-use and recycled; 80% recycled for gas discharge lamps
- After 15/8/2018: 80% recycled for all lamps.

Note: this is related to article 5 and therefore only applicable to *fluorescent lamps containing mercury and small luminaires (≤50 cm), and not applicable to HID.*

Annex VII mentions "mercury containing components such as switches or backlighting lamps", "cathode ray tubes" and "gas discharge lamps" as components to be removed from separately collected WEEE. The fluorescent coating shall be removed from cathode ray tubes and the mercury shall be removed from gas discharge lamps.

[11] See, for example, Recital (23) of the directive.

2.3.8 Energy Efficiency Directive (EED)

The Energy Efficiency Directive (EED) 2012/27/EU amends Directive 2009/125/EC on Ecodesign requirements for energy-related products and Directive 2010/30/EU on energy efficiency labelling of energy-related products, and repeals Directive 2004/8/EC on the promotion of cogeneration and Directive 2006/32/EC on energy end-use efficiency and energy services.

Article 6 of this Directive deals with purchasing by public bodies, stating Member States shall ensure that central governments purchase only products, services and buildings with high energy-efficiency performance, insofar as that is consistent with cost-effectiveness, economic feasibility, wider sustainability, technical suitability, as well as sufficient competition, as referred to in Annex III. A threshold for the value of these contracts applies[12].

2.3.9 Environmental Impact Assessment Directive (EIA) (2011/92/EU)

The Environmental Impact Assessment (EIA) Directive 2011/92/EU ensures that the environmental consequences of projects are identified and assessed before authorisation is given. The need for the development of an EIA is determined by the local or national authorities in the individual Member States. The EIA Directive outlines which project categories shall be made subject to an EIA, which procedure shall be followed and the content of the assessment (see section 2.1.2). New motorways and expressways must be assessed by an EIA and road lighting might be part of such a study with regards to light pollution. Other roads and expansion of existing roads must be screened for the EIA requirement and then possibly assessed through a full EIA depending on the result of the EIA screening.

The EIA must cover the direct and indirect effects of a project on the following factors:

- Human beings, fauna and flora.
- Soil, water, air, climate and the landscape.
- Material assets and the cultural heritage.
- The interaction between the factors mentioned in the first, second and third indents.

The assessment has to consider whether any alternatives would have lesser impacts. The other important requirement of the directive is public consultation and information.

A distinction is made between categories of projects where assessment is mandatory and other categories where an assessment is only required if a significant environmental effect is highly likely or certain. Large roads that service areas with populations beyond a certain size are covered by the first category, whereas other roads are covered by the second category.

An EIA must be performed before a project can be approved. Thus the EIA becomes relevant at the earliest phases of the planning of a project. For projects where an EIA is not automatically mandatory, the competent national authorities must establish procedures for screening of projects to check for likely environmental effects that would require EIA.

2.3.10 Waste framework directive (2008/98/EC)

The Waste Framework Directive establishes rules on how waste should be managed in the EU. It provides general principles for doing so, such as the waste hierarchy, the

[12] Article 7 of Directive 2004/18/EC

polluter pays principle and extended producer responsibility. The Directive aims to reduce the environmental impact of waste and to encourage resource efficiency through reuse, recycling and recovery.

This might be relevant for recycling of packaging material only, because lamps and luminaires are part of the WEEE Directive (see 2.3.7).

2.3.11 Directive on harmonisation of laws on EMC (2014/30/EU)

regarding Electromagnetic Compatibility (EMC) was issued in February 2014 and repeals the existing directive 2004/108/EC with effect from April 2016. On the one hand, the directive aims to ensure that electromagnetic emissions from equipment do not disturb radio and telecommunication signals or prevent the correct functioning of other equipment. On the other hand, the directive governs the immunity of equipment to interference and seeks to ensure that this equipment is not disturbed by radio emissions normally present. Important herein is article 13 that says that equipment which is in conformity with harmonised standards or parts thereof the references of which have been published in the Official Journal of the European Union shall be presumed to be in conformity with the essential requirements set out in Annex I covered by those standards or parts thereof. It also specifies the procedures for documentation and verification.

The Directive does not explicitly mention lighting products, but it is relevant for control gears/ ballasts / drivers and luminaires containing such components that have to follow harmonized European standards to proof compliance based on article 13.

2.3.12 Directive on harmonisation of laws on Low Voltage equipment (LVD) (2014/35/EU)

Directive 2014/35/EU regarding Low Voltage electrical equipment (LVD) was issued in February 2014, repealing the existing directive 2006/95/EC with effect from April 2016. The purpose of this Directive is to ensure that electrical equipment on the market fulfils the requirements providing for a high level of protection of health and safety of persons, and of domestic animals and property, while guaranteeing the functioning of the internal market. The Directive applies to electrical equipment designed for use with a voltage rating between 50 and 1 000 V for alternating current and between 75 and 1 500 V for direct current. These voltage ratings refer to the voltage of the electrical input or output, not to voltages that may appear inside the equipment. For electrical equipment within its scope, the directive covers all health and safety risks, thus ensuring that electrical equipment will be used safely and in applications for which it was made. For most electrical equipment, the health aspects of emissions of electromagnetic fields are also under the domain of the Low Voltage Directive.

The Directive does not explicitly mention lighting products, but they are in the scope. Presumption of conformity can be done on the basis of harmonised standards (article 12).

2.3.13 Regulation on CE marking (765/2008)

Regulation (EC) No 765/2008 established the legal basis for accreditation and market surveillance and consolidated the meaning of the CE marking.

Amongst others it defines the responsibilities of the manufacturer, i.e.:

- carry Carry out the applicable conformity assessment or have it carried out, for example verify compliance with applicable European Directives.

- draw Draw up the required technical documentation.
- draw Draw up the EU Declaration of Conformity (EU DoC).
- accompany Accompany the product with instructions and safety information.
- satisfy Satisfy the following traceability requirements:
    - Keep the technical documentation and the EU Declaration of Conformity for 10 years after the product has been placed on the market or for the period specified in the relevant Union harmonisation act.
    - Ensure that the product bears a type, batch or serial number or other element allowing its identification.
    - Indicate the following three elements: his (1) name, (2) registered trade name or registered trade mark and (3) a single contact postal address on the product or when not possible because of the size or physical characteristics of the products85, on its packaging and/or on the accompanying documentation.
- affix Attach the conformity marking (CE marking and where relevant other markings) to the product in accordance with the applicable legislation, e.g. label from the Ecodesign Regulation (see 2.3.4).
- ensure Ensure that procedures are in place for series production to remain in conformity.
- Where relevant, certify the product and/or the quality system.

This is applicable to all lighting products. When HID lamp luminaires are converted to for example LED lighting the full CE marking procedure might have to be redone including new technical documentation, EU DoC, serial number, etc. The reason is a possible change of control gear and re-wiring of the components.

2.4 Non-EU legislation and other initiatives

As already defined in section 2.1.2 there is a lot of variation in the classification of roads according to their lighting classes. A consequence is that different countries, and even different regions in the same country, apply different requirements for road lighting which can have an effect on the product criteria, installation criteria, sourcing of Best Available Technologies (BAT) examples and reference projects, and elaborating an alternative approach based in Energy Performance Contracting. The following sections provide some examples and are illustrative on the different actions that are taken. Given the vast amount of studies and data in the public domain, the following list is by no means meant to be exhaustive. During the course of the revision process, stakeholders are invited to flag up potentially important information that may have been overlooked in this report.

Additionally, with the arrival of luminaires equipped with LEDs, the lighting technology has made a big step forward which poses new challenges to procurers (see Table 4) that will need to be further elaborated in subsequent tasks and in consultation with stakeholders. On public procurement of solid state lighting a full report is available with country specific public procurement initiatives (JRC, 2012), which describes the green public procurement of LED lighting in different EU Member States.

2.4.1 Product criteria

2.4.1.1 The Belgian public tender specification for road lighting lamps and luminaires

Syngrid C4/11-1 describes the technical specifications for construction and maintenance of luminaires for public lighting. It provides the Belgian distribution system operators with tender specifications for minimum performance requirements on street lighting luminaires.

Synergrid C4/9 describes the specifications for lamps for public lighting. It provides the Belgian distribution system operators with tender specifications for setting minimum requirement for street lighting lamps.

Municipalities have a financial incentive on annual maintenance cost when they select tested and compliant luminaires. Selection of the correct photometry and lighting design to fit with EN 13201-2:2016 requirements is done by the distribution system operator (DSO) who is in Belgium also in charge for the maintenance of road lighting on behalf of the municipalities. A full list of tested and compliant LED road lighting luminaires is available and it contains 79 street lighting luminaires from 9 different manufacturers (anno 2/2016). It is important to be aware that tenders also often require the availability of repair components, such as lamp and/or control gear.

2.4.1.2 ENEC+ mark for LED luminaire performance

Recently a new initiative was launched called 'ENEC+' marking[13]. ENEC is a European quality marking for electrical products and demonstrates compliance with European standards (EN). European certification bodies in the electrical sector have opened the European ENEC mark to all electrical product sectors. Testing takes place in independent ENEC approved testing laboratories.

With the arrival of luminaires equipped with LEDs, the lighting technology has indeed made an important step forward. However, one should be aware that there is a large spread in quality and performance within LED products. This was also one of the outcomes of the consultation described in section 2.3.3 where SSL quality concerns were top ranked in the survey (see Table 4). Within the LED product family not all available LEDs de facto outperform HID lamp luminaires; it depends on the technology and/or production batch. As a consequence users of LED based products find themselves faced with various claims regarding the long-term benefits and performance of the new technology and want validation of these claims. ENEC+ is responding to this need of the market. It is a pan-European independent third party certification scheme. ENEC+ is based on an evolution model: as technology and standardisation progress, the requirements of the mark will evolve simultaneously and new performance related elements will be added. The scheme verifies initial performance claims and assesses the robustness of product design, therefore providing an objective basis for fair comparison of lighting products. The aim is to reduce the costs related to tenders: no need for repeated product tests against varying qualification rules included in calls for tender. The aim is to cover all initial specification elements of LED luminaires and modules. So far (3/2016) no product database is available yet, hence it is work in progress.

2.4.1.3 UNEP-GEF enlighten

The United Nations Environment Programme (UNEP)-Global Environment Facility (GEF) enlighten initiative[14] was established in 2009 to accelerate a global market

[13] http://www.eepca.eu/page.php?p=7
[14] http://www.enlighten-initiative.org/Home.aspx

transformation to environmentally sustainable, energy efficient lighting technologies, as well as to develop strategies to phase-out inefficient incandescent lamps to reduce CO2 emissions and the release of mercury from fossil fuel combustion.

CLASP, with UNEP, has recently announced a series of monitoring, verification, and evaluation (MV&E) guides[15] for energy efficient lighting programs. The new UNEP-GEF enlighten series of MV&E guidance notes provides a practical resource for governments in establishing and implementing an effective MV&E program. The series consists of six guidance notes:

- Developing Lighting Product Registration Systems
- Efficient Lighting Market Baselines and Assessment
- Enforcing Efficient Lighting Regulations
- Good Practices for Photometric Laboratories
- Performance Testing of Lighting Products
- Product Selection and Procurement for Lamp Performance Testing

Each guidance note focuses on an individual aspect of a MV&E infrastructure, provides best practice guidance and examples for its implementation, and describes how it contributes to improved product compliance and the success of policies aimed at transforming the market to efficient lighting.

2.4.1.4 IEA 4E SSL Annex maintains voluntary performance tiers

The IEA 4E SSL Annex is a joint initiative of nine countries working together to address common challenges with SSL technologies. Sponsoring governments of the SSL Annex include Australia, Denmark, France, Korea, the Netherlands, Sweden, the United Kingdom and the United States. China also participates as an expert member of the SSL Annex.

The IEA-4E SSL Annex maintains voluntary performance tiers (IEA 4E, 2014c) to address product attributes such as colour, lifetime, power, and efficacy for common SSL applications including street lighting. An update for public review has been released in December 2015 (IEA 4E, 2015).

2.4.1.5 International Dark-Sky Association Fixture Seal of Approval

The International Dark-Sky Association provides a fixture seal approval program. It provides third-party certification for luminaires that minimize glare, reduce light trespass, and do not pollute the night sky.

2.4.1.6 French Public Deposit Bank initiative on Economy and Biodiversity guide on impact of colour spectrum on species

The French National Deposit Bank supports research in biodiversity.[16] They have issued a guide to support taking into account the externality of outdoor lighting with regards to biodiversity (Biodiv, 2015). The rationale is that compared to humans, other species observe different colour spectra. Negative impact on biodiversity could result from compelling and/or attracting those species. A literature review was conducted (CDC (FR), 2015) and resulted in an overview table of spectral bands to be avoided for impact on different species (see Table 5). Ecological impact of outdoor lighting is also described in

[15] http://www.enlighten-initiative.org/ResourcesTools/Publications.aspx
[16] http://www.cdc-biodiversite.fr/

other literature, e.g. (Rich, 2006). According to Table 5 it can be concluded that yellow/orange lighting (585 nm), such as from HPS lamps, has the least impact on the studied species.

Table 5. Spectral bands to be avoided for impact on different species (according to (CDC(FR), 2015))

	UV	Violet	Blue	Green	Yellow	Orange	Red	IR
wavelength (nm)	<400	400-420	420-500	500-575	575-585	585-605	605-700	>700
freshwater fish	x	x	x	x	x	x	x	
marine fish	x	x	x	x				
shellfish (zooplankton)	x	(x)	(x)					
amphibia&reptiles	x	x	x	>550	x	x	x	x
birds	x	x	x	x		x	x	x
mammals (excluding bats)	x	x	x	x			x	
bats	x	x	x	x				
insects	x	x	x	x				
	note: (x) = assumed possible but not identified in literature							

2.4.2 Installation

2.4.2.1 Spanish Royal Decree 1890/2008

This Spanish Royal Decree specifies minimum street lighting installation efficacy. The energy efficiency regulations in street lighting installations, approved by the Spanish Royal Decree 1890/2008 aims at improving the energy efficiency and energy saving, and therefore, decreasing greenhouse gas emissions. It provides the necessary feasibility conditions for both car drivers and pedestrians to have their security guaranteed. It also provides city life with a pleasant visual night time atmosphere and curbs nightlight brightness or light pollution, reducing intrusive or unpleasant light.

The Spanish decree refers to a technical guide EA-01 (Spain, 2013) for calculating limits to energy consumption of outdoor lighting installations (see Table 6). It defines the installation efficacy (in lx.m²/W or lm/W) which is the reciprocal value of the lighting power density (PDI) (in W/(lx.m²)) used in recent standard EN 13201-5:2015. The technical guide also defines labels for road lighting installations. Efficacies 10 % above the reference values in Table 6 will receive an 'A' label. The technical guide EA-01 can be updated according to the state-of-art in outdoor lighting.

Table 6. Minimum and reference installation efficacy values for outdoor lighting used in Spain (translated from version 2013: ITC EA-01)

Maintained illuminance (lx)	Functional lighting			Decorative outdoor lighting	
	Minimum installation efficacy (lx.m2/W)	Reference installation efficacy (lx.m2/W)	Maintained illuminance (lx)	Minimum installation efficacy (lx.m2/W)	Reference installation efficacy (lx.m2/W)
≥30	22	32	≥20	9	13
25	20	29	15	7.5	11
20	17.5	26	10	6	9
15	15	23	7.5	5	7
10	12	18	≤5	3.5	5
≤7.5	9.5	14			

2.4.2.2 Italian decree of the 23th December 2013

This decree on public lighting, including sports lighting, refers to the European regulations and gives guidance for design and tendering. The decree goes beyond European specifications for maximum Annual Energy Consumption (in kWh/(y.m²)) for different types of road lighting similar to the approach of EN 13201-5:2015, but with different terminology based on what was available in the EN 13201 draft in 2013.

2.4.2.3 Finnish Guide on 'Road and rail areas lighting design'

In Finland recently a guide for road lighting was published (Finland, 2015) that describes the local road lighting and design requirements, as well as the grounds of cost accounting and comparisons. It also contains dimming methods. It includes the method for selection of road classes in line with classes defined in EN 13201-2:2016. Cost and efficiency examples are given for motorways.

2.4.2.4 Criteria from a private bank in Germany to provide green loans to municipalities for energy efficient road lighting renovation

In Germany it is possible for municipalities to obtain green loans for renovating road lighting from the KfW bank (IKK, 2015). In order to have access to these green loans minimum road lighting efficiency criteria were set based on maximum annual energy consumption per km per type of road and lighting levels (see Table 7).

Table 7. Maximum annual energy consumption per km per type of road and lighting level [kWh/(y.km)] used by KfW Bank to provide green loans

Road type	Light level					
	1.5 cd/m2 or 20lx	1 dc/m2 or 15 lx	0.75 cd/m2 or 10lx	0.5 cd/m2 or 7.5 lx	0.3 cd/m2 or 5 lx	3 lx
Main traffic roads	21500	17500	15500	12500		
Secondary traffic roads with functional luminaires		16500	14000	11500	8000	
Secondary traffic roads with decorative luminaires					13500	
Residential area traffic roads with functional luminaires			15000	1150	8500	7000
Residential area traffic roads with decorative luminaires					13500	11000

2.4.2.5 Labels from the French 'Association Nationale pour la Protection du Ciel et de l'Environnement Nocturne'

The French 'Association Nationale pour la Protection du Ciel et de l'Environnement Nocturne' (ANPCEN)[17] promotes labels to reduce light pollution and the installed luminaire lumen per km of road. The labels classify the amount of emitted light from the source divided by the length of the road or the area to be lit (see Figure 5). Because it limits the installed photometric flux in lumen it will also limit the maximum illumination levels that can be achieved. For example a road class C5 (lowest possible) will need an average maintained illuminance of 7.5 lx and on a road of 8 m width the minimum required flux is 60 kLux (7.5x8x1000). With an installation Utilance (U) of 80% (see Task 3) this would require 75000 lumen, hence label A. As a consequence this label

[17] http://www.anpcen.fr/

promotes selecting the lowest lighting level possible in EN 13201-2:2016 with the highest Utilance (U).

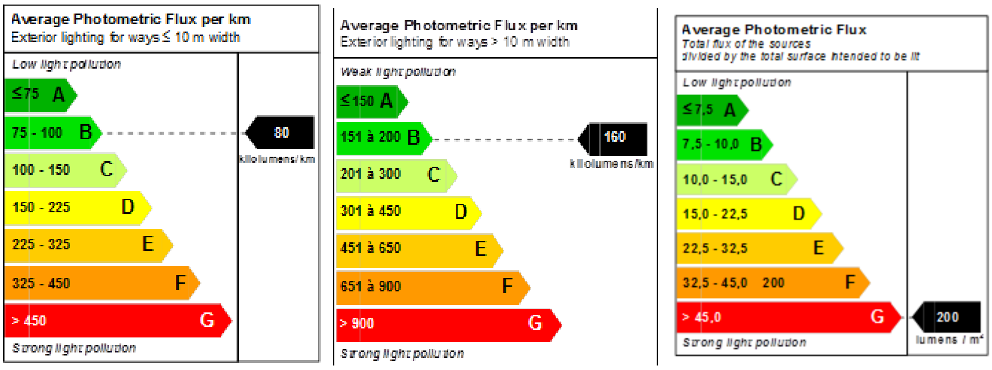

Figure 5 Light emission limits from light sources per road length or surface area in order to reduce light pollution from ANPCEN

2.4.2.6 Catalonian law (LLei/2001) following CIE 126:1997 'Guidelines for minimizing sky glow'

CIE126:1997 proposes limitations to the Upward Light Output Ratio (RULO) depending on 4 environmental zones. The installed upward light output ratio (RULO) limitations are varying between 0% and 25% (see Table 8). This approach has been implemented in Catalonia (Llei 6/2001) where the territory was classified in a similar way and light pollution requirements were set to minimize sky glow and light pollution.

Table 8. Recommended limits from CIE 126:1997 for Installed Upward Light Output Ratio (ULORinst or R_{ULO}) depending on environmental zones and distance between zones

Zone rating	Zone Description	R_{ULO}	Recommended minimum distance (km) with surrounding zone		
			E1-E2	E2-E3	E3-E4
E1	Areas with intrinsically dark landscapes: national parks, areas of outstanding beauty	0	1	10	100
E2	Areas of "low district brightness": generally outer urban and rural residential areas	0-5		1	10
E3	Areas of "middle district brightness": generally urban residential areas	0-15			1
E4	Areas of "high district brightness": generally urban areas having mixed residential and commercial use with high night time activity	0-25	none	none	none

2.4.3 BAT and reference projects

2.4.3.1 Good practice examples of GPP in practice

Since January 2010, the European Commission has collected examples of GPP in practice[18] to illustrate how European public authorities have successfully launched 'green' tenders, and provide guidance for others who wish to do the same. The following examples are listed for street lighting and traffic signals:

- Purchasing energy-efficient outdoor lighting, Cascais, Portugal
- Kolding's procurement of climate-friendly lighting solutions, Kolding, Denmark
- Energy efficient lighting on Budapest's bridges, Budapest, Hungary

[18] http://ec.europa.eu/environment/gpp/case_group_en.htm

- Procurement of energy efficient street lighting, Croatia

2.4.3.2 GPP 2020 initiative

GPP 2020 aims to mainstream low-carbon procurement across Europe through the following activities:

- Project partners will implement more than 100 low-carbon tenders
- Training and networking events - both for procurers and procurement training providers - on the implementation of energy-related GPP in Austria, Croatia, Germany, Italy, the Netherlands, Portugal, Slovenia and Spain.
- Enhancing permanent GPP support structures such as helpdesks in the same eight target countries: Austria, Croatia, Germany, Italy, the Netherlands, Portugal, Slovenia and Spain.

For street lighting two tenders have been identified, one for the municipality of Župa Dubrovačka, Croatia and one for the municipality of Tkon, Croatia[19] The specifications of these tenders had been designed to replace existing street lighting with LED lighting. For the tender in Župa Dubrovačka 686 new LED luminaires were installed to replace high pressure mercury lamps, including a control system reacting on the intensity of natural lighting.

A webinar on low carbon street lighting has been broadcasted as well.[20]

2.4.3.3 ENIGMA project

ENIGMA[21] is an FP7 project that aims to implement a joint transnational pre-commercial procurement (PCP) procedure in the field of public lighting. The project is coordinated by the city of Eindhoven. The project's 5 partner municipalities (Eindhoven, Malmo, Stavanger, Espoo and Bassano del Grappa) cooperate on procuring innovation and testing in a real life environment the technologies that their commercial subcontractors develop.

2.4.3.4 The European GreenLight Programme

The GreenLight Programme[22] is a voluntary pollution prevention initiative encouraging non-residential electricity consumers (public and private) to commit towards the European Commission to install energy-efficient lighting technologies in their facilities when it is profitable, and lighting quality is maintained or improved. The websites also contains case studies.

2.4.3.5 Life cycle cost tools

Following the new rules of the public procurement reform on life cycle costing, the Commission had commissioned a first study to develop a life-cycle costing tool for a number of electricity-using products, including street lighting. This tool can be found at http://ec.europa.eu/environment/gpp/pdf/SF_SSSUP_ELCC.xlsm. Other organisations provide life cycle cost tools as well, e.g.

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19 http://www.gpp2020.eu/low-carbon-tenders/?cmd=teaser_view&tag_id=3&category=products
20 http://www.gpp2020.eu/events-and-training/webinar-series/
21 http://www.enigma-project.eu/en/
22 http://iet.jrc.ec.europa.eu/energyefficiency/greenlight

- SEAD street lighting tool (http://www.superefficient.org/Tools/Street-Lighting-Tool): the SEAD Street Lighting Tool provides a quick way for government procurement officials to evaluate the quality, efficiency, technical compatibility, and lifetime cost of different street lighting products. The tool is available in English, French, Russian, and Spanish.
- In the Swedish sustainable procurement criteria, an option is offered to use a life cycle costing tool (only in Swedish) and can be found at http://www.upphandlingsmyndigheten.se/en/sustainable-public-procurement/sustainable-procurement-criteria/building-and-property/outdoor-lighting/lighting-design/the-lighting-systems-life-cycle-cost-lcc/#bas.
- ADEME also provides a pre-diagnosis tool for public lighting (OPEPA) which can be found at http://opepa.ademe.fr/ .

It should be noted that these tools might be useful, but a case by case study done by experts is usually preferred.

2.4.4 Guidelines on energy performance contracting (EPC)

The project "STREETLIGHT-EPC"[23] creates demand and supply for EPC projects in 9 regions by setting up regional EPC facilitation services.

2.5 Relevant standards and guidelines

Standards are an indispensable part of a road lighting designer’s daily work. The standards define the needed lighting quality, products, installation, quality assurance, etc. The goal of the standards is to provide risk minimization for public authorities by ensuring quality and safety. A general overview of standards related to lighting is given in Annex 6.1.

2.5.1 Development of standards

The following European and International standardization bodies are involved in road and traffic lighting standardisation. The role of harmonised standards and the responsibilities of the European standardisation organisations are now defined in Regulation (EU) No 1025/2012 together with relevant Union harmonisation legislation.

CEN, the European Committee for Standardization is an international non-profit organisation. CEN is working to promote the international harmonisation of standards in the framework of technical cooperation agreements with ISO (International Organization for Standardization).

CENELEC is the European Committee for Electrotechnical Standardization and is responsible for standardization in the electrotechnical engineering field. CENELEC prepares voluntary standards. CENELEC creates market access at European level but also at international level, adopting international standards wherever possible, through its close collaboration with the International Electrotechnical Commission (IEC).

ETSI, the European Telecommunications Standards Institute, produces globally-applicable standards for Information and Communications Technologies (ICT), including fixed, mobile, radio, converged, broadcast and internet technologies.

[23] http://www.streetlight-epc.eu/the-project/

2.5.1.1 European Standards (EN)

A European Standard (EN) is a standard that has been adopted by one of the three recognized European Standardisation Organisations (ESOs): CEN, CENELEC or ETSI. It is produced by all interested parties through a transparent, open and consensus based process.

There are many CEN Technical Committees developing EN Standards, the CEN/TC 169 is responsible for "Light and Lighting".

2.5.1.2 Local standards in EU28 member states (DIN, ÖNORM, NBN, NF, etc.)

Members[24] of CEN and CENELEC can also have local standards. This is in Europe still common practice for installation standards, because they do not conflict with the free movement of goods within the EU and are fitted to the local situation.

2.5.1.3 Beyond Europe

European Standards are drafted in a global perspective. CEN has signed the 'Vienna Agreement' with the International Organization for Standardization (ISO), through which European and international standards can be developed in parallel. About 30 % of the ENs in the CEN collection are identical to ISO standards. These EN ISO standards have the dual benefits of automatic and identical implementation in all CEN Member countries, and global applicability.

The **International Electrotechnical Commission (IEC)** is an organization that prepares and publishes international standards for all electrical, electronic and related technologies. All IEC international standards are fully consensus-based and represent the needs of key stakeholders of every nation participating in IEC work. Every member country has one vote and a say in what goes into an IEC International Standard. The IEC is one of three global sister organizations (IEC, ISO, ITU) that develop International Standards for the world. When appropriate, IEC cooperates with ISO (International Organization for Standardization) or ITU (International Telecommunication Union) to ensure that International Standards fit together seamlessly and complement each other. Joint committees ensure that International Standards combine all relevant knowledge of experts working in related areas.

ISO (International Organization for Standardization) is the world's largest developer of voluntary international standards. ISO/TC 274 focuses on 'Light and lighting' and does standardization in the field of application of lighting in specific cases complementary to the work items of the International Commission on Illumination (CIE) and the coordination of drafts from the CIE, concerning vision, photometry and colorimetry, involving natural and man-made radiation over the UV, the visible and the IR regions of the spectrum, and application subjects covering all usage of light, indoors and outdoors, energy performance, including environmental, non-visual biological and health effects.

The **International Commission on Illumination** - also known as the **CIE** from its French title - Commission Internationale de l'Eclairage - is devoted to worldwide cooperation and the exchange of information on all matters relating to the science and art of light and lighting, colour and vision, photobiology and image technology. With strong technical, scientific and cultural foundations, the CIE is an independent, non-profit organization that serves member countries on a voluntary basis. The CIE has been accepted by ISO as an international standardization body. Many CIE standards become European Standards (EN) with no or only few modifications.

[24] http://standards.cen.eu/dyn/www/f?p=CENWEB:5

2.5.2 Relevant standards for GPP and road lighting in the EU

In this section the most relevant standards related to road lighting and traffic signals in the EU are shortly described. A complete list of standards can be found in Annex 6.1 of this report.

2.5.2.1 CEN/TR 13201-1 'Road lighting - Part 1: Selection of lighting classes'

This 'standard' actually has only the status of a technical report. It specifies the lighting classes set out in EN 13201-2:2016 and gives guidelines on the application of these classes. To do this, it includes a system to define an outdoor public traffic area in terms of parameters relevant to lighting. To assist in the application of classes, it suggests a practical relationship between the various series of lighting classes, in terms of comparable or alternative classes. It also gives guidelines on the selection of the relevant area to which the lighting classes from EN 13201-2:2016 and the calculation grids and procedure from EN 13201-3:2015 should be applied.

2.5.2.2 EN 13201-2 'Road lighting - Part 2: Performance requirements'

This part of the European standard defines lighting classes for road lighting aiming at the visual needs of road users. The definitions are according to photometric requirements.

Installed intensity classes for the restriction of disability glare and control of obtrusive light and installed glare index classes for the restriction of discomfort glare are defined in Annex A of this standard. Lighting of pedestrian crossings is discussed in the informative Annex B. Disability glare evaluation for conflict areas (C classes) and pedestrian and pedal cyclists (P classes) is discussed in the informative Annex C of this standard.

2.5.2.3 EN 13201-3 'Road lighting - Part 3: Calculation of performance'

This European standard defines and describes the conventions and mathematical procedures to be adopted in calculating the photometric performance of road lighting installations designed in accordance with EN 13201-2:2016.

The calculation methods described in EN 13201-3:2015 enable road lighting quality characteristics to be calculated by agreed procedures so that results obtained from different sources have a uniform basis.

2.5.2.4 EN 13201-4 'Road lighting - Part 4: Methods of measuring lighting performance'

This part specifies the procedures for making photometric and related measurements of road lighting installations, and gives advice on the use and selection of luminance meters and illuminance meters.

It aims to establish conventions and procedures for lighting measurements of road lighting installations.

The conventions for observer position and location of measurement points are those adopted in EN 13201-3:2015. Conditions which may lead to inaccuracies are identified and precautions are given to minimize these.

A format for the presentation of measurements is also provided.

2.5.2.5 EN 13201-5 'Road lighting-Part 5: Energy performance indicators'

This part defines how to calculate two energy performance indicators for road lighting installations, which are the so-called Power Density Indicator (PDI) (sometimes abbreviated as DP) in [W/(lx.m²)] and the Annual Energy Consumption indicator (AECI) (sometimes abbreviated as DE) in [kWh/(m²y)].

The PDI demonstrates the energy needed for a road lighting installation, while it is fulfilling the relevant lighting requirements specified in EN 13201-2:2016. The annual energy consumption indicator (AECI) determines the power consumption during the year, even if the relevant lighting requirements change during the night or seasons. The luminaire power is the power needed to have a lighting system compliant with minimum illumination requirements obtained from classes defined EN 13201-2:2016. This means that in AECI also dimming is taken into account.

The PDI is calculated based on the calculated maintained average horizontal illuminances, hence it does not compensate for over-lighting compared to the minimum required illuminance or taking constant light output regulation into account. The PDI and the AECI do not include all the reference road sub-areas. Areas of strips for calculation of the edge illuminance ratio are excluded from the calculation of energy performance indicators although requirements apply to these strips.

Because neither AECI nor PDI cover all improvement options it is important to use both parameters together to assess system efficacy.

