European
Commission

JRC TECHNICAL REPORTS

Revision of the EU Green Public Procurement Criteria for Road Lighting

Technical report and criteria proposal (3rd draft)

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March 2018

EUR xxxxx xx

Joint
Research
Centre

This report has been developed in the context of the Administrative Arrangement "Development of implementation measures for SCP instruments (SUSTIM)" between DG Environment and DG Joint Research Centre. The project officer responsible for DG Environment was: Enrico Degiorgis.

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Abstract
The development of EU GPP criteria for road lighting aim to address the key environmental impacts associated with road lighting, respecting impacts that can be identified with LCA analysis and those which cannot. The criteria are set-up to ensure that the installation will be energy efficient, minimise adverse impacts associated with light pollution and guarantee the purchase of good quality, durable equipment that will last and be relatively straightforward to repair.
The implementation of these criteria should also help procurers understand better about the actual products they are procuring and to keep accurate information about their infrastructure (labels) and its performance (metering).

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1. Glossary

AC – Award Criteria
AECI – Annual Energy Consumption Indicator
AHWG – Ad Hoc Working Group
ALARA – As Low As Reasonably Achievable
CCT – Correlated Colour Temperature
CFL – Compact Fluorescent Lamp
CLO – Constant Light Output
CPO – Virtual Power Output
CPC – Contract Performance Clause
CRI – Colour Rendering Index
EIR – Edge Illumination Ratio
ENEC+ - European Norms Electrical Certification
HID – High Intensity Discharge
HPM – High Pressure Mercury
HPS – High Pressure Sodium
IP – Ingress Protection
IPEA – Parameterized Energy Index for Luminaires
IPEI – Parameterized Energy Index for Lighting Systems
ITT – Invitation To Tender
LCA – Life Cycle Assessment
LCC – Life Cycle Cost
LED – Light Emitting Diode
LPS – Low Pressure Sodium
LLMF/F_{LLM} – Lamp Lumen Maintenance Factor
LMF/F_{LM} – Luminaire Maintenance Factor
LSF/F_{LS} – Lamp Survival Factor
MH – Metal Halide
PDI – Power Density Index
RW – Road Width
SC – Selection Criteria
TR – Technical Report
TS – Technical Specification
ULOR/R_{ULO} – Upward Light Output Ratio / Ratio of Upward Light Output

2. Introduction

Public authorities' expenditures in the purchase of goods, services and works (excluding utilities and defence) constitute approximately 14% of the overall Gross Domestic Product (GDP) in Europe, accounting for roughly EUR 1.8 trillion annually (EC, 2016).

Thus, public procurement has the potential to provide significant leverage in seeking to influence the market and to achieve environmental improvements in the public sector. This effect can be particularly significant for goods, services and works (referred to collectively as products) that account for a high share of public purchasing combined with the substantial improvement potential for environmental performance.

Green Public Procurement (GPP) is defined in the Commission's Communication "COM (2008) 400 - Public procurement for a better environment" as "*…a process whereby public authorities seek to procure goods, services and works with a reduced environmental impact throughout their life cycle when compared to goods, services and works with the same primary function that would otherwise be procured.*"

Therefore, by choosing to purchase products with lower environmental impacts, public authorities can make an important contribution to reducing the direct environmental impact resulting from their activities. Moreover, by promoting and using GPP, public authorities can provide industry with real incentives for developing green technologies and products. In some sectors, public purchasers command a large share of the market (e.g. public transport and construction, health services and education) and so their decisions have considerable impact. In fact, COM (2008) 400 mentions that public procurement has the capability to shape production and consumption trends, increase demand for "greener" products and services and provide incentives for companies to develop environmental friendly technologies is clearly emphasised. Many examples of what is being done with GPP can be found online, for example at the Green Public Procurement in Action website or the GPP2020 Procurement for a low-carbon economy website.

GPP is a voluntary instrument, meaning that Member States and public authorities can determine the extent to which they implement it.

The development of EU GPP criteria aims to help public authorities ensure that the goods, services and works they require are procured and executed in a way that reduces their associated environmental impacts. The criteria are thus formulated in such a way that they can be, if deemed appropriate by the individual authority, integrated into its tender documents with minimal editing.

GPP criteria are to be understood as being part of the procurement process and must conform to its standard format and rules as laid out by Public Procurement Directive 2014/24/EU (public works, supply and service contracts). Hence, EU GPP criteria must comply with the guiding principles of: Free movement of goods and services and freedom of establishment; Non-discrimination and equal treatment; Transparency; Proportionality and Mutual recognition. GPP criteria must be verifiable and it should be formulated either as Selection criteria, Technical specifications, Award criteria or Contract performance clauses, which can be understood as follows:

Selection Criteria (SC): Selection criteria refer to the tenderer, i.e., the company tendering for the contract, and not to the product being procured. It may relate to suitability to pursue the professional activity, economic and financial standing and technical and professional ability and may- for services and works contracts - ask specifically about their ability to apply environmental management measures when carrying out the contract.

Technical Specifications (TS): Technical specifications constitute minimum compliance requirements that must be met by all tenders. It must be linked to the contract's subject matter (the 'subject matter' of a contract is about what good, service or work is intended to be procured. It can consist in a description of the product, but can also take the form of a functional or performance based definition.) and must not concern general corporate practices but only characteristics specific to the product being procured. Link to the subject matter can concern any stage of the product's life-cycle, including its supply-chain, even if not obvious in the final product, i.e., not part of the material substance of the product. Offers not complying with the technical specifications must be rejected. Technical specifications are not scored for award purposes; they are strictly pass/fail requirements.

Award Criteria (AC): At the award stage, the contracting authority evaluates the quality of the tenders and compares costs. Contracts are awarded on the basis of most economically advantageous tender (MEAT). MEAT includes a cost element and a wide range of other factors that may influence the value of a tender from the point of view of the contracting authority including environmental aspects (refer to the Buying Green guide (EC, 2016) for further details). Everything that is evaluated and scored for award purposes is an award criterion. These may refer to characteristics of goods or to the way in which services or works will be performed (in this case they cannot be verified at the award stage since they refer to future events. Therefore, in this case, the criteria are to be understood as commitments to carry out services or works in a specific way and should be monitored/verified during the execution of the contract via a contract performance clause). As technical specifications, also award criteria must be linked to the contract's subject matter and must not concern general corporate practices but only characteristics specific to the product being procured. Link to the subject matter can concern any stage of the product's life-cycle, including its supply-chain, even if not obvious in the final product, i.e., not part of the material substance of the product. Award criteria can be used to stimulate additional environmental performance without being mandatory and, therefore, without foreclosing the market for products not reaching the proposed level of performance.

Contract Performance Clauses (CPC): Contract performance clauses are used to specify how a contract must be carried out. As technical specifications and award criteria, also contract performance clauses must be linked to the contract's subject matter and must not concern general corporate practices but only those specific to the product being procured. Link to the subject matter can concern any stage of the product's life-cycle, including its supply-chain, even if not obvious in the final product, i.e., not part of the material substance of the product. The economic operator may not be requested to prove compliance with the contract performance clauses during the procurement procedure. Contract performance clauses are not scored for award purposes. Compliance with contract performance clauses should be monitored during the execution of the contract, therefore after it has been awarded. It may be linked to penalties or bonuses under the contract in order to ensure compliance.

For each criterion there is a choice between two levels of environmental ambition, which the contracting authority can choose from according to its particular goals and/or constraints:

> The **Core criteria** are designed to allow easy application of GPP, focussing on the key areas of environmental performance of a product and aimed at keeping administrative costs for companies to a minimum.
>
> The **Comprehensive criteria** take into account more aspects or higher levels of environmental performance, for use by authorities that want to go further in supporting environmental and innovation goals.

As said before, the development of EU GPP criteria aims to help public authorities ensure that the goods, services and works they require are procured and executed in a way that reduces their associated environmental impacts and is focused on the products' most significant improvement areas, resulting from the cross-check between the key environmental hot-spots and market analysis. This development also requires an understanding of commonly used procurement practices and processes and the taking on board of learnings from the actors involved in successfully fulfilling contracts.

For this reason, the European Commission has developed a process aimed at bringing together both technical and procurement experts to collate a broad body of evidence and to develop, in a consensus oriented manner, a proposal for precise and verifiable criteria that can be used to procure products with a reduced environmental impact.

This report presents the findings resulting from that process up to the 1st ad-hoc working group meeting that will be held in Seville on 22 November 2016. Consultation questions are integrated in the document and will serve for updating the document in a later stage of the project.

A detailed environmental and market analysis, as well as an assessment of potential improvement areas, was conducted within the framework of this project and was presented in the Preliminary Report on EU Green Public Procurement Criteria for road lighting and traffic signals. This report can be publicly accessed at the JRC website for road lighting and traffic signals. The main findings presented in the Preliminary Report are summarised in the next section.

Based on the findings from the Preliminary report, a first draft of the Technical report and criteria proposal was produced and presented at the 1st ad-hoc working group meeting held in Seville on 22nd November 2016. Apart from the comments received at this meeting, written feedback was conveyed by means of a written consultation and via a conference call specifically focussing on energy efficiency, light pollution and product lifetime criteria with the most active stakeholders in those areas. This second draft of the Technical Report and criteria proposals has been produced taking into account the input received in the course of this consultation process.

3. Summary of the Preliminary report

The Preliminary Report provides a general analysis of the product group in question, assessing the relevance of its scope and identifying the most relevant legislation, standards and definitions that apply. As part of the Preliminary Report, a market analysis is also conducted as well as an assessment of the main environment impacts associated with road lighting and the potential for technical improvements to reduce those impacts. These aspects ensure that the Preliminary Report forms the basis for the revision and development of EU GPP criteria in subsequent draft Technical Reports.

3.1. Scope and definitions

The scope of existing EU GPP criteria (published in 2012) for this product group covers two different types of lighting, namely "street lighting" and "traffic signals", whose definitions are linked to EN 13201 and EN 12368 respectively.