Annex B of this standard describes a method for analysing and disaggregating the installation losses into installation efficiency, light source efficacy, periodic reduction factor and power (gear) efficiency. Therefore Annex B defines the 'installation luminous efficacy' (η_{inst}) which takes over-lighting into account.

2.5.2.6 IEC 62717 'Requirements for the performance of LED modules'

This international standard specifies the performance requirements for LED modules, together with the test methods and conditions required to show compliance with this standard.

2.5.2.7 IEC 62722-2-1 'Particular requirements for the performance of LED luminaires'

This international standard specifies the performance requirements for LED luminaires, together with the test methods and conditions required to show compliance with this standard.

2.5.2.8 Standard CIE 115:2011 on lighting of roads for motor and pedestrian traffic

This is the international standard from which the Technical Report CEN/TR 13201-1:2014 is derived and the European Standard EN 13201-2:2016 on the definition of road classes (see 2.5.2.1 and 2.5.2.2).

In this standard a structured model has been developed for the selection of the appropriate lighting classes (M, C, or P), based on the luminance or illuminance concept taking into account the different parameters relevant for the given visual tasks. Applying for example time dependent variables like traffic volume or weather conditions, the model offers the possibility to use adaptive lighting systems.

2.6 Scope and definition proposal

2.6.1 Stakeholder input on the current scope from the first questionnaire

In the beginning of the study a questionnaire has been sent out including questions related to scope and definition.

In total 16 replies were received from 7 EU countries, Norway and three European wide organisations including specifiers/procurers, manufacturers and green NGOs. Due to emerging LED solutions the current criteria are reported to be outdated. There are few procurers that use the current criteria directly. More often they are used indirectly as a source of inspiration for elaborating tender specifications.

On road lighting most respondents (10/16, i.e. 10 out of 16 answers), did support to keep the scope aligned to EN 13201. Others (3/16) suggested extending the current scope. The key point is that the current scope is limited to road lighting but other lighted areas could benefit from the GPP criteria when they use the same approach and lighting equipment as road lighting. These other areas are car parks of commercial or industrial outdoor sites and recreational sports or leisure fields. They could benefit from the same approach and some respondents suggested including them in the updated scope. It has also been suggested to pay more attention to dimming and control systems for street lighting.

With regard to LED retrofit lamps most replies (9/16) proposed to include them. Those who proposed to exclude them did not believe that the current state of art provide suitable and performant retrofit solutions. The questionnaire also showed that there is no interest (12/15) to include poles. The positive answers suggested that the pole lifetime (corrosion) is an important element to consider in a street lighting installation, despite not being a topic of the scope related to EN 13201. Most replies (12/13) suggest excluding power cables.

Regarding updated criteria for street lighting, there is a general support to include a metering and billing requirement (10/15) despite that this is not part of EN 13201. The questionnaire also showed that there is a general need to include more smart controls specifications apart from dimming. Further, it was mentioned that the maintenance factor selection criteria for LEDs are urgently required and that a bonus for modular designed LED products would be welcome (for repair and lifetime). One stakeholder also suggested paying more attention to the colour spectrum of the light source and impact on light pollution. The criteria will be reviewed in the Technical Report (Task 4) of the study.

On traffic signals no procurers have replied and most respondents suggest removing them from this GPP criteria set even though some stakeholders want to keep them in the scope of the criteria. The main argument for removing them is that they form a complete different product group with different end users. Nevertheless, the argument for keeping them included is the fact that replacing inefficient incandescent lamps with LEDs is an important improvement option. However, such a retrofit is obvious and probably common practice wherever it is technically possible and has a short return on investment. The main barrier for not retrofitting is probably related to incompatibilities with the traffic lighting control system and more specific failure detection based on current lamp monitoring.

Finally, a name change for the product group from "Street Lighting" to "Road Lighting" is proposed to be more in line with the terminology used in EN 13201.

2.6.2 Reviewed scope and definition

2.6.2.1 Current scope and definition

The current criteria describe the scope for street lighting as follows:

"Fixed lighting installation intended to provide good visibility to users of outdoor public traffic areas during the hours of darkness to support traffic safety, traffic flow and public security"

This is derived from EN 13201 and does not include tunnel lighting, private car park lighting, commercial or industrial outdoor lighting, sports fields or installations for flood lighting (for example monument, building or tree lighting). It does include functional lighting of pedestrian and cycle paths as well as roadway lighting.

Replacement lamps form the majority of regular procurement, and in the replacement lamps criteria of this GPP specification, only high intensity discharge lamps for street lighting are considered. In particular high pressure sodium and metal halide lamps are the focus of the lamp efficacy criteria. These are both used in street lighting, but for different kinds of applications, each with its own advantages.

Poles, building mounts, or any other type of support and the required fixing mounts are currently not covered.

2.6.2.2 Proposal for revised scope and definition

Taking into account the information section 2.6.1 and the current state-of-the-art in street lighting technology and standardisation it is proposed to change the scope to road lighting and similar applications defined as:

"Fixed lighting installation intended to provide good visibility to users of outdoor public traffic areas during the hours of darkness to support traffic safety, traffic flow and public security according to standard EN 13201 on road lighting including similar applications as used for car parks of commercial or industrial outdoor sites and traffic routes in recreational sports or leisure facilities"

This scope is derived from EN 13201 and includes car parks of commercial or industrial outdoor sites and traffic routes in recreational sports or leisure facilities. The car parks and traffic routes in recreational sports and leisure facilities are out of scope of EN 13201, but they use similar technologies. The scope also includes functional lighting of pedestrian and cycle paths as well as roadway lighting.

In line with the terminology of EN 13201 it is also proposed to change the name from 'street' lighting to 'road' lighting.

The new proposal means that the following are excluded:

- Lighting poles: light poles are out of scope of EN 13201. It was suggested however that it might be useful to include some optional criteria to increase the pole lifetime (e.g. taking into account corrosion). As a starting point lighting poles are excluded from the scope because of being a complete different product group.
- Building mounts, catenary wire systems or any other type of support and the required fixing mounts
- Tunnel lighting. Tunnel lighting is defined in standard CIE 88(2004). Tunnel lighting is not defined in any European Standard (EN) but local standards are used. They use totally different lighting conditions because they have to reduce the contrast during daytime while entering and leaving the tunnel. Daytime outdoor illumination (up to 100 000 lx) is far higher compared to normal road lighting (up to 20 lx). A good design will take into account orientation, surface properties, etc. Tunnel design is a complete other technical area including luminaires and their control systems. Luminaires have very different optics for this purpose, tunnels enclosed the light sources and light reflects on the walls which is more similar to indoor lighting.

- Monument, building or tree lighting are not included in the standard series EN 13201. Design is most often based on decorative criteria, e.g. luminance, colour and contrast of the object to be illuminated. For this purpose other type of luminaires and light sources are used. For this application it is important that the colour of the light source matches with the object to be illuminated rather than looking for a maximum lamp efficacy.
- Outdoor lighting of work places (e.g. industrial sites) is defined in European Standard EN 12464-2 and have different lighting criteria (e.g. on colour rendering).
- Outdoor sport field lighting, such as defined in standard EN 12193 on minimum lighting requirements for indoor and outdoor sports events most practised in Europe. They use different lighting conditions and equipment.

Traffic signals can maintain the current definition as:

"Red, yellow and green signal lights for road traffic with 200mm and 300mm roundels. Portable signal lights are specifically excluded."

This is in accordance with EN12368:2006 Traffic Control Equipment – Signal Heads.

3 MARKET ANALYSIS

3.1 Introduction

The aim of the market analysis is to collect and update key data which will enable a quantitative assessment of the economic relevance of the product group. The data will also provide information on the functioning of the market for the product group, facilitating the identification of relevant trends, drivers, innovation and initiatives, which could impact the formulation of GPP criteria.

Initially, the general economic situation for Europe is presented to support the quantification and assessment of the market. This mainly includes generic economic indicators. Furthermore, the total road length in all Member States is provided together with lighting statistics to describe the current situation and provide forecasting the future growth in new or replacement projects. Therefore also data regarding the current and expected sales is provided which can assist in an assessment of the potential for future improvements. Finally, the street lighting sector is further analysed to provide a sound basis for assessing the size of this sector.

For procuring road and traffic lighting it is quite common to calculate the Total Cost of Ownership (TCO). Total cost of ownership (TCO) is a concept that aims to estimate the full cost of a system and therefore the Capital Expenditures (CAPEX) and Operational Expenditures (OPEX) are calculated. CAPEX are used to acquire the lighting installation and consist mainly of product and installation costs. The OPEX is the ongoing cost for running the lighting system and consist of costs for electriciy, relamping, repair, maintenance and end of life.

3.2 Generic economic indicators

In this section generic economic indicators are provided to assess the market potential for GPP in road and traffic lighting.

3.2.1 Labour cost in Europe

Part of the Capital Expenditures (CAPEX) and Operational Expenditures (OPEX) of road and traffic lighting is related to labour cost, e.g. for installing luminaires and relamping. The typical repair, installation and maintenance times are discussed later in section 3.3.9. The average hourly rates in the EU28 are used as the installer's hourly rate or for repairs and maintenance such as lamp replacement and cleaning.

Labour costs are usually presented excluding overhead costs. For road lighting maintenance and installation, however, overhead costs should be included because an electrician for public lighting has these costs, e.g. for the use of a tower wagon (Van Tichelen et al., 2007). Therefore the presented labour cost should be at least multiplied by 1.5. The average hourly labour cost for EU28 in 2015 is 25 euro[25] Including overhead costs, this would lead to an EU28 average cost of 37.5 euro per hour (2015). This hourly cost can be used in cost benefit analysis which is discussed in section 3.3.9.

3.2.2 Electricity prices

Operational Expenditure (OPEX) is to a large extent related to the electricity cost. Eurostat provides electricity price statistics.[26] For road lighting and traffic lighting it can be assumed that the industrial electricity rates are the most representative. These rates

[25] http://ec.europa.eu/eurostat/statistics-explained/index.php/Hourly_labour_costs
[26] http://ec.europa.eu/eurostat/statistics-explained/index.php/Electricity_price_statistics

are lower compared to household tariffs. In 2015 (semester 1) the EU average electricity price for industry was 0.12 euro per kWh. The lowest price was noted in Sweden (0.062 euro/kWh) and the highest in Italy (0.161 euro/kWh).

3.2.3 Interest, inflation and discount rates

Interest, inflation and discount rates have an important impact on the calculation of the Total Cost of Ownership (TCO) or Life cycle costing (LCC) which is discussed in section 3.3.9.

The annual inflation rate is an annual increase in the general price level of goods and services. The annual interest rate is the amount of interest due per year as a proportion of the amount lent. Both data are provided by the European Central Bank[27] In March 2016 the annual inflation in the Eurozone was 0.0 % and the average interest rate for corporations was 2%.

A common approach is to calculate the discount rate r as interest rate minus inflation rate. Discount rates are used to calculate the Net Present Value (NPV) in TCO or LCC calculations to compare costs and benefits that occur in different time periods (Van Tichelen et al., 2007). The Total Cost of Ownership (TCO) is equal to the Capital Expenditures (APEX) and the Net Present Value (NPV) of all Operational Expenditures (OPEX).

Currently in preparatory studies for ecodesign a discount rate of 4 % is used (MEEr, 2011), but given the current economic conditions this can be lower, e.g. 2%.

3.3 Market data on stock and sales of road lighting

3.3.1 Quantity, length and types of roads in Europe

Eurostat provides road transport infrastructure statistics[28]. Even though the Eurostat data is not used further in the report, it is shown for completeness. The Eurostat data is incomplete as data for certain countries is missing in certain years. Therefore other sources and data will be used for further estimations.

The Eurostat data contain the following road categories:

- Motorways: total length reported is 63 660 km in EU28 (2010), with large networks in Spain, France and Germany.
- E-roads: which belong typically to EN 13201-2:2016 or CIE 115 road class M. Total length reported is 42 409 km in the EU28 (2010).
- State, province and communal roads: total length reported is 3 616 472 km in the EU28 (2010).
- Other roads inside or outside built up areas: total length reported is identical to state, province and communal roads.

Another source of information for the lengths of different road types in the different EU28 Member States are the "European Road Statistics" of the European Road Federation for 2011[29] (ERF, 2014) (see Table 9). This data is more reliable and can be further used to develop a road lighting market model. It should be noted that this data does not include statistics on lit roads and therefore further processing is necessary.

[27] https://www.ecb.europa.eu/stats/money/aggregates/nace/html/index.en.html
[28] http://ec.europa.eu/eurostat/web/transport/data/database
[29] ERF, European Road Statistics 2011, http://www.irfnet.eu/index.php/publications/publications/european-road-statistics-handbook

Table 9. Length of total road network by category in km in 2011 (ERF, 2014)

Road length statistics	Motorways	Main or national roads	Secondary or regional roads	Other roads	Total	Population
Member State	**length (km)**	**length (km)**	**length (km)**	**length (km)**	**length (km)**	**capita[30]**
Belgium	1 763	13 229	1 349	138 869	155 210	11 000 638
Bulgaria	458	2 970	4 030	12 054	19 512	7 364 570
Czech Republic	745	6 254	48 743	74 919	130 661	10 436 560
Denmark	1 143	2 697	35 045	35 045	73 930	5 560 628
Germany	12 845	39 673	178 184	413 000	643 517	80 219 695
Estonia	115	3 896	12 458	42 299	58 768	1 294 455
Ireland	900	4 780	11 631	78 958	96 269	4 574 888
Greece	1 197	9 299	30 864	75 600	116 960	10 816 286
Spain	14 554	15 056	136 298	501 053	666 961	46 815 910
France	11 412	9 745	377 857	654 201	1 053 215	64 933 400
Croatia	1 254	6 843	10 967	10 346	29 410	4 284 889
Italy	6 668	20 773	151 583	312 100	491 124	59 433 744
Cyprus	257	2 197	2 779	4 732	9 965	840 407
Latvia	N.A.	1 651	5 17	61 549	68 517	2 070 371
Lithuania	309	6 367	14 589	51 064	72 329	3 043 429
Luxembourg	152	837	946	946	2 880	512 353
Hungary	1 516	6 824	23 358	169 263	200 961	9 937 628
Malta	N.A.	184	665	1 379	2 228	9 937 628
The Netherlands	2 658	2 462	7 802	126 373	139 295	16 655 799
Austria	1 719	10 013	23 639	88 753	124 124	8 401 940
Poland	1 070	17 731	156 219	237 244	412 264	38 044 565
Portugal	2 737	6 284	4 420	63 900	77 341	10 562 178
Romania	350	16 690	35 374	31 639	84 053	20 121 641
Slovenia	768	817	5 144	32 248	38 976	5 416 851
Slovakia	419	3 507	14 050	25 351	43 328	5 397 036
Finland	790	12 539	13 573	51 236	78 138	5 375 276
Sweden	1 920	13 465	83 079	116 832	215 296	9 482 855
United Kingdom	3 686	49 067	122 665	244 334	419 752	63 182 180
EU28	71 405	285 849	1 512 628	3 655 287	5 524 984	508 223 624

Notes: The definition of road types varies from country to country, the data are therefore not comparable. "Other roads" sometimes includes roads without a hard surface. Denmark and Luxemburg do not give a distribution between secondary or regional roads but is assumed 50/50.

The lot 9 preparatory study (Van Tichelen et al., 2007) on street lighting sent out a questionnaire in 2006 to estimate the share of lit roads in 1990. The following answers were received: 10% of so-called category fast traffic roads or typically motorways, 15%

[30] Data sources 2011 https://ec.europa.eu/CensusHub2/intermediate.do?&method=forwardResult

of so-called mixed traffic roads or typically intercommunal roads and 30% of so-called slow traffic roads or typically roads in residential areas are lit.

In section 3.3.2 a new stock estimate is made on the installed stock in 2015 and a new cross-check can be done with typical information on average pole distances, see section 3.3.4. It was judged that the expert estimation for 1990 for the distribution between these categories is correct but that the amount of roads with lighting is higher in 2015. The new results are shown in Table 10.

Table 10. Estimated share of lit roads in 2015

	Motorways	Main or national roads	Secondary or regional roads	Other roads
EU28 road length [km]	71 405	285 849	1 512 628	3 655 287
2015 share lit (%) corrected	12%	12%	18%	37%

In the framework of the ongoing ecodesign study on lighting systems[31] the lighting industry[32] provided an estimate for 2016 on which road classes (according to EN 13201-2:2016) correspond to the sales data. The result can be found in Table 11.

Table 11. Typical lighting class installed according to EN 13201-2:2016 on European roads and their estimated share (source: Lighting Europe)

ERF category	Motorway	Main or national roads	Secondary or regional roads		Other roads		
Subcategory			**Rural roads or mixed with residential**	**Mixed conflict**	**Mixed traffic**	**Residential streets P4**	**Residential streets M5**
share(%) in ERF road category	100%	100%	92%	8%	40%	30%	30%
Typical EN 13201-2:2016 class	M2	M3	M4	C3	P2	P4	M5

3.3.2 Road lighting luminaires per capita and stock growth

In the ecodesign street lighting study (Van Tichelen et al., 2007), scattered data on the number of luminaires per capita were retrieved from various sources for modelling the stock in 2005.

This 2005 data is reviewed with the following sources to estimate the stock in 2015:

- Accurate data were supplied from Belgium and Sweden in the first questionnaire for this study for 2005 versus 2015. It showed that in Belgium the stock increased from 2 005 000 (2005) to 2 154 280 (2015) or 0.48 % per year and in the Stockholm area from 144 122 (2005) to 147 626 (2015) or 0.18 % per year. The Swedish stock data from 2005 has been updated proportional to the Stockholm growth rate data. This stock increase is a relatively low figure and is supported by the fact that the EU has a mature road infrastructure which requires relatively low levels of new road construction each year;
- New literature data from the ESOLI FP 7 project (ESOLI, 2012a) on road lighting stock in the Czech Republic, Finland, Germany, the Netherlands and the UK. Also for France there is updated data available from literature (AFE, 2015);

[31] http://ecodesign-lightingsystems.eu/
[32] http://www.lightingeurope.org/

- For other countries the average growth rate of 0.33 % (the average for Belgium and Stockholm) was used to estimate the 2015 stock versus 2005.
- Bulgaria, Croatia and Romania were not part of the EU in 2005. No accurate data was supplied in the questionnaire so 2015 data was simply extrapolated from the EU average.

An overview of the estimated stock of installed road lighting luminaires in the EU28 in 2005 and 2015 can be found in Table 12 based on the previous data and assumptions. It shows also that there are strong differences between countries. In general, countries with a relative high share of habitants living in apartments will have a relative low amount of luminaires per capita. For example in Belgium (0.19) a large share of the population lives in single family houses resulting in a relative high amount of luminaires compared to EU28 the average (0.13). Another potential explanation is the use of low wattage lamps with short distance between poles, which will result in a relative high amount of luminaires per capita. For example the Netherlands (0.22), they also have relative much lower wattage fluorescent lamps installed (see Table 12). **I**n the EU28 on average 0.13 luminaires are installed per capita.

Table 12. Estimated stock of road lighting luminaires in EU-28 in 2005 and 2015

Country	Habitants 2015	Total stock luminaires 2005	Total stock luminaires 2015	Luminaires per capita 2015
Austria	8 551 081	1 000 000	1 033 494	0.12
Belgium	11 336 943	2 005 000	2 154 280	0.19
Bulgaria	7 199 931		910 708	0.13
Croatia	4 244 995		536 943	0.13
Cyprus	873 003	88 000	90 948	0.10
Czech republic	10 536 043	300 000	1 300 000	0.12
Denmark	5 649 584	780 000	806 126	0.14
Estonia	1 311 505	50 000	51 675	0.04
Finland	5 478 486	400 000	1 100 000	0.20
France	66 175 754	9 000 000	9 000 000	0.14
Germany	80 709 056	9 250 000	9 250 000	0.11
Greece	10 977 945	900 000	930 145	0.08
Hungary	9 863 193	600 000	620 097	0.06
Ireland	4 602 854	401 000	414 431	0.09
Italy	60 944 960	9 000 000	9 301 449	0.15
Latvia	1 985 887	85 000	87 847	0.04
Lithuania	2 901 039	125 000	129 187	0.04
Luxembourg	562 848	61 000	63 043	0.11
Malta	426 144	45 000	46 507	0.11
Netherlands	16 876 904	2 500 000	3 652 286	0.22
Poland	38 499 953	4 200 000	4 340 676	0.11
Portugal	10 367 550	1 100 000	1 136 844	0.11
Romania	19 909 323		2 518 300	0.13
Slovakia	5 416 851	200 000	206 699	0.04
Slovenia	2 066 511	74 000	76 479	0.04
Spain	46 390 269	4 200 000	4 340 676	0.09
Sweden	9 721 642	2 500 000	2 545 366	0.26
UK	64 643 370	7 851 000	7 640 227	0.12
EU28	**508 223 624**		**64 284 433**	**0.13**

3.3.3 Market distribution of lamp technologies

The ecodesign street lighting study (Van Tichelen et al., 2007) also contained an estimate on how lamp technologies are used in countries in the EU in 2005 (see Table 13). Strong differences between countries in lamp distribution can be observed. Some countries had already relative low share of inefficient HPM lamps, e.g. Belgium, Ireland, Netherlands, Sweden and the UK, independent from the fact that these will be banned from the market.

For 2015 no new data is available. However a new average for the total EU28 is made based on the following assumptions:

- EC Regulation 245/2009 phases out inefficient HPM and FL lamp types (see section 2.3.4). It can therefore be assumed that HPM and FL were substituted by HPS and MH lamps between 2010 and 2014 with a replacement rate equivalent to the average lifetime of 30 years (see section 3.3.5);
- Precise data on the uptake of LED luminaires in road lighting is missing and therefore assumptions were made. Before 2014 it can be assumed that the market uptake for LED luminaires remained relative low and therefore for simplicity they are neglected. In 2015 however it is assumed that LED luminaires became the mainstream luminaire for replacement and new sales. Therefore the assumption of 90 % LED and 10 % HID sales in 2015 was made. A recent visit (April 2016) to the light and building trade fair[33] learned that nearly only LED luminaires were on display and the manufacturers indicated that new projects are mainly based on LED luminaires. This resulted in the assumption that the stock change of 2015 is towards LED. Due to this transition accurate stock projections are difficult.

The estimated share of lamp technologies in the EU 28 in 2015 are presented in the last row of Table 13 and in Figure 6.

Table 13. Use of different lamp technologies per country in 2005 and estimated EU28 average in 2015

Country	HPM 2005 %	HPS 2005 %	LPS 2005 %	MH 2005 %	FL 2005%	LED 2005 %
Austria	30%	67%	0%	3%	0%	0%
Belgium	5%	51%	32%	3%	7%	0%
Bulgaria	33%	48%	9%	2%	8%	0%
Croatia	33%	48%	9%	2%	8%	0%
Cyprus	48%	49%	0%	3%	0%	0%
Czech Republic	40%	56%	0%	2%	2%	0%
Denmark	40%	35%	3%	3%	20%	0%
Estonia	40%	56%	0%	2%	2%	0%
Finland	40%	54%	3%	3%	0%	0%
France	33%	62%	0%	5%	0%	0%
Germany	45%	34%	0%	3%	18%	0%
Greece	50%	42%	0%	3%	5%	0%
Hungary	33%	67%	0%	0%	0%	0%
Ireland	3%	42%	55%	0%	0%	0%
Italy	64%	28%	1%	5%	2%	0%
Latvia	40%	56%	0%	2%	2%	0%
Lithuania	40%	56%	0%	2%	2%	0%
Luxembourg	25%	71%	1%	3%	0%	0%
Malta	33%	64%	0%	3%	0%	0%
Netherlands	5%	47%	30%	3%	20%	0%
Poland	49%	50%	0%	1%	0%	0%
Portugal	30%	65%	0%	0%	5%	0%
Romania	33%	48%	9%	2%	8%	0%
Slovakia	40%	56%	0%	2%	2%	0%
Slovenia	41%	56%	0%	2%	2%	0%
Spain	20%	70%	0%	0%	10%	0%
Sweden	5%	90%	3%	3%	0%	0%
UK	0%	41%	44%	0%	15%	0%
EU28	**32.8%**	**48.5%**	**8.6%**	**2.5%**	**7.7%**	**0%**
	HPM 2015 %	**HPS 2015 %**	**LPS 2015 %**	**MH 2015 %**	**FL 2015 %**	**LED 2015 %**
EU28	**23.4%**	**53.5%**	**6.1%**	**7.7%**	**5.5%**	**3.8%**

[33] http://light-building.messefrankfurt.com/frankfurt/en/besucher/willkommen.html

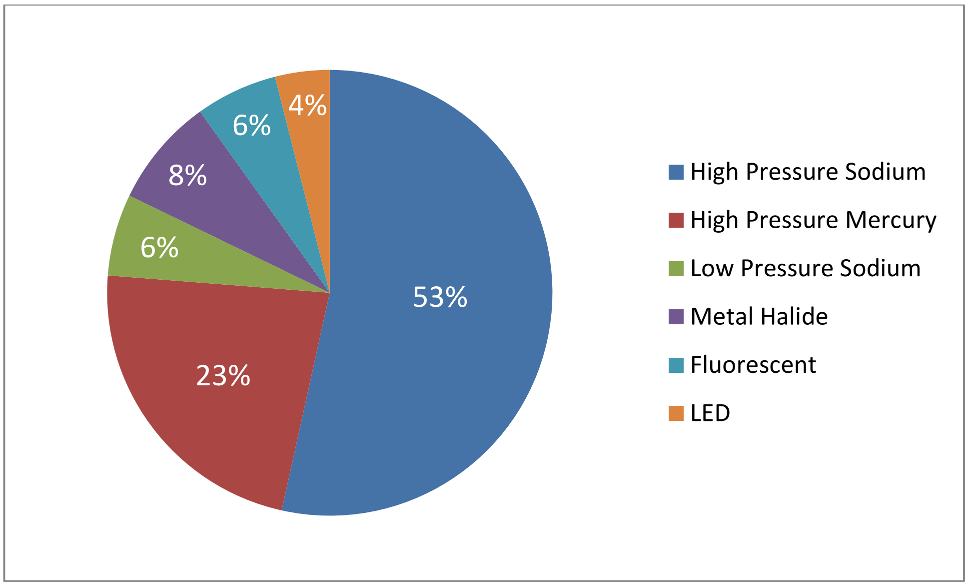

Figure 6 Estimate of relative share of lamp technologies used in road lighting in EU28 in 2015

3.3.4 Lighting point spacing and spacing to height ratio (SHR)

In order to estimate the share of lit roads and have a view on future trends, the distance between the lighting poles can be used (section 3.3.1). The distance between the lighting poles is related to their height and the type of road. The spacing between lighting poles versus the height of the luminaires, i.e. the Space to Height Ratio (SHR), can vary substantially for different types of roads and/or countries.

In the lot 9 study a questionnaire was sent out to the stakeholders. A summary of their replies in 2007 are:

- For the fast traffic road classes there was a large difference in the spacing of lighting poles in the EU, varying from 40 to 90 m. The SHR varies between 3.1 and 4.5 (e.g. 90/20, 60/15, 48/12, 40/13).
- For the mixed traffic road classes the SHR applied varies between 3.2 and 4.5 (e.g. 45/10, 50/12.5, 35/11).
- For the low traffic roads classes the SHR was between 4 and 5 (e.g. 40/8, 36/8, 25/5, 30/7, 20/4).

M and C classes of EN 13201-2:2016 are typical for fast and mixed traffic roads. P classes of EN 13201-2:2016 are often found in slow traffic roads with pedestrians and/or cyclists. The SHR of M and C classes are lower compared to the SHR of P classes because the classes M and C impose stricter limitations on glare. This means that the luminaires for M and C classes cannot have wide beam light distributions. In class P of EN 13201-2:2016, however, the limitations on glare are much lower and also lower lumen luminaires are used. This implies that the luminaires can have wide beam optics and therefore the SHR can be higher.

In residential areas there is generally a limitation on the pole height and relative small spacing distances between poles can occur (e.g. up to 20 m).

3.3.5 Economic lifetime of road lighting installations

The average overall lifetime for luminaires is expressed in years after placement. The lifetime is only influenced by local conditions such as weather, pollution, vibrations caused by traffic density, etc. The lifetime of a luminaire is not dependent on the amount of burning hours of the lamps as the lamps can be replaced during the lifetime of a luminaire.

According to the lot 9 preparatory study (Van Tichelen et al., 2007) a lifetime of 30 years for a luminaire is common. The variation can be considerable however. In the centre of municipalities and in shopping streets - where public lighting is an element of street furniture - replacement times can be much shorter, e.g. 15 years. In rural areas - with very low traffic density - luminaires with an age of 35 years and even more can be found. Typical lifetimes are included in Table 14 with an average lifetime of 30 years.

Table 14. Typical luminaire lifetimes in road lighting

	Roads for fast traffic			**Roads for mixed traffic**			**Roads for slow traffic**		
	min.	**avg.**	**max.**	**min.**	**avg.**	**max.**	**min.**	**avg.**	**max.**
Lifetime (years)	**25**	**30**	**35**	**25**	**30**	**35**	**15**	**30**	**35**

Regular cleaning of the luminaire is necessary. This cleaning necessity depends strongly on the characteristics of the luminaire. Where the reflector of an open luminaire needs a new polish and anodizing at least every 10 years, a cleaning of the outer glazing at lamp replacement can be sufficient for luminaires with a closed optical compartment.

3.3.6 Road lighting lamp sales and relamping

The lifetime of lamps used for road lighting is limited. Therefore they have to be replaced over the lifetime of the road lighting luminaire. Typical lamp lifetimes are included in Table 15 based on a combination of lamp survival factor (LSF) and lamp luminance maintenance factor (LLMF). These data are provided in standard CIE 154:2003 and were selected according to the typical user data of the preparatory study in 2007 (Van Tichelen et al., 2007). Combined with the stock data from section 3.3.2 the total EU28 sales volumes can be estimated (see Table 15). HPM lamps are phased out for new sales by Regulation 245/2009 but it can be assumed that some municipalities have stocked replacement lamps to avoid new investments in more efficient lighting.

The estimates provided in Table 15 take into account that in road lighting it is not possible to switch lamp type in an existing luminaire because each of these lamps (HPM, FL, HPS, LPS, HM) has its own type of ballast or control gear and starter. Therefore the possibility of simple retrofitting with a more efficient lamp is limited. In most cases it is not possible without rebuilding and rewiring the luminaire. Exceptions are HPS and HID retrofit lamps for HPM lamps. However, due to the ballast the power consumption will be the same or maximum 10% lower. These retrofit solutions do increase the light output, but the absolute energy saving is limited. These lamps will be further discussed in Chapter 3. These limited retrofitting possibilities without changing the luminaire are an important barrier for renovating road lighting with more efficient equipment.

Note that LED is included in the luminaire sales that are discussed in section 3.3.7. LED luminaires have very long lifetimes (> 15 years) and therefore it is too early to have them in current sales figures for replacement LED modules or parts. A potential vulnerable component in LED luminaires is the electronic driver and it could make sense to have them sold as a separate component. Some manufacturers already do this. Road lighting manufacturers typically claim 'lifetimes' between 60 000 and 90 000 hours. Because the technology is relatively new, LED luminaire lifetime data is mainly based on research projections and complementary standards (ZVEI, 2013). Additional technical parameters for road lighting luminaires are further discussed in Chapter 3.