An initial scoping questionnaire was circulated to stakeholders at the beginning of the project. The majority of responses supported the removal of traffic signals from the scope based on the consideration that this would normally form a different subject matter in procurement contracts. With regards to the scope for street lighting, respondents generally agreed to link the definition to that of EN 13201-1. However, it was also mentioned that aspects relating to metering and dimming controls could be referred to, even though they are not explicitly included in the EN 13201 definition. Power cables and poles were not considered important and can continue to be excluded from the scope. One other comment was that the term "*road lighting*" should be used instead of "*street lighting*" in order to ensure better alignment with EN 13201.

A number of definitions were included in the Preliminary Report that are of high relevance to the product group and are summarised below:

a) **M class road areas:** for drivers of motorized vehicles on traffic routes, and in some countries also residential roads, allowing medium to high driving speeds (for EN 13201-1:2014 suggested associated light levels, see Figure 1).

b) **C class road areas:** for use in 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 (for EN 13201-1:2014 suggested associated light levels, see Figure 1).

c) **P class road areas**: 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. (for EN 13201-1:2014 suggested associated light levels, see Figure 1).

d) **Adaptive lighting**: temporal controlled changes in luminance or illuminance in relation to traffic volume, time, weather or other parameters (EN 13201-1:2014).

e) **Luminaire**: an apparatus which distributes, filters or transforms the light transmitted from one or more lamps and which includes, except the lamps themselves, all the parts necessary for fixing and protecting the lamps and, where necessary, circuit auxiliaries together with the means for connecting them to the electric supply (EN 12665:2011).

f) **Lamp:** 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.

g) **Light source:** 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.

h) **Light Emitting Diode (LED):** 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.

i) **LED package:** an assembly having one or more LED(s). The assembly may include an optical element and thermal, mechanical and electrical interfaces.

j) **LED module:** 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.

k) **LED lamp:** a lamp incorporating one or more LED modules. The lamp may be equipped with a cap.

l) **Ballast:** a device connected between the supply and one or more discharge lamps which serves mainly to limit the current of the lamp(s) to the required value

m) **Control gear:** 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, provide the necessary conditions for starting the lamp(s).

n) **Light pollution:** Several different definitions have been provide, including: (i) "*any adverse effect of artificial light including skyglow, glare, light trespass, light clutter, decreased visibility at night, and energy waste*", (Rajkhowa, 2014); (ii) "*the sum-total of all adverse effects of artificial light*" (CIE 126:1997); (iii) "*the introduction by humans, directly or indirectly, of artificial light into the environment*" (UNESCO, IAU and IAC);

3.2. Relevant standards

Road lighting and traffic signals are well defined by their corresponding standards EN 13201 series and EN 12368. Stakeholders expressed such strong opinions about the EN 13201 standard that it is considered worthwhile to add additional information relating to the standard here in this Technical Report, even though it was only provided after the Preliminary Report was published.

The technical report CEN/TR 13201-1:2014 gives guidelines on the selection of the most appropriate lighting class for a given situation. The standard only provides **recommendations** on road class definition and associated lighting levels - it is not legally binding. The choice of the lighting level is still in the authorities/technician's hands. In order to reduce light pollution the selection of the class shall be made by using the principle "*As Low As Reasonably Achievable*" (ALARA) at any moment of time.

The European standard EN 13201-2:2016 contains performance requirements (light level, uniformity, glare) for different classes (M1….M6, C1….C5, P1….P6). Herein, class M1 requires much higher light levels compared to class M6, see Figure 1.

Luminance		Illuminance			Illuminance		
							
= see road		= see objects			= see objects		
view point: car driver		view point: any			view point: any		
EN 13201	L,m	EN 13201	E,m	Emin	EN 13201	E,m	Emin
Class	Cd/m²	class	lx	lx	class	lx	lx
		C0	50				
M1	2	C1	30				
M2	1,5	C2	20				
M3	1	C3	15		P1	15	3
M4	0,75	C4	10		P2	10	2
M5	0,5	C5	7,5		P3	7,5	1,5
M6	0,3				P4	5	1
					P5	3	0,6
					P6	2	0,4
Mesopic vision(max)	0,1				Moonlight	0,3	

Figure 1. EN 13201-2 road classes and their required light levels and Mesopic vision boundary and maximum moonlight levels for comparison

In fact, the EN 13201 lighting levels in general are considered as very high by many stakeholders, especially for the higher class roads (i.e. M1 and C0). Concerns about these levels (and the associated extra electricity consumption and light pollution) led to the development of the national standard UNI 11248/2016 in Italy. The Italian standard recognises that the criteria used to define a road class (e.g. traffic volume) are not constant and so an allowance is made to reduce lighting levels by up to 4 classes (e.g. M1 → M5 or M2 → M6) in periods when the traffic flow is expected to be lower.

For reference, the light level of a full moon shining through a clear night sky is added. A number of stakeholders considered that a full moon level of luminance should be the target level, at least for C and P class roads, since it has been reported that pedestrians and cyclists can still navigate at this light level. Figure 1 shows that the lowest EN 13201 lighting level for P class roads is more than 6 times higher than the illuminance of a full moon.

EN 13201 Part 3 deals with calculation of performance, Part 4 contains methods of measuring lighting performance and Part 5 defines energy performance indicators that are presented later in proposed EU GPP criteria. The use of standardised calculations and methodology means that designs of different manufacturers are more comparable, which is essential for evaluating competitive offers in procurement.

When renovating, there is the risk that an EN 13201 light class is specified that is much higher than the lighting level that the existing installation delivers. Ideally, procurers should be fully aware of what level of light they actually want or need and should embrace the ALARA (As Low As Reasonably Achievable) principle when deciding on light levels.

3.3. Market analysis

The road lighting luminaire sector is a 520 million euro per year industry that provides lighting for some 1.5 million km of roads in the EU28 via an estimated 64 million luminaires. Around 2.38 million luminaires are sold each year in the EU28, with 2.16 million of those (91%) being for the replacement of existing luminaires. This demonstrates the mature nature of the road lighting sector in Europe and suggests a typical luminaire replacement rate of 29 years.

The split in lamp technology amongst existing luminaries on EU roads in 2015 was estimated as shown in Figure 2.

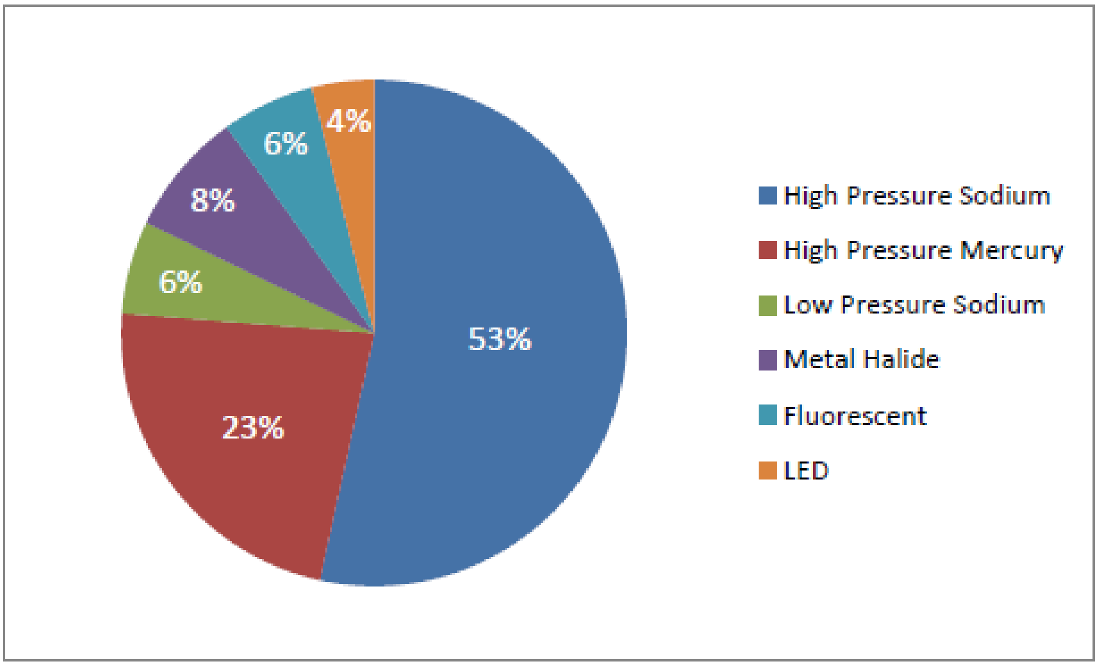


Figure 2. Estimated split of lamp technologies in EU28 road lighting in 2015

Luminaire prices can vary strongly and especially new LED luminaires are substantially more expensive than the average 220 euro, but the price of LED packages for use within luminaires has decreased significantly and is expected to continue decreasing in the future (see Figure 3).

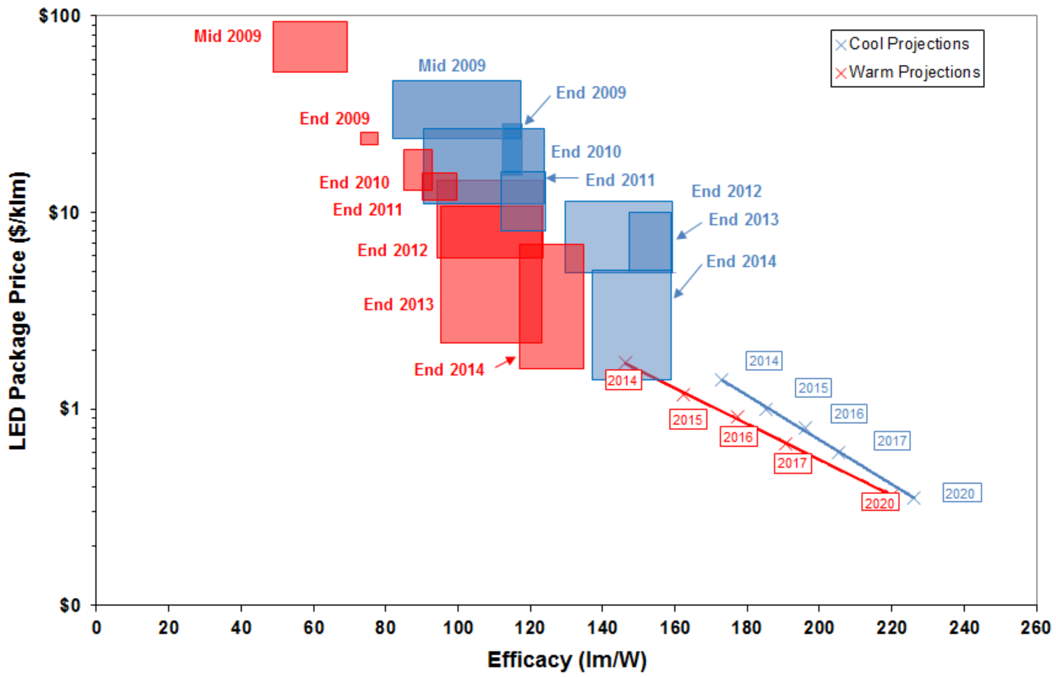


Figure 3. Price-efficacy trade-off for LED packages at 1 W/mm^2 (equiv. 35 A/cm^2) and 25°C (DOE, 2015).

The data in Figure 3 not only demonstrates the decrease in prices but also the increase in lumen efficacy, which will result in lower operating costs for a given necessary light output. However, in order to avoid unrealistic expectations about how low the cost of LED luminaires will become in the future, it is worth highlighting here that the LED package price only accounts for around 10-15% of the total cost of an LED luminaire.

When considering the split of lamp technologies in existing road lighting installations in Europe in 2015, shown in Figure 2, and how this split will look in the near future, there are three key points to consider:

- High Pressure Mercury lamps (HPM) have been phased out since April 2015 as per Regulation 245/2009, so this 23% share will eventually drop to 0%.
- 2015 was a breakthrough year for LED technology in road lighting applications. New sales of road lighting lamps and luminaires have since been dominated by LED technology and so the current 4% share will increase significantly in the next few years.
- Typical service lives of non-LED lamps are of the range of 2-4 years whereas LED lamps may last >15 years.

Consequently, it is widely accepted that LED technology will quite quickly become the dominant road lighting lamp technology in Europe.

3.4. Environmental analysis

3.4.1. LCA-modelled impacts

The environmental impacts associated with the road lighting installations have been investigated by conducting a review of relevant LCA studies published in the literature.

Despite the many nuances that apply to LCA studies, such as the appropriate choice of functional unit, scope and boundaries, assumed product lifetime, inventory data and the different impact categories that can be reported on, the literature was unanimous in showing that the use phase was the dominant source of all LCA impact categories as a direct result of electricity consumption. This is not surprising when it is considered that approximately 1.3% of all electricity consumed by the EU25 in 2005 (35 TWh) was by road lighting installations.

It was also 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. All LCA studies were done including assumptions on LED luminaire life time (>15 years). Therefore, the most important parameters that have to be considered in the GPP criteria are the *energy efficiency, durability and lifetime*.

3.4.2. Non-LCA-modelled impacts

The main "non-LCA-modelled" impact associated with road lighting is light pollution. While there are several different definitions of light pollution, it is clear that they all refer to unnatural light caused by anthropogenic activities. The potential adverse impacts of man-made light pollution can be split into the following:

- Skyglow, specifically man-made skyglow (as per CIE 126:1997) with particular importance given to light emitted between the horizontal and 10 degrees above the horizontal. Blue rich light scatters more in the night sky than red light and hence can contribute more to skyglow. Blue rich light has typically higher Correlated Colour Temperature.
- Obtrusive light (as per CIE 150:2003) that causes annoyance, discomfort glare or distraction glare which can affect residents in their homes, drivers trying to look ahead and drivers trying to read traffic signals.
- Ecological impact, in the sense that artificial lighting has been shown to affect a wide range of behavioural traits and biological processes including metabolism, foraging, displacement, reproduction, predator-prey dynamics and migrations, across a large number of taxa. The spectrum of the light (visible electromagnetic radiation) emitted may be important.

One key factor for combatting light pollution is to avoid over-lighting roads. A central concept to consider when a lighting level has been decided for a particular road section is that of "*As Low As Reasonably Achievable*" (ALARA) and this may include the possibility to dim lights during low traffic periods.

3.5. Technical analysis

A review of the key components and technology involved in road lighting installations was carried out and the main points are summarised below and are related to the main lamp technologies which are: LED (Light Emitting Diode); HID (High Intensity Discharge); MH (Metal Halide); HPS (High Pressure Sodium); HPM

(High Pressure Mercury); LPS (Low Pressure Sodium) and CFL (Compact Fluorescent Lamp).

3.5.1. Ballast/control gear/drivers

The purpose of ballasts and control gears is to limit the current supplied to the lamp – this is especially important for HID and LED lamps which cannot be directly connected to a 230VAC source. Ballasts or control gear can be of the magnetic or electronic type, with LED requiring the latter while HPS and MH lamps can use either. Electronic control gears can offer better power control and lamp ignition to HID lamps, which may be linked to improved lamp survival factors (LSF/F_{LS}) and lamp lumen maintenance factors (LLMF/F_{LLM}). However, the lifetime of magnetic ballasts is very long (30-50 years possible) whereas the failure of the weakest individual component in an electronic control gear (e.g. electrolytic capacitors) can bring about the abrupt failure of the lamp.

All ballasts for HID cause a loss of some power, which tends to be more significant when the rated lamp power is lower and when smaller loads are applied in dimmable lamps. Minimum ballast efficiencies have been set in the Ecodesign Regulation 245/2009 and also in the existing GPP criteria published in 2012.

3.5.2. Dimming and control systems

Dimming of light output will always reduce the energy consumption of a lighting installation although energy reductions are not perfectly proportional to light reductions because of standby power needs and the operation of control circuits.

It is possible to retrofit dimming systems between an LED module and its control gear. Besides the obvious benefits of reduced energy consumption, dimming controls allow greater flexibility to prevent over-lighting during certain periods of the night. Another possibility with dimming controls is to allow for overdesigned light sources to be used with initial dimming used to prevent overlighting which can gradually be reduced as the lumen output of the light source decreases with ageing. This is also often referred to as constant light output (CLO) control and/or virtual power output (VPO) control.

There are several different control systems available for dimming controls which can be linked to communication systems in what is a rapidly developing field. Taken to the extreme, dimming controls and two-way communication linked to other sensors at the individual luminaire level could play a vital role in intelligent lighting systems as part of smart city networks. It is also possible to have a local astronomical clock control circuit that sets a fixed curfew control cycle without the need for any communication system.

3.5.3. Lamps and light sources

The market analysis revealed the main lamp technologies used in road lighting (i.e. LED, HID, MH, HPS, HPM, LPS and CFL). The key technical considerations for a particular lamp or light source are:

- The luminous efficacy (i.e. light output divided by power consumption)
- The lamp survival factor (i.e. how many abrupt failures in a certain time)
- The lamp lumen maintenance factor (i.e. gradual reduction of light output with ageing of the light source).

Other considerations relate to the colour rendering index and the correlated colour temperature of a lamp but these will be presented in more detail as supporting rationale and background research for proposed light pollution criteria later in this report.

3.4.3.1 Luminous efficacy (η)

The luminous efficacy of light sources tends to increase as the lamp rated power increases. However, while this relationship is clear for HPS lamps, it is only partially true for LED lamps. Regulation (EC) No 245/2009 sets minimum luminous efficacy requirements as a function of (i) lamp technology, (ii) nominal lamp wattage and in some cases (iii) if the lamp is "clear" or not (i.e. if frostings or coatings are used to reduce glare) and (iv) the colour rendering index (Ra).

The existing GPP criteria published in 2012 follows the same approach as the requirements of Regulation (EC) No 245/2009 by setting minimum luminous efficacy requirements in core and comprehensive criteria.

When comparing discharge lamp technologies for luminous efficacy, LPS performs very well with 140-170 lm/W (for rated power of 26-66W), CFL produces around 81 lm/W (for a rated power of 36W) and HPM lamps produced only 51 lm/W (for a rated power of 250W).

LED can be considered to perform well in comparison to discharge lamp technologies, with efficacies of 100-175 lm/W for lamps and 100-140 lm/W when considering control gear and optical losses. However, there are also poor examples of LED lamps on the market where the luminous efficacy can be as low as 50 lm/W. One possible reason for this was cited as the reuse of LED chips that had been rejected from high level performance group production lines. Such concerns lend greater value to quality monitoring schemes for LED products like ENEC+ (an independent and pan-European thirs party certification scheme jointly developed by LightingEurope and the ENEC Mark for the verification of LED-based products). Further advances in LED efficacy can be expected to continue in the near future. A theoretical maximum efficacy of around 300 lm/W for white light is achievable with LED and it would not be unrealistic to expect future road lighting installations to be equipped with luminaires delivering light with an efficacy of >200 lm/W.

3.4.3.2 Lamp Survival Factor (LSF/F_{LS} for HID lamps, LxCz for LED lamps)

The terms in the title above refer to the abrupt failure of light sources. Survival factors are expressed as decimals (e.g. 0.8 = 80% and 0.99 = 99%) of units "surviving" after a defined time period. It should be noted that an operating period of 1 year for road lighting typically corresponds to 4000h.

Regulation (EC) No 245/2009 sets minimum LSFs for MH (0.8 at 12000 hours) and HPS (0.9 at 12000 hours or 16000 hours depending on the rated wattage). Current BAT is estimated to greatly exceed these minimum requirements (i.e. 0.99 at 16000 hours for both MH and HPS).

For LED technology the term LxCz is used instead of LSF/F_{LS}. The LxCz term is also linked to a defined time (the abrupt failure fraction as per IEC 62717). A value of L0C10 at 60000h would mean that after 60000 hours of use, 10% of the light sources have failed.