Table 15. Typical service life of lamps in road lighting and projected sales volumes

Lamp type	HPM	FL	HPS	LPS	MH
Years of service	3	3	4	3	2
Typical service hours	12 000	12 000	16 000	12 000	8 000
EU28 luminaire stock 2015 (units)	15 017 472	3 541304	34 419 921	3 922 309	4 971 775
EU28 lamp sales 2015 (units)	-	1 189 721	8 672 676	1 317 722	2 505 444
Typical unit price(Q1/2016)[34] - lamp (euro)	-	€ 4	€ 15	€ 48	€ 22
Total EU28 lamp sales (euro)	-	€ 4 758 884	€ 130 090 140	€ 63 250 656	€ 55 119 768

3.3.7 Road lighting luminaire sales for replacement and new projects

The total annual volume of luminaire sales can be forecasted from the installed stock (see 3.3.2) and the average lifetime (30 years). This results in a projected annual sales of 2.38 million road lighting luminaires for which the majority in replacement sales (2.16 million). With the phase out of HPM and retrofit HPS lamps due to EC Regulation 245/2009 and the interest in energy savings the annual amount of road lighting luminaire sales could increase in the upcoming years.

With a typical luminaire price data of 220 euro (e.g. for a 250 W HPS lamp as used in standard CIE 115:2010), this represents an annual EU28 sales volume of 520 million euro. Note that for HPS/MH lamps there is little influence from the lamp wattage on the price, hence a 150 W HPS lamp luminaire will be about the same price.

It should be noted that luminaire prices can vary strongly and especially new LED luminaires are substantially more expensive than 220 euro. For example, a recent study (Tähkämö L. et al., 2016) used a price of 401 euro for a HPS base case luminaire (176 Watt, 73 lm/W) to be compared with a LED luminaire (11 Watt, 97 lm/W) of 686 euro. In the ecodesign preparatory study in 2007 (Van Tichelen et al., 2007) luminaire prices including lamp and ballasts ranged between 160 and 280 euro. Anno 2016 low cost road lighting HPS luminaires can still be found on the market for a unit price below 100 euro (excl. VAT) in online web stores[35].

It can be expected that LED luminaires will decrease in price in the future. The US R&D roadmap 2016 (DOE, 2016) contains an overview of the state-of-art in LED luminaire efficacy and pieces of luminaires on which progress can be expected. An overview is shown in Table 16. The main progress is expected from increasing the LED package efficacy for which also a future price drop is expected as illustrated in Figure 7. Road

[34] sourced from online catalogues (Q1/2016) and rounded off to the unit and for the average wattage, e.g. at https://www.lampdirect.be/fr/lampe-a-decharge, https://www.eibmarkt.com/cgi-bin/eibmarkt.storefront/5805d41a002c5d9227564debae39062b/Ext/Custom/Search?query=Entladungslampen&filterCatalogs=5412, https://www.dmlights.be/en/electrical-supplies/bulbs/discharge_lamps (accessed 21 April 2016)

[35] http://www.eibmarkt.com/cgi-bin/eibmarkt.storefront/5716864b00a7e47e27564debae3906c4/Product/View/NS1526528 (accessed 21 April 2016)

lighting luminaires need to be compact and therefore often use high power LEDs which have lower efficacies due to relative high current densities (> 35 A/cm²).

Table 16. Present and Future Target Luminaire Efficiencies (DOE, 2016)

Properties and efficacies of white light production and direction by luminaire, then of use by end user	Units	Present	Future (targets)			
		2015	2018	2020	2025	Goal
Driver efficiency	%	0.88	0.91	0.93	0.95	0.95
Package efficacy (at 25°C)	lm/W	137	175	208	237	255
Thermal efficiency drop	%	0.88	0.91	0.93	0.95	0.95
Fixture (optical) efficiency	%	0.90	0.92	0.94	0.95	0.95
Luminaire efficacy of white light production/direction	lm/W	95	133	169	203	218

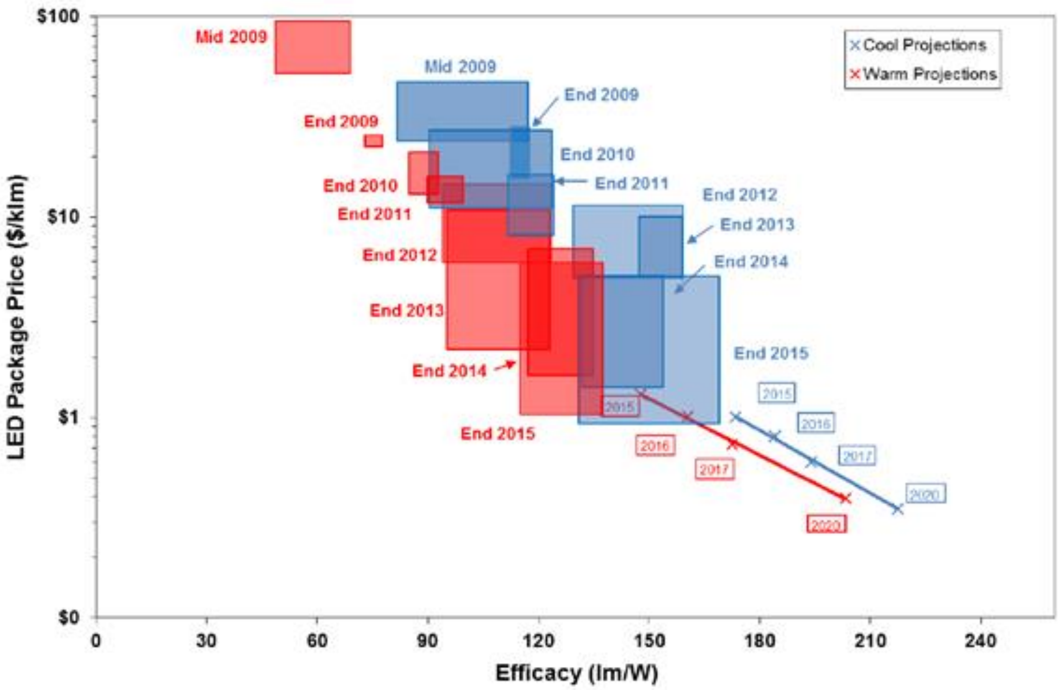

Figure 7 Price-Efficacy trade-off for LED Packages at 1 W/mm² (equiv. 35 A/cm²) and 25°C (DOE, 2016)

3.3.8 End of life and recycling

Lamps and luminaires are in part covered by the Waste Electrical and Electronic Equipment (WEEE) Directive 2012/19/EU. Therefore Member States have to organize the collection and recycling. For this purpose they have to set up collection points where the installer of new lamps or luminaires can return the used equipment.

The WEEE directive puts the responsibility for handling of WEEE on the producers of such equipment. They shall finance the collection and treatment of their WEEE in a harmonised way that avoids false competition. Producers will shift payments to the consumers under the principle that the 'polluter pays', avoiding costs for the general tax payer. Therefore the recycling fee is included in a local sales tax and there is no extra charge or financial barrier at the return of these products. Note that filament lamps such as used for traffic signals are excluded from that directive. As a consequence they will form part of the general waste stream, ending up in landfills or incinerators.

The main concern in the collection and processing of lamps at their end of life is to avoid that the amounts of mercury contained in fluorescent and HID-lamps are released to the environment. Fluorescent lamps and LEDs contain economic valuable rare earth materials and therefore they are also recovered. Both mercury and rare earth materials can be recovered in specialized recycling plants with dedicated recycling processes for these products (ZVEI, 2008; AFE, 2015).

EucoLight[36] is the European association of collection and recycling organisations for WEEE lamps and lighting which groups the recycling companies from different Member States. More information on local compliance schemes is available on their website.

3.3.9 Typical total cost of ownership or life cycle costing of road lighting

Evaluation of many large road construction projects is based on their life cycle costing (LCC). This method is also useful for road lighting installations.

The life cycle costing (LCC) is calculated using the following formula:

$$LCC = \sum CAPEX + \sum (PWF\ x\ OPEX)$$

where,

LCC is the life cycle costing,

CAPEX is the purchase price (including installation) or so-called capital expenditures,

OPEX are the operating expenses per year or so-called operational expenditures,

PWF is the present worth factor with PWF = $(1 - 1/(1+ r)^N)/r$,

N is the product life in years,

r is the discount rate (for recent data see section 3.2.3).

Note that the Net Present Value (NPV) of the OPEX is equal to PWF x OPEX. OPEX can be composed of several expenditures, e.g. electricity and relamping. The PWF is usually smaller than one which means that an advantage is given to costs and expenses that can be postponed.

The following provides an example of an LCC calculation from the preparatory study on street lighting (Van Tichelen et al., 2007) for a slow traffic road. In that study, a life cycle costing (LCC) evaluation was applied to compare the average performers to the best performers on the market.

Apart from the product (lamp, luminaire) and electricity cost the study used the following costing parameters:

- Luminaire Lifetime of 30 years (= N).
- Discount rate of 2 % (= r);
- Times for installing, maintenance and relamping (see Table 17);
- Electricity cost of 0.08 euro/kWh (reference year 2006)
- Labour cost of 31.82 euro per hour including overhead (reference year 2006);
- Reference road width 2x3 m for traffic lanes and 2x1 m for pedestrian walk (8 m total), class S4 road (EN 13201-2).

The electricity cost is according to the study (Van Tichelen et al., 2007) and its value is referred to data of 2006. The labour cost was calculated also using the data available for the study (Van Tichelen et al., 2007), the average hourly labour cost of €21.22,

[36] http://www.eucolight.org/

representative for EU25 (source Eurostat, data for 2006) multiplied by 1.5 to consider the overhead costs (see section 3.2.1).

Table 17. Estimation of maintenance and installation time parameters for use in LCC of road lighting

Time required for installing one luminaire (group installation)	20 min.
Time required for lamp replacement (group replacement)	10 min.
Time required for lamp replacement (spot replacement)	20 min.
Time required for maintenance including ballast replacement	30 min.

The results were scaled per so-called maintained useful flux received by the target area (unit lumen). 'Maintained' means that performance depreciation parameters are taken into account, such as lumen depreciation (FLLM), luminaire maintenance factor (FLM), etc. The maintained useful luminous flux is directly related to the illuminance of the target area: illuminance [lx] = luminous flux [lm] / surface [m²].

As the life cycle costing evaluation was applied to compare the average performers to the best performers, the following options were considered:

- Options 1 & 13: Retrofitting of low efficient HPM by standard HPS lamps with external starter (option 1), wherein option 13 also assumed that HPM luminaires were excluded and therefore the lower efficient HPS lamps have an internal starter;
- Option 2 and 3: use of HPS or MH with highest efficacy and/or increased lumen maintenance (FLLM);
- Option 4: use magnetic ballast with highest efficiency;
- Option 5: increasing luminaire maintenance factor (FLM) by IP65 rating;
- Option 6: option 5 with self-cleaning glass (FLM);
- Option 7: increasing the installation efficacy and lamp efficacy by using only tubular clear lamps;
- Option 8: increasing the installation efficacy by decreasing upward light flux (FULO), e.g. such as substituting a globe and diffusor luminaire with a simple reflector luminaire;
- Option 9: is a similar option as option 8 but where the optics and lighting design are fully optimized to direct the light as efficient as possible to the target area and therefore increasing the utilisation factor (Fu) and Utilance (U);
- Option 10: using magnetic bi-level dimmable ballasts to reduce light output at hours of low traffic;
- Option 11: using electronic dimmable ballast that also use constant light output regulation with continuous fitting to the minimum required illumination level and light level reduction during hours of low traffic;
- Option 12: using mercury free HPS lamps.

The results of this LCC analysis are shown in Figure 8. The option with the least life cycle costing (LLCC) was a combination of options (2, 6, 7, 8, 9 and 11). All options that reduce the energy consumption reduce the total LCC, which indicates that the LCC is dominated by the operational electricity expenditure. It is also worth noting that the previously identified options are not only about replacing the light source by a more efficient one (at 100000h lifetime) but also includes improving maintained lumen output, luminaire efficiency, installation optical design and electronic components to implement dimming.

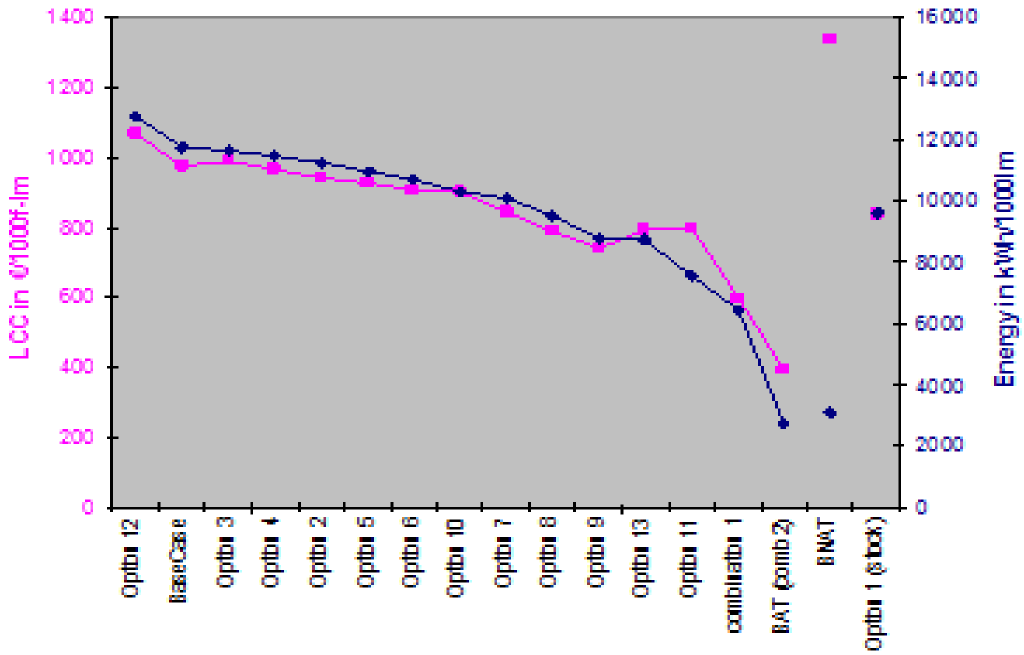

Figure 8 Different options ranked according to their 'energy saving potential' with LCC information for a reference slow traffic road (category S). The y-axis on the left side represents the life cycle costing in euro per 1000 useful lumen. The y-axis on the right represents the total energy consumption per 1000 useful lumen (1 lux on 1 m²) (Van Tichelen et al., 2007)

Some Member States have implemented life cycle costing calculations in public procurement of lighting.[37] They often refer to an annex of standard CIE 115:2010 that includes a description of the LCC method used for total cost of ownership analysis.

Recently, a life cycle costing comparison between HPS and LED luminaires for road lighting (Tähkämö L. et al., 2016) could not conclude that LED luminaires outperform HPS on the basis of costs. An important cost factor was the potential repair cost of LED luminaires and therefore they suggest a modular approach as improvement option, e.g. including a replaceable LED driver. Price and performance data were based on 2014 data (see also section 3.3.7 on LED luminaires). Price and performance data might therefore be outdated and as a consequence this conclusion on LED luminaires versus HPS lamp luminaires should not be generalized to reflect the current status.

To support LCC calcuations some projects developed free software tools, e.g. the Smart SPP Project[38] or the Buy Smart project[39].

3.3.10 Total EU electricity cost for road lighting

The estimated annual energy consumption in 2005 for road lighting was 35 TWh for the EU25 representing approximately 1.3% of the final energy consumption of electricity in the EU25 (Van Tichelen et al., 2007). With the current electricity price (see 3.2.2) this represents an annual cost of about 3 850 million euro. A recent update of the annual energy consumption is not available but it can be assumed that this value has remained

[37] e.g. in Sweden: http://www.upphandlingsmyndigheten.se/en/sustainable-public-procurement/sustainable-procurement-criteria/building-and-property/outdoor-lighting/lighting-design/the-lighting-systems-life-cycle-cost-lcc/#bas (accessed 30 August 2016)
[38] http://www.smart-spp.eu/index.php?id=7633
[39] http://www.buy-smart.info/downloads2/downloads3

similar. The stock values slightly increased but there has been a shift towards more efficient light sources as well (see section 3.3.2). Operational expenditure for electricity is currently the main cost factor in road lighting.

3.4 Market data on stock and sales of traffic lighting

3.4.1 Stock of traffic signal heads

There is no specific data available in Eurostat statistics for this product group. The authors are not aware of actual sales data for this product group.

In the Netherlands there were around 5 500 traffic light control installations containing approximately 600 000 installed lamps in 2000 (ECN, 2000).

The UK had estimated 420 000 traffic signal heads[40], each containing two or three lamps, installed and managed by individual highway authorities[41] in 2006 (UK, 2006).

Extrapolating the data from the Netherlands to the EU28 would result in 140 000 traffic light control installations sites, which leads to almost 15 000 000 installed lamps in total.

3.4.2 Traffic signal lamp sales

Traffic signal lamps are a niche product and accurate sales data are not available. However, based on the estimated traffic signal stock in the EU28 (15 million) and the lamp lifetime, an annual sales estimate can be made. A 60 Watt incandescent lamp for traffic lighting has a maximum service life of 3000 h (2% failure rate)[42]. Because lamps operate sequentially (33 %) a single signal head would need around one new lamp per year. Therefore incandescent lamp sales for traffic signs can be estimated up to 15 million per year based on the assumption that all traffic signal lamps are incandescent lamps. However, nowadays LEDs are used in traffic signals. LED traffic lights have significant longer lifetimes, e.g. 60 000 h or 15 years at 4000 h/y, based on the parameters defined in LED luminaire specific standards (ZVEI, 2013). This will result in a decrease of sales for lamps in traffic signals.

3.4.3 Total EU electricity cost for traffic lighting

For traffic signal lighting no accurate EU28 energy consumption data is available but it can be estimated from the estimated stock of signal heads (15 million). Assuming that an incandescent lamp of 60 Watt is operated about 3000 h per signal head per year results in an EU28 annual estimated electricity consumption of 2.6 TWh per year. Nevertheless LED traffic signals will consume much less (about 20%) and therefore this consumption is likely overestimated.

3.5 Ownership and procurement of road and traffic lighting

3.5.1 Ownership of road lighting

The actual ownership and thereby responsibility for installation and maintenance of outdoor lighting equipment varies a lot (see for example (ESOLI, 2012a) and illustrated for the Netherlands in Table 18). It can be private land plot associations responsible for

[40] Each traffic head consists of a single red, amber and green light, with an arrow (filter) light if applicable. A pedestrian head will consist of just the two lights (red and green)

[41] The highway authority is usually the county or unitary council for the local area

[42] https://www.radium.de/en/product-catalogue/lamps-for-traffic-lights (accessed 21 April 2016)

local private roads and paths, municipalities responsible for public roads, paths and outdoor spaces, and regions, state or private investors who may own and operate public main roads and motorways (EC CONNECT, 2013). In many cases the owners do not have the staff themselves to do the installation and maintenance of outdoor lighting installations. Therefore this is usually outsourced to private companies based on a service contract. In many cases the maintenance work, such as relamping, is outsourced to the distribution network operator (for example in Belgium in the Flemish Region)[43]. In some larger cities, the municipalities may have an in-house lighting service department and simple activities such as relamping and cleaning are done with own personnel. Design of new road lighting is also often subcontracted to private companies. Nevertheless, the planning and approval of outdoor lighting installations is according to national spatial planning and road legislation which is under the responsibility of municipalities or other authorities (EC CONNECT, 2013). General requirements for outdoor lighting concepts can be defined and demanded by the authorities and laid down in various planning documents. In conclusion, road lighting responsibilities can be covered by various authorities.

Table 18. Authorities responsible for road lighting in the Netherlands and their relative share in installed power (ESOLI, 2012a)

Managing authority	MWh/year	Percentage of total	Number of authorities	MWh/manager
Road authorities	68 600	8.6%	10	6 860
Provinces	19 172	2.4%	12	1 598
Municipalities	676 408	85.1%	443	1 527
Rail	15 344	1.9%	2	7 672
Waterships	15 000	1.9%	26	577

3.5.2 Procurement process for maintenance and installation

The procurement process for lighting installations and lamps is decribed in section 2.2. As explained before, the service for lamp replacement and cleaning of luminaires is usually subcontracted per item or can be done by own personnel.

3.5.3 Energy procurement for road lighting and traffic signs

Operational costs for electricity are the major cost in the total cost of ownership of road lighting installations. Electricity needs to be billed and purchased for road lighting. In this context it is important to note that not all countries have installed electrical meters for billing in road lighting. Therefore they calculate the monthly bill based on lamp power and the switching scheme or schedule (e.g. all night on). However, this does not allow to implement adaptive road lighting systems that dim the lighting without a fixed or predefined scheme, because they have variable energy consumption depending on the traffic and weather conditions. Adaptive lighting and dimming can contribute to important savings. In the questionnaire for this study 10 out of 15 respondents replied that metering should be included in GPP of road lighting.

[43] http://www.vreg.be/nl/andere-openbaredienstverplichtingen

3.5.4 High capital expenditure and long pay-back times for renovating with more efficient road lighting

All typical road lighting lamps (HPS, LPS, MH, FL) have external control gear such as lamp ballasts and starters installed in the luminaire. This does not allow simple retrofitting of road lighting luminaires with more efficient lamps the same way as you can retrofit at home a halogen lamp with a LED retrofit lamp. The lifetime of a road lighting luminaire goes up to 35 years (see section 3.3.5). Consequently, a so-called lock-in effect into inefficient road lighting installations can occur (Van Tichelen et al., 2007; Van Tichelen et al., 2009). Nevertheless, much energy could be saved in the EU when the existing stock is replaced much faster than the current maximum lifetime of a luminaire, for example by replacing the stock of inefficient HPM luminaires. An important driver could be to motivate authorities to consider accelerated replacement and calculate the related payback times, e.g. replacing an existing HPM luminaire by a LED luminaire. For a positive business case the initial CAPEX of the new LED luminaire should be compensated by a lower OPEX from electricity use. The payback time can be several years and it is possible that the initial investment is never paid back. This also depends on the status of the existing installation in place. For example in 2014, when considering HPS lamp luminaires versus LED luminaires (Tähkämö L. et al., 2016), there was no positive business case with payback times below 30 years. In principle this should be evaluated case by case but installations constructed with inefficient light sources such as HPM and FL lamps are the most obvious cases to result in shorter payback times. They might be considered much earlier for renovation as their projected lifetime would allow.

3.5.5 Contracts and financing possibilities for renovating and installing road lighting

Different models of financing are explained in (ESOLI, 2012b; EC CONNECT, 2013) and are summarized below.

From the point of view of the owner of the street lighting system, an energy service project can be funded by three types of sources:

- self-financing - the customer provides the financing from own funds
- debt financing - the customer takes a loan from a financial institution
- Energy service provider financing (third party financing) - the funding comes from an external service provider (e.g. ESCO) and is included in the periodic fee of the service contract.

Additionally, a combination of the above options is possible, for example a part of the financing may come from the ESCO and another part from the municipality owning the street lighting.

There are many models and various classifications used, but according to a widely recognized classification, depending on the system approach or the aim of energy service, the following basic models can be distinguished:

- Technical Plant Management (also Operation Management Contracting or Technical Building Management)
- Energy Supply Contracting (also Facility Contracting or Energy Delivery Contracting/delivery of useful energy)
- Energy Performance Contracting (EPC) (also Saving Contracting or Energy Saving Contracting).

In the road lighting sector, these three basic models are equivalent respectively to:

- Lighting Contracting – a pure service model, where the lighting system ownership remains at the public authority. It is the simplest and the most widely used model.

- Light Supply Contracting – a complete transfer of the system to a private company. The contracting providers take over the planning and construction of lighting system, the financing and operation of system, and invoicing of the finished end product, namely lighting.
- Energy Performance Contracting (EPC) – a combination of elements from the two above models. The ESCO is responsible for the implementation of the energy saving measures and the operation and maintenance of the lighting system. The payment to the ESCO is based on the actual energy savings. See also (IET, 2016) for more info on EPC.

Lighting contracting is highly common and well-known in many EU countries, so it is not described further.

Light supply contracts have one special difference from lighting contracts: the contractor takes over the whole responsibility over the lighting system, including the purchase of electricity. This might be of interest, if the contractor is a utility and therefore has access to good electricity purchasing conditions. However, this contract could be a disadvantage for the municipality, as they are bound to the contractor over the whole contract period.

Energy performance contracting (EPC), has potential to finance modern and energy efficient street lighting solutions, especially in municipalities with limited budget for investments and staff with limited know-how in street lighting. An example of an EPC applied in Jimena de la Frontera, a historic town located in the province of Cadiz, Spain can be found in (Cadiz, 2016).

Note that warranties on LED luminaire performance parameters are often unclear and limited in time compared to the return on investment period. Additionally, the occurrence of abrupt failures is unacceptable given the safety function road lighting might have. As a consequence an energy service contract that includes repair and maintenance can be an interesting procurement option compared to an extended product performance warranty. An extended product performance warranty could be useful in a lighting contracting model depending on the extension in time of such a warranty.

4 TECHNICAL AND ENVIRONMENTAL ANALYSIS

In this part of the document a life cycle assessment (LCA) review is done to identify the environmental hotspots of street lighting and traffic signals. Few case studies can be found of a life cycle assessment of traffic signals and most of them are focusing mainly on street lighting in general with a short reference to the traffic signals. From section 4.3 the technical characteristics of street lighting and street lighting systems are explained together with the performance of available technologies on the market.

4.1 Life cycle assessment literature review

Lighting can have environmental impacts at a number of different stages in its life:

a. Production. This includes extraction of raw materials (resources) and manufacture of the lamps, luminaires and ballasts, which involves the use of hazardous substances.
b. Distribution. This covers emissions from transport, and the use of packaging.
c. Use. This is principally CO_2 emissions from the energy used by the lighting.
d. End of life. This could include release of hazardous substances, such as mercury, following disposal of lamps, and waste management.

The different components of street lighting, i.e. the lamp that provides the light, the ballast or control gear that regulates the current and the luminaires that direct and shade the light, have different environmental impacts at different stages of the life cycle.

In order to take the environmental impacts into account in a holistic manner, life cycle assessment (LCA) can be used. LCA was introduced in the 1970's, and is a standardized scientific method for quantifying and comparing environmental impacts of products. (IEA 4E, 2014a; ISO 14040, 2006)

LCA is a tool for identifying and quantifying potential environmental burdens. It has become more systematic and robust over the past three decades. It can help quantify the materials and energy used, as well as the emissions and waste produced along the life cycle of public lighting. LCA enables the assessment of potential environmental impacts resulting from all stages of the product's life cycle from cradle to grave, often including some impacts not considered in more traditional analyses (e.g. greenhouse gases emissions, water use, energy cumulative consumption) (Lukman and Krajnc, 2011).

Environmental impact assessment of lamps over their life cycle is based on an inventory of environmental effects that result from all activities needed to generate a certain quantity of light. The LCA method can be used to compare environmental performances of products and technologies and indicates which product alternative or measures should be taken to minimise impacts. The results of an LCA are often given as environmental impact categories which can be at midpoint or endpoint level. Midpoint impact categories translate impacts into environmental themes such as climate change, acidification, human toxicity, etc. This is also known as a problem-oriented approach. Endpoint impact categories, also known as the damage-oriented approach, translate environmental impacts into issues of concern such as human health, natural environment, and natural resources. Endpoint results have a higher level of uncertainty compared to midpoint results but are usually easier to understand for the general public.

The life cycle assessment method is standardized on a general level (ISO 14040/44, 2006), but the ISO standard does not give specific rules for conducting a life cycle assessment of light sources in detail. Related to LCA are environmental product declarations[44] and its product category rules (PCRs) for LED Luminaries for general

[44] Such as the Schréder product environmental profile of Ampera Maxi

lighting (Everlight Electronics, 2012). Such product declaration and its PCR usually provide a model on how an LCA can be done, but the manufacturer is still free on how to implement this. Indeed, when comparing different LCA studies there is no harmonized approach on which environmental impacts to take into account neither on the functional unit[45] to choose. Yabumoto et al. (Yabumoto et al., 2010) showed that the choice of the functional unit affects the results of an LCA. This is important in order to be able to compare LCA results of different light sources and in most cases it is impossible to directly compare the results of different assessments. Manufacturing process data are often difficult to obtain, as manufacturers are reluctant to share or publish them. In addition, LED technology is evolving rapidly in terms of performance (luminous efficacy, lifetime, colour rendering and lumen maintenance) (US DOE, 2016). In view of the large product variety, it is difficult to choose the right luminaire or lamp. Finally, the impact of light itself, such as glare or light pollution, should be included. However, there is no method for quantifying the impacts of light on humans and flora and fauna (De Almeida A. et al., 2012). Despite the above-mentioned caveats and the uncertainties in the assessment of the end of life stage, LCAs indicate that the energy consumption in the use (or operational) phase is the major environmental aspect (Figure 9 and Figure 10). For LED lights, the situation is more favorable than for traditional light sources Figure 15).

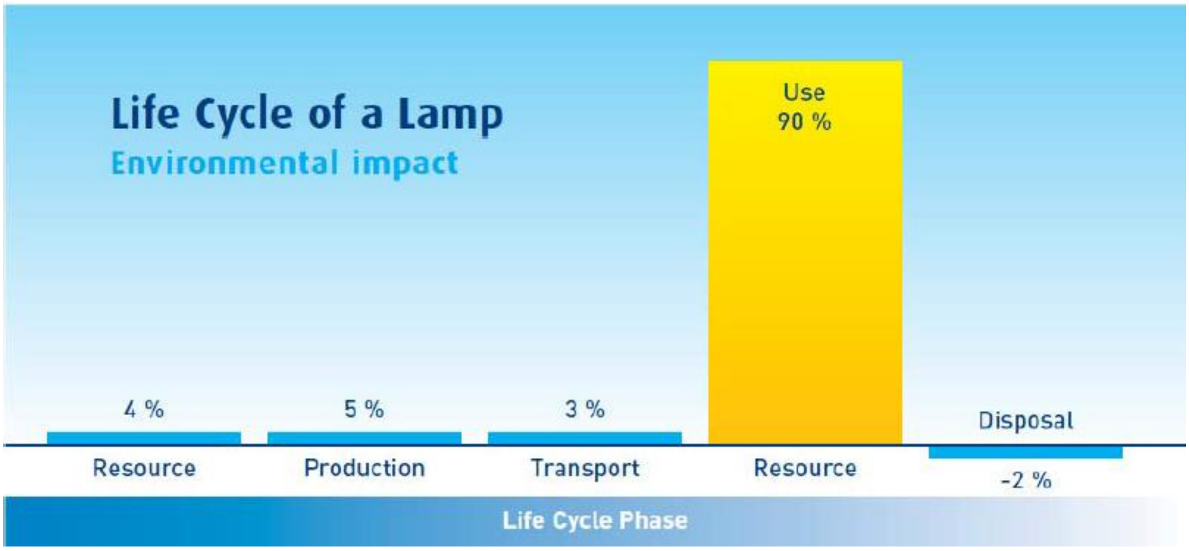

Figure 9 Typical impact of different life cycle stages of a lamp (ELC, 2009 in De Almeida A. et al., 2012)

In Figure 10 the environmental impact of the LEDs life cycle are measured by midpoint impacts categories such as Global Warming Potential (GWP), Eutrophication Potential (EP), Acidification Potential (AP), Ozone Depletion Potential (ODP) and so on. The Figure 10 shows how much each impact category affects the different life cycle phases of a LED downlight luminaire. However for all impact categories showed in the figure the use phase has the highest contribution.

[45] The functional unit is a key term in the LCA and it is defined as the "quantified performance of a product system for use as a reference unit" (ISO 14040 standard). It is a unit to which all the inputs, outputs and the possible environmental impacts are related. It should be related to the function of the product system, which, in case of lamps and luminaires, is generally to illuminate. The lumen-hour seems to be an appropriate and easy-to-use functional unit of light sources. However, it does not relate to the actual illumination but only to the luminous flux and time (quantity of light).