Actual LxCz values for the survival of LED lamps are difficult to predict due to the rapidly developing nature of the technology but in general, LED lamps survive considerably longer than other technologies. This has meant that predictions of LED survival have to be based on extrapolations of test results and should not be considered independently of failure of other components (i.e. control gear components).

3.4.3.3 Lamp Lumen Maintenance Factor (LLMF or F_{LLM} for HID lamps, LxBy for LED lamps)

The terms in the title above refer to the gradual decrease in light output as the light source ages. With the LLMF/F_{LLM} term, values are expressed as a decimal (e.g. 0.8 = 80%) and linked to a specific operating time. A LLMF/F_{LLM} value of 0.85 after 16000 hours means that the light output has decreased by 20% after 16000 hours operation purely due to ageing of the light source.

With LED technologies, the term LxBy is used instead of LLMF/F_{LLM} and is also linked to a defined operating time. A value of L70B10 at 50000h means that after 50000h of operation, 10% of the LED light sources will fail to meet 70% of the initial light output.

3.5.4. Luminaires and Luminaire Maintenance Factor (LMF or F_{LM})

The luminaire is the collective housing for all lamps and light sources, together with any necessary control gear and connections. The luminaire will last longer than any of the components it houses (with the possible exception of magnetic ballasts).

The two primary functions of the luminaire are to (i) distribute the light from the lamp(s) in a manner that fits the lighting installation design needs and (ii) to protect the lamp(s) from potentially damaging external environments (e.g. water ingress and dirt).

The light distribution from a luminaire can be adequately assessed by the provision of a full photometric file. The ability of the luminaire to protect its contents from the environment can be assessed by a standard methodology that results in an "Ingress Protection" (IP) rating being provided (see Annex 5.3 of Preliminary Report for more details).

Luminaires will gradually build up a layer of dust or dirt on its housing which will restrict light output efficacy. With normal discharge lamp technologies, because the lamp needed to be replaced every 2-4 years, cleaning was normally carried out in conjunction with lamp replacement. However, with longer lasting LED lamps, dedicated cleaning cycles will need to be somehow incorporated into the maintenance schedule.

This luminaire pollution effect is taken into account with the Luminaire Maintenance Factor (LMF or F_{LM}) (CIE 154), frequent cleaning and a high IP rating will help to maintain the light output and also results in energy saving. Finally, the Maintenance Factor (MF or F_M) for road lighting is a combination of the lamp maintenance factor F_{LLM} and luminaire maintenance FLM (F_M=F_{LLM}xF_{LM}) (CIE 154).

One key aspect to consider is the reparability (or serviceability) of an LED luminaire. The primary distinction between a repairable and non-repairable LED luminaire is the ability to open the luminaire with normal service tools and to remove and replace electronic components and the lamp itself.

4. Summary of main changes from previous TRs

The purpose of this section is to explain to readers how the draft Technical Report (TR) has evolved during this revision project.

Table 1. Comparison of criteria structure in TRs 1.0, 2.0 and 3.0.

TR 1.0	TR 2.0	TR 3.0
	Road lighting	**Road lighting**
Design stage	**Selection criteria**	**Selection criteria**
SC – Competencies of the design team	SC1 – Competencies of the design team	Same as TR2.0
TS1 – AECI and PDI	SC2 – Competencies of the installation team	Same as TR2.0
TS2 – Light pollution	CPC1 - Assurance of adequately qualified staff responsible for project	Same as TR2.0
AC1 Life Cycle Costing	**Energy efficiency**	**Energy efficiency**
AC2 - Metering	TS1 – Luminaire luminous efficacy	Same as TR2.0
Installation stage	AC1 – Enhanced luminaire luminous efficacy	Same as TR2.0
SC - Competencies of the installation team	CPC2 - Provision of originally specified lighting equipment	Same as TR2.0
TS – Provision of instructions	TS2 – Dimming control capability	Same as TR2.0
CP1 – Putting into service of lighting systems and controls	TS3 – Minimum dimming performance	Same as TR2.0
CP2 – Correct installation	CPC3 – Dimming Controls	Same as TR2.0
CP3 – Reduction and recovery of waste	TS4 – PDI	Deleted
Road lighting equipment	TS5 – AECI	Same as TR2.0
TS1 – Efficacy and lifetime of luminaires	AC2 – Enhanced AECI	Same as TR2.0
TS2 – Compatibility with dimming and other controls	TS6 – Metering	Same as TR2.0
TS3 – Product lifetime extension	CPC4 - Commissioning and correct operation of lighting controls	Same as TR2.0
TS4 - Reparability	CPC5 - Provision of originally specified lighting equipment	Same as TR2.0
TS5 – Ingress protection	CPC6: Compliance of actual energy efficiency and lighting levels with design claims	Same as TR2.0
Light sources	**Light pollution**	**Light pollution**
TS1 - Efficacy and lifetime of light sources	TS7 – Ratio of Upward Light Output	Same as TR2.0 plus flux code requirement
TS2 – Failure rate of control gear	TS8 – Ecological light pollution and annoyance	Same as TR2.0 plus C-Index requirement
	Lifetime	**Lifetime**
	TS9 – Provision of instructions	Same as TR2.0
	TS10 – Waste recovery	Same as TR2.0
	CPC7 – Commitment to waste recovery and transport to suitable sites	Same as TR2.0
	TS11 – LED lamp product lifetime, spare parts and warranty	Same as TR2.0
	AC3 – Extended warranty	Same as TR2.0
	TS12 - Reparability	Same as TR2.0
	TS13 – Ingress Protection (IP rating)	Same as TR2.0
	TS14 – Failure rate of control gear	Same as TR2.0
		TS14 – Labelling of LED luminaires
		CPC8 – Labelling of LED luminaires
Traffic signals	**Traffic signals**	**Traffic signals**
TS1 – Efficacy and lifetime of traffic signal modules	TS1 – Life Cycle Cost	Same as TR2.0
	AC1 – Lowest Life Cycle Cost	Same as TR2.0
	TS2 – Warranty	Same as TR2.0
	AC1 – Extended warranty	Same as TR2.0

From TR 1.0 to TR 2.0

The main differences between TR 1.0 and TR 2.0 can be explained both at the level of the criteria structure and at the level of the criteria content.

In TR 1.0, criteria were grouped by project stage (e.g. design, installation, lighting equipment etc.) whereas now they are grouped by criteria area (i.e.

selection criteria, energy efficiency, light pollution and lifetime). The change in restructuring can be easily understood by looking at Table 1.

The scope was reworded to specifically exclude certain applications such as tunnel lighting and car parks, which are covered by specific technical standards.

With selection criteria, the main change was that requirements were detailed better in TR 2.0 and set to apply to the person from the contractor who signs off the project (i.e. takes responsibility). It was considered unfair to set minimum requirements for all staff working for the contractor as it would limit opportunities for new staff to get involved. A CPC was inserted to make sure that the competencies are actually available within the contractor team to cover cases when staff changes between the award of the contract and execution of the works may occur.

The approach to PDI and AECI was completely reworked and a new way of linking luminaire efficacy, maintenance factor and utilance was established that would allow for a simplified calculation of PDI. No actual reference values were set for PDI as it was left up to the procurer to define this (it would be influenced by factors such as road width and luminaire efficacy).

For luminaire efficacy, the major change was to move away from a single fixed value to a reference value that would be raised every 2 years in order to reflect the continuing improvements in LED luminaire efficacies.

With regards to light pollution, in TR 1.0 requirements were set for RULO <1% and, for comprehensive level, that CCT would be <3000K and CRI <70. In TR 2.0, the RULO requirements were tightened to 0% and CCT was set at <3000K (core) or <2700k (comprehensive). Furthermore, a limit of blue light output was set for the comprehensive criterion. A greater emphasis on dimming was evident in TR 2.0 by not just requiring compatibility with dimming but to actually install dimming controls (except under limited circumstances).

With lifetime criteria, the warranty of 10 years set out as a TS in TR 1.0 was split into a shorter warranty TS in TR2.0 but complemented by an AC for warranty – which would allow those producers offering longer warranties to be more competitive.

The award criterion for life cycle costing was removed because, depending on how financial offers are submitted, it could result in double rewarding of the cheapest offer. In any case, it is recommended that the basis for any investment in lighting installations should be supported by a strong case for delivering lower life cycle costs than a business as usual scenario.

From TR 2.0 to TR 3.0

The main differences between TR 2.0 and TR 3.0 were related to the nuancing of ambition levels for luminaire efficacy (lower ambition level for low power LED luminaires), the removal of a dedicated criterion for PDI (now simply a table of reference PDI values is provided), a new requirement for CIE flux code #3 being at least 95 (to encourage better luminaire shielding that reduces risk of glare and skyglow and may improve the actual maintenance factor) a different requirement relating to blue light content (the C-Index is proposed because CCT is not a perfect measure of blue light) and the requirement for labelling of LED luminaires (to ensure that public authorities can keep track of installed LED infrastructure as the technology continues to evolve rapidly).

5. Scope of criteria

The proposal for the scope of the product group in versions 1.0 and 2.0 are compared with a modified proposal for this report (TR 3.0) in Table 2 below.