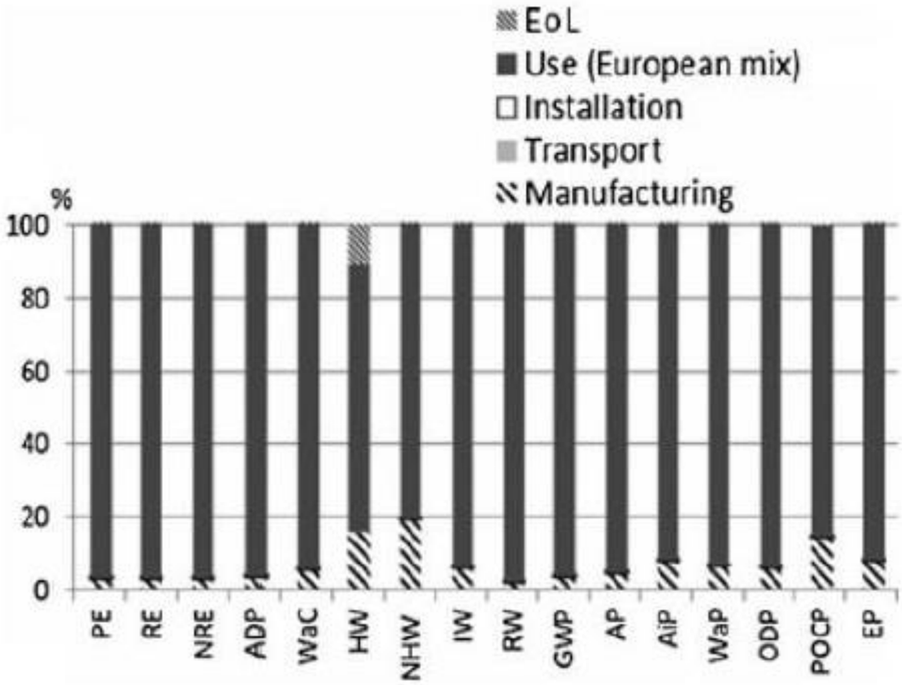

Figure 10 Division of environmental impacts of a LED downlight luminaire into life cycle stages with the energy consumption modelled with an average European electricity mix. Adapted from (Tähkämö, 2013).

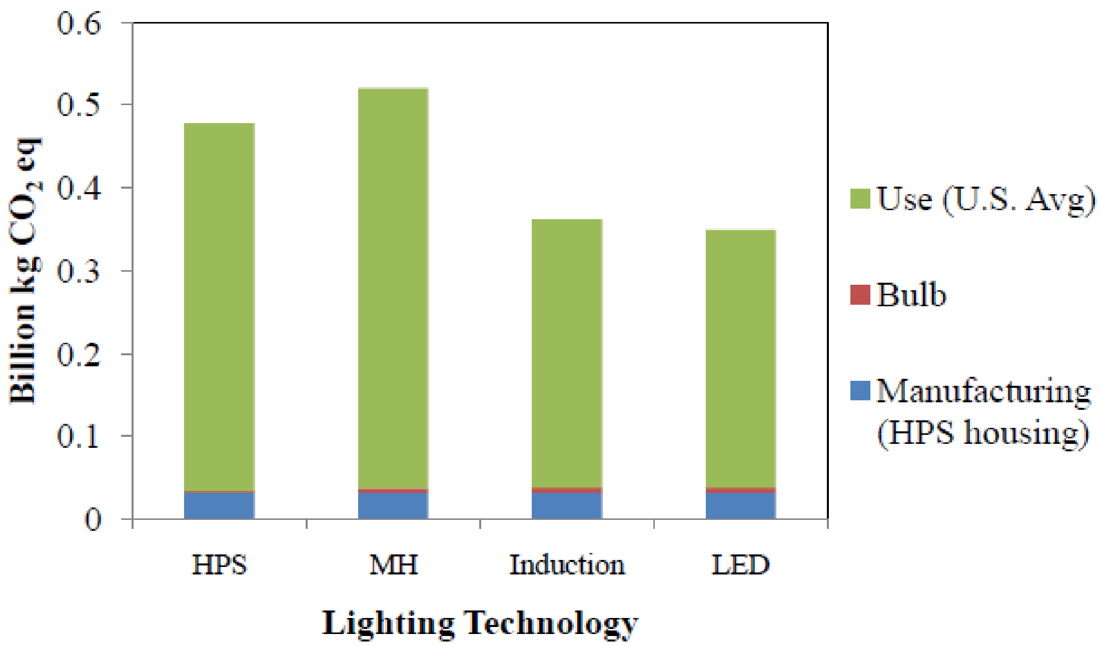

Figure 11 GWP emissions split for the manufacturing phase of bulb and housing and the use phase for different lamp technologies. The use phase was calculated with the US electricity mix (Hartley, D. et al. 2009)

Even for LED technology, the life cycle phase contributing most to the total environmental impact is the use phase (see Figure 10), and accounts for more than 90 % for most of the environmental impacts. The manufacturing and End of Life (EoL) phase contribute much less to the environmental impacts. The same results are shown for HPS technology in Figure 11 where the use phase is compared to the manufacturing phase and produces about 90% of the GWP emissions. The same results can be found for other environmental impact categories.

Figure 12 clearly shows that the contribution of the electricity use during the life of the street lighting is substantial for all impact categories. Indeed the material-related impacts from production, distribution and end of life waste treatment of lamps, ballast and luminaire are clearly less than the electricity use. More in detail, the impact categories dominated by electricity use are total energy consumption (or gross energy requirement GER), water use, non-hazardous waste, GHG, acidification, VOC, POP and HM to air and water. Instead, impact categories where material aspects contribute largely are hazardous waste (where the contribution from the luminaire is almost exclusively from polyester housing in the end-of-life phase), PAH (largely due to aluminium production), PM (due to incineration of the luminaire polyester housing), eutrophication (contribution from the production of the luminaire polyester (Van Tichelen et al., 2007).

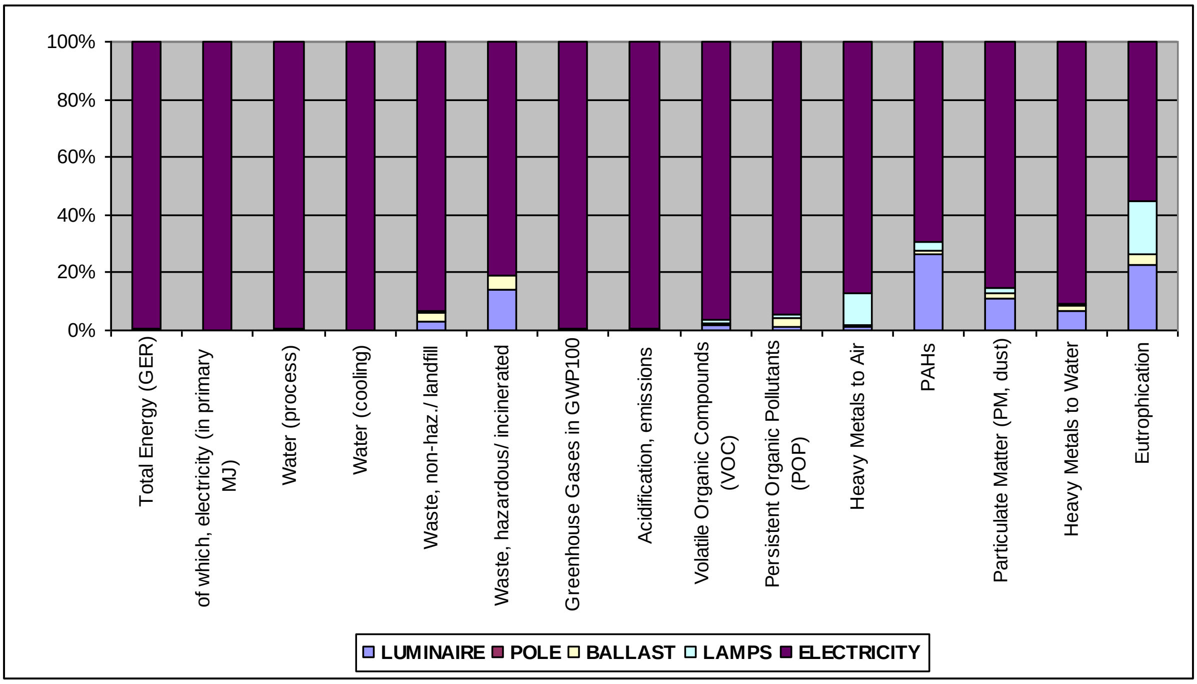

Figure 12 Life Cycle Impact (contribution of environmental impacts of lamps, ballast, luminaire and electricity use along their life cycle) (Van Tichelen et al., 2007)

4.1.1 Sources of LCA information

Different LCA studies have been selected to draw conclusions on the environmental hotspots of street lighting. Several references are available and all studies confirm the conclusion mentioned before that the energy consumption and the relative impacts of the operational stage are contributing the most to the environmental impact.

Few LCA studies of traffic signals can be found and most of them are still focusing mainly on the street lighting in general with a short reference to the traffic signals. For example the 'IEA 4E (2014) Life Cycle Assessment of Solid State Lighting' (IEA 4E, 2014a) study can also be considered relevant for traffic signals. According to that study the energy consumption in the use phase is again the most relevant phase.

A sShort descriptions of the selected studies that are used for the screening of the hotspots are reported in the following sections.

4.1.1.1 EuP study lot 9 (2007): Ecodesign for public street lighting

In 2007, the EuP study Lot 9 (Van Tichelen et al., 2007) for street lighting concluded that energy consumption in the use phase of the street lighting installation (including the production of the luminaire, lamp and ballast) was contributing most to the main environmental impact indicator Global Warming Potential (GWP) due to the greenhouse gas emissions associated with the electricity consumption.

The environmental impact assessment of lamps along their life cycle was based on an inventory of environmental effects that result from all activities needed to generate a certain quantity of light. The life cycle assessment performed in the lot 9 study showed that resources (materials), lamp manufacturing and lamp disposal have a small impact on the environment compared to electricity consumption during lamp use as illustrated before in Figure 10. This analysis used the so-called MEEuP Methodology tool for impact modelling based on a European average electricity mix (VHK, 2005). If the electricity mix is different, e.g. by the use of more renewable energy sources, the impacts related to electricity consumption could be reduced.

A summary of the results obtained by this methodology is reported by Figure 10 which clearly shows that the electricity causes more than 80% of the impact in all indicators except for the eutrophication potential and PAHs. For the eutrophication potential an important role is played by the production of the luminaire (about 22%) and the lamps (about 18%). The luminaire causes about 30% of the impact for the PAHs.

4.1.1.2 IEA 4E, 2014: Life Cycle Assessment of Solid State Lighting (IEA 4E, 2014a)

The IEA 4E report presents an overview of published life cycle assessments of lighting equipment. Note that this report does not focus on solid state lighting for road lighting alone, but on other lighting applications as well. Hence, the conclusions are also relevant for traffic signals. LCA data from literature was used to assess the environmental impacts of LED products, including a comparison with different lighting technologies. In addition, the challenges and uncertainties associated with the published LED LCA studies are discussed, as the actual environmental impact of LED products can be difficult to assess.

The final report 'Life Cycle Assessment of Solid State Lighting' of IEA 4E (IEA 4E, 2014a) came to the following conclusions:

- Dominance of the use stage and most influential parameters

When the environmental performances of an LED product life cycle were assessed, the use stage was found to dominate the environmental impacts over the manufacturing and the EoL stages. On average, 85% of the environmental impact is linked to the use phase, while the remaining 15% is shared mainly between manufacturing and end-of-life treatment. The environmental impact of the transport phase only accounts for 1% to 2%. Thus, the two most significant parameters contributing to the environmental impacts are luminous efficacy (lm/W) and useful life (hours of operation during lifetime). Studies have found that the replacement of low efficacy lighting (e.g. high-pressure mercury lamp) with high efficiency, long-life LED-based lamps and luminaires brings a strong environmental benefit[46]. However, lifetime of SSL products should be accurately

[46] Thus, the luminous efficacy of the light source determines the environmental performance of the light source for the most part. Lamps and luminaires having high luminous efficacies, such as fluorescent lamps, LED lamps and luminaires, and induction luminaires, were found to be the most environmentally friendly

and realistically specified, taking into account replacement rates and the potential for premature failure.

- Importance of the electricity production

The magnitude of the environmental impacts during the use stage is strongly influenced by the mix of generating technologies used to produce the electricity in a given region. Next to the replacement of low efficacy lamps with more efficacious sources, the use of renewable electricity sources has the largest positive environmental impact. It should be noted that the energy production in the EU will be changed towards low-emission energy sources, thus reducing the importance of the use stage of the energy using products such as light sources. Obviously, those renewable energy sources do not come without any environmental impact themselves.

- Highest contributors to the environmental impacts of LED product manufacturing

The manufacturing was modelled to include either the raw material acquisition and the manufacturing processes or only one or the other. The LCAs found that the manufacturing of an incandescent lamp caused approximately 1-7 %, a CFL 1-30 % and an LED lamp 2-20 % of the total life cycle impacts on average. It must be noted that single environmental impact categories may have higher scores, e.g., in case of CFL or LED lamp the manufacturing was found to cause approximately 50% of hazardous waste to landfill and 40% of human toxicity potential (DEFRA, 2009). Generally, the environmental impacts in CFL manufacturing are mainly due to the ballast (printed circuit board and components), while the LED lamp manufacturing caused environmental impacts primarily due to the aluminium heat sink. However, today there are several new LED lamp designs on the market that have greatly reduced or completely eliminated aluminium heat sinks.

In conclusion, the lesser the lamp's energy consumption and the higher its luminous efficacy and lifetime, the lower its environmental impacts are compared to a lamp that has a lower luminous efficacy. Therefore, the change towards light sources of high luminous efficacy is recommended regardless of the energy source used. However, the greatest benefits are achieved when the two changes (lamps of higher luminous flux and energy production of lower emissions) occur simultaneously.

4.1.1.3 Hartley D, et al., 2009: Life cycle assessment of streetlight technologies (Hartley D. et al, 2009)

This life cycle assessment of street light technologies was written when the council of Pittsburgh, USA needed to replace 40 000 streetlights. In this report, an LCA was performed on high-pressure sodium (HPS), metal halide (MH), induction, and light-emitting diode (LED) street light technologies and focused on the categories of global warming, ecotoxicity, and respiratory effects. These categories were selected for their relevance to climate change and to the historic concerns of air quality and industrial pollution in Pittsburgh. Primary and secondary data on materials and prices were collected from sales companies, manufacturers, government documents, lighting professionals, and industry reports to build the models. The main results show that even though in the manufacturing phase the induction and LED technologies have environmental impacts three times higher than HPS and MH lamps, their overall impact is lower because they use about half of the electrical power. The induction and LED lights have also lower maintenance costs because their lifespan is up to five times that of HPS and MH.

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compared to the lamps and luminaires of lower luminous efficacies, such as high pressure sodium (HPS) luminaires and metal halide (MH) luminaires.

4.1.1.4 Tähkämo L., 2013: Life cycle assessment of light sources – case studies and review of the analysis (Tähkämo L., 2013)

In this report four case studies were conducted, i.e. a life cycle assessment of a fluorescent lamp luminaire and a LED downlight luminaire, a life cycle costing (LCC) analysis of street lighting luminaires, and an analysis combining both LCA and LCC of non-directional lamps. A literature review of LCA case studies was carried out to complete the assessment.

The case studies and the literature review concluded similar findings despite the differences in the methods, scopes and evaluated light sources. The main conclusion of the life cycle assessments was the clear dominance of the use stage energy consumption. The environmental impacts of the use phase were found to be sensitive to the lifetime of the light source and the used energy source. As can be seen from Figure 13 the use phase has a higher contribution in GWP with the European electricity mix than with the French one. The dominance of the use stage was most clear for light sources of low luminous efficacy and low manufacturing efforts and when using high emission energy sources. The manufacturing phase was usually found to be the second biggest contributor to the environmental impacts. The average environmental impacts of other life cycle stages, such as transport and end-of-life, were found practically negligible, but notable in certain impact categories.

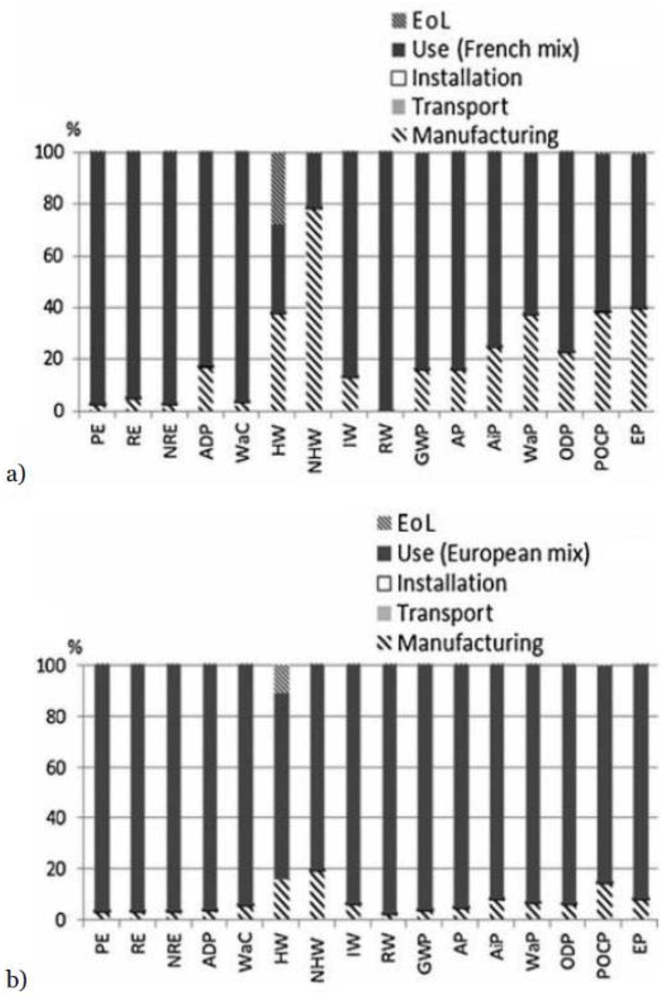

Figure 13 Division of environmental impacts of a LED downlight luminaire into life cycle stages with the energy consumption modelled with a) an average French electricity mix and b) an average European electricity mix. Adapted from (Tähkämö et al., 2013).

4.1.1.5 *Hadi, S. et al. (2013): Comparative Life Cycle Assessment (LCA) of streetlight technologies for minor roads in United Arab Emirates (Hadi et al., 2013)*

In this report the LCA method is used to investigate the environmental impacts of two recent energy efficient streetlight technologies, i.e. Ceramic Metal Halide (CMH) and Light Emitting Diode (LED), with the aim of assessing their application in Abu Dhabi — United Arab Emirates (UAE). The cradle to grave analysis for CMH and LED streetlights includes raw material extraction, production of streetlight fixture, use and end of life phase, all modeled using the SimaPro software package. The results show that LED lights have larger environmental impact during the production stage, but this is offset during the operational life of the lamp, due to the lower energy consumption of LEDs (see Figure 14). For both types of lamps, the production stage has significantly less overall impact when compared to the impact during their operational life.

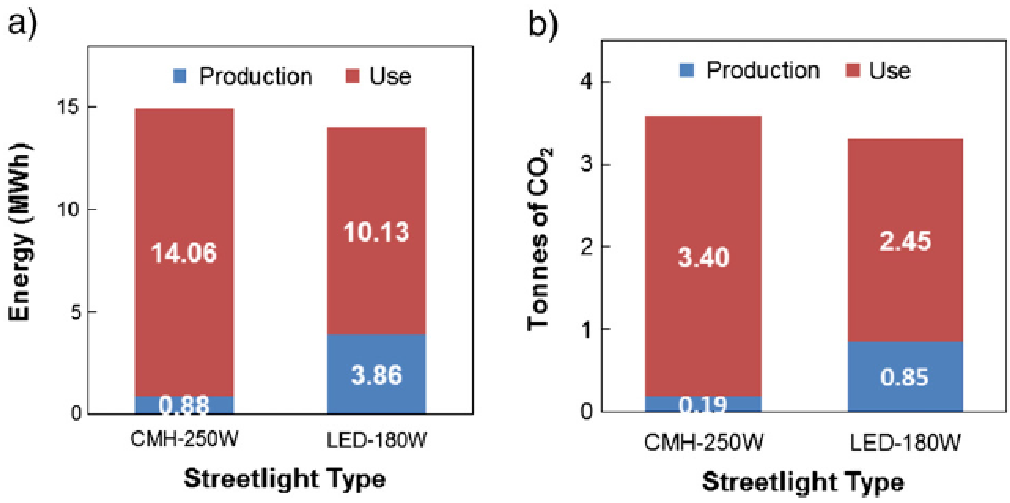

Figure 14 (a) Energy consumption and (b) carbon dioxide emissions during production and use phase for CMH and LED streetlights (Hadi, S. et al., 2013)

4.1.1.6 *Lukman, R. and Krajnc, D. (2011) Environmental impact assessment of two different streetlight technologies (Lukman and Krajnc, 2011)*

The study of Lukman, R. and Krajnc, D. (2011) evaluates the environmental impacts of public lighting services from the aspects of two different technologies, i.e. LED and high pressure sodium (HPS) lights, during all phases of their life cycle (production, operation, end-of-life). The research presents the case study of a pilot project for changing the technology of public lighting in the Maribor municipality (Slovenia).

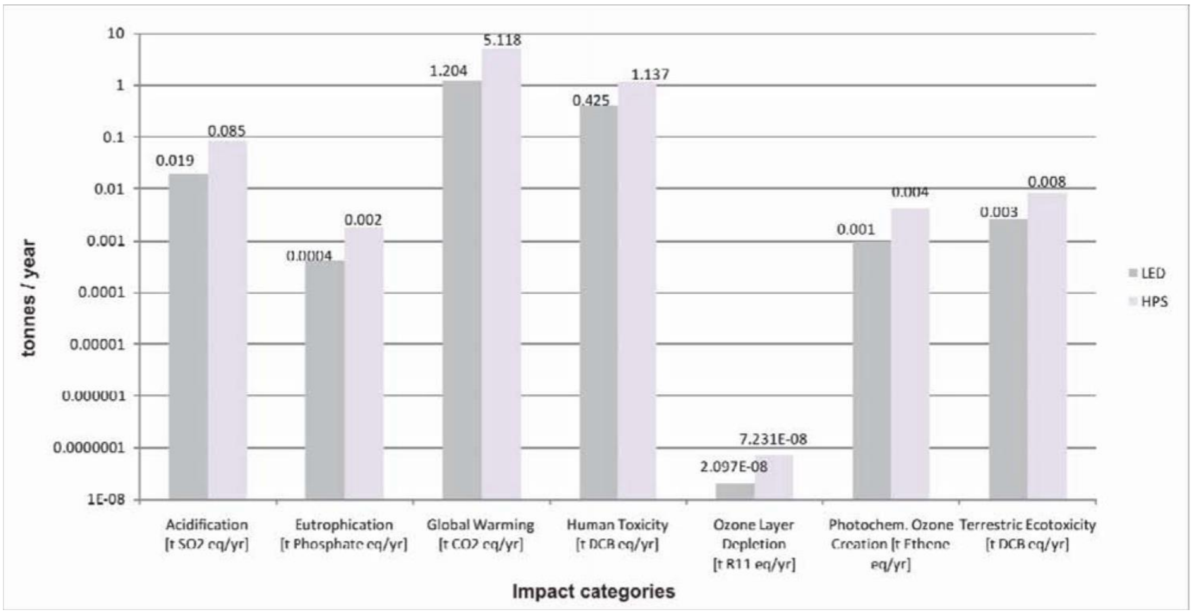

Figure 15 Overall environmental impacts of the LED and HPS technologies for public lighting (Lukman and Krajnc, 2011)

Figure 15 shows the overall environmental impacts of the two streetlight technologies (LED and HPS) covering their three life cycle phases (production, operation, end-of-life). It can be observed that the LED technology has during its whole life cycle smaller environmental impacts within all the categories compared to the HPS technology.

The life cycle phase that contributes most to the total environmental impacts is the operational one (see Figure 15) for both technologies, and accounts for more than 90 % of all environmental impacts. The production and end-of-life phases make smaller contributions to the environmental impacts.

4.1.1.7 Environmental product declarations

One street lighting lamp and luminaire manufacturer has been identified that publishes their product environmental profiles. Schréder (Schreder, 2016) reports the following results for its 'Ampere Maxi – the green light' (see Table 19). This assessment takes into account the manufacturing (including the processing of raw materials), transport, use phase (including electricity consumption, and maintenance), and end of life. The Ampere Maxi luminaire is assumed to be recycled in accordance with the WEEE Directive (see section 2.3.7). The end-of-life for LED products is thus comparable to other electronic waste and it is therefore not assumed that particular material of LEDs such as rare earth materials are recycled.

Table 19. Environmental profile of Ampere Maxi (Schreder, 2016)

Indicators	Unit	Life cycle assessment	Manufacturing	Distribution	Utilisation		End-of-life
					Electricity	Maintenance	
Non renewable resources depletion	Person-reserve	**0.0314**	35.9 %	0.1 %	44.8 %	19.1 %	-0 %
Energy consumption	MJ	**6304**	4.4 %	0.2 %	95 %	1.7 %	-1.2 %
Water consumption	m^3	**2.1342**	7.4 %	0.3 %	89 %	4.1 %	-0.8 %
Greenhouse effect	Kg eq CO2	**287.2**	5.7 %	0.1 %	93.7 %	2.2 %	-1.6 %
Ozone depletion	Kg eq CFC11	**1.957E-05**	6.9 %	0.2 %	90.8 %	3.4 %	-1.4 %
Human toxicity	CTU	**1.201E-05**	17.4 %	0.2 %	70.6 %	6.8 %	5 %
Water toxicity	CTU	**28.319**	35 %	0.5 %	63.7 %	10.6 %	-9.7 %
Photochemical ozone creation	Kg NMVOC	**0.6489**	6.6 %	0.3 %	92 %	2.8 %	-1.8 %
Air acidification	Kg eq H+	**1.1326**	7.6 %	0.2 %	90.6 %	3.5 %	-1.9 %
Eutrophication	Kg eq PO	**0.1198**	11.2 %	0.3 %	84.1 %	6 %	-1.6 %
Hazardous waste production	Kg	**0.0412**	4.3 %	0 %	20.2 %	1.2 %	74.4 %

4.1.1.8 Environmental impact of traffic signals

As mentioned before no specific LCA studies of traffic signals could be found in literature, but there are a few studies that include them in a more general perspective, e.g. (IEA 4E, 2014a). It is assumed that also for traffic signals the main impacts are related to the energy consumption in the operational phase. For traffic signals, LEDs offer improved energy efficiency compared to incandescent lamps. The use of LEDs is considered the best available technology for traffic signals and can reduce energy consumption by at least a factor three compared to incandescent lamps that are used in traffic lights (UK, 2006).

In the UK for example (UK, 2006), it was estimated that converting all traffic signals to LED lights would have saved 57 000 tonnes of CO_2 per year in 2010. It was also estimated that upgrading all traffic signals in London by the use of LEDs would reduce CO_2 emissions by up to 10 000 tonnes per year. The energy consumption for LED traffic signals can be around 8-12W in bright mode and 5-7W in dimming mode, compared to respectively 50W and 25W for ordinary incandescent signals. Recently, even better efficiencies have been posted down to 1 W (Siemens, 2016). This offers significant savings in energy consumption without detracting from the performance of the lighting system. LED traffic signals usually also require less maintenance.

In more remote areas where grid electricity can be difficult to connect to, further greenhouse gas emissions savings can be made through the use of photovoltaic (PV) cells to power traffic signals.

4.1.2 Conclusions from the LCA review

The screened LCA studies conclude similar findings despite the differences in methods and scope. The main conclusions of the LCA review are:

1. The clear dominance of the use stage energy consumption: the environmental impacts of the use phase were found to be sensitive to the lifetime of the light source and the used energy source. The dominance of the use stage was most clear in light sources with low luminous efficacy and low manufacturing efforts, and when using high-emission energy sources;
2. The manufacturing phase was usually the second most significant cause contributing to environmental impacts. The importance of the manufacturing is

estimated to increase if street lighting becomes more energy efficient in the future and/or a low emission electricity mix is used. The lifetime of LEDs is important because of the higher influence of the manufacturing phase compared to more traditional light sources;

3. The average environmental impacts of other life cycle stages, such as transport and EoL, were found to be practically negligible.

4.2 Environmental impacts not covered by LCA

The life cycle assessment studies consider the impact generated at global level. An example of impact categories considered are the Global Warming Potential (GWP) generated by the greenhouse gas emissions. However, there are a range of other environmental impacts that are not so easily defined or quantified by LCA. The main known non covered impact from road lighting is related to light pollution. Light pollution is defined in guideline CIE 126:1997 as a generic term indicating the sum-total of all adverse effects of artificial light. Various forms of light pollution are discussed in the subsequent sections.

4.2.1 Sky glow

Sky glow is defined in CIE 126:1997 as the brightening of the night sky that results from the reflection of radiation (visible and non-visible), scattered from constituents of the atmosphere (gas molecules, aerosols and particulate matter), in the direction of the observation. It comprises two separate components:

(a) Natural sky glow – That part of the sky glow which is attributed to radiation from celestial sources and luminescent processes in the earth's upper atmosphere.

(b) Man-made sky glow – That part of the sky glow which is attributable to man-made sources of radiation (e.g. outdoor electric lighting), including radiation that is emitted directly upwards and radiation that is reflected from the surfaces of the earth.

Man-made sky glow is directly related to astronomical light pollution because the glow of uncontrolled outdoor lighting has hidden the stars and changed our perception of the night.

In the case of road lighting luminaires, research shows that the emission angle of the upward light flux plays a role in reducing sky glow. It was found that with increasing distance from the city, the effects of the emission at high angles above the horizontal decrease relatively to the effects of emission at lower angles above the horizontal (Cinzano et al., 2000). Some kilometres from cities or towns, the light emitted by luminaires between the horizontal and 10 degrees above is as important as the light emitted at all the other angles in producing the artificial sky luminance. Therefore to reduce the light emitted between the horizontal and 10 degrees above could be an objective in reducing light pollution.

Standard CIE 126:1997 contains guidelines for minimizing sky flow and is related to the upward light output ratio (RULO).

Selecting monochromatic light, such as from low pressure sodium lamps or monochromatic LEDs, can also be useful for decreasing impact on astronomical light pollution, because it can be easily filtered out when observing the night sky.

4.2.2 Obtrusive light

CIE 150:2003 defines ‘obtrusive light’ as spill light, which because of quantitative, directional or spectral attributes in a given context, gives rise to annoyance, discomfort, distraction or a reduction in the ability to see essential information'

There are various forms of obtrusive light which are illustrated in Figure 16:

- Light trespass, a more localised issue, occurs where artificial light sources are visible beyond the areas they are supposed to light. It is often associated with poorly aimed floodlights or over-lighting of areas. Light trespass can disturb and annoy people, e.g. when they may find their bedrooms lit to the extent that they cannot sleep.
- Glare occurs when a source of artificial light is so much brighter than the area around it that it causes discomfort and inability to see, something which can be dangerous for road users. A common example is the effect of main beam headlights on an oncoming car when driving along a dark road, but it can also be caused by fixed lighting systems, such as a light which directly faces an observer.
- Visual clutter occurs where important lights such as traffic signals are viewed against a competing background which reduces their visual impact. The effect is worse if the competing lights are coloured.

The reduction of glare is covered by the glare related parameters such as threshold increment (TI) in the EN 13201-2:2016 standard while other forms of nuisance are covered by guideline CIE 150:2003. In general, the guidance focuses on avoiding over-lighting areas and directing the light as well as possible to the area where it is intended. This can be done through a combination of a correct luminaire with a correct installation and a correct light (lumen) output. This will not only reduce obtrusive light, but can also improve energy efficiency by requiring less energy to light the desired area.

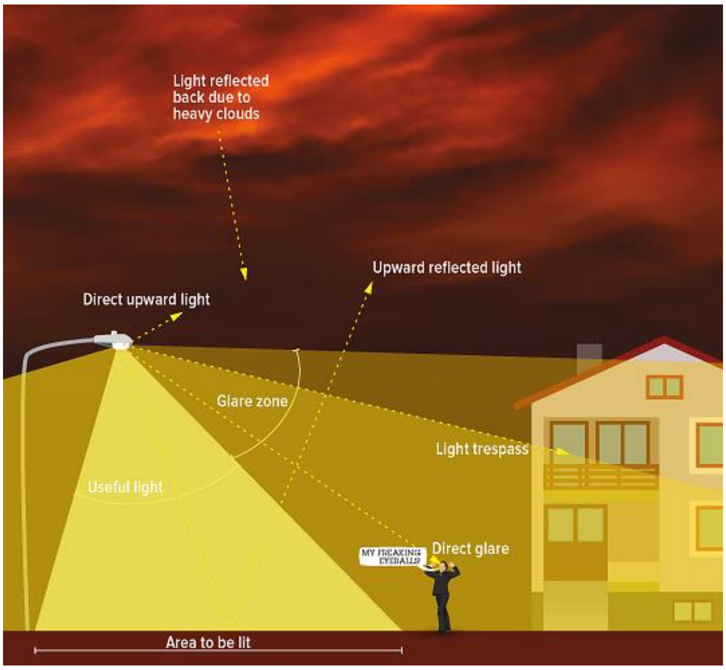

Figure 16 The info-graphic above illustrates the different components of light pollution and what “good” lighting looks like. (Image credit: Anezka Gocova, taken from https://astronomynow.com/2015/04/11/international-dark-sky-week-2015/)

4.2.3 Ecological impact from outdoor lighting

Excessive light into the local environment can disturb the natural night-time biorhythms of human activity and other plant and animal ecosystems (Rich and Langcore, 2006). There is limited research available to allow obtrusive light to be quantified. However, there are indications that it affects the natural biorhythm of terrestrial and aquatic ecosystems. For example artificial light can extend the length of the day, affecting insect populations, nocturnal mammal species, and nesting and roosting birds.

Night flying insects such as moths can either cease flying and settle when exposed to high levels of general illumination or fly in spirals where they are misled by an individual light. Some entomologists believe that increased street lighting is a significant factor in the reduction of moth species in urban areas.

Bright light is likely to deter nocturnal mammals from using established foraging sites. This can be an additional risk factor, particularly if the lighting is along important areas like river corridors. Conversely, if road lighting deters animals from crossing the carriageways, it may have a positive effect. Fast flying bat species can benefit from the insects attracted to street lights, but slower-flying species, which include most of those considered particularly vulnerable in Europe, do not experience the same benefits. (RC, 2009)

The behaviour of birds is strongly affected by light. Artificial increases in day length can induce hormonal, physiological and behavioural changes in birds initiating breeding (UK, 1997). Very bright lights can also attract and disorient birds. Nocturnal species are particularly likely to be disturbed.

Some short-day plants will not flower if the night is shorter than the critical length. Others might flower prematurely.

The French National Deposit Bank supports research in biodiversity (Biodiv, 2015). They have issued a guide to support taking into account the externality of outdoor lighting with regards to biodiversity. They also described that compared to humans, other species observe different colour spectra and therefore selecting the appropriate colour of the light source can reduce impact (see section 2.4.1.6).

The principles for reducing the ecological impact from outdoor lighting are based on selecting the road classes with the lowest light levels as low as reasonably achievable (ALARA) and for reducing the impact on species selecting the appropriate colour spectrum of the light source.

4.3 Road lighting installation as a holistic system

In this section the road lighting installation will be considered as a holistic system comprising light sources, ballasts or control gear, luminaires, or multiple luminaires in a system with sensors and controls and also the design and installation of the system including its geometry and road reflections. Definitions for the components can be found in section 2.1.6.

4.3.1 Energy efficiency

In order to design a road lighting scheme compliant with EN 13201-2:2016 a lighting system will have to be composed of control gear, lamps, luminaires and an electric power system. Based on the photometric file of the luminaire, the road geometry and the surface reflection data, compliance with EN 13201-2:2016 requirements can be simulated and verified. How these road lighting system components finally relate to the EN 13201-5:2015 energy efficiency parameters (power density, annual energy, installation efficacy) is illustrated in Figure 17. Note that the technical parameters are explained in Annex 6.2.

The design parameters can be calculated with lighting design software based on the photometric file of the luminaire. In many cases lighting design software also includes design optimization modules that verify various designs (luminaires, positions, etc.) and enable to look for a solution that best fits with minimum energy use. Examples of such simulation software are Dialux Evo and Relux.

In Figure 17 each road lighting system level (control gear, lamp, luminaire, installation and control system) has its own colour code. The colour coding applied is: electrical efficiency (dark green), installation (dark blue), luminaire (sky blue), lamp (orange), control system (light green), control gear (red) and design process (yellow).

Efficiencies of the individual components are discussed in section 4.4 with the system approach further elaborated in section 4.4.4.

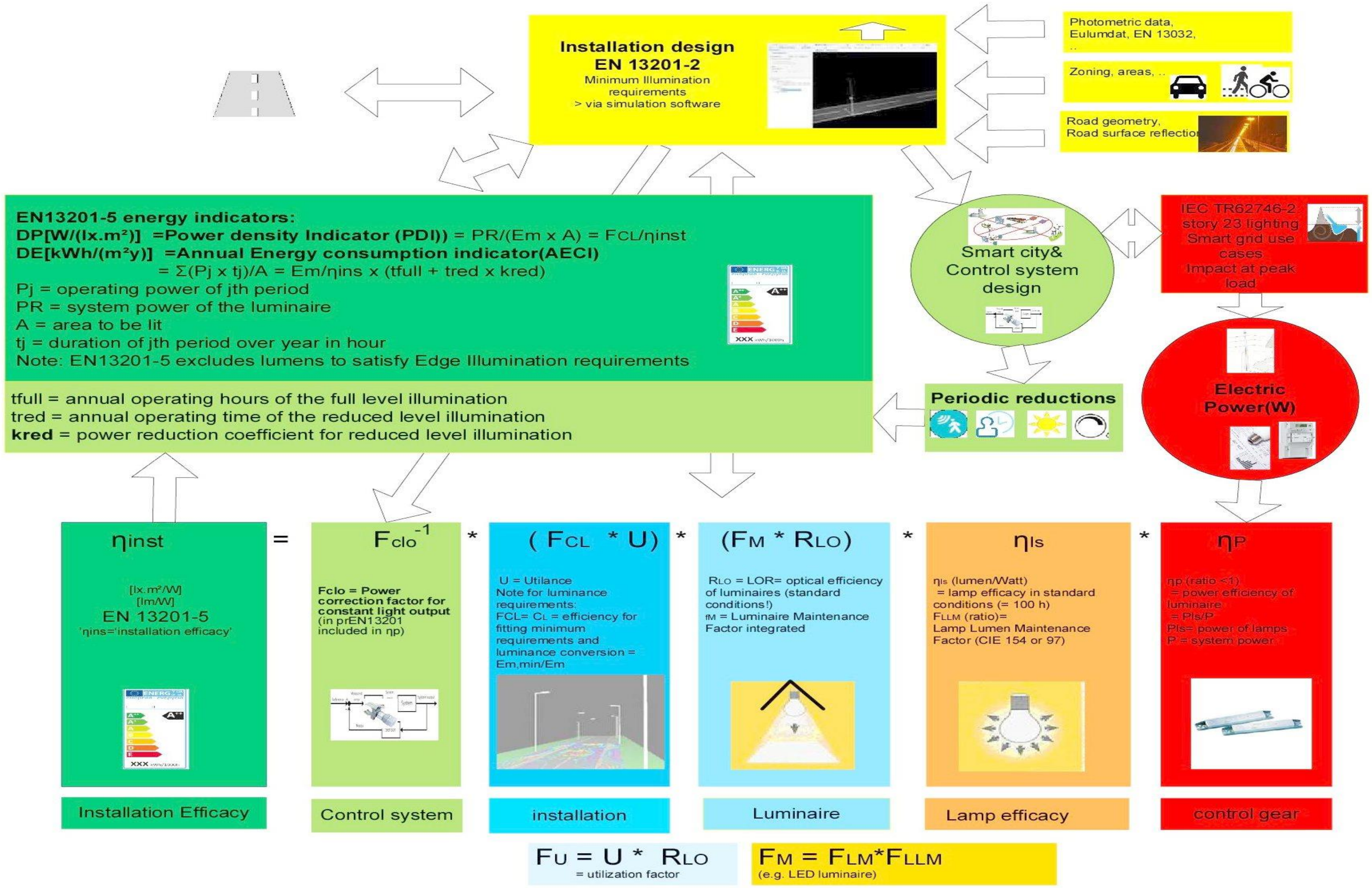

Figure 17 Components of a road lighting system and the most relevant performance parameters related to energy efficiency. The colour coding applied is: electrical efficiency (dark green), installation (dark blue), luminaire (sky blue), lamp (orange), control system (light green), control gear (red) and design process (yellow).

4.3.2 Durability and lifetime

The lifetime of a road lighting installation is important as a longer lifetime will reduce costs for renovation and maintenance. A transition to LED lighting is beneficial in these aspects as well. LED lighting might become more efficient in the future even though LEDs can already compete with current lamp efficacies of HPS and MH. Additionally, LED lighting has a longer lifetime than other lamp technologies.

However, when implementing LED lighting in road lighting applications, the whole LED system, i.e. the LED luminaire, should be taken into account. This is illustrated in Figure 18.

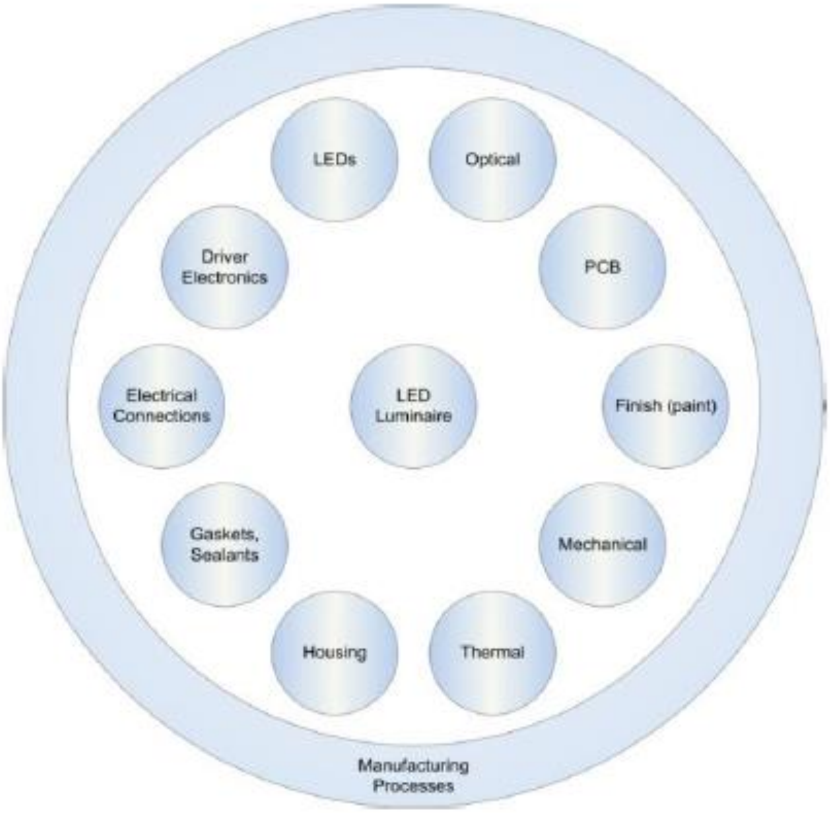

Figure 18 Total system or luminaire reliability is the product of all the individual reliability considerations:

$$R_{luminaire} = R_{LEDs}*R_{optical}*R_{PCB}*R_{finish}*R_{mechanical}*R_{thermal}*R_{housing}*R_{gaskets/sealants}*R_{connections}*R_{driver}*R_{manufacturing}$$

(taken from (LRSC, 2014))

Figure 19 shows an example of a failure-distribution chart that shows the frequency of various failure modes that had been documented for a family of outdoor solid-state lighting (SSL) luminaires from a manufacturer's installed base. The overall failure rate of this product family was low, representing a > 5% cumulative failure rate in the field across more than seven years of production deliveries. The chart shows the relative incidence of failure modes. (LRSC, 2014)

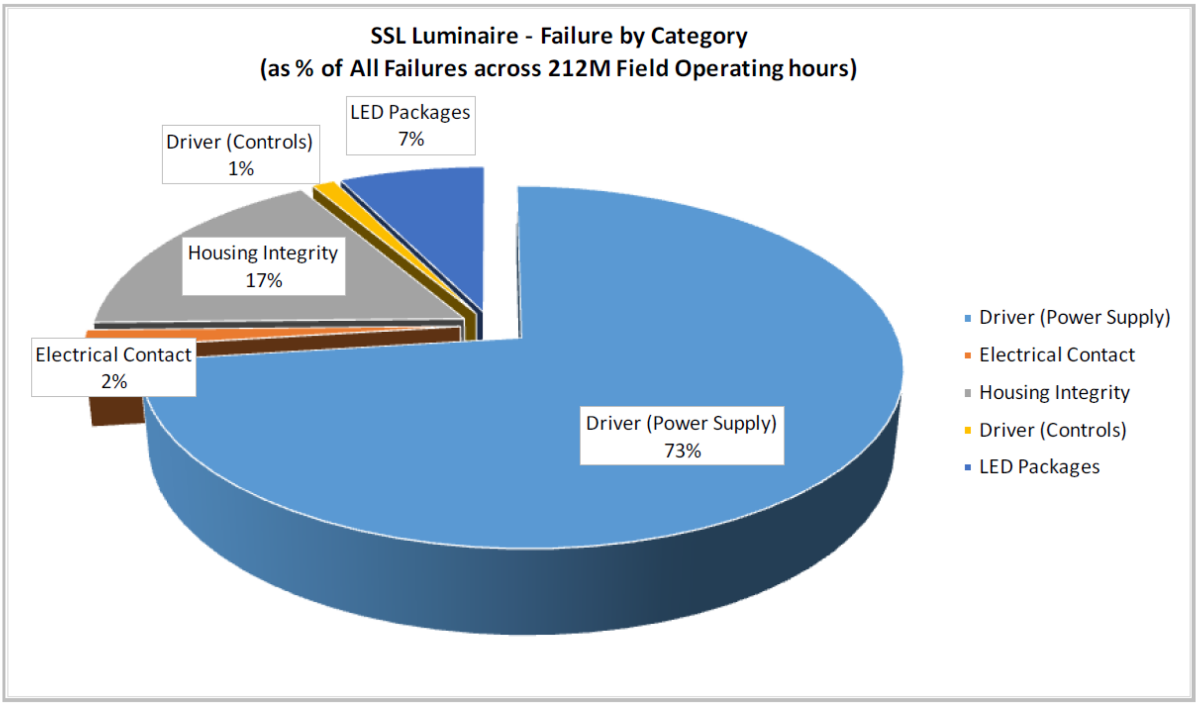

Figure 19 SSL luminaire failure modes, across 212 million field hours. Source: Appalachian Lighting Systems, Inc. (taken from LRSC (2014))

The failure categories in the chart above are defined as follows:

- Driver (Power Supply) includes traditional 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. These devices are often used to split and/or electronically condition the output of the power supply, and in some cases may also include wireless, wired or other types of 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 colour shifts, etc.
- Electrical Contact includes wiring and connector failures and any general connectivity issues resulting in failure of the luminaire to light and/or to otherwise operate in a manner that is deemed non-functional.

These categories are further described in section 4.4, except for the category electrical contacts.

4.3.3 Smart city control system design

In the future, switching to LED lighting alone will not be enough to meet cities' energy consumption and cost reduction targets. Further adaptive and interoperable lighting solutions are needed to bring savings to a next level. Urban leaders now face a dilemma: cities are complex entities where inefficiencies arise because systems are not interconnected and have no way to "talk" to one another. (Crowther et al., 2012).

As demonstrated by market studies (McKinsey, 2012), more and more cities understand that a metering system with a streetlight network may play a strategic role in helping to overcome several inefficiencies, by increasing street safety, improving maintenance processes, contribute to maintenance budget reductions, and reducing energy consumption and communicate on associated CO_2 savings.

Indeed, switching from a traditional lighting operation to the intelligent lighting networks, several improvements for the service can be achieved, such as:

- Remote monitoring allows a faster intervention in case of lighting failures. In fact they are automatically reported by the system by saving time and costs.
- A digital system that smarts plans and routes the maintenance works to minimize street blockages
- Smart dimming and scene setting that allows dimming lights during low traffic hours in order to saving energy or enhancing problematic neighbourhood to improve safety.
- Intelligent energy metering and billing.

The last is particular important for the city energy manager to accurately calculate the energy consumption by taking into account the varying rates and automatically bills all entities.

An intelligent lighting network should be carried out with networked LED street lighting. A networked lighting system can squeeze about 30 percent out of energy use of existing streetlight systems, as well as drive a 20 percent reduction in operations and maintenance costs through more visibility into the assets. A metering and monitoring system can be added to the existing street lighting system, even if no-LED technologies are in place.

This kind of systems introduce some challenges on the operational level, such as bringing variety of communication protocols, consortia, alliances, patent positions, and licensing policies. The market is still waiting to see which alliance or standard will establish itself as the widely adopted interoperability platform.

4.4 Typical and best performance of the road lighting system and its components

In this section the different components relevant for GPP of road lighting will be discussed together with their performance with regards to efficiency and lifetime. The component definition is given in section 2.1.6. The components that are discussed here are:

- Ballast/control gear/driver
- Lamp/light source
- Luminaires

Finally, a view on the complete system is given according to section 4.3.1 and Figure 17. Traffic signals are discussed in section 4.5.

The use of more efficient installations, luminaires, lamps and ballasts/control gear will reduce the energy consumption of road lighting. Similarly, there will be less maintenance required for more efficient and longer lasting lamps and luminaires.

4.4.1 Typical ballast or control gear performance

4.4.1.1 Efficiency

The type of ballast or control gear used and its efficiency has an impact on the overall energy efficiency of road lighting. Magnetic or electronic ballasts can be used and, depending on the wattage, electronic ballasts are most often the most efficient ones. Magnetic ballasts are more efficient for high power lamps. The efficiency of electronic ballasts is less dependent on the lamp power, because they use electronic control circuits instead of series inductance and/or resistance to stabilize the lamp power (Van Tichelen, 2000). It is important to be aware that HID and LED lamps cannot be directly connected to a voltage source (e.g. 230 VAC), but they need a current control for stable operation. This is the role of the ballast or control gear. LED lighting requires electronic control gear in any case. HPS and MH lamps can use both magnetic and electronic ballasts.

Requirements on ballasts for HID lamps and fluorescent lamps are set in the ecodesign Regulation 245/2009. In Table 20 the third stage ecodesign requirements (into force in 2017) are displayed together with the current GPP criteria (GPP, 2012). Note that only the requirements for HID lamps are displayed. For fluorescent lamps, ecodesign requirements are set to at least 91% efficiency for P > 100 W. In practical terms this means that mainly electronic ballasts will be on the market for fluorescent lamps, because magnetic ballasts that reach those efficiencies for fluorescent lamps are large and expensive due to the copper and steel needed.

The ecodesign stage 3 requirements are seen to be ambitious. Technology for ballasts for HID lamps and fluorescent lamps is mature and little improvement is expected, also because most investments are currently on LED technology (Lot 8/9/19, 2015).

Table 20. HID ballast efficiency requirements in ecodesign and current GPP criteria

Rated lamp power	Ecodesign 245/2009 stage 3 (2017)	GPP award core criteria 2012	GPP award comprehensive criteria 2012
Pr[W]	**ηballast**	**ηballast**	**ηballast**
P ≤ 30	78%	85%	90%
30 < P ≤ 75	85%	85%	90%
75 < P ≤ 105	87%	85%	90%
105 < P ≤ 405	90%	92%	94%
P > 450	92%	92%	94%

Comparing publicly available data of different manufacturers on the internet shows that external LED control gears have efficiencies ranging from 89% to 94% at full load for drivers with mains input voltage 230 VAC[47,48,49] and only a few percent improvement is expected in the future (see Table 16). The efficiency includes stand-by losses and depends on the lamp wattage, the load and the input voltage (see Figure 20). At low load the standby power loss for the control electronics can become relative important and will decrease the efficiency. Usually specifications are given for 100% load and at ambient temperature of 25°C. Standby power losses are typically 0.3 W and usually specified as ≤ 0.5 Watt.

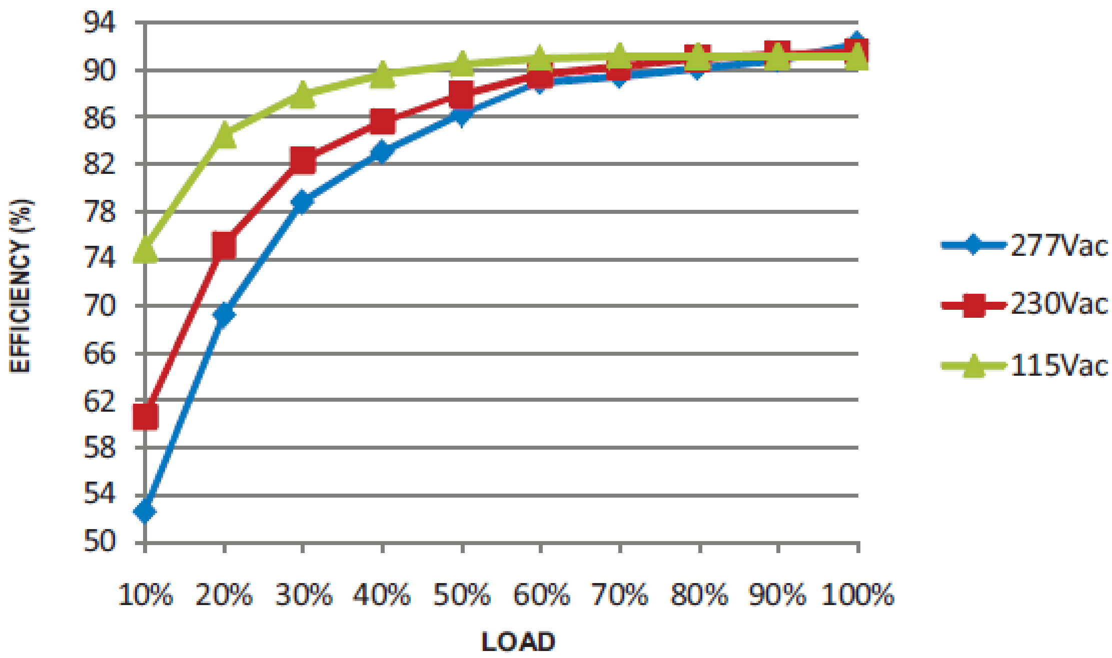

Figure 20 Efficiency vs. load for a LED driver (Mean Well, 2016)

An improved lamp survival factor (FLS) and lamp lumen maintenance factor (FLLM) (see section 4.4.2.3) are often connected to electronic ballasts that offer better power control and lamp ignition (Van Tichelen, 2000).

4.4.1.2 Lifetime of ballast and electronic control systems

Magnetic ballast

Magnetic ballasts usually have a minimum specified lifetime of ten years continuous operation. This specification is related to the maximum winding temperature (130°C) (see Figure 21). The winding temperature is the ambient temperature plus the increase in temperature due to the power consumption of the unit. In practice this minimum life of ten years can be exceeded and field experience has shown that lifetimes of thirty or even fifty years can be achieved (Van Tichelen et al., 2007) because the real operational temperature during life is lower. Therefore, for magnetic ballasts the lifetime has never

47 http://www.meanwell.com/product/led/LED.html (type HLG-40H .. -600H)

48 http://www.helvar.com/products/led-drivers

49 http://www.tridonic.com/com/en/products/lca-50w-100-400mA-one4all-lp-pre.asp

been an issue. In most cases it is even much longer compared to a typical lifetime of the luminaires, i.e. > 35 years.

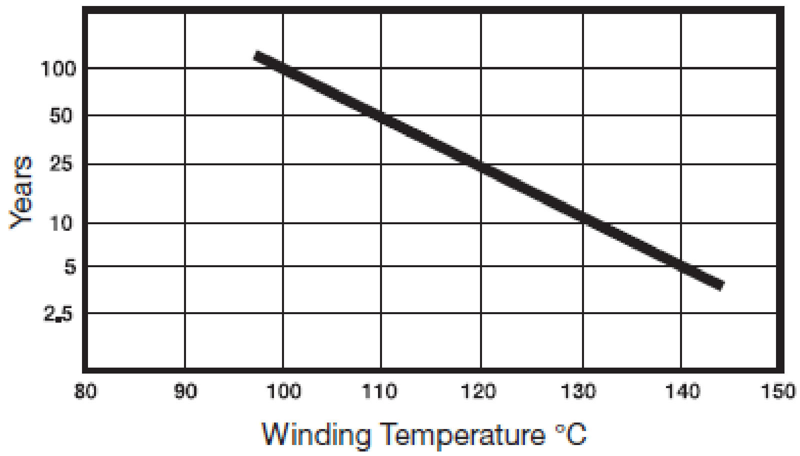

Figure 21 Typical trend of lifetime specification of magnetic control gear for HID lamps[50] with the winding temperature (°C)

Electronic ballast or control gear

For electronic control gear the lifetime can be an issue just as for any other electronic equipment. Basically, the lifetime depends on the weakest component in the electronic system and is affected by external conditions such as the working temperature. For example, electrolytic capacitors are often used in electronic control gear and they are probably the shortest-living component for most control gear (DOE, 2011). Moreover, the typical lifetime of an electrolytic capacitor is cut to half for every 10°C temperature rise (DOE, 2011). Apart from the lifetime of individual components, also the ability of the luminaire to resist ingress of dust and moisture affects the lifetime of the electronic ballast.

Experience from indoor applications show that the failure rate of electronic ballasts compared to magnetic ballasts is higher and it is expected that electronic control gear would need to be replaced during the lifetime of the luminaire.

Lifetime data is only useful when the service life is stated together with the percentage of failure at that lifetime. The operation temperature is another parameter which is useful to make a good judgement of the lifetime. Belgian tender specifications for street lighting[51] for example require less than 10% failures at 50 000 hours lifetime with an operation temperature tc (°C) to be marked on the ballast. If the failure rate is not mentioned in the specifications, a 50% failure rate can be assumed, even though this is not always clear from the data sheets. Manufacturers offer control gear with a service life of ≥ 50 000 hours with a failure rate of 0.2% per 1 000 hours.[52]

It is worth mentioning that these lifetime statements are based on a manufacturer's declaration and that an official standard is not available. Some manufacturers already claim lifetimes of more than 85 000 hours at 10% failure rate. Additionally, it should be kept in mind that lifetime data is based on statistics and there is a risk that a single product fails before the mentioned lifetime even when thoroughly tested. Therefore, manufacturers sometimes offer a single product warranty ranging from 3 to 7 years. Such a warranty can imply a plain replacement of each defected unit.

[50] Tridonic, "Catalogue 2012 Magnetic chokes for HID", http://www.tridonic.com/com/en/
[51] http://www.synergrid.be/index.cfm?PageID=16832
[52] https://www.vossloh-schwabe.com/uploads/tx_sbdownloader/Leitfaden_Treiber_EN.pdf

Another issue related to the lifetime of electronic gear is the protection against overvoltage transients that can occur in the grid (ECI, 2015), e.g. due to lightning. Some manufacturers offer electronic control gear with improved immunity against overvoltage transients (e.g. 4 kV[53] according to EN 61000-5-4:2014). This feature is however not always useful at control gear level because protection against overvoltage transients can also happen at system level, i.e. before the electronic control gear at the pole connection.

Similarly, lifetime can also be an issue for electronic control systems added for dimming and smart control. Apart from the hardware lifetime discussed above, it is also important that communication protocols and/or software are supported over the lifetime of the electronics. Therefore using open protocols and replaceable communication modules could be useful requirements.

4.4.1.3 Dimming and control systems

Ballasts or control gear that can dim the light output reduce the energy consumption. The reduction in energy consumption does not always react linear with the dimming factor, but energy is saved in any case. This non-linearity is mostly due to power needed to operate the control circuit within the control gear which in turn is related to the standby power. It should be noted that LED dimming systems exist that can be retrofitted between the LED module and its control gear when the original control gear does not allow dimming.

There are a number of factors that will influence if the use of a dimming system is suitable, e.g. the location of the street lighting, levels of ambient lighting (e.g. from shop windows), traffic intensity, weather conditions, lumen depreciation over lifetime, luminaire cleaning interval and security considerations.

In general, when road lighting is designed above the minimum levels defined in EN 13201-2:2016, dimming can be foreseen, e.g. in hours of low traffic and good weather conditions.

Additionally, dimming can be useful to account for constant light output and relates to the maintenance interval, the lifetime and the lumen maintenance. According to standard EN 13201-2:2016, light levels should be maintained over its lifetime. As will be explained in section 4.4.3 luminaire lumen maintenance depends on the cleaning interval and dimming can be used to compensate for this lumen decrease. Also due to lumen depreciation of the light source itself, the system can be overpowered at the beginning which leads to increased energy cost and dimming can be useful. This increase in energy cost can be countered by means of a so-called constant light output control function as the operating output is adjusted continuously to compensate for the lumen loss.

Dimming can be analogue or digital and different systems of control are possible. The most common controls are currently DALI (digital addressable lighting interface) (IEC 62386) and 0-10 V analogue controls. Interfaces with a variety of sensors can be implemented as well and therefore communication systems can be added, e.g. wireless systems (such as LoRa, SigFox), powerline communication (such as LonWorks (EN 14908), KNX (EN 50090), etc.). This is a fast developing domain so the ability to change the control system/software is judged to be important.

In DALI mode the driver can be integrated in a light management system. The standardized DALI interface enables bi-directional communication between the driver and the light management system which means that stepless dimming, status requests and addressing of each individual luminaire is possible. DALI is a wired control interface with a digital communication protocol and needs a wired connection. The system will therefore hold an extra wire in addition to the two wires for the mains connection.

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[53] http://www.synergrid.be/download.cfm?fileId=C4_10_v201410_VoorschriftenHulpapparatuur.pdf

Also with a 0-10 V interface the driver can be integrated in a light management system. This uni-directional interface allows adjusting the light output of the system.

For LED luminaires, digital Pulse Width Modulation (PWM) dimmers exist that can be retrofitted between the LED module and its control gear. Their duty cycle or on/off ratio (0-100 %) is the main control parameter for dimming.

Other controls are possible such as presence control and night control. In this dimming mode the light output can be adjusted to the activity around each light point with an additional external sensor powered by the mains. Night control can be implemented by (multi-stage) night-time power reduction based on an internal timer.

4.4.2 Typical lamp or light source parameters

The most relevant parameters for the light source for this study are efficiency and lifetime. Efficiency is usually expressed as the lamp's luminous efficacy while lifetime parameters are expressed as lamp survival factor (FLS) and lamp lumen maintenance factor (FLLM). The light output of a lamp is measured in lumen and lamps are available in a wide range of lumen output to meet different requirements. In order to achieve this, lamps will likewise have a range of power consumptions. The efficiency by which a lamp uses the electricity to create the lumen output is denoted as the lamp's luminous efficacy. Further, the mercury content of lamps is discussed. Colour temperature, colour rendering and colour maintenance are shortly discussed at the end of this section.