Table 2. Scope for existing EU GPP criteria

Road lighting and traffic signals	Road lighting
Technical report 1.0 (October 2016) **Road lighting**: fixed lighting installation intended to provide good visibility to users of outdoor public traffic areas during hours of darkness to support traffic safety, traffic flow and public security according to standard EN 13201-2 road classes 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” **Traffic signals**: red, yellow and green signal lights for road traffic with 200mm and 300mm roundels according to EN 12368. Portable signal lights are specifically excluded.	
Technical Report 2.0 (July 2017) **Road lighting:** In accordance with EN 13201-2, the term road lighting refers to fixed lighting installations intended to provide good visibility to users of outdoor public traffic areas during hours of darkness in order to support traffic safety, traffic flow and public security. Specifically excluded are lighting installations for tunnels, toll stations, canals and locks, parking lots, commercial or industrial sites, sports installations, monuments and building facades. **Traffic signals**: red, yellow and green signal lights for road traffic with 200mm and 300mm roundels according to EN 12368. Portable signal lights are specifically excluded.	
Technical Report 3.0 (March 2018) **Road lighting:** The scope of these criteria covers the procurement of lighting equipment for road lighting in new lighting installations, for retrofitting of existing lighting installations, or the replacement of light sources, lamps or luminaires on a like-for-like basis in existing lighting installations. In accordance with EN 13201-2, the term road lighting refers to fixed lighting installations intended to provide good visibility to users of outdoor public traffic areas during hours of darkness in order to support traffic safety, traffic flow and public security. Specifically excluded are lighting installations for tunnels, toll stations, canals and locks, parking lots, commercial or industrial sites, sports installations, monuments and building facades. **Traffic signals**: red, yellow and green signal lights for road traffic with 200mm and 300mm roundels according to EN 12368. Portable signal lights are specifically excluded.	

The scope of these criteria covers the procurement of lighting equipment for road lighting in: new lighting installations, for retrofitting of existing lighting installations, or the replacement of light sources, lamps or luminaires on a like-for-like basis in existing lighting installations.

By referring to EN 13201-2 in the product group scope, it is implied that all of the road classes defined therein are included. The standard splits roads into three broad classes (M, C or P) and grades (e.g. M1-M6, C0-C5 and P0-P5) based on the main types of road user, the volume of traffic, speed limits for vehicles and road geometries.

Stakeholder discussion

Initial stakeholder input was received in the form of responses to the initial scoping questionnaire. Some of the main findings were:

Table 3. Summary of responses from questionnaire (16 responses)

Scoping question	Yes	No	No opinion
Should the scope continue to be aligned with EN 13201?	9.5	5.5	1
Should the scope continue to include traffic signals?	4	4	8
Should there be specific criteria for LED retrofit situations?	10	6	0
Should there be criteria for poles?	3	12	1
Should there be criteria or power cables?	1	11	4
Should there be criteria for metering or billing?	10	5	1
Should there be specific criteria for LED luminaires?	15	1	0

A minority of stakeholders wanted to extend the scope of the product group beyond EN 13201 to include other applications such as parking lots and other areas in commercial and industrial zones. However, when discussing issues such as the calculations for PDI and AECI values for energy efficiency, it quickly became apparent that it would be complicated to set particular ambition levels for energy efficiency for these types of lighting installations.

Some stakeholders criticised the alignment with EN 13201 in the scope because they felt that the standard encourages over-lighting of roads when compared to current typical practice in many EN Member States. However, JRC emphasised that the alignment of the scope with EN 13201-2 does not in any way imply that the EN 13201-1 guidance for setting lighting levels for each road class are to be followed or complied with by procurers who wish to apply the EU GPP criteria. EN 13201-1 simply provides guidance for how to define what class of road you have and then suggests minimum lighting levels for each road class. The choice of lighting levels is ultimately up to the procurer and will be influenced by local, regional or national planning rules. Lighting levels will always be nuanced by site specific factors such as the need for vertical lighting and facial recognition, pole heights, the use of decorative luminaires in residential areas and historical areas and the potential for obtrusive light. The JRC encourage that procurers wishing to follow the EU GPP criteria follow the ALARA (As Low As Reasonably Achievable) principle when deciding on required lighting levels.

Most respondents had no opinion on whether to include traffic signals in the scope or not. All specific comments from respondents on this matter are presented below:

Table 4. Comments about traffic signals received from respondents

For traffic signals in scope	Against traffic signals in scope
Yes, sadly, there still seems to be a market for halogen traffic signals among municipalities, perhaps due to controls or some other factor. This also allows for a detailed review and further improvement in the criteria, including for example efficacy, materials, lifetime and so-on which would no longer be addressed if they were taken out of scope.	I would remove traffic signals as street lighting is quite different area.
	Yes, it would be better to have specifications for street lighting in one (standing alone) document because of different technical system.
	Too many documents will increase the complexity and make it harder to keep the document actual.

Discussions with stakeholders during the project so far have revealed that experience of the group is almost exclusively with road lighting applications instead of traffic signals. While it was quite clear that traffic signals is a separate area of expertise from road lighting and that the background research for one is not automatically valid for the other, the impacts associated with energy consumption of traffic signals was not insignificant (see C4O cities and COMPETENCE references). This fact, coupled with the knowledge that there is no other product group where traffic signals would be included in the foreseeable future led to the decision to keep traffic signals in the scope..

Other feedback revealed that there was a strong demand for criteria specifically about LED luminaires and that there should be no criteria for poles and cables. There was also a reasonable level of support to include criteria for metering and for LED retrofit situations. New criteria have been proposed for LED luminaires and metering.

5.1. Different applications for road lighting criteria

All municipalities and road authorities require road lighting to some degree and public procurement activities may cover one or more of the following areas:

a. Lighting for a new outdoor public traffic area (road or pathway).

b. Lighting for an outdoor public traffic area that is being completely refurbished.

c. Replacement of luminaires within an outdoor public traffic area, while keeping wiring and lighting controls.

d. Retrofit of lighting controls, while keeping original luminaires.

e. Replacement lamps.

For new installations, the approach is quite straight-forward in the sense that a design will be needed which will specify the optimum placement of poles and the luminaire mounting heights and tilt angles. When specifying luminaires and light sources, it is enough to simply look at what are the better performing products on the market and set the energy efficiency criteria accordingly. The design of a new system may be carried out by the contracting authority’s in-house staff, or by a street lighting contractor or an independent lighting designer. The installation work is usually carried out by a contractor.

Existing installations will represent the vast majority of procurement exercises in Europe. Due to the continual improvements in energy efficiency of LED lighting technology in the last 5 years and rapidly decreasing costs, procurers with HID lamps in their lighting installations are under pressure to consider alternatives (i.e. points b, c or d above) instead of simply buying the same lamps as before to replace old ones (i.e. point e above).

The overall approach to the GPP criteria is illustrated in Figure 4. In cases where the road lighting installation already exists, the procurer is recommended to do a quick preliminary estimation of the luminous efficacy or PDI or AECI of existing installed road lighting light sources and/or luminaires. If the result is that the existing light sources have a very high luminous efficacy already, this may be sufficient justification to simply relamp the installation. However, in cases where there are doubts about the energy efficiency of the existing installation, any relamping scenario should be costed and checked against life cycle costs of LED retrofitting or redesigns using estimated energy efficiency data. These preliminary assessments do not form part of the EU GPP criteria themselves but further details about them can be found in a separate guidance document for road lighting procurement.

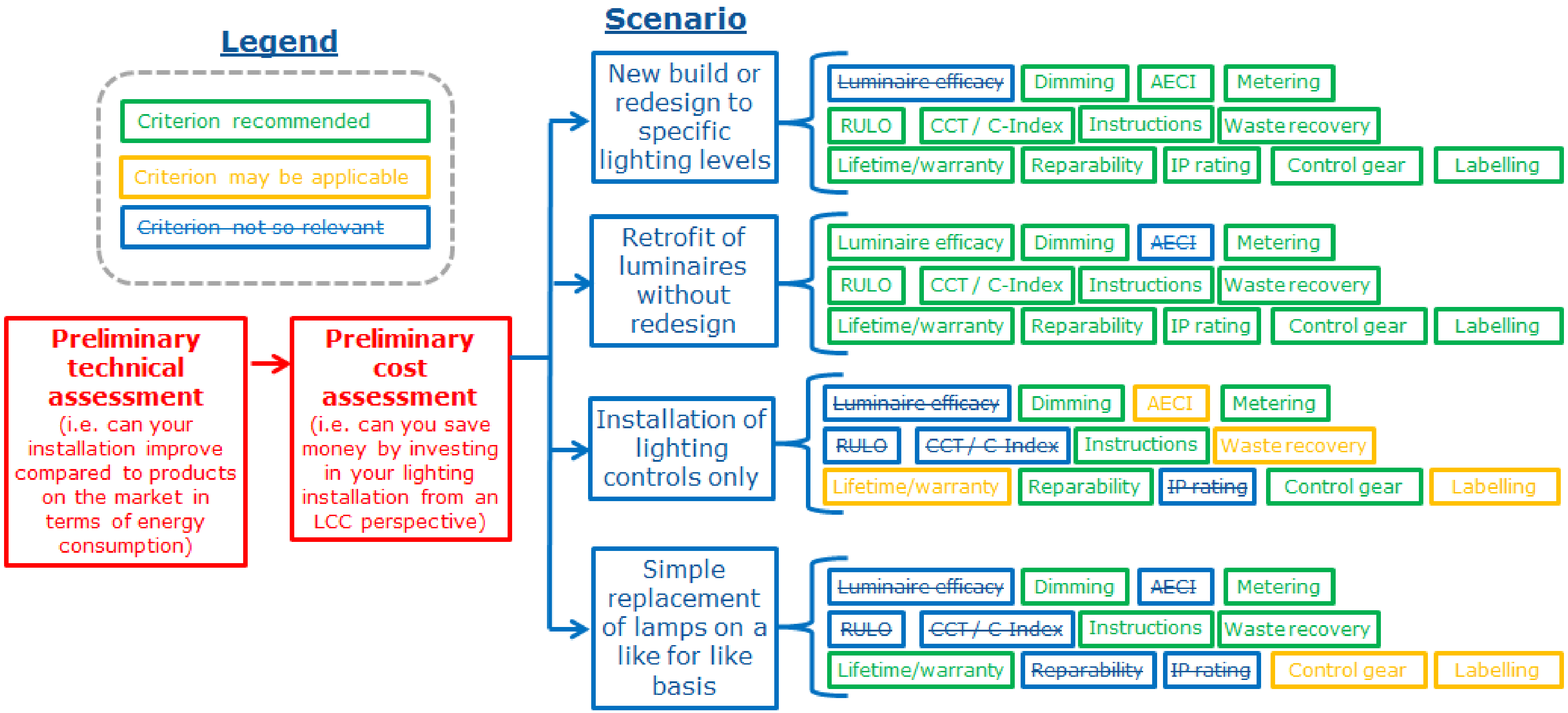


Figure 4. Overview of approach to GPP criteria for the product group "road lighting"

The overall aim of the preliminary checks is to first know how energy efficient the current installation is and second, to determine what kind of savings (energy and cost) are possible with the different options (i.e. redesign with new luminaires, luminaire replacement or only light source/controls replacement).

As can be seen in Figure 4, there are three main options for procurement. For each option, criteria are split into one of three groups: Energy Efficiency, Product Lifetime and Light Pollution. Criteria in green are considered as being highly relevant, those in orange as potentially relevant and those in blue and strikethrough as not so relevant, depending on the situation.

The top option is the most comprehensive because a lighting design (or redesign) is required. This option is most likely for any new roads and renovation on existing heavily trafficked roads and where speed limits and conflict areas represent a sufficient risk to road users. In countries and regions where road lighting classes are specified for the road in question, then a re-design will inevitably be required.

The middle and bottom options are more likely to apply to smaller roads and P class roads (i.e. predominantly for pedestrians) with lower lighting requirements or where minimum lighting classes and other characteristics defined in EN 13201 are not stipulated by regional or national legislation.

The criteria for road lighting are split into three broad criteria groups: energy efficiency, light pollution and product lifetime and durability.

For a given criteria area, minimum technical specifications and/or award criteria are provided together with any notes that explain in what situation these should apply/not apply. When there is an obvious need for a contract performance clause (CPC), a suggested CPC is also provided.

Each criterion is preceded by sections about relevant background research, supporting rationale and stakeholder discussion. Closely related criteria may be grouped together with a common background research and stakeholder discussion.

6. Selection Criteria

As stated earlier in the introduction, selection criteria apply to the tenderer and should focus on aspects related to the capability of the tenderer to meet to the requirements of the contract, should they be successful in the bidding process. Criteria presented here focus on technical aspects although it should be noted that financial aspects can also be specified here.

6.1. Background research and supporting rationale

For lighting installation design teams

In order to properly design a road lighting installation, a thorough knowledge of the current market and underlying trends, the EN 13201 standard series, lighting design software and installation practices is needed. Furthermore, a good understanding of the planning and approval processes of outdoor lighting installations will be needed. These processes will be subject to national spatial planning and road legislation and which may fall under the responsibility of municipalities or other authorities. Therefore, this criterion requests evidence to prove that the tenderer will meet clear minimum requirements that will help demonstrate that they have the required know-how and range of competencies to successfully design a new or renovated lighting system. It is also worth highlighting the recent introduction and recognition of the degree of European Lighting Expert in several countries, which could potentially be used as a reference in relevant countries.

For teams installing lighting equipment

The same rationale as for the selection criteria for the design team applies to the selection criteria for the installation team. In order to properly install a road lighting installations excellent knowledge is required from the market status, the EN 13201 standard series and installation practices. Therefore this criterion searches for evidence to proof that the required skills are available for the service requested.

Aspects common to designers and installers

In both selection criteria, requirements should not be too stringent as to present a barrier to the market for new or emerging companies. For this reason, the minimum requirements for experience are limited only to the senior member of staff working for the tenderer who will ultimately sign off any final design or approve the adequacy of installation works.

The level of experience can be misleading if only considered in terms of time. Thus it is also important to allow for the recognition of the number of projects and scale of projects as part of experience in tenderer teams.

In some cases, a successful tenderer may sub-contract a more experienced consultant to check and approve their design. In such cases, the tenderer may simply commit to contracting such a consultant should they be awarded the contract but without knowing precisely who that consultant would be yet. Even if sufficiently qualified staff is already directly employed by the tenderer, they may leave the company before the contract is undertaken. For these reasons, it is important that the selection criteria are also covered by a contract performance clause.

6.2. Stakeholder discussion

One point that was raised was the lack of any mention of specific lighting design software when stating minimum experience and requirements for the design team or designer. It was added that in some cases the use of different software for the same design can generate variations in the final results although the scale of these variations is uncertain.

One of the basic principles of EU GPP criteria is to try to remain impartial with respect to selection criteria and so it would not be recommendable to stipulate a specific software program and not another one that can be used for the same purpose. However, if the procurer has a history of working with designs using particular software, then they are of course free to specify this in their individual ITT – but one particular piece of software cannot be promoted over others in EU GPP criteria.

Another discussion point was to try to be more specific about the quantity of relevant experience for installers and designers. The need to strike the right balance between a certain minimum experience and unintentionally creating barriers to potential tenderers was emphasised. One potential solution is to place quite stringent requirements only on the person who will finally check, approve and sign off the lighting design / installation work.

The drawback of only requiring a minimum amount of time in the job (i.e. 3 years) does not mean that much relevant project experience has been gained and the drawback of only requiring a minimum number of completed projects is that there is the possibility that 3 small short-term projects are valued more than 1 major long-term project. For this reason, a clause has been inserted to allow the procuring authority to accept experience in a lower number of projects if they are of a sufficient scale.

Support was expressed for recognising the membership of professional bodies as it ensures that the individuals undergo continuous professional development and can easily be checked. Nonetheless, other experience and qualifications should not be ruled out. One example mentioned was the Lighting Certificate course run by the UK Lighting Industry Association. However, the usefulness of asking for experience with validating software according to CIE 171 was questioned because it deals with indoor lighting and daylight conditions but not with road surface reflectance and thus luminance calculations.

The other main discussion point was the risk that tenderers insert the names of highly qualified individuals simply to pass the selection criteria but then, if awarded the contract, they would then go and employ someone less qualified, either to save costs or due to the unforeseen unavailability of the original person/people. For this reason, a contract performance clause covering this potential situation has been inserted.

6.3. Proposed selection criteria

Core criteria	**Comprehensive criteria**

SC1 - Competences of the design team

(Applies when a lighting design is requested in the procurement exercise).

The tenderer shall demonstrate that the design will be checked and approved by personnel with the following minimum experience and qualifications:

- at least three years of experience in lighting design, dimensioning of electrical circuits and electrical distribution networks and having been involved in the design of at least three different outdoor lighting installations,
- certified level of competency in the use of lighting design software for PDI and AECI calculations (e.g. European Lighting Expert certificate)
- experience with the use of validated lighting calculation software (e.g. according to CIE 171, road surface reflectance tables or other relevant standards),
- holding a suitable professional qualification in lighting engineering or membership of a professional body in the field of lighting design.

Verification: The tenderer shall supply a list of the person(s) who will be responsible for the project should the tender be successful, indicating their educational and professional qualifications, relevant design experience in real projects and, if relevant, any lighting design software quality certification. This should include persons employed by subcontractors if design work is to be sub-contracted.

The procuring authority, at its own discretion, may accept experience in less than three lighting installation designs if the scale of the design project(s) was sufficiently large (i.e. amounting to at least 70% of the scale of the design project that is the subject of the Invitation To Tender), and duration of the design project(s) sufficiently long (i.e. amounting to at least three years.

Core criteria	**Comprehensive criteria**

SC2 - Competences of the installation team

(Applies when responsibility for installation is not assumed by the procuring authorities own maintenance staff)

The tenderer shall demonstrate that the installation works will be planned, checked and approved by personnel with the following minimum experience and qualifications:

- at least three years of relevant experience in the installation of outdoor lighting systems and having been involved in the installation of at least three different installation projects,
- having a suitable professional qualification in electrical engineering and membership of a professional body in the field of lighting (e.g. certified lighting technician). The list of relevant installed lighting systems with relative 'scale of the project' should be reported.

Verification:

The tenderer shall supply a list of person(s) responsible for the installation works should the tender be successful, indicating their educational and professional qualifications, training logs and relevant installation experience in real projects. This should include persons employed by subcontractors if installation work is to be sub-contracted.

<table>
<tr><td colspan="2">The procuring authority, at its own discretion, may accept experience in less than three lighting installation works if the scale of the works was sufficiently large (i.e. amounting to at least 70% of the scale of the design project that is the subject of the Invitation To Tender), and duration of the works sufficiently long (i.e. amounting to at least three years).</td></tr>
<tr><th>Core criteria</th><th>Comprehensive criteria</th></tr>
<tr><td colspan="2">**CPC1 – Assurance of adequately qualified staff to carry out contracted tasks**</td></tr>
<tr><td colspan="2">*(Applies when SC1 and/or SC2 have been applied)*

The successful tenderer (contractor) shall ensure that the same staff mentioned in the documentation provided to demonstrate compliance with SC1 and/or SC2 are indeed involved in the works covered by the contract.
When original personnel assigned to the project are not available for whatever reason, the contractor must communicate this to the procuring authority and provide a substitute of equivalent or higher experience and competency.
Proof of the credentials of any substitute personnel shall be submitted in the same manner as described in SC1 and/or SC2, as appropriate.</td></tr>
</table>

7. Energy consumption criteria

With road lighting installations, for any fixed lighting level requirement, there is a clear link between environmental benefits and improved energy efficiency of light sources and luminaires. Cost saving is also a clear driver for improved energy efficiency although in this respect care has to be taken to focus on life cycle costs and not simply operational costs. As the market for LEDs in outdoor lighting matures, capital costs are decreasing all the time and, as electricity costs continue to increase, the relative importance of energy efficiency in life cycle cost calculations increases too.

Due to the importance of energy efficiency criteria on both environmental and economic aspects, a minimum cut-off requirement is proposed as a technical specification and an award criterion is proposed in order to encourage tenderers to go further.

A potential contract performance clause is also provided to ensure that the lighting installation actually delivers on the minimum energy efficiency and lighting requirements. Arguably the best way to ensure compliance with predicted energy consumption performance is to have a metering system for the lighting installation split by defined zones or even to monitor power consumption at the level of the individual luminaire which would be reported automatically to a remote system.