4.4.2.1 Efficacy of lamps used in street lighting

As discussed earlier, different lamp types can be used in street lighting, i.e. HPS, LPS, MH, fluorescent and LED. The different types of lamps have their own efficiencies, usually depending on their characteristic wattage. Lamps with low power are usually relatively less efficient, except LED lamps where the efficiency does not depend on the power. As mentioned in section 3.5.4 all typical road lighting lamps (HPS, LPS, MH, FL) have external control gear such as lamp ballasts and starters installed in the luminaire. Because this control gear regulates the energy consumption of the luminaire, retrofitting of these kind of lamps with more efficient lamps does not result in any energy saving as long as the control gear is not replaced. Retrofitting a more efficient lamp in an existing luminaire without replacing the control gear will only result in more light output without any energy saving. LED retrofits are discussed in section 4.4.2.2.

Further, it should be noted that stage 2 requirements (applicable from 2015) and stage 3 requirements (applicable from 2017) in the ecodesign Regulation 245/2009 are seen to be ambitious for the non-LED lamps, especially for HPS lamps. The requirements for these lamps together with the current GPP criteria are shown in Table 21.

It is expected that since the development of the previous GPP criteria (GPP, 2012) not much progress is made on HPS and MH technologies because these lamp technologies are mature and recent development spending is on LED technology (Lot 8/9/19, 2015). The ecodesign criteria (stage 2) for HPS lamps can be met with mercury free lamps, the comprehensive GPP criteria in Table 21 will need mercury. The mercury content is discussed in section 4.4.2.4.

The data together with the requirements are plotted in Figure 22, Figure 23 and Figure 24. From these figures it can be seen that the ecodesign requirements for HPS lamps are ambitious, while for MH lamps the ecodesign requirements seem less ambitious. The rationale behind this is that the ecodesign requirements kept quartz discharge tube MH lamps on the market. These quartz MH lamps substantially underperform compared to ceramic discharge tube MH lamps. The quartz technology comes at a lower cost, but has apart from poor efficacy also a lower lifetime and lumen maintenance factor. Due to their poor lifetime quartz MH lamps have been used only very rarely in road lighting. Road lighting usually uses ceramic MH lamps.

HPS lamps are the most used lamps in road lighting (see Table 13). MH lamps on the other hand can be an alternative to HPS lamps in many cases and they can operate with the same control gear. In terms of efficacy, such a retrofit might in principle be an option for lower wattage HPS lamps, especially 35W and 50W, because MH lamps have higher efficacies in that wattage range. However, replacing a lamp in an existing luminaire without changing the control gear will only result in a higher light output and not in lower power consumption. However, from a lifetime perspective it could be better to keep low wattage HPS lamps because they have a better lumen maintenance factor (FLLM) and a better lamp survival factor (FLS) (see section 4.4.3.2). Retrofitting LEDs in non-LED luminaires would require the changing of the control gear in the luminaire in any case and is discussed in section 4.4.2.2.

Fluorescent lamps do not have current GPP criteria. The minimum efficacy levels defined in the ecodesign criteria are ambitious and no additional criteria in GPP were found to be necessary. Moreover, fluorescent lamps are not used much in road lighting and the efficacy depends on the shape of the lamp.

Table 21. Ecodesign and GPP criteria for rated lamp efficacies for high pressure sodium lamps with Ra[54] < 60

Nominal lamp wattage	Ecodesign 245/2009 stage 2 (2015)		GPP core criteria, 2012		GPP comprehensive criteria, 2012	
	Rated lamp efficacy [lm/W]		Rated lamp efficacy [lm/W]		Rated lamp efficacy [lm/W]	
	Clear lamps	Not clear lamps	Clear lamps	Not clear lamps	Clear lamps	Not clear lamps
P ≤ 45	≥ 60	≥ 60	≥ 62	≥ 60	≥ 65	≥ 62
45 < P ≤ 55	≥ 80	≥ 70	≥ 80	≥ 70	≥ 82	≥ 72
55 < P ≤ 75	≥ 90	≥ 80	≥ 91	≥ 82	≥ 93	≥ 83
75 < P ≤ 105	≥ 100	≥ 95	≥ 105	≥ 95	≥ 107	≥ 96
105 < P ≤ 155	≥ 110	≥ 105	≥ 114	≥ 107	≥ 117	≥ 110
155 < P ≤ 255	≥ 125	≥ 115	≥ 125	≥ 120	≥ 130	≥ 121
255 < P ≤ 605	≥ 135	≥ 130	≥ 138	≥ 133	≥ 140	≥ 136

Table 22. Ecodesign and GPP criteria for rated lamp efficacies for metal halide lamps

Nominal lamp wattage	Ecodesign 245/2009 stage 3 (2017)		GPP core criteria, 2012				GPP comprehensive criteria, 2012			
	Rated lamp efficacy [lm/W]		Rated lamp efficacy [lm/W]				Rated lamp efficacy [lm/W]			
	Clear lamps	Not clear lamps	Clear lamps		Not clear lamps		Clear lamps		Not clear lamps	
			Ra[54] < 80	Ra ≥ 80	Ra < 80	Ra ≥ 80	Ra < 80	Ra ≥ 80	Ra < 80	Ra ≥ 80
P ≤ 55	≥ 70	≥ 65	≥ 85	≥ 85	≥ 80	≥ 65	≥ 95	≥ 90	≥ 85	≥ 70
55 < P ≤ 75	≥ 80	≥ 75	≥ 100	≥ 94	≥ 85	≥ 70	≥ 105	≥ 100	≥ 90	≥ 75
75 < P ≤ 105	≥ 85	≥ 80	≥ 105	≥ 95	≥ 90	≥ 75	≥ 115	≥ 101	≥ 95	≥ 80
105 < P ≤ 155	≥ 85	≥ 80	≥ 110	≥ 96	≥ 95	≥ 75	≥ 118	≥ 102	≥ 98	≥ 80
155 < P ≤ 255	≥ 85	≥ 80	≥ 100	≥ 97	≥ 92	≥ 80	≥ 105	≥ 103	≥ 100	≥ 85
255 < P ≤ 405	≥ 90	≥ 85	≥ 92	≥ 98	≥ 100	≥ 80	≥ 110	≥ 104	≥ 105	≥ 85

[54] for a definition of the colour rendering index, CRI [Ra], see Annex B , chapter 6.2.2

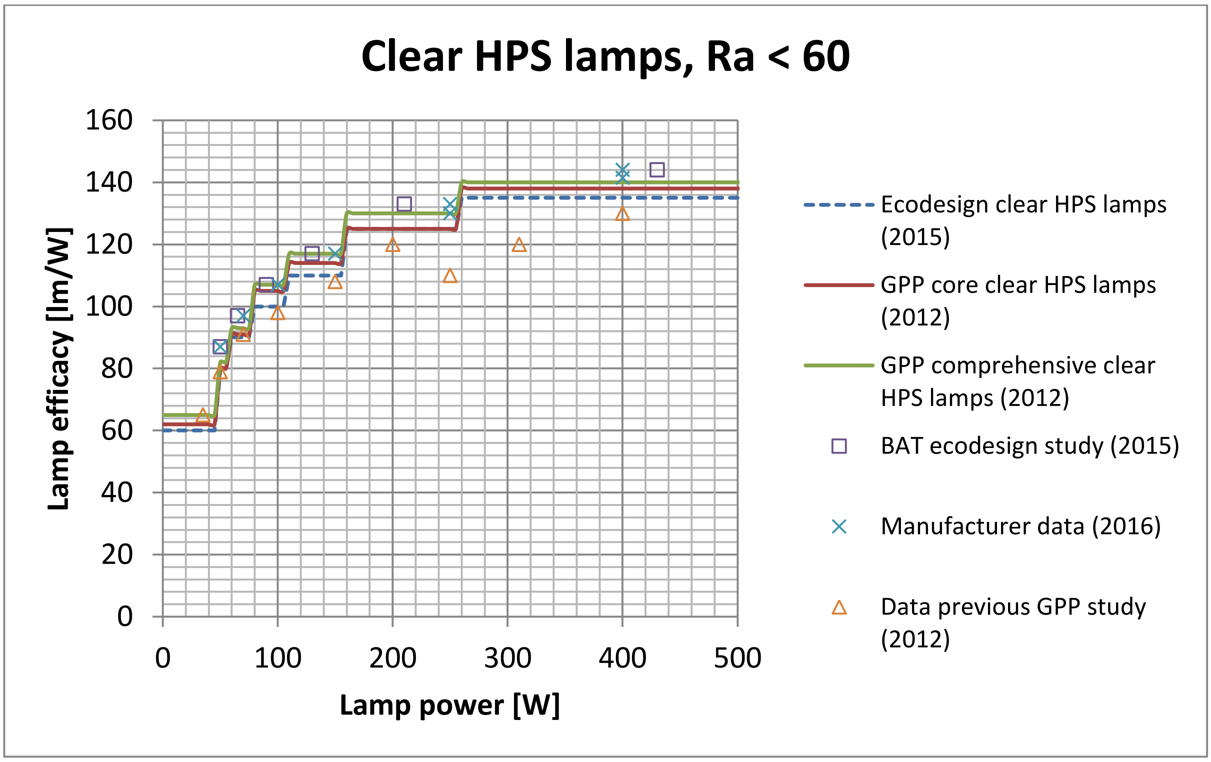


Figure 22 Lamp efficacy in function of lamp wattage for clear HPS lamps with Ra < 60

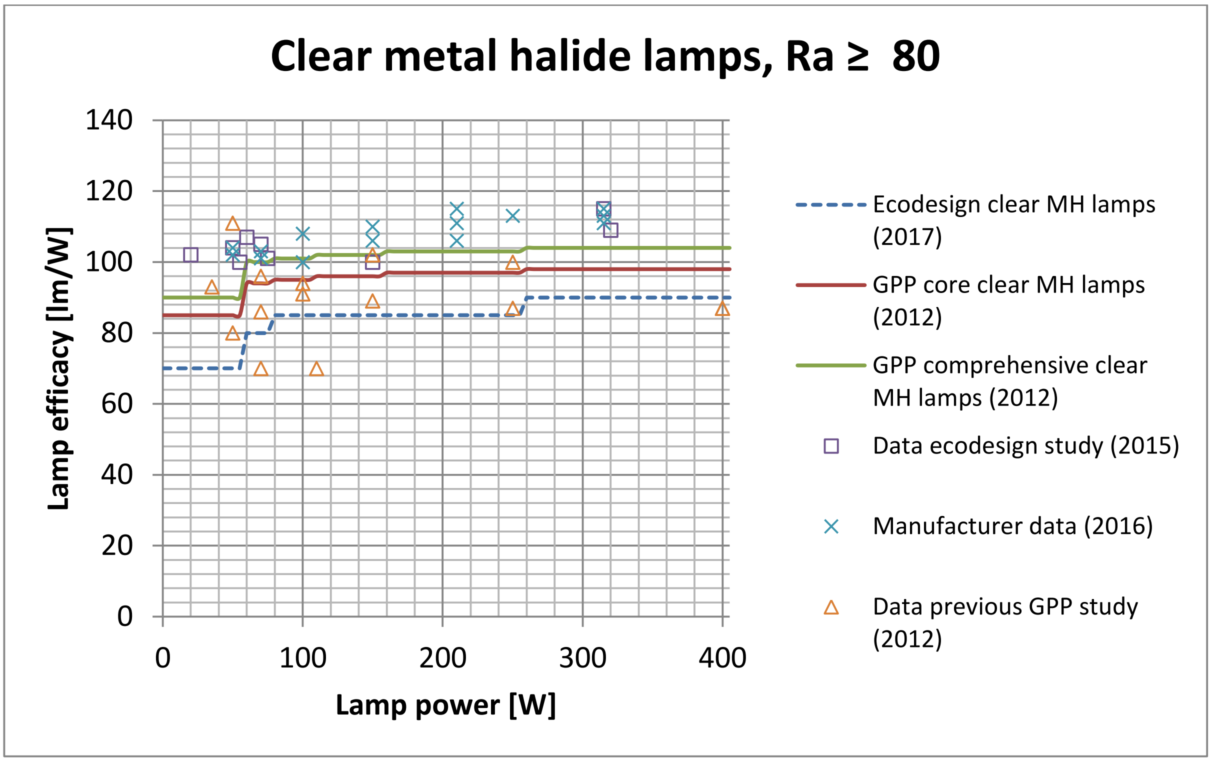


Figure 23 Lamp efficacy in function of lamp wattage for clear MH lamps with Ra ≥ 80

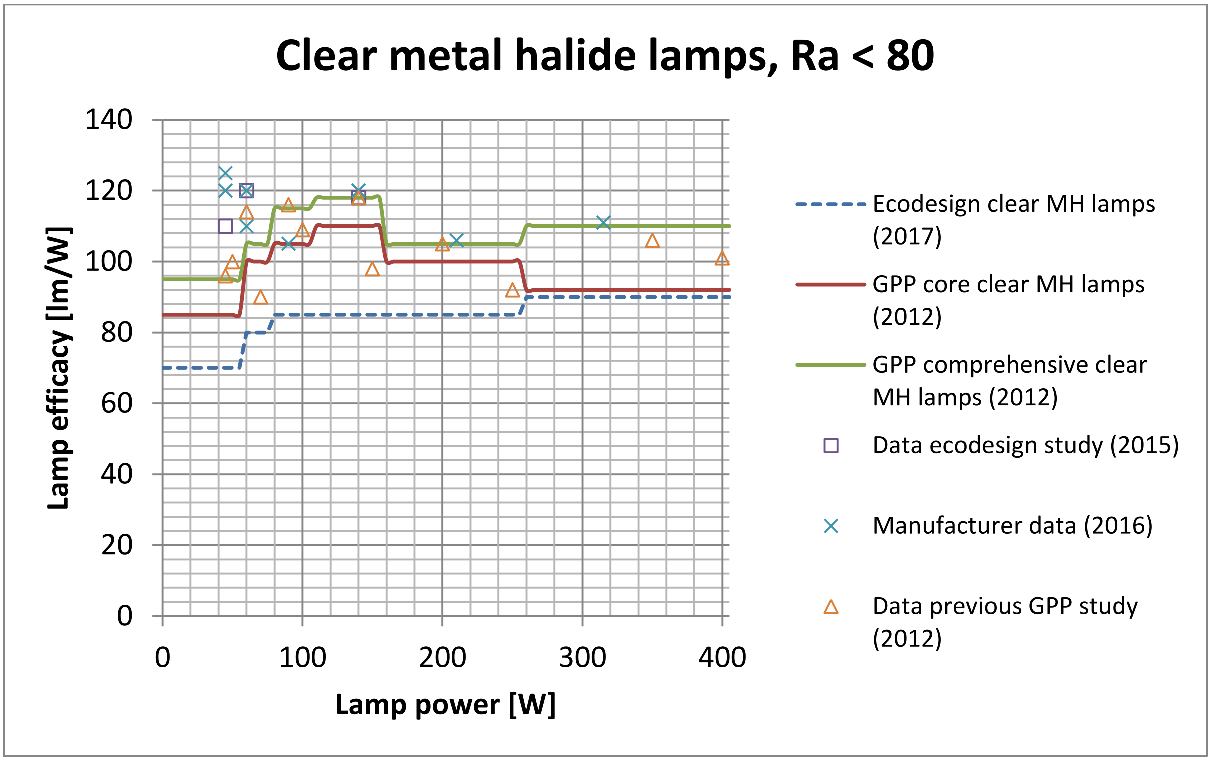


Figure 24 Lamp efficacy in function of lamp wattage for clear MH lamps with Ra < 80

From Table 21 and Table 22 it can be noticed that a difference is made between clear and not clear lamps. HPS and MH lamps sold in non-clear versions (also named elliptical, frosted or coated) have about 5 % lower lumen output due to losses in the coatings. They are also not compatible with efficient luminaire optics. The main reason for using these more expensive non-clear, coated lamps is to avoid glare when they are used in luminaires without glare reduction optics. High end road lighting luminaires however avoid glare without the need of coated lamps (Van Tichelen et al., 2007).

HPM lamps are phased out by EC Regulation 245/2009 because of their low efficacy. A 250W HPM lamp for example has only about 51 lm/W efficacy. HPM lamps were popular because they were cheap (around 5 euro, anno 2016)[55] and produce white light.

Low pressure sodium lamps (LPS) have the highest efficacy possible for discharge lamps. A 26W LPS lamp has an efficacy of about 140 lm/W while a 66W LPS lamp has an efficacy of 170 lm/W. However, LPS lamps are expensive (> 30 euro[56]) and produce monochromatic orange light and are therefore seldom installed in new projects (see Table 13).

In lower light output applications, white light compact fluorescent lamps (CFLni) were used in some countries (see Table 13). A typical outdoor 36W CFLni has an efficacy of 81 lm/W with a cost of about 4 euro.

LED modules without control gear and without additional luminaire optics are estimated to produce 100 to 175 lm/W in 2016 with improvements expected in the future (see Figure 7). LED luminaire road lighting efficacy currently ranges typically from 100 lm/W to 140 lm/W[57] including all luminaire optical losses and control gear losses. LED luminaire efficacy tends to vary within this range depending on colour temperature (Tc),

[55] https://www.lampdirect.be/nl/osram-hql-e27
[56] https://www.lampdirect.be/nl/gasontladingslampen
[57] based on a screening of available road lighting luminaires in the DOE 'Lighting Facts' database : http://www.lightingfacts.com/Products

colour coordinates, optics for glare and light distribution and the product quality of the LED module (LED, 2016). LED module current density can also impact efficacy.

It should be noted that there is a large spread in LED technology performance; LEDs with only 50 lm/W efficacy are available on the market as well and therefore verification or quality certificates are deemed necessary. One explanation is that LED chips from the same manufacturer are sometimes binned[58] and sold in different performance groups. Each of these performance groups can have a different efficacy range (CREE, 2016). In that case the differences are entirely due to variations that occur within the production and can even occur within the same production batch. Therefore, a test sample could be provided based on the top selected performance group while a lower cost performance group could be used for the delivered installation. In order to deal with this potential variations quality monitoring schemes are used, such as the European ENEC+ mark[59] for LED products.

4.4.2.2 LED retrofit

There is a wide variety of LED retrofit lamps for HID lamps on the market. These retrofit options differ in their ease of use. Some are plug-and-play solutions, requiring only substitution of the lamp itself (but maintaining existing ballast losses), while others require the existing ballast to be replaced or removed/by-passed. Some LED retrofit kits are specific for a certain type of HID-lamp and/or for a certain type of luminaire.

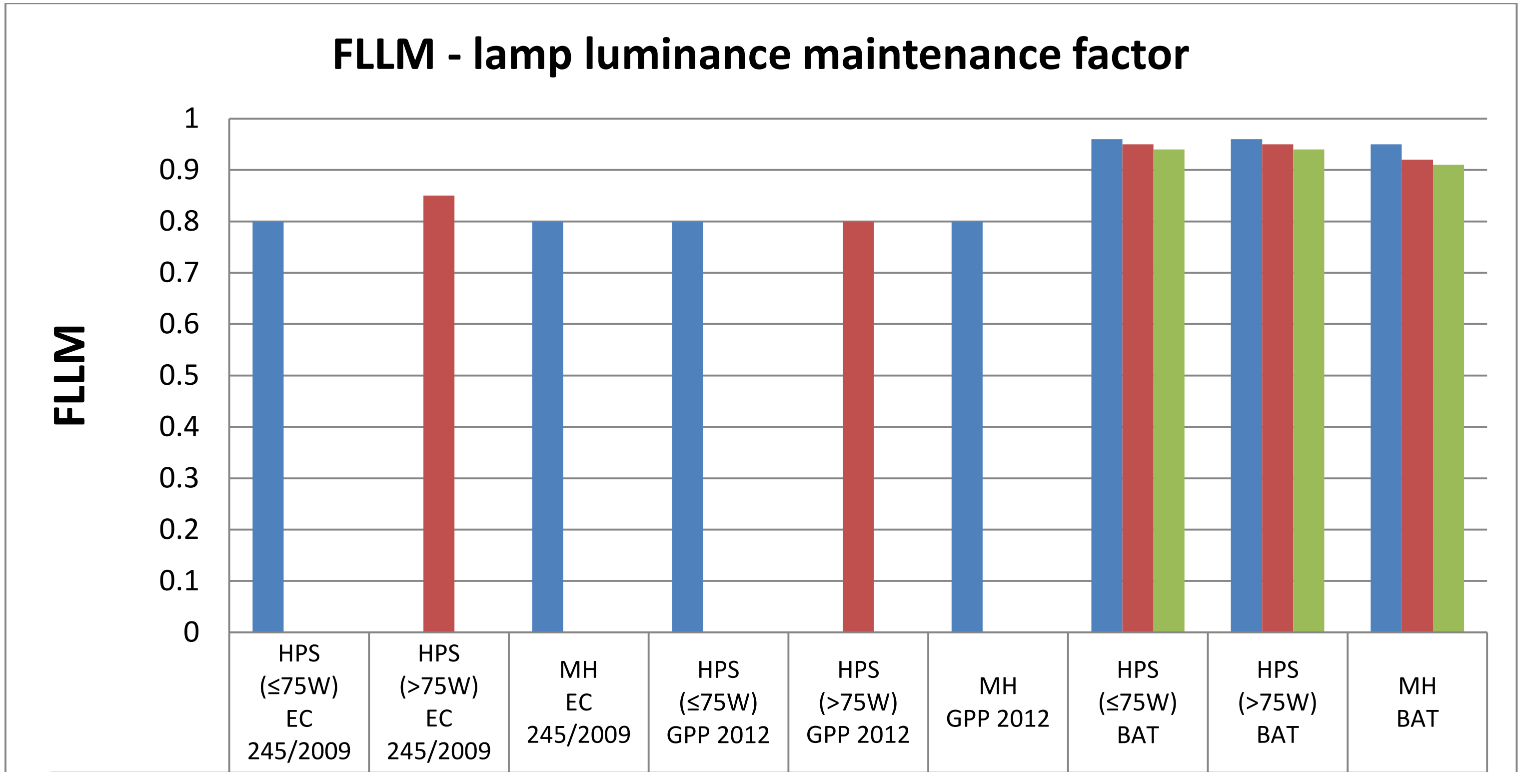
As explained in section 2.3.13, it is not easy to upgrade or convert existing luminaires correctly to LED technology because the re-wiring requires qualified personnel, entails costs and has consequences for the safety certification of the luminaires. Also in many cases LED retrofit lamps cannot meet the high light intensities when placed in the compact space where HID-lamps are usually placed. At the moment, LED retrofit solutions tend to be heavier with larger dimensions than the HID lamps they aim to replace, especially in the higher lumen range (> 50 Watt). In all retrofit options attention is therefore required to make sure that the lamp fits in the available space in the luminaire, that thermal management conditions are met and that the amount and distribution of the light is satisfactory. Therefore even new lighting calculations might be needed to ensure that street lighting requirements are still met in accordance with EN 13201-2:2016. Some road lighting luminaire manufacturers already start offering conversion kits for their older luminaires[60]. These retrofit solutions are mainly for decorative road lighting luminaires that currently use frosted elliptical (non-clear) lamps that can be retrofitted with LEDs.

4.4.2.3 Lamp survival factor (FLS) and lamp lumen maintenance factor (FLLM)

Apart from increased lamp efficacy and reduced energy consumption, the other major benefits linked with the use of certain types of lamps or light sources for road lighting and traffic signals are the lamp survival factor (FLS) and how well they maintain their light output, i.e. the lamp lumen maintenance factor (FLLM). These parameters are shown in Figure 25 and Figure 26 for HPS and MH lamps. The figures show the minimum criteria for FLLM and FLS included in the Ecodesign Regulation 245/2009, the current GPP criteria and the best available technologies (BAT) currently on the market[61,62]. EC 245/2009 denotes the stage 3 ecodesign requirements (into force from 2017).

Since 2009 HPS lamps have improved in FLLM, FLS and efficacy due to technical improvements in the lamp ignition process. Due to the relatively long life span of luminaires and ballasts in comparison to the lifetime of HPS lamps, HPS lamps can be seen as a component to be replaced during the lifetime of a luminaire.

[58] http://blog.luxexcel.com/lighting/led-binning-ansi/
[59] http://www.enec.com/page.php?p=7
[60] http://www.siteco.com/en/uk_en/products/outdoor-luminaires-catalogue/chapter/1546/category/13234/family/12038.html

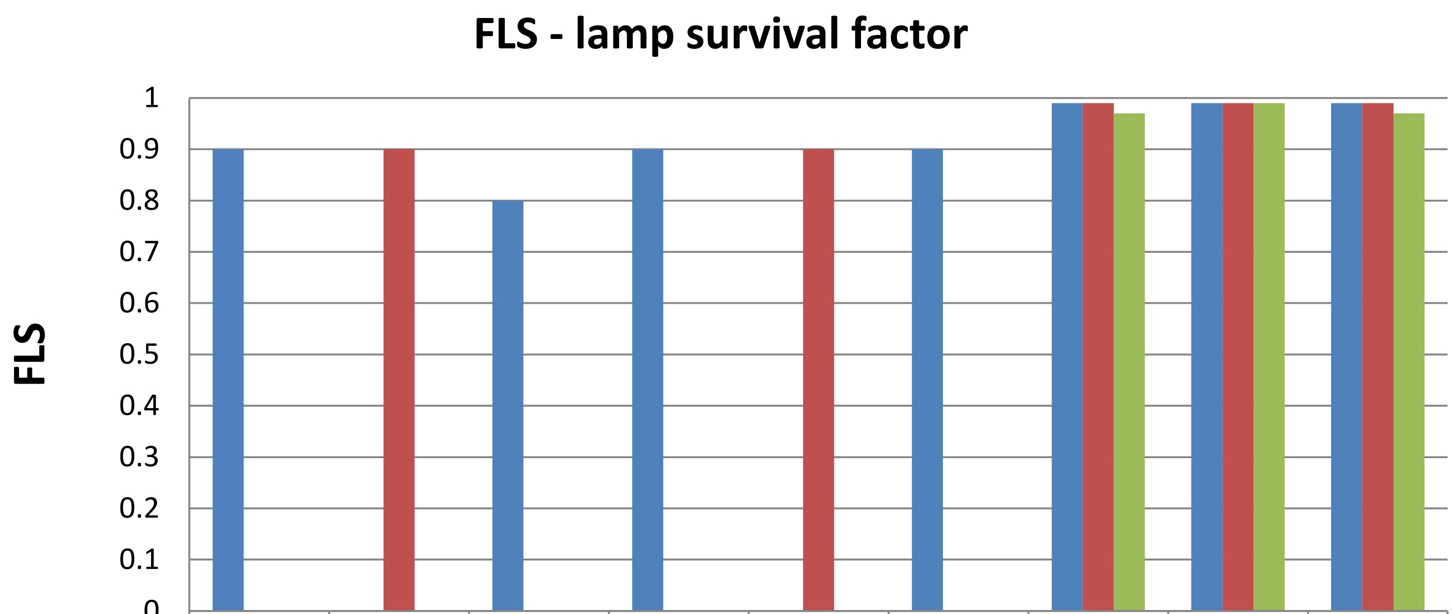


	HPS (≤75W) EC 245/2009	HPS (>75W) EC 245/2009	MH EC 245/2009	HPS (≤75W) GPP 2012	HPS (>75W) GPP 2012	MH GPP 2012	HPS (≤75W) BAT	HPS (>75W) BAT	MH BAT
12 000 hours	0.8		0.8	0.8		0.8	0.96	0.96	0.95
16 000 hours		0.85			0.8		0.95	0.95	0.92
20 000 hours							0.94	0.94	0.91

Figure 25 Lamp luminance maintenance factor for HPS and MH lamps according to the ecodesign regulation, the current GPP criteria and the best available technologies (BAT) [61,62]

[61] source (6/2016), Philips MASTER SON-T APIA Plus Xtra: http://www.lighting.philips.co.uk/prof/lamps/high-intensity-discharge-lamps/son-high-pressure-sodium/master-son-t-apia-plus-xtra/productsinfamily

[62] source (6/2016), MASTER CityWhite CDO-TT: http://www.lighting.philips.co.uk/prof/lamps/high-intensity-discharge-lamps/outdoor-ceramic-white-light/master-citywhite-cdo-tt



	HPS (≤75W) EC 245/2009	HPS (>75W) EC 245/2009	MH EC 245/2009	HPS (≤75W) GPP 2012	HPS (>75W) GPP 2012	MH GPP 2012	HPS (≤75W) BAT	HPS (>75W) BAT	MH BAT
12 000 hours	0.9		0.8	0.9		0.9	0.99	0.99	0.99
16 000 hours		0.9			0.9		0.99	0.99	0.99
20 000 hours							0.97	0.99	0.97

Figure 26 Lamp survival factor for HPS and MH lamps according to the ecodesign regulation, the current GPP criteria and the best available technologies (BAT)

LED road light sources are marketed today mostly as LED luminaires, i.e. luminaires including LED modules, electronic ballast, optics, housing, etc. The LED modules are discussed here in the lamp section, while the control gear has been discussed in section 4.4.1. The luminaire section 4.4.3 describes the housing without the light source.

Compared to HID lamps LED modules for road lighting luminaires have better FLLM and FLS per operating hour. LED luminaires do not provide directly FLLM and FLS data, but their lifetime is usually expressed in LxBy and LxCz. LxBy relates to the lumen maintenance and is expressed in hours, where x[%] represents the percentage of light output still maintained, and y[%] represents the number of units that no longer meet the minimum criteria. For example, if a fixture has a lumen maintenance of 50 000 hours L70B10, it means that after 50 000 hours of use it will still provide 70% of its initial light output, but 10% of the fixtures will not meet this level of light output. The percentage of LED luminaires that have failed completely by the end of the rated life Lx is expressed by Cz. This is illustrated in Figure 27.

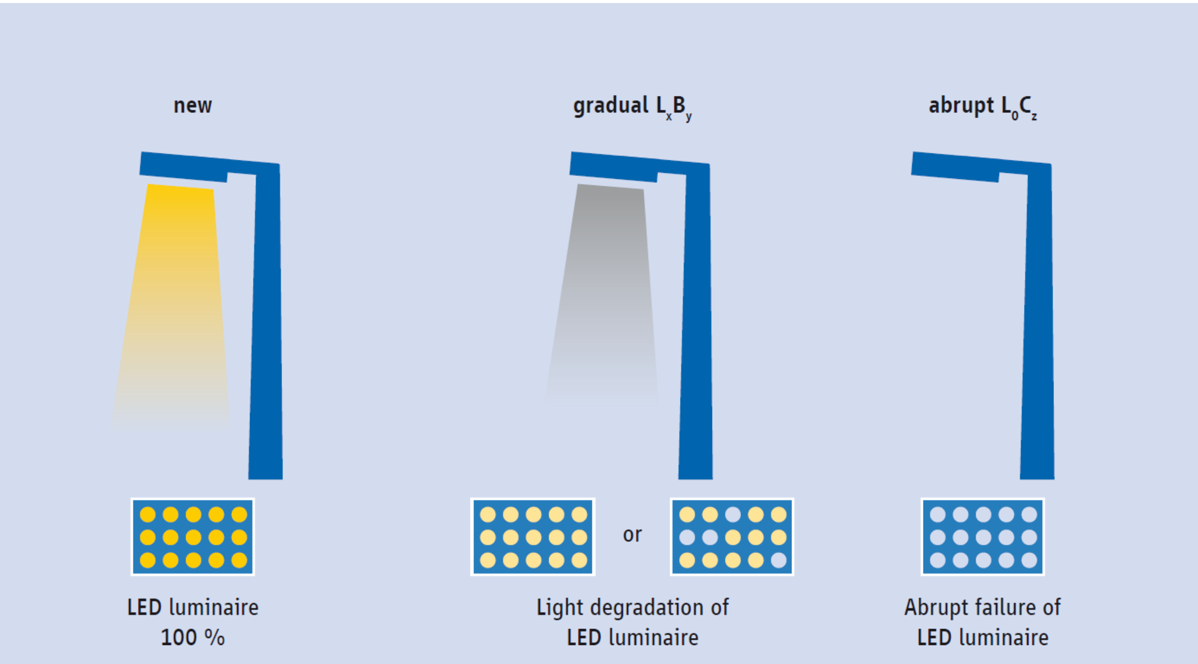


Figure 27 Failure state of a luminaire (original state, degradation and abrupt failure). Taken from (ZVEI, 2013).