Apart from more efficient lighting, attention must be paid to the potential savings via the use of dimming controls to reduce light output, and thus energy consumption, during programmed periods of expected low use of roads. The importance of dimming is reflected in a technical specification for compatibility of light sources and luminaires with dimming controls and minimum % dimming possibilities and controls.

For each criterion, it is stating under what type of situation it should be applied, i.e. the design of a new lighting installation, the re-design of an existing installation or simple re-lamping of an existing installation.

<u>The importance of energy efficiency</u>

There is broad agreement in the life cycle assessment community that the dominant source of LCA environmental impacts associated with road lighting is electricity consumption during the use phase. The outputs of studies in the literature generally follow the same tendency as given below in Figure 5.

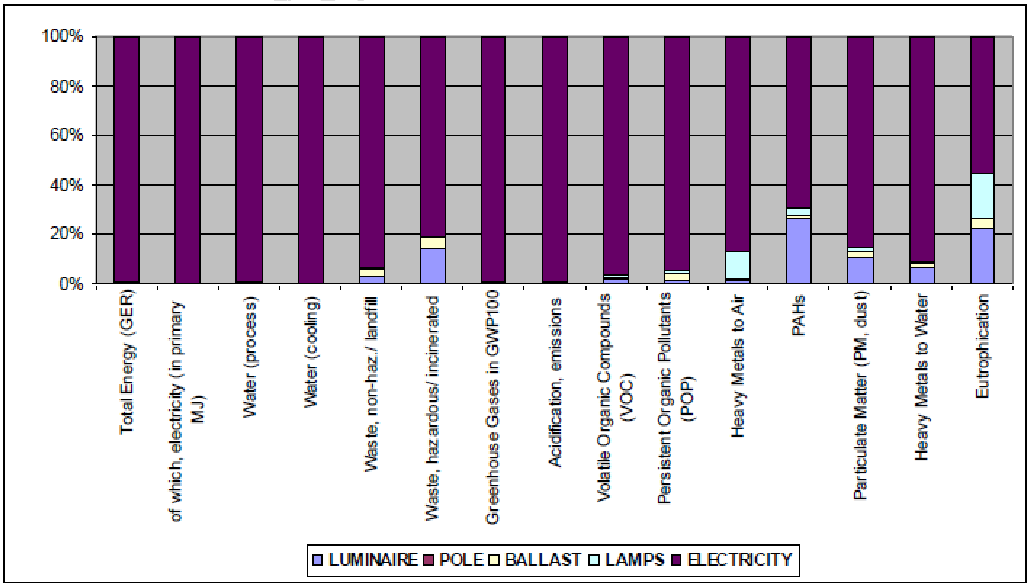


Figure 5. Breakdown of the life cycle environmental impacts of road lighting (Van Tichelen et al., 2007)

Despite this clear relationship, it is worth noting that as lamp technologies become more energy efficient, impacts associated with materials used may become relatively more important. This will ultimately depend on the environmental footprint of the specific materials used and the lifetime over which the lamp and other components can be expected to last.

Per capita energy consumption of municipalities and regions

During stakeholder discussion, the possibility of setting an EU GPP criterion based on the per capita energy consumption of public lighting was raised. The indicator has been promoted via the Covenant of Mayors (COM) initiative. The indicator is quite simple and is calculated by dividing the total annual power consumption (kWh) of public lighting by the population of the same region. It is possible that in areas where energy bills are not well disaggregated, some assumptions will be made based on the installed power of public lighting (kW) and assumptions about their operating conditions made (e.g. number of hours per day and average dimming).

Although the JRC dismissed the idea of inserting such a criterion in ITTs for a number of reasons, it was agreed that it could be interesting to investigate this subject further in order to gain an understanding of how per capita electricity consumption due to public lighting can vary in different regions. Some data provided by stakeholders was:

- France: national average 86 kWh/pe/yr
- Graz (AT): 15-20 kWh/pe/yr
- Milan (IT): 40 kWh/pe/yr

The JRC consulted comprehensive public data about installed lighting installations in Andalucia (Spain) which was available for the years 2005 and 2008-2013. Data was available for over 700 towns and villages, although data for the larger cities, such as Sevilla, Cordoba and Malaga was not included.

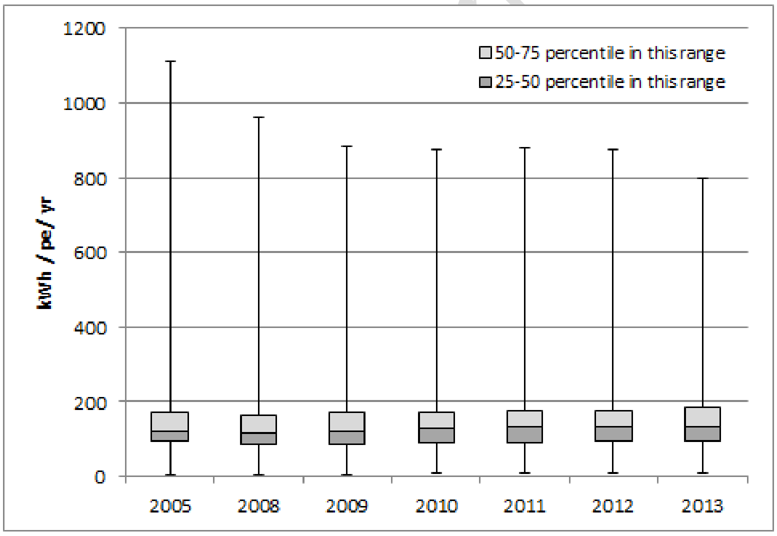


Figure 6. Summary of per capita energy consumption by public lighting in over 700 Andalucian towns and villages

From the almost 5000 data points, it was necessary to delete around 20 values due to them being unrealistically high (e.g. 2000-7000 kWh/pe/yr) and not keeping in line with data for other years in the same town or village.

The raw data available was basically installed power for public lighting (in kW) and the population (in pe). Consequently it was necessary to assume a certain operating period (11 hours per day, 4015 hours per year) and that no dimming took place (a reasonable assumption since significant LED uptake not expected prior to 2013).

Looking at the overall data there is no clear trend except that the most extreme consumers have decreased between 2005 and 2009. Although difficult to see in the graph due to its scale, the middle 50% of performers (i.e. between the 25th and 75th percentiles) were consistently in the range of 85 to 185 kWh/pe/yr.

At the level of individual towns and villages there was a huge range of % changes in per capita energy consumption for public lighting. The 4 best performers were Benahadux, Paterna de Rivera, Belmez de la Moraleda and Tarifa, where consumption was reduced by more than 80% between 2005 and 2013. However, at the other extreme, Cabra, Atarfe, Chimeneas, Ezcuzar and Carboneros showed per capita energy consumption for public lighting increased by 250-450% between 2005 and 2013. Specific mention of Pedroche is also merited, where the increase was around 4000% during the same period.

Existing EU GPP criteria for energy efficiency

In the 2012 EU GPP criteria, minimum requirements for luminous efficacy were defined for different lamp technologies when *lamps, ballasts or luminaires were being purchased*. Apart from the effect of different lamp technologies, the minimum required luminous efficacies varied as a function of the rated wattage because the power rating has an influence on the energy efficiency of the main lamp technologies used in 2012. Energy losses due to ballasts were treated separately.

This was a far from ideal solution because simply replacing existing lamps and ballasts with more energy efficient ones may simply result in over-lighting while the energy consumption remains the same.

When considering criteria for *new lighting installations or renovation of existing installations*, the 2012 EU GPP criteria did make some attempt to link energy efficiency to the lighting level of class C and class P roads:

- Maximum 0,044 W/(lux·m²) if $E \leq 15$ lux
- Maximum 0,034 W/(lux·m²) if $E > 15$ lux

However, energy efficiency requirements linked to only two lighting levels (above or below 15 lux) is not appropriate considering that EN 13201-1:2014 suggested lighting levels for C and P class roads are set at 0.4, 0.6, 1.0, 1.5, 2.0, 3.0, 7.5, 10, 15, 20, 30 and 50 lux (see Figure 1).

The rise of LED lighting technology means that there are now many options for improving the energy efficiency of road lighting installations and that energy efficiency criteria should aim to be as horizontal as possible, without being nuanced for different installed power ratings and lamp technologies.

Key terms and definitions from EN 13201-5

In order to ensure a consistent approach to defining the energy efficiency of a road lighting installation, it is recommended to follow the definitions and methodology provided in EN 13201-5: 2016 "Road lighting – energy performance indicators". This standard introduces several key definitions:

- **Luminous efficacy** (η), expressed in lm/W.
- **Power Density Indicator** (PDI) expressed in W/(lx.m²).
- **Annual Energy Consumption indicator** (AECI) expressed in kWh/(m².y).
- **Operational profile**: the number of hours the lighting installation will be switched on for each day and at what percentage of full power it will operate at for each hour.
- **Road profile**: the layout of the road, including any sidewalks and other areas intended to be lit and excluding any intermediate areas, such as vegetated strips and central reservations, not intended to be lit.

The key terms for measuring energy efficiency are PDI and AECI, although these cannot be calculated without first knowing the luminaire efficacy, road profile and operational profile.

7.1. Luminaire efficacy

7.1.1. Background research and supporting rationale

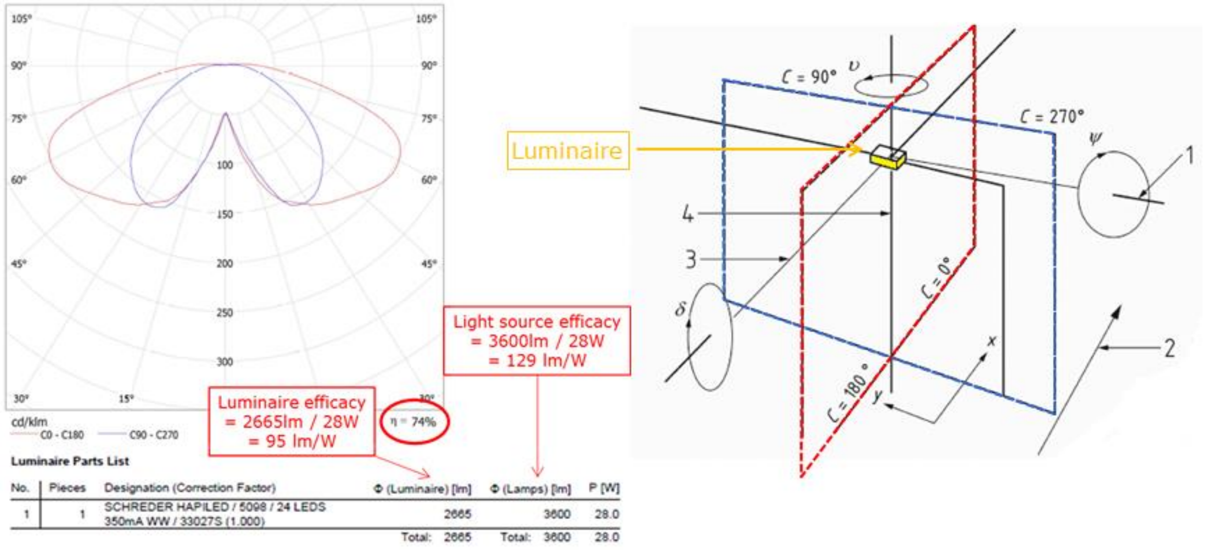
The luminous efficacy is basically how much useful light (in lumens) can be produced by a given unit of power (1 Watt). Luminous efficacy can be defined at various different levels: of the light source, of the luminaire containing the light source or the installation containing all the luminaires. A calculation defined in EN 13201-5:2016 for luminous efficacy of an installation is as follows:

$$\eta_{inst} = C_L \, x \, F_M \, x \, U \, x \, R_{LO} \, x \, \eta_{ls} \, x \, \eta_P$$

Where:

- η_{inst} is the installation luminous efficacy in lm/W
- C_L is the correction factor where a design is based on luminance or hemispherical illuminance instead of illuminance
- F_M is the overall maintenance factor of the lighting installation (this is a combination of individual maintenance factors for decreased lumen output from the light source and for dirt gathering on the housing), it is the product of F_{LLM} and F_{LM}.
- U is the utilance of the installation (i.e. the fraction of light output reaching the target area)
- R_{LO} is the optical efficiency of the luminaire (i.e. how much of the light output of the light source leaves the luminaire)
- η_{ls} is the luminous efficacy of the light source alone (in lm/W)
- η_p is the power efficiency of the luminaire (i.e. accounting for power losses in control gear).

Data provided by lighting equipment manufacturers about luminous efficacy will provide information about the light output and power consumption of the light source alone and when mounted in the luminaire. Power losses in control gear may or may not be reported separately, although this should not be important for the currently proposed EU GPP criteria so long as the combined overall power consumption figure is provided.



Luminaire efficacy = 2665lm / 28W = 95 lm/W

Light source efficacy = 3600lm / 28W = 129 lm/W

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	1	SCHREDER HAPILED / 5098 / 24 LEDS 350mA WW / 33027S (1.000)	2665	3600	28.0
			Total: 2665	Total: 3600	28.0

Figure 7. Example of light output and power consumption data provided in a luminaire manufacturer data sheet (left) and, adapted from EN 13201-3, a 3-D illustration of the 0-180 and 90-270 axes (right).

In the above case, a luminaire data sheet for SCHREDER HAPILED/5098/24 LEDS 350mA WW/33027S, the optical efficiency (R_{LO}) of the luminaire was 74% (or 0.74) and the luminaire efficacy (the product of R_{LO}, η_{ls} and η_p) was around 95 lm/W. The step from luminous efficacy of luminaire to the luminous efficacy of the installation is quite a big one.

One crucial aspect is the utilance (U). To better estimate the utilance, detailed information about the road layout, target areas to be illuminated, pole layout, mounting height of luminaires and tilt angles of luminaires would be required. The Belgian approach to this is described later in section 7.3.1 when describing approaches to PDI and AECI specifications.

Maintenance factors will mean that the luminaire efficacy will vary with time, even if dimming controls are installed to gradually "dim less" in order to maintain a constant light output in deliberately over-designed lighting installations. This aspect is presented in more detail in section 7.3.4.

Initial proposal in TR 1.0

In TR 1.0, it was proposed to have some minimum requirements for luminaire efficacy (105 lm/W for core level and 120 lm/W for comprehensive level). The main justification for this criterion was that it forms the basis for any calculations of energy efficiency of the installation (i.e. PDI or AECI) and is much easier to verify, with data readily available from suppliers. In projects where a detailed design is not specified for whatever reason, especially when light sources are to be retrofitted to existing luminaires, the luminaire efficacy will be an important contribution to demonstrating the energy efficiency of the installation.

7.1.2. Stakeholder discussion

The main criticism of criteria for luminaire efficacy was that a good efficacy value does not guarantee an energy efficient road lighting installation. However, the counter argument is that it is extremely difficult, if not impossible, to deliver an energy efficient road lighting installation using luminaires with a poor luminous efficacy.

It was felt by some stakeholders that ambition levels should not be varied for different types of luminaire, but paradoxically concern was expressed that the current proposals would only allow for luminaires with white LED light sources, effectively excluding warm LED and low wattage HPS. Other stakeholders felt that a clear distinction must be made between efficacies for “pure” road lighting luminaires and efficacies in urban areas where luminaires may also have some sort of decorative design and also need to provide amenity lighting as well as road lighting. It was suggested that a more reasonable luminaire efficacy to ask for in amenity applications would be 80-85 lm/W. In Belgium, the Synergrid technical specification C4/11-3 for LED luminaires excludes luminaires that are used in ground lamps and spotlights, used in illuminated markers or lighting columns less than 3m high or used in appliances that are purely for artistic or architectural purposes.

Italian GPP approach

It was claimed that in Italy, a distinction is indeed made between “pure road lighting” and road lighting for pedestrian walkways and in historic city centres. National legislation has been introduced to support the implementation of a Parameterized Energy Index for Luminaires (IPEA) – essentially a labelling system for road lighting luminaires that is largely based on luminous efficacy that results in labels from A+++++ (A5+) to F.

This label is scaled according to the relevant reference luminaire efficacy, which varies according to the lamp wattage and the road type as shown below.

Table 5. Italian reference values for luminaire efficacy for different outdoor lighting applications

Rated Power	Luminaire efficacy reference values				
	Road lighting	Area lighting, roundabout, parking lot	Pedestrian area, bike lane	Green area lighting	City centre with historic lantern
P < 65	73	70	75	75	60
65 < P < 85	75	70	80	80	60
85 < P < 115	83	70	85	85	65
115 < P < 175	90	72	88	88	65
175 < P < 285	98	75	90	90	70
285 < P < 450	100	80	92	92	70
450 > P	100	83	92	92	75

Dividing the actual luminaire efficacy by the reference luminaire efficacy generates the IPEA value. The higher the IPEA value, the higher the performance label assigned to the actual luminaire. For example, "G" is <0.40, "F" is 0.40-0.55, "E" is 0.55-0.70, "D" is 0.70-0.85 and "C" is 0.85-1.00. The B (1.00-1.10), A (1.10-1.20), A+ (1.20-1.30), A++ (1.30-1.40) and higher labels apply when the actual luminaire performance exceeds the reference efficacy value.

Looking specifically at the reference efficacy values for "road lighting", the different luminaire efficacies required to achieve a particular IPEA label can be easily calculated.

Table 6. Translation of Italian IPEA values into luminaire efficacies for different labelling classes for "road lighting".

Rated power (W)	Reference Luminaire efficacy (lm/W)	IPEA labelling class										
		A5+	A4+	A3+	A2+	A+	A	B	C	D	E	F
<65	73	116.8	109.5	102.2	94.9	87.6	80.3	73	62	51.1	40.1	29.2
65-85	75	120	112.5	105	97.5	90	82.5	75	63.8	52.5	41.3	30
85-115	83	132.8	124.5	116.2	107.9	99.6	91.3	83	70.6	58.1	45.7	33.2
115-175	90	144	135	126	117	108	99	90	76.5	63	49.5	36
175-285	98	156.8	147	137.2	127.4	117.6	107.8	98	83.3	68.6	53.9	39.2
285-450	100	160	150	140	130	120	110	100	85	70	55	40
>450	100	160	150	140	130	120	110	100	85	70	55	40

In terms of ambition level, minimum requirements for EU GPP criteria would fall somewhere between A+ and A5+. The above levels and classes apply only for "road lighting", but the reference luminaire efficacy values for different roads, such as pedestrian paths, cycle paths and historic city centres is included in the table below for comparison.

According to Italian stakeholders, the IPEA values above were developed based on EN 13201, 245/2009/EC and 347/2010/EC as well as market enquiries and field experience. From the Italian experience, it is clear that city centre lighting is considered as less efficient than road lighting but that lighting of bike lanes and pedestrian areas can be more efficient

For pure road lighting luminaires, one stakeholder felt that the proposed efficacies in TR 1.0 (i.e. 105 and 120 lm/W) could be made even more ambitious. There is a plethora of market data for LED-based luminaire efficacy from the US. Therefore it is worthwhile to consider ambition levels in the context of this market data.

From an EU GPP perspective, the main drawbacks of the Italian approach are related to the labelling going well beyond A and complications with updating the reference levels to account for technological progress. The reference to a national level energy labelling system, which has presumably not been developed in accordance with the Energy Labelling Directive (2010/30/EU), is not recommended in EU GPP criteria published by the Commission. However, the actual numbers linked to the labels for luminaire efficacy (IPEA) and PDI (IPEI) could be used to support particular ambition levels for lighting in certain circumstances.

DesignLights Consortium (DLC)

An example of a tiered approach can be seen from the DesignLights