A LED luminaire is therefore characterised by the useful service life defined for the project, e.g. a lifetime of 15 years or another way of expressing this could be 60 000 h at 4 000 h/year. For this service life [h] the x[%] from the corresponding LxBy value provides the FLLM value and the z[%] from the corresponding LxCz provides the FLS value. For example: the LED luminous flux class "L80B50 @ 60 000 h" describes a drop in luminous flux to 80% or FLLM = 0.80 and FLS = 0.50 failure rate after 60 000 hours.

LED technology is in full development and data is based on extrapolations and standards. For example, the IEA 4E SLL has proposed a minimum value of 50 000 hours L70B50@50 000 hours and L95B05@6 000 h (IEA 4E, 2015). Significant better products are announced on the market[63]. This means that designing installations with FLLM > 0.9 at 80 000 h or 20 years lifetime seems to be a realistic option. Hence, only luminaire cleaning and spot repair for failed control gears and/or LED modules are likely. LED control gear failures are discussed in section 4.4.1.2.

[63] http://www.schreder.com/beu-nl/Documents/Producten/Product-Sheets/Schreder-Ampera-13-03-2015-Dutch.pdf

4.4.2.4 Mercury content

Regarding mercury content, it is assumed that the data that was used during the development of the previous criteria (GPP TBR, 2011) are still valid as it is believed that there have been few new technical developments on HID lamps since 2011. It should be noted however that mercury free HPS lamps are on the market. These mercury free HPS lamps have about 7% lower efficacy compared to the BAT. For example, a mercury free 70 W HPS has 90 lm/W compared to 97 lm/W for a HPS lamp with mercury. Hence, ecodesign stage 2 requirements for lamp efficacy can be met with mercury-free HPS lamps, but the current comprehensive GPP criteria cannot be met (see Table 21).

In Table 23 the RoHS values are compared with the current comprehensive GPP award criteria on mercury content. It shows that the comprehensive award criteria on mercury content are a little below the RoHs requirements (GPP, 2012). Given a total annual EU28 HID lamp sales for 2015 of 11.2 million and 20 mg mercury per lamp, this would result in an annual EU28 mercury consumption of 220 kg. Due to recycling and correct waste collection significantly less mercury will be released as waste to the environment. For comparison the global annual mercury consumption for mercury for dental filling was estimated 340 tonnes per year, of which about 70 - 100 tonnes (i.e. 20 - 30%) likely enters in the solid waste stream (UNEP, 2013). Therefore, no significant impact is expected from introducing further mercury reductions compared to the existing GPP criteria. Moreover, the production of these mercury-containing lamps is decreasing due to the introduction of LEDs in road lighting.

Table 23. Comprehensive GPP award criteria for HID lamps and RoHS requirements (GPP, 2012)

Lamp type	Mercury content (mg/lamp)	
	Comprehensive GPP criteria 2012	RoHS requirements
HPS lamps (W ≤ 155)	20	25
HPS lamps (155 < W ≤ 405)	25	30
HPS lamps (W > 405)	35	40
MH lamps (W ≤ 95)	2	none

4.4.2.5 Colour quality

Minimum road lighting requirements for road classes are defined in standard EN 13201-2:2016. In this standard no requirements are included related to colour quality such as colour temperature, colour rendering index and colour tolerance. Colour temperature (Tc) and CIE colour coordinates can be relevant for reducing light pollution and ambient lighting.

Colour temperature

An illustration of colour temperature can be found in Figure 28. According to (OPCC-OTPC, 2010) new neutral cool white (>3000 K) LED lamps emit at 470 nm making them potentially harmful to health (EN 62471:2008) and the environment. When white light is required, warm white LEDs (<3 000 K), which are now available on the market, are recommended. Tolerances on colour temperature had been set for road lighting in (IEA 4E, 2014c), but later on these requirements have been removed in (IEA 4E, 2015). From the point of view of the road user, the selection of colour and/or colour temperature in road lighting is mainly an issue of taste. However, the selection of colour can have an impact on certain species which is discussed in section 2.4.1.6. White LEDs with colour temperature <3 000 K for example attract less insects.

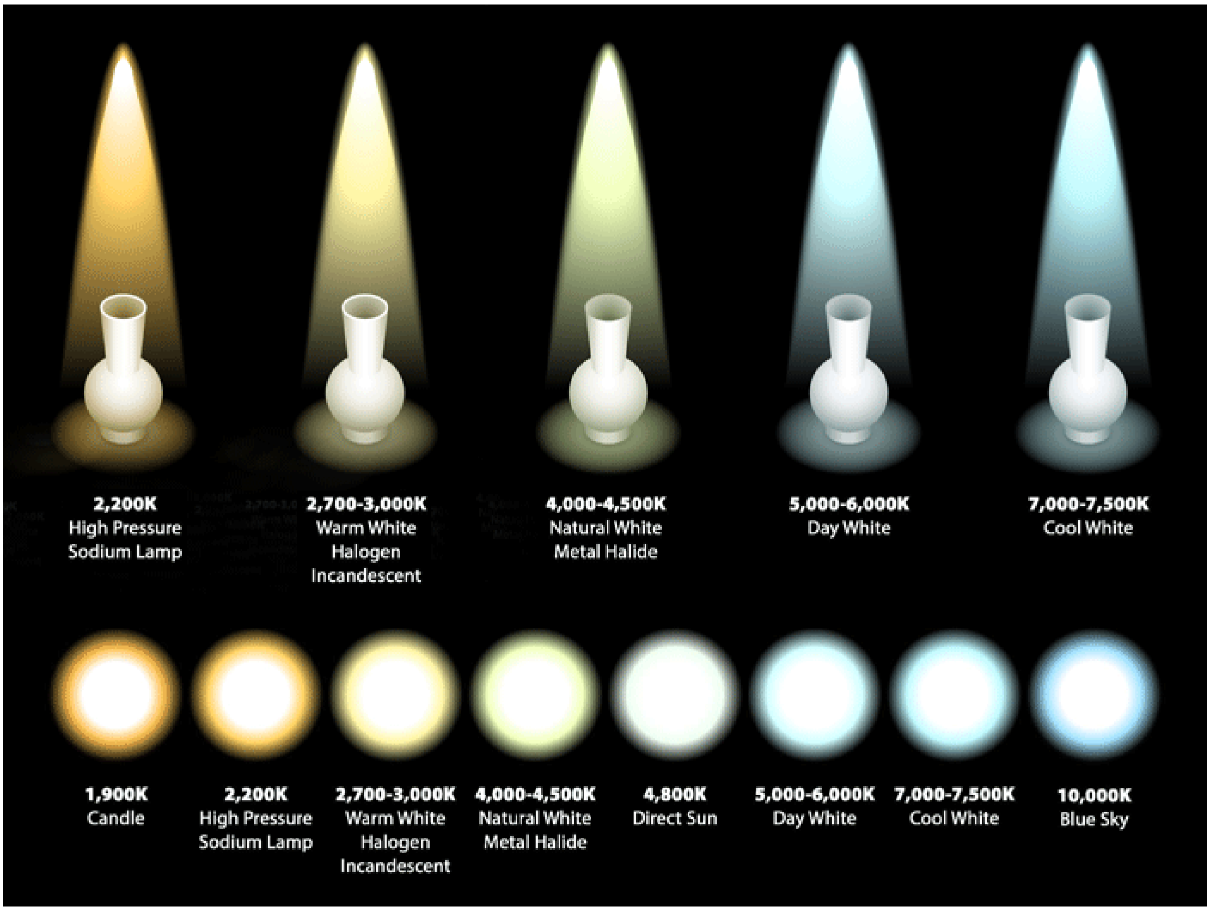


Figure 28 Illustration of colour temperature (taken from http://solutions.borderstates.com/color-temperature-and-led-understanding-how-to-choose-led-lamps-for-warm-and-cool-applications/ , accessed on 25 August 2016)

Colour Rendering Index (CRI)

The colour rendering index is a quantitative measure of the ability of a light source to reveal the colours of an object faithfully in comparison with an ideal or natural light source. For example, Low Pressure Sodium (LPS) lamps were historically often used in road lighting and they are monochromatic and thus have a close to zero colour rendering index. So far this has never resulted in complaints confirming the relative low importance of colour parameters for road lighting. High Pressure Sodium (HPS) lamps used for road lighting have typically a CRI of 25. HID lamps with high CRI are used in industrial and commercial indoor lighting and have different performance criteria in EC Regulation 245/2009 such as e.g. ceramic metal halide HID lamps

Also a high CRI and hence a broad spectral visible light emission does not align with the requirement to reduce the light ecological light pollution as discussed in section 2.4.1.6. For example in the Netherlands, amber LEDs are used in road lighting to avoid impact on bats[64].

At very low light levels colour vision can change. Photopic vision (CIE 1931) is the scientific term for human colour vision under normal lighting conditions during the day at high light levels. The human eye uses therefore three types of cones to sense light in three respective bands of colour. Scotopic vision (CIE 1951) is the scientific term for human vision in the dark. In that range, the human eye uses rods to sense light and

[64] http://www.rws.nl/wegen/wegbeheer/natuur-en-milieu/verbinden-natuurgebieden/vleermuisvriendelijke-verlichting/

therefore scotopic vision is colour blind. Mesopic vision is the scientific term for a combination between photopic and scotopic vision in low (but not quite dark) lighting situations. For road lighting due to the low light conditions often mesopic conditions are relevant. This is another reason why colour rendering is not seen as an important criterion in road lighting due to the low light conditions.

Colour tolerance

As an extra comfort requirement colour tolerances could be set for road lighting. The impact would be that the full series of road lights will have the same colour appearance. A unit for this is the 'Standard Deviation Colour Matching' (SDCM) (IEC 62717:2014).

4.4.3 Luminaires for road lighting

This section discusses luminaires and not the light source or control gear that are incorporated in these luminaires. Note that new luminaires including LEDs are sold and installed together with control gear and lamp - otherwise the lighting design calculation cannot be done. Lamps and control gear are usually repair components for road lighting luminaires.

4.4.3.1 Optical performance of a luminaire

In order to improve the energy efficiency and to reduce light pollution, the luminaires have to be designed and installed in order to limit the proportion of light being emitted above the horizon. Therefore, limits on upward light output ratio (RULO) are formulated in guide CIE 126:1997. The current GPP upward light output limits (GPP, 2012) seem to be sourced from the benchmark values in Annex VII in EC Regulation 245/2009 but are not identical. Nevertheless, one should take into account that in some urban applications the upward light serves to light buildings or trees as a decorative function. In the current criteria these luminaires are referred to as amenity lighting.

For a good lighting design that targets the light towards the intended road surface it is of primary importance to have an accurate photometric file. This will allow for an accurate lighting design calculation including installation efficacy parameters (see also section 4.4.4). For luminaires, it is imperative that local conditions of climate, geography as well as national legislation are taken into account in any procurement decision, as these conditions will affect the design, installation and operation parameters.

LED luminaires typically include glass envelopes, lenses, optical mixing chambers, reflectors and/or diffusers to obtain the desired light distribution. These features reduce the light output ratio RLO, which is an important metric for a luminaire. US DoE (DOE, 2016) reports a light utilization for LED luminaires of 85% in 2015 and projects to have light utilization of 90% for 2020. In a typical lighting system light losses occur because of a combination of light trapped in the luminaire, light absorption on surrounding surfaces and light directed to areas where it is not needed. There is a range of luminaires commercially available with significantly different optical properties which have a large impact on the efficiency of the overall lighting system. Inefficient luminaires may produce half as much light as highly efficient ones with the same lamps (Van Tichelen et al., 2007).

It should be noted that when calculating lighting design, LED luminaires start from absolute photometry data based on luminaire lumen that includes the light output ratio (RLO) and the control gear power efficiency (ηp) as illustrated in Figure 17. Because LED luminaires are becoming increasingly popular, setting minimum requirements for RLO is less relevant and it would be better to set minimum luminaire efficacy requirements, e.g. 105 lm/W such as Tier 2 in (IEA 4E, 2015). The market status for LED luminaires (including control gear and optics) is estimated (June 2016[65]) at 100 - 140 lm/W (for the

[65] http://www.lightingfacts.com/products

complete luminaire including lamps, control gear and optics) depending on the light distribution, colour temperature, colour coordinates and LED product quality.

4.4.3.2 Lifetime and maintenance of a luminaire (without light source and control gear)

The lifetime of the luminaire itself, i.e. the housing, cabling and optics, is usually not an issue, but the output of good quality light depends on design and maintenance.

The amount of dirt and water getting inside the luminaire should be reduced as much as possible and the luminaire's resistance to heat should be optimized as well. The resistance of the luminaire against dirt and water getting inside is described by the ingress protection (IP rating). It describes how well the luminaire performs against these environmental factors, including when they are repeatedly opened for lamp or control gear replacement. The exact definition of what the IP codes mean can be found in Annex 6.3.

During the lifetime of a lighting system, the luminaire itself contributes to a progressive decrease of the available light. The reduction rates are a function of time, environmental conditions and operating conditions. Lighting design takes this into account by the use of a maintenance factor FM (= FLM x FLLM x FLS) and a suitable luminaire cleaning schedule.

Cleaning of HID lamp luminaires is most often combined with group replacement of lamps, because these lamps lose light output over time (see section 4.4.2.3). The guide CIE 154:2003 on 'Maintenance of Outdoor Lighting Systems' contains luminaire maintenance factors (FLM) and cleaning schedules, for example:

- Open luminaires (IP2x): FLM = 0.5, medium pollution, 2 year cleaning cycle
- Closed luminaires (IP5x): FLM = 0.86, medium pollution, 2 year cleaning cycle
- Closed luminaires (IP6x): FLM = 0.89, medium pollution, 2 year cleaning cycle

A study in the UK (CSS, 2007) showed that these CIE 154:2003 values are conservative and can be improved (see Table 24). That study proposes to use pole height in combination with environmental zones of guide CIE 150 (with zone E1/E2 natural/rural surroundings and zone E3/E4 suburban/urban surroundings). Using these reviewed values will reduce over-lighting and over-dimensioning of new installations.

Table 24. Reviewed luminaire maintenance factors for IP6x road lighting luminaires (CSS, 2007)

Cleaning cycle	12 months	24 months	36 months	48 months
Zone and Mounting Height	**FLM**	**FLM**	**FLM**	**FLM**
rural/natural (E1/E2) 6m or less	0.98	0.96	0.95	0.94
rural/natural (E1/E2) >7m	0.98	0.96	0.95	0.94
suburban/urban (E3/E4) 6m or less	0.94	0.92	0.9	0.89
suburban/urban (E3/E4) >7m	0.97	0.96	0.95	0.94

4.4.3.3 Reparability

In view of a prolonged lifetime of a luminaire (and its components) it might be useful to be able to repair the luminaire easily. Some LED luminaires are designed to be repairable and some are not. Sometimes this is also called serviceability (LSRC, 2014).

- Non-repairable LED luminaires. If one part fails the entire unit no longer works. If a critical part fails or the light output falls below the needed light output, the entire luminaire has reached its end of life.

- Repairable LED luminaires. If a critical component of the luminaire fails, it can be replaced and the luminaire becomes operable again. Thus, if a LED power supply or LED array fails and it can be replaced, the luminaire becomes operative again. Therefore, the lifetime of a serviceable LED luminaire ends when a major mechanical or optical part fails that is not serviceable, or when replacement parts are no longer available, or when luminaires that are more energy efficient or have additional features and benefits can be economically justified to replace the current one.

Reparability does not preclude the use of reliability parameters. The replaceable components of a repairable product can still be classified according to provide an overall performance estimate of the luminaire product.

In practice reparability means that the luminaire can be opened by normal service tools and the control electronic can be unscrewed. The marginal cost is only a sealing and some screws and/or handles; but the luminaire needs to be designed for that.

4.4.4 Road lighting energy efficiency installation parameters

It is important in the design and installation phases that the correct lighting system is chosen for the intended application (see also section 2.1.3). Afterwards, a good road lighting designer will optimize the energy efficiency installation parameters (AECI [kWh/m²year], PDI [W/(lx.m²)]) and ηinst according to standard EN 13201-5:2015. In the AECI parameter all the projected savings for dimming can be integrated. PDI does not take dimming into account. Therefore it is recommended to use both values. Dimming that compensates for over-lighting and lumen maintenance is taken into account in the installation efficacy ηinst. The installation efficacy ηinst is an optional parameter to compare and understand alternative designs.

How these lighting system parameters are related to the previous lamp, ballast and luminaire parameters is illustrated in Figure 17.

Amongst others, the designer can optimize the Utilance (U) taking into account all lighting design parameters and will therefore look at the correct tilt angle, pole height, distance from the road and luminaire optics. As mentioned before, a luminaire photometric file is needed for this and calculations can be done with lighting design calculation software.

Finally, also a dimming and control strategy needs to be implemented. For road classes that are not yet specified at the lowest levels of illuminance or luminance in EN 13201-2:2016, dimming can make sense and should be considered for implementation because it will allow dimming to the minimum requirements (i.e. for M6, C5 and P6 road classes) whenever traffic and weather conditions allow this. Dimming is also useful to compensate for lamp and luminaire lumen maintenance factors (FLM, FLLM) and over-lighting. Therefore the standard defines a factor to compensate for over-lighting (CL) and for constant light output regulation (FCLO). The requirements of standard EN 13201-5:2015 are in 'maintained' illuminance or luminance meaning that there will be over-lighting in the beginning of their life in the case where there is no constant output regulation with dimming provided. Dimming can be modelled with a reduction factor (kred) and the corresponding time periods (tred, tfull).

The standard EN 13201-5:2015 contains reference values for AECI and PDI in its annexes and it defines several road profiles for that, e.g. road profiles A, B and E in Figure 29, Figure 30 and Figure 31.

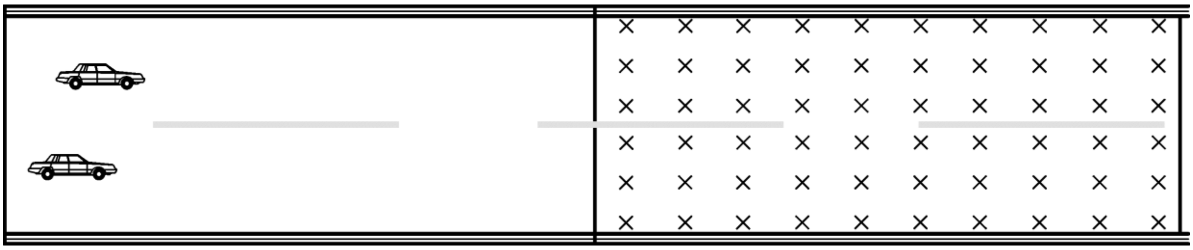


Figure 29 Two-lane road for motorized traffic (road profile A)

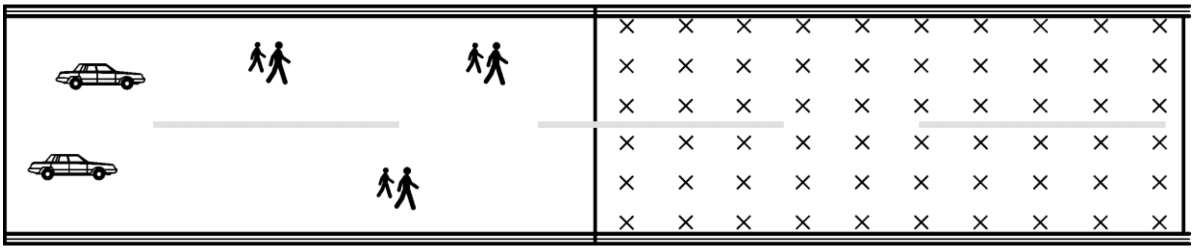


Figure 30 Road with mixed motorized and pedestrian traffic without sidewalks (road profile B)

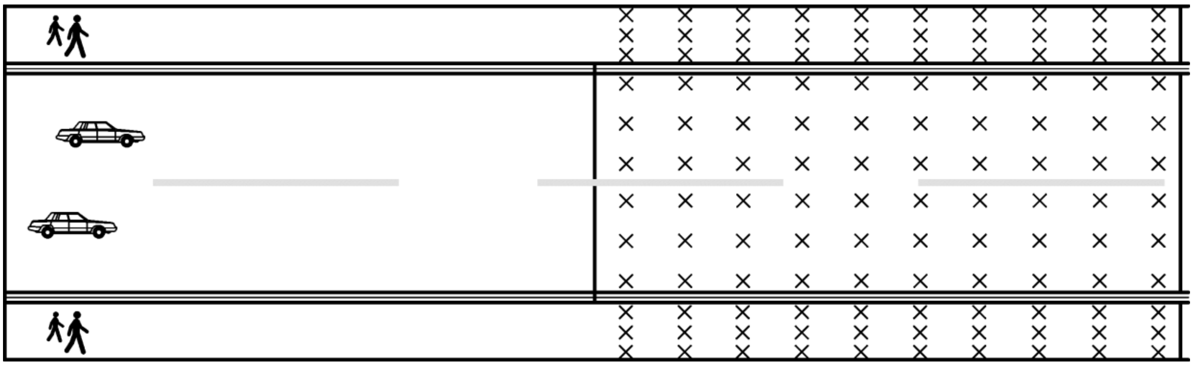


Figure 31 Road and two sidewalks on both sides (road profile E)

Table 25 and Table 26 contain typical values of PDI [mW/(lx.m²)] and AECI [kWh/m²year] based on EN 13201-5:2015. For these tables the following assumptions are made: 2m width of sidewalks, maintenance factor FM = 0.8, road reflection R3, optimized mounting height, optimized pole spacing, optimized arm overhang, no luminaire tilt and 4 000 burning hours per year. Calculations were based on lighting products (luminaires) available in the first quarter of 2014 (Q1/2014) and therefore they do not yet include the most recent LED luminaires anno 2016. More recent values and calculations are provided in the Technical Report, i.e. the report on the proposed GPP criteria with its rationale.

Table 25. Typical values in EN 13201-5:2015 of the Power Density Indicator PDI [mW/(lx.m²)] (anno Q1/2014)

road class	Width of carriageway	Lamp type				
	m	HPM	MH	HPS non-clear	HPS clear	LED
Typical road profile A for an M3 road, e.g. motorway						
M3	10	85	42	43	31 - 32	25 - 27
	8	83	42	40	30 - 33	27
	7	84	47	40	34 - 38	23 - 25
	6	103	51	43	40 - 44	25 - 28
Typical road profile B for a C3 road, e.g. secondary road in urban area						
C3	10	98	44	43	32	18 - 23
	7	92	51	39 - 45	35 - 41	24
	6	103	57	48	43	25 - 28
Typical road profile E for a M5/C5 road, e.g. residential area street						
M5/P5	7	63	22	33	28 - 32	17

Table 26. Typical values in EN 13201-5:2015 of the Annual Energy Consumption Indicator AECI [kWh/m²] (anno Q1/2014)

	Width of carriageway	Lamp type				
road class	m	HPM	MH	HPS non-clear	HPS clear	LED
Typical road profile A for an M3 road, e.g. motorway						
M3	10	6.0	3.4	3.0	2.3	1.6
	8	6.0	3.4	3.0	2.2 - 2.4	1.6
	7	6.0	3.6	2.8 - 3.1	2.5 - 2.6	1.5
	6	7.0	3.9	3.2	2.7 - 2.8	1.6
Typical road profile B for a C3 road, e.g. secondary road in urban area						
C3	10	6.0	2.7	3.1	1.9 – 2.0	1.1 - 1.4
	7	5.6	3.2	2.6 - 3.1	2.2 - 2.6	1.5 - 1.6
	6	6.3	3.8	3.0	2.6	1.6 - 1.8
Typical road profile E for a M5/C5 road, e.g. residential area street						
M5/P5	7	2.0	0.6	1.0	0.7 - 1	0.5

How the different components of the road lighting system can contribute to the AECI and PDI parameters is illustrated in Table 27. Note that these parameters just give an example and are illustrative of possible differences between HPS and LED light sources.

Table 27. Example overview of road lighting system component parameters contributing to the total road lighting energy efficiency parameters of EN13201-5:2015 (road class C3)

Lamp type	*Unit*	HPS	LED 2015
FLLM		0.95	0.90
ηp		0.90	1.00
ηls	*lm/W*	105	114
IP rating		66	66
FLM		0.82	0.89
FM		0.78	0.80
RULO		0.03	0.03
RLO		0.69	1.00
t full	*h/y*	2 000	2 000
t red	*h/y*	2 000	2 000
k red		0.70	0.70
FU		0.30	0.79
U		0.43	0.79
CL		0.67	0.70
CLO regulation	y/n	n	n
Fclo		1.00	1.00
ηinst	lm/W	14.8	50.9
DP (PDI)	W/(m².lx)	0.045	0.014
P luminaire	*W*	444	118
DE (AECI)	kWh/(m².y)	6.044	0.802
P per km road	W per km	17 778	2 360

4.5 LED traffic signals

4.5.1 Energy efficiency of LED traffic signals

The use of LEDs can be considered mainstream for traffic signals (DOE, 2016). The main progress for LEDs made in recent years is related to the invention and market introduction of white LEDs based on blue LEDs and white light conversion, but this is not very relevant for red/green/orange LEDs that were already on the market long time before. Therefore, LEDs for traffic signals are a mature technology and the current state of the art already allows operating wattages of a LED traffic signal head to be minimised down to 1-2W (Siemens, 2016).

Apart from the higher efficacy, also the longer LED lifetime is an important environmental benefit.

In the US, a minimum federal efficiency standard for traffic signals applies for traffic signals manufactured on or after January 1, 2006.[66] These minimum requirements are based on earlier Energy Star specifications which are suspended since May 2007 and are shown Table 28 together with efficiencies as found on the market and in the current GPP criteria. The wattage requirements in the table below are to be met by the individual traffic signal module and not only by the lamp.

[66] http://www.ecfr.gov/cgi-bin/text-idx?SID=b21ebe49c1882d3b7e090491715f4f7f&mc=true&node=sp10.3.431.m&rgn=div6#se10.3.431_1226 (accessed on 25 August 2016)

Table 28. Energy efficiency of traffic signal modules

Module Type	Nominal wattage (at 25°C)			
	US minimum requirements (since 2006)	Dialight,2009	GPP criteria (2012)	
			Core	Comprehensive
12" Red Ball	11	6	10	8
8" Red Bal	8	6	8	7.5
12" Green Ball	15	7	12	9.5
8" Green Ball	12	8	9	8
12" Yellow Ball	-	12	10	9
8" Yellow Ball	-	7	8	8
Combination Walking Man/Hand	13	7-8	-	-
Walking Man	9	6	-	-
Orange Hand	13	8	-	-

4.5.2 Smart traffic light

Traffic signals are installed at an intersection when traffic becomes too heavy to efficiently or safely assign the right of way of the road users. Their main function is the traffic control.

Generally, traffic signals operate in either pre-timed or actuated mode or some combination of the two (Koonce et al, 2008):

- Pre-timed control consists of a series of intervals that are fixed in duration, they are also called fixed-time signals. Collectively, the preset green, yellow, and red intervals result in a deterministic sequence and fixed cycle length for the intersection. In contrast to pre-timed control, actuated control consists of intervals that are called and extended in response to vehicle detectors. Detection is used to provide information about traffic demand to the controller. The duration of each phase is determined by detector input and corresponding controller parameters (Koonce et al, 2008).
- Actuated control can be characterized as fully-actuated or semi-actuated, depending on the number of traffic movements that are detected. An example of actuated control is reported in Figure 32.

Figure 32 summarizes the general attributes of each mode of operation to aid in the determination of the most appropriate type of traffic signal control for an intersection.

	Pre-timed		Actuated		
Type of Operation	**Isolated**	**Coordinated**	**Semi-Actuated**	**Fully Actuated**	**Coordinated**
Fixed Cycle Length	Yes	Yes	No	No	Yes
Conditions Where Applicable	Where detection is not available	Where traffic is consistent, closely spaced intersections, and where cross street is consistent	Where defaulting to one movement is desirable, major road is posted <40 mph and cross road carries light traffic demand	Where detection is provided on all approaches, isolated locations where posted speed is >40 mph	Arterial where traffic is heavy and adjacent intersections are nearby
Example Application	Work zones	Central business districts, interchanges	Highway operations	Locations without nearby signals; rural, high speed locations; intersection of two arterials	Suburban arterial
Key Benefit	Temporary application keeps signals operational	Predictable operations, lowest cost of equipment and maintenance	Lower cost for highway maintenance	Responsive to changing traffic patterns, efficient allocation of green time, reduced delay and improved safety	Lower arterial delay, potential reduction in delay for the system, depending on the settings

Figure 32 Relationship between intersection operation and control type (US. Department of Transportation, 2008)

Fixed-time signals are recommended in all downtown areas, central business districts, and urban areas in which pedestrians are anticipated or desired and speeds are intended to be low (NACTO, 2016). Fixed-time signals help make pedestrians an equal part of the traffic signal system by providing them with regular and consistent intervals at which to cross. They have lower initial and ongoing maintenance costs than actuated signals.

Actuated signal control differs from pre-timed in that it requires "actuation" by a vehicle or pedestrian in order for certain phases or traffic movements to be serviced. Actuation is achieved by vehicle detection devices and pedestrian push buttons. The most common method of detecting vehicles is to install inductive loop wires in the pavement at or near the painted stop bar. Video detection is also used at select locations. Actuated signals consist of two types: semi-actuated and fully-actuated. Use of semi- or fully-actuated signal operations should mainly be restricted to suburban arterials and rural roads. In suburban corridors, motorist compliance can be increased and delay reduced through use of actuation.

Another possibility, but more complex, for monitoring and controlling the traffic could be the introduction of intelligent transport system (ITS). EU Directive 2010/40/EU defines intelligent transport systems as "advanced applications which without embodying intelligence as such aim to provide innovative services relating to different modes of transport and traffic management and enable various users to be better informed and make safer, more coordinated and 'smarter' use of transport networks". This kind of system is however out of scope for this study.

5 Conclusions

The goal of this project is to update the GPP criteria for street lighting and traffic signals, with a high degree of leverage in procurement decision-making combined with a significant improvement potential for environmental performance.

The development of criteria for a greener public procurement requires in-depth information about the technical and environmental performance of street lighting and traffic signals, as well as the procurement processes. This report is considered the Preliminary report which is the basis for producing the Technical Report including draft criteria proposals. Both reports comprise the working documents for the 1st Ad Hoc Working group meeting which will be held on 22 November in Seville, Spain. The Technical Report will be revised in light of the output of this meeting.

Street lighting and traffic signals are well defined by their corresponding standards EN 13201 and EN 12368. *Street* lighting however is called *road* lighting in that standard. EN 13201 clearly describes the selection of the road lighting classes and the corresponding performance requirements. It should be noted however that the selection of the road lighting classes can be different per country according to specific circumstances regarding road layout and use, and the national approaches which can be based on tradition, climate or other conditions.

In section 3.3 the market data on stock and sales of road lighting are given. Different lamp technologies are used in the EU28, i.e. 53% high pressure sodium (HPS) lamps, 23% high pressure mercury (HPM) lamps, 6% low pressure sodium (LPS) lamps, 8% metal halide (HM) lamps, 6% fluorescent (FL) lamps and 4% LEDs. Note that HPM lamps were phased out in 2015 by ecodesign requirements.

The total annual volume of luminaire sales is forecasted from the installed stock (section 3.3.2) and the average lifetime (section 3.3.5). As presented in section 3.3.7, this results in a projected annual sales of 2.38 million road lighting luminaires for which the majority in replacement sales (2.16 million). With a typical luminaire price data of 220 euro, this represents an annual EU28 sales volume of 520 million euro. It should be noted that luminaire prices can vary strongly and especially new LED luminaires are substantially more expensive than 220 euro but their price is expected to decrease in the future.

A screening of LCA studies identified the main environmental hotspots in terms of environmental impacts and life cycle stages of the product. It shows that the energy consumption of the operational phase should be the focus of the environmental criteria for reducing the impact of the entire product. The second most significant life cycle stage regarding the environmental impacts is manufacturing. Moreover, it is clear that the importance of the manufacturing stage is going to increase if road lighting becomes more energy efficient and/or a low emission electricity mix is used. The lifetime of LEDs becomes relevant because of the higher influence of the manufacturing phase compared to more traditional light sources. Therefore, the most important parameters that have to be considered in the GPP criteria are the energy efficiency, durability and lifetime for both road lighting and traffic signals.

The life cycle assessment studies consider the impact generated at global level. However, there are a range of other environmental impacts that are not so easily defined or quantified by LCA. The main known non covered impact from road lighting is related to light pollution. Light pollution is defined in guideline CIE 126:1997 as a generic term indicating the sum-total of all adverse effects of artificial light. The aspects of light pollution discussed in the report are sky glow, obtrusive light, and ecological impact from outdoor lighting. These kinds of light pollution can be reduced through a combination of a correct luminaire choice and installation as well as a light source with a correct light (lumen) output

For traffic signals LED technology is rather mainstream nowadays while for road lighting applications LED technology is being introduced at the expense of other technologies such as high intensity discharge (HID) and metal halide (MH) lamps. In projects where new luminaires are installed LED is becoming mainstream technology as well.

The reason for a switch to LED technology is that LEDs outperform the other technologies in energy efficiency and lifetime. No frequent relamping is needed so additional saving potential on operational expenditures for LED luminaires can be expected

Converting to LED technologies in existing HID or CFL luminaires, and thereby saving energy, is not straightforward, because the HID and CFL luminaires (i.e. lamp, control gear or ballast, optics and housing) are rather specific per lamp technology. In most cases it would not be beneficial to only change the existing lamp with a LED module, but the whole luminaire, or at least the control gear, has to be replaced as well. Also due to the Regulation on CE marking (765/2008) such a luminaire conversion could require additional paperwork, e.g. related to the Low Voltage Directive (2014/35/EU) including safety certification, new documentation, new serial numbers, etc. Therefore, other costs than the energy cost should be taken into account on a case by case basis. It might even be possible that in case of switching to new technologies new lighting design parameters have to be calculated. The most important output parameters for such a calculation are the power density indicator (PDI) and the annual energy consumption indicator (AECI). The big advantages of these parameters are that they are technology independent and take dimming into account. The implementation of these design parameters should then be fulfilled by a correct installation of the components of the road lighting installation. Minimum energy and lifetime requirements of these components, i.e. lamps and luminaires, are in most cases regulated by ecodesign regulations which are currently under revision. Therefore, these components already perform on a high level. Moreover, little progress has been made in recent years with regard to HID lamp efficacy as the focus is on improving LED technology further.

Finally, road lighting is a complex system made of different components such as light sources, ballasts or control gear, luminaires, and sensors and controls. Next to the components, also the installation has to be considered together with the characteristics of the road. To guarantee that the road lighting system achieves a good environmental performance, criteria for the entire system must be defined with complementary criteria for single components.

6 Annexes

6.1 Annex A CEN and other standards

General overview of standards in the lighting industry. Note that not all standards are relevant for road lighting.

Reference	Title
Lighting in General	
EN 12665:2011	'Light and lighting - Basic terms and criteria for specifying lighting requirements'
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IEC 62321-4:2013	'Determination of certain substances in electrotechnical products - Part 4: Mercury in polymers, metals and electronics by CV-AAS, CV-AFS, ICP-OES and ICP-MS'
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FprEN 62776:2013 (under approval)	'Double-capped LED lamps for general lighting services - Safety specifications'
IEC/TR 62778: 2012	'Application of IEC/EN 62471 for the assessment of blue light hazard to light sources and luminaires (Technical report)'
prEN 62838:201X (under drafting)	'Semi-integrated LED lamps for general lighting services with supply voltages not exceeding 50 V a.c. r.m.s. or 120V ripple free d.c. - Safety specification'
FprEN 62868:2013 (under approval)	'Organic light emitting diode (OLED) panels for general lighting - Safety requirements'
CEN/TC 169, (WI=00169063) (under drafting, expected 2015)	'Eye mediated non visual effects of light on humans - Measures of neurophysiological and melanopic photosensitivity'
Emission aspects of Lighting	

EN 14255-1:2005	‘Measurement and assessment of personal exposures to incoherent optical radiation - Ultraviolet radiation emitted by artificial sources in the workplace’
EN 14255-2:2005	‘Measurement and assessment of personal exposures to incoherent optical radiation - Visible and infrared radiation emitted by artificial sources in the workplace’
EN 14255-4:2006	‘Measurement and assessment of personal exposures to incoherent optical radiation - Terminology and quantities used in UV-, visible and IR-exposure measurements’
EN 55015:2013 ; FprA1:2014 (under approval)	‘Limits and methods of measurement of radio disturbance characteristics of electrical lighting and similar equipment’
EN 55103-1:2009/A1:2012	‘Electromagnetic compatibility - Product family standard for audio, video, audio-visual and entertainment lighting control apparatus for professional use - Part 1: Emissions’
EN 55103-2:2009/IS1:2012	‘Electromagnetic compatibility - Product family standard for audio, video, audio-visual and entertainment lighting control apparatus for professional use - Part 2: Immunity’
EN 60335-2-27:2013	‘Household and similar electrical appliances - Safety - Part 2-27: Particular requirements for appliances for skin exposure to ultraviolet and infrared radiation’
EN 61000-3-2:2006 ; FprA3:2013 (under approval)	‘Electromagnetic compatibility (EMC) Limits. Limits for harmonic current emissions (equipment input current ≤ 16 A per phase)’
EN 61000-3-3:2013	‘Electromagnetic compatibility (EMC) - Part 3-3: Limits - Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems, for equipment with rated current <= 16 A per phase and not subject to conditional connection’
EN 61000-4-1:2007	‘Electromagnetic compatibility (EMC) - Part 4-1: Testing and measurement techniques - Overview of EN 61000-4 series’
EN 61000-4-6:2014	‘Electromagnetic compatibility (EMC) - Part 4-6: Testing and measurement techniques - Immunity to conducted disturbances, induced by radio-frequency fields’
EN 61000-4-15:2011	‘Electromagnetic compatibility (EMC) - Part 4-15: Testing and measurement techniques - Flickermeter - Functional and design specifications’
EN 61547:2009	‘Equipment for general lighting purposes - EMC immunity requirements’
EN 62493:2010	‘Assessment of lighting equipment related to human exposure to electromagnetic fields’
Colour and Colour Rendering	
CIE 013.3:1995	‘Method of measuring and specifying colour rendering properties of light sources’
CIE 015:2004	‘Colourimetry, 3rd edition’
CIE S004/E-2001	‘Colours of light signals’
CIE S 014-1/E:2006 (ISO 11664-1:2007)	‘CIE Standard Colourimetric Observers’
CIE S 014-2/E:2006/ (ISO 11664-2:2007(E))	‘CIE Standard Illuminants for Colourimetry’
CIE S 014-3/E:2011 (ISO 11664-3:2012)	‘Colourimetry - Part 3: CIE Tristimulus Values’
CIE S 014-4/E:2007 (ISO 11664-4:2008)	‘Colourimetry - Part 4: CIE 1976 L*a*b* Colour Spaces’

CIE S 014-5/E:2009 (ISO 11664-5:2009)	'Colourimetry - Part 5: CIE 1976 L*u*v* Colour Space and u', v' Uniform Chromaticity Scale Diagram'
ISO/CIE 11664-6:2014(E)	'Colourimetry – Part 6: CIEDE2000 Colour-Difference Formula'
CIE 177:2007	'Colour Rendering of White LED Light Sources'
IEC/TR 62732:2012	'Three-digit code for designation of colour rendering and correlated colour temperature'
Light Measurement and Photometry	
EN 13032-1:2004+A1:2012	'Light and lighting — Measurement and presentation of photometric data of lamps and luminaires — Part 1: Measurement and file format.'
EN 13032-2:2004/AC:2007	'Light and lighting - Measurement and presentation of photometric data of lamps and luminaires - Part 2: Presentation of data for indoor and outdoor work places.'
EN 13032-3:2007	'Light and lighting - Measurement and presentation of photometric data of lamps and luminaires - Part 3: Presentation of data for emergency lighting of work places'
prEN 13032-4:201X (under approval in 2014)	'Light and lighting - Measurement and presentation of photometric data - Part 4: LED lamps, modules and luminaires'
IES TM-25-13	'Ray File Format for the Description of the Emission Property of Light Sources.'
CIE 102:1993	'Recommended file format for electronic transfer of luminaire photometric data'
CIE S 010/E:2004 (ISO 23539:2005)	'Photometry - The CIE system of physical photometry'
CIE 018.2:1983	'The Basis of Physical Photometry, 2nd ed.'
CIE 041:1978	'Light as a true visual quantity: Principles of measurement'
CIE 043:1979	'Photometry of floodlights'
CIE 063:1984	'The spectroradiometric measurement of light sources'
CIE 067:1986	'Guide for the photometric specification and measurement of sports lighting installations'
CIE 070:1987	'The measurement of absolute luminous intensity distributions'
CIE 084:1989	'Measurement of luminous flux'
CIE 121:1996	'The photometry and goniophotometry of luminaires'
CIE 194:2011	'On Site Measurement of the Photometric Properties of Road and Tunnel Lighting'
Glare	
CIE 031-1976	'Glare and uniformity in road lighting installations'
CIE 055:1983	'Discomfort glare in the interior working environment'
CIE 112:1994	'Glare evaluation system for use within outdoor sports and area lighting'
CIE 117:1995	'Discomfort glare in interior lighting'
CIE 146:2002	'CIE Equations for Disability Glare'
CIE 147:2002	'Glare from Small, Large and Complex Sources'
CIE 190:2010	'Calculation and Presentation of Unified Glare Rating Tables for Indoor Lighting Luminaires'

Others	
prEN 50625-2-1 (under drafting)	'Collection, logistics & Treatment requirements for WEEE - Part 2-1: Treatment requirements for lamps'
EN 61995-1:2008	'Devices for the connection of luminaires for household and similar purposes - Part 1: General requirements'
EN 61995-2:2009	'Devices for the connection of luminaires for household and similar purposes - Part 2: Standard sheets for DCL'
HD 60364-7-715:2012	'Low-voltage electrical installations - Part 7-715: Requirements for special installations or locations - Extra-low-voltage lighting installations'
prHD 60364-7-719:2011 (under approval)	'Low-voltage installations - Part 7-719: Requirements for special installations or locations - Lighting installations for advertising signs with a rated output voltage not exceeding 1 000 V, which are illuminated by hot-cathode-fluorescent-lamps, luminous-discharge tubes (neon-tubes), inductive discharge lamps, light emitting diodes (LED) and/or LED modules'
EN ISO 24502:2010	'Ergonomics - Accessible design - Specification of age-related luminance contrast for coloured light (ISO 24502:2010)'
CIE 123:1997	'Low vision - Lighting needs for the partially sighted'
CIE 196:2011	'CIE Guide to Increasing Accessibility in Light and Lighting'

6.2 Annex B Technical parameters of lighting systems

6.2.1 General performance parameters used in lighting

This section describes general performance parameters used in lighting. Additional details on a framework for the specification of lighting requirements can be found in standard EN 12665:2011.

The primary performance parameter for a non-directional light source is luminous flux

Luminous flux is the measure of the perceived power of light. It indicates the particular light output of a lamp or lighting system and is measured in lumen (lm). One lumen is the luminous flux of light produced by a light source that emits one candela of luminous intensity over a solid angle of one steradian (sr). It is defined as the quantity derived from radiant flux Φe by evaluating the radiation according to its action upon the CIE standard photometric observer [1 lm = 1 Cd x sr], see **Figure 33**.

Figure 33 Luminous flux

The primary performance parameter for a directional light source is luminous intensity

Luminous Intensity (I) of a source in a given direction is the quotient of the luminous flux $d\Phi$ leaving the source and propagated in the element of solid angle $d\Omega$, the corresponding unit is a candela [Cd], see **Figure 34**.

Figure 34 Luminous intensity

The primary performance parameter for providing light in an installation is illuminance

Illuminance is the total luminous flux incident on a surface, per unit area. The SI unit for illuminance is lux [lx]. One lux equals one lumen per square metre, see Figure 35. For road lighting such requirements are defined in EN 13201-2:2016 especially for road classes C and P, see section 2.1.2.

Figure 35 Illuminance

The primary performance parameter for light emitted or reflected by an object is luminance

Luminance is a photometric measure of the luminous intensity per unit area of light travelling in a given direction. It describes the amount of light that passes through or is emitted from a particular area, and falls within a given solid angle. The SI unit for luminance is candela per square metre [cd/m²], see Figure 36. For road lighting such requirements are defined in EN 13201-2:2016 especially for road class M, see section 2.1.2.

Figure 36 Luminance

Setting lighting requirements on perceived colour is a secondary performance parameter

Perceived colour is defined as an attribute of visual perception consisting of any combination of chromatic and achromatic content. This attribute can be described by chromatic colour names such as yellow, orange, brown, red, pink, green, blue, purple, etc., or by achromatic colour names such as white, grey, black, etc., and qualified by bright, dim, light, dark, etc., or by combinations of such names. Primary parameters for specifying perceived colour requirements are general colour rendering index (CRI), correlated colour temperature (CCT) and chromaticity tolerances (SDMC) and chromaticity coordinates (CIE xy).

Setting requirements to prevent glare is also common practice and can provide important secondary performance parameters

Glare is defined as a condition of vision in which there is discomfort or a reduction in the ability to see details or objects, caused by an unsuitable distribution or range of luminance, or to extreme contrasts. Disability glare may be expressed in a number of different ways, for example by values of threshold increment (TI) as defined in standard CIE 31.

Important technical characteristics of the luminaires

With reference to IEC 62722-2-1 on 'Luminaire performance' important technical characteristics of the luminaire are: photometric code, rated input luminaire power (W), rated luminaire luminous flux (lm), luminaire luminous efficacy (lm/W), correlated colour temperature CCT (K), colour rendering index CRI (Ra 8) - initial/maintained, chromaticity tolerance (CDCM) - within steps of MacAdam ellipses - initial/maintained, rated life (h) and the related lumen maintenance factor (Lx), failure fraction (By) corresponding to rated life, useful nominal lifetime (LxBy/hours), rated ambient temperature (ta), luminous intensity distribution (cd/1000lm) and ingress protection (IPXX).

Electrical power

The electrical power is measured in Watt [W]. Part of the power input is transformed into useful light (visible radiation), while the rest is considered as loss (heat) and spilled light.

Energy consumption

The amount of electric energy consumed over a certain period is generally expressed in kWh (kilowatt–hours). For example a 100W high-pressure sodium (HPS) lamp consumes 1 kWh in 10 hours (10 hours × 100W = 1000Wh or 1 kWh).

6.2.2 Key functional paramaters for road and traffic lighting systems and components

In this section the principal parameters for road and traffic lighting are presented.

The principal design parameters which shall be considered when determining the lighting requirements are (according to standard EN 13201-2:2016):

- **Maintained level:** design level reduced by a maintenance factor to allow for depreciation.
- **Average illuminance, E [1 lx = 1 lm/m²];** horizontal illuminance averaged over a road area. It is a measure of how much the incident light illuminates the road surface, independent of the road reflection.
- **Semi-cylindrical illuminance, Esc [1 lx**]: total luminous flux falling on the curved surface of a very small semi cylinder divided by the curved surface area of the semi cylinder. The purpose is to identify faces at a distance. To permit this, semi-cylindrical illuminance needs to be at least 1 lux. Measurements are taken 1.5 metres above the ground. Semi-cylindrical illuminance for facial recognition can be a supplementary requirement to horizontal illuminance of the road surface.
- **Hemispherical illuminance, Ehs [1 lx**]: luminous flux on a small hemisphere with a horizontal base divided by the surface area of the hemisphere. Hemispherical illuminance, instead of horizontal illuminance, is mainly used in Denmark but not in other countries.
- **Average road surface luminance, L [1 Cd/m²]:** luminance of the road surface averaged over the carriageway. The ratio of the lowest to the highest road surface luminance found in a line in the centre along the driving lane is measured/modelled. The average road surface luminance is the lowest of the ratios determined for each driving lane of the carriageway. Luminance is thus an indicator of how bright the road surface will appear and will depend on the road reflection.
- **Threshold Increment, TI [%]:** percentage increase of contrast of an object that is needed to make it stay at threshold visibility in presence of disability glare generated by luminaires of a road lighting installation (calculated according to standard EN 13201-3). TI is a measure of the loss of visibility caused by the disability glare from the road lighting luminaires.
- **Longitudinal uniformity, Ul:** Ul is the ratio of the minimum to the maximum luminance along a line or lines parallel to the run of the road. It is mainly a criterion relating to comfort and its purpose is to prevent the repeated pattern of high and low luminance values on a lit run of road becoming too pronounced. It only applies to long uninterrupted sections of road.
- **Overall uniformity, Uo:** ratio of the lowest to the average luminance value. This criterion is important since it considers both the control of minimum visibility on the road and user comfort.
- **Edge illuminance ratio, EIR:** average horizontal illuminance on a strip just outside the edge of a carriageway in proportion to the average horizontal illuminance on a strip inside the edge, where the strips have the width of one driving lane of the carriageway.

Note that all previous design parameters can be calculated with lighting design software based on the photometric file of the luminaire. In many cases lighting design software also includes design optimization modules that verify various designs (luminaires, positions, etc.) and enable to look for the solution that best fits the criteria with a minimum energy use. Examples of such simulation software are Dialux Evo or Relux.

The principal energy performance parameters of road lighting installations are (according to standard EN 13201-5):

- **Annual Energy Consumption Indicator, AECI or PE [kWh/m²year]:** the estimated annual power consumption of the road lighting system. Note in this value the savings from dimming is included.
- **Lighting power density indicator, PDI or DP[W/(lx.m²) = W/lm]:** 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. This value does not include the savings from dimming systems neither its potential saving to compensate for over-lighting.
- **Installation luminous efficacy, ηinst [lm/W]:** the quotient of the functional lumen needed to satisfy the minimum illumination requirements versus the input power. This value takes into account over-lighting compared to the minimum requirements from EN 13201-2:2016.
- **Correction factor for over-lighting, CL**: ratio of the luminous flux just sufficient to comply with the lighting requirements received by the reference surface to the (actual) luminous flux received by the reference surface.
- **Utilization factor, FU:** ratio of the luminous flux received by the reference surface to the sum of the individual total fluxes of the lamps of the installation. Note that the UF is not only dependent on the luminaire itself but also on the accordance between the light distribution and the geometry of the surface to be lit and especially on the exact installation of the luminaire.
- **Utilance of an installation for a reference surface, U:** ratio of the luminous flux received by the reference surface to the sum of the individual total fluxes of the luminaires of the installation (according to IEC 50/CIE 17.4). This can be calculated with lighting design software. In street lighting the utilance is of particular importance, as it is a measure of the proportion of the light that is directed towards the area to be lit. However, not all light is directed to this area, as sometimes light is directed towards the sky and is wasted. Even the most efficient luminaires can lead to a waste of light when they are not properly used due to wrong tilt angle orientation or the optics used in the luminaire. Therefore proper lighting design and installation is important to obtain energy efficient street lighting;
- **tfull:** annual operating hours of the full level illumination;
- **tred:** annual operating time of the reduced level illumination;
- **kred**: power reduction coefficient for reduced level illumination. This can be deducted from comparing the reduced road class requirements with the highest road class according to EN 13201-2. For example when road class M2 (1.5 Cd/m²) is dimmed to M6 (0.3 Cd/m²) this is about 0.3/1.5 or 20 %.

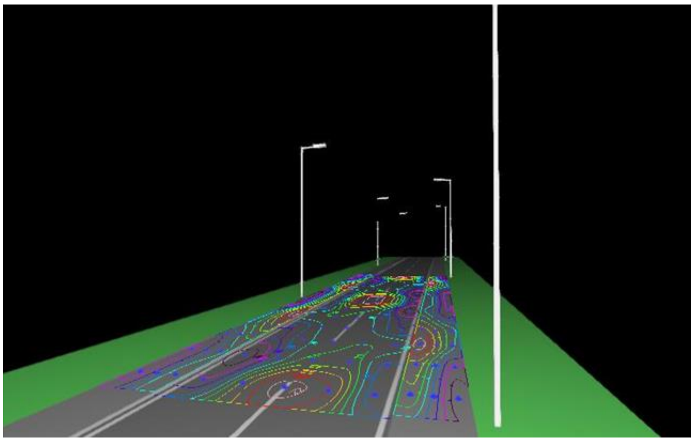

Figure 37 Utilance and other road lighting design parameters can be obtained from lighting design calculation software based on the photometric file of the luminaire[67]

The principal lamp/light source parameters are (according to standard EN 12665:2011):

- **Rated luminous flux, Φr [lm]:** value of the initial luminous flux of a given type of lamp declared by the manufacturer or the responsible vendor, the lamp being operated under specified conditions, usually at 100 hours of operation depending on the standard for this particular lamp type (see Annex A). This value can be used with the rated lamp power for calculating the lamp efficacy.
- **Nominal luminous flux, Φn [lm]:** a suitable approximate quantity value of the initial luminous flux of the lamp, usually used on the package and catalogue for reference purposes (e.g. 1000 lm). This value cannot be used for calculating the lamp efficacy.
- **Rated lamp power, P_r [W]:** value of the power consumed by the lamp for specified operating conditions. The value and conditions are specified in the relevant standard, usually at 100 hours of operation depending on the standard for this particular lamp type (see Annex A), This value can be used for calculating the lamp efficacy or other parameters (e.g. PDI).
- **Nominal lamp power, W_{lamp} [W]:** approximate wattage used to designate or identify the lamp, For example a lamp with nominal wattage of 70 W can have a rated wattage according to its standard of 71,7 W.
- **Luminous efficacy of a light source, , ηlamp [lm/W]:** quotient of the rated luminous flux and the rated power consumed by the light source.
- **Luminous efficacy of a light source used in the installation, ηls [lm/W]:** quotient of rated luminous flux and the rated power consumed by the light source excluding energy consumed by the gear and any other electrical devices (according to Annex B of prEN 13201-5).
- **Lamp Lumen Maintenance Factor, FLLM:** ratio of the luminous flux of the light source at a given time in its life and the initial luminous flux.
- **Lamp Survival Factor, FLS:** fraction of the total number of lamps which continue to operate at a given time under defined conditions and switching frequency. For example the switching cycle for HID lamps can be 1 hour off and 11 hours on depending on the requirements of the lamp standard (Annex A).

[67] Simulation done by Dialux Evo: www.dial.de

- **CIE general colour rendering index, CRI [Ra]:** mean of the CIE special colour rendering indices for a specific set of a test colour samples. 'a' indicates the number of colour samples the colour rendering index is based on, e.g. R8 or R20. It should be noted that the colour rendering index (CRI) is not included in the minimum lighting requirements for road lighting according to EN 13201-2:2016. It is per definition not important in M road classes, because they require the road luminance. In road classes C and M illumination levels are low and therefore colour perception is difficult and considered not relevant.
- **Chromaticity coordinates:** coordinates which characterise a colour stimulus (e.g. a lamp) by a ratio of each set of tristimulus values to their sum. The CIE defines different colour spaces with its own coordinates, for light sources the most common system is 'CIE xy' also known as 'CIE 1931 colour space'. This defines the colour which can be an important parameter for reducing light pollution, see 4.2.3.
- **Colour temperature, Tc [K]:** temperature of a Planckian (black body) radiator whose radiation has the same chromaticity as that of a given stimulus. Colour temperature (Tc) can have an impact on light pollution and is in this context a relevant parameter, see 4.2. Some users could also have a preference for warmer colour temperatures while others prefer cooler colour temperatures.
- **Correlated colour temperature, Tcp [K]:** temperature of a Planckian (black body) radiator whose perceived colour most closely resembles that of a given stimulus at the same brightness and under specified viewing conditions. The recommended method for calculation is included in CIE 15:2004.
- **Standard Deviation Colour Matching, SDCM (IEC 62717):** SDCM has the same meaning as a MacAdam ellipse. A 1-step MacAdam ellipse defines a zone in the CIE 1931 2 deg (xy) colour space within which the human eye cannot discern colour difference.

The principal parameters for defining control gear efficiency such as lamp ballasts, LED drivers and their controls are:

- **Maximum luminaire power, P_I [W]:** the luminaire power P_I shall be the declared circuit power of the luminaire when operating at maximum power. The value of P_I shall include the power supplied to operate all lamp(s), ballast(s) and other component(s) when operating at maximum power (according to EN 15193).
- **Additional power for controls: Pad[W]:** total active power of any devices not considered in the operational power P but necessary for operation of the road lighting installation.
- **Power efficiency of luminaires η_p: :** ratio between the power of the lamp(s) and the maximum luminaire power (according to Annex B of EN13201-5).
- **Ballast or driver efficiency, ηballast [%]**: ratio between the power of the lamp(s) and the input power.
- **Ballast or driver Reliability, BR**: The percentage of failed ballast per 1000h @70°C operating temperature.
- **Interface for dimming:** for example 0-10 V control signal or digital control interface such as DALI (Digital Addressable Lighting Interface) (IEC 62386-102:2014).
- **Lifetime:** a statistical measure (or estimate) of how long a product is expected to perform its intended functions under a specific set of environmental, electrical and mechanical conditions. Lifetime specifications can only describe the behavior of a population; any single product may fail before or after the rated lifetime.
- **Mean Time Between Failures (MTBF):** the average time between failures during useful life for repairable or redundant systems. For example a driver MTBF

of 100 000 hours means that over a 10-year (continuous) useful life period (= 87 600 hours), 87.6% of the units will likely fail and need to be replaced.

The principal parameters for defining road lighting luminaires are:

- **Luminous Intensity, I, of a source in a given direction, [Cd]:** ratio of the luminous flux dΦ leaving the source and propagated in the element of solid angle dΩ.
- **Photometric data file and/or polar intensity curve:** a file containing data on the distribution of luminous intensity relative to the light source, usually in Cd/1000 lm but can also be in absolute luminous intensity values [Cd], for different axial planes of the luminaire**.**
- **Light output ratio (of a luminaire), RLO**: ratio of the total flux of the luminaire, measured under specified practical conditions with its own lamps and equipment, to the sum of the individual luminous fluxes of the same lamps when operated outside the luminaire with the same equipment, under specified conditions.
- **Light output ratio working (of a luminaire), RLOw:** ratio of the total flux of the luminaire, measured under specified practical conditions with its own lamps and equipment, to the sum of the individual luminous fluxes of the same lamps when operating outside the luminaire with a reference ballast, under reference conditions.
- **Upward light output ratio (of a luminaire), RULO:** ratio of the upward flux of the luminaire, measured under specified practical conditions with its own lamps and equipment, to the sum of the individual luminous fluxes of the same lamps when operated outside the luminaire with the same equipment, under specified conditions.
- **Ingress protection code IP X1 X2:** ingress protection defines the protection of the light source inside the luminaire**.** X1 indicates the degree that equipment is protected against solid foreign bodies intruding into an enclosure, X2 indicates the degree of protection of the equipment inside the enclosure against the entry of various forms of moisture.
- **Luminaire maintenance factor, FLM:** defined as the ratio of the light output ratio of a luminaire at a given time to the initial light output ratio.
- **LED luminaire rated life, Lx;** length of time during which a LED module provides more than claimed percentage x of the initial luminous flux, under standard conditions (IEC 62717). LED modules lose some of their luminance over their service life. This process (known as degradation) is denoted by Lx.
- **LED luminaire gradual failure fraction, LxBy (IEC 62717):** the percentage (y of By) of LED luminaires that fall below the target luminous flux of x percent (x of Lx) at the end of their designated life. Gradual lumen loss refers to the LED luminaire or LED module and can occur as a result of a gradual decline in luminous flux or the abrupt failure of individual LEDs in the module. The By value is directly dependent on the L value and denotes how many modules (in per cent) are permitted to fall short of the Lx value.
- **LED luminaire catastrophic failure rate or abrubt failure fraction, LxCz (IEC 62717):** the percentage (z of Cz) of LED luminaires that have failed completely by the end of rated life 'Lx'. For example, when 0.2% of all LED modules will fail per 1 000 hours, it means that no more than 10% of all modules are permitted to fail after 50 000 hours.
- **LED luminaire failure fraction, LxFy (IEC 62717):** the percentage (fraction) of failures at the rated life of the LED luminaire. It is a combination of By and Cz.

This specification is mainly used in integrated LED lamps for the residential market, in the professional market more often both LxBy and LxCz are used.

- **Rated ambient temperature performance, tp (°C) (IEC 62717):** highest ambient temperature around the luminaire related to a rated performance of the luminaire under normal operating conditions, both as declared by the manufacturer or responsible vendor. Note that where a rated ambient performance temperature tp other than 25 °C is advised by the manufacturer a correction factor will need to be established to correct the measured luminous flux value at 25 °C to the luminous flux value at the declared ambient. This is usually done by relative photometry in a temperature controlled cabinet.

6.3 Annex C Ingress protection (IP) codes

Ingress protection is defined with a two digit code, e.g. IP65[68].

First digit: the first digit indicates the level of protection that the enclosure provides against access to hazardous parts (e.g., electrical conductors, moving parts) and the ingress of solid foreign objects.

Level	Object size protected against	Effective against
0	—	No protection against contact and ingress of objects
1	>50 mm	Any large surface of the body, such as the back of a hand, but no protection against deliberate contact with a body part
2	>12.5 mm	Fingers or similar objects
3	>2.5 mm	Tools, thick wires, etc.
4	>1 mm	Most wires, screws, etc.
5	Dust protected	Ingress of dust is not entirely prevented, but it must not enter in sufficient quantity to interfere with the satisfactory operation of the equipment; complete protection against contact
6	dust tight	No ingress of dust; complete protection against contact

Second digit: protection of the equipment inside the enclosure against harmful ingress of water.

Level	Protected against	Details
0	not protected	—
1	dripping water	Dripping water (vertically falling drops) shall have no harmful effect.
2	dripping water when tilted up to 15°	Vertically dripping water shall have no harmful effect when the enclosure is tilted at an angle up to 15° from its normal position.
3	spraying water	Water falling as a spray at any angle up to 60° from the vertical shall have no harmful effect.
4	splashing water	Water splashing against the enclosure from any direction shall have no harmful effect.
5	water jets	Water projected by a nozzle against enclosure from any direction shall have no harmful effects.
6	powerful water jets	Water projected in powerful jets against the enclosure from any direction shall have no harmful effects.
7	immersion up to 1 m	Ingress of water in harmful quantity shall not be possible when the enclosure is immersed in water under defined conditions of pressure and time (up to 1 m of submersion).
8	immersion beyond 1 m	The equipment is suitable for continuous immersion in water under conditions which shall be specified by the manufacturer. NOTE: Normally, this will mean that the equipment is hermetically sealed. However, with certain types of equipment, it can mean that water can enter but only in such a manner that produces no harmful effects.

[68] Taken from https://www.energystar.gov/ia/partners/downloads/meetings/lighting/2009/SSL-Overview_Questions_to_ask_your_LED_Fixture_provider-Riesebosch.pdf?5442-a1e8

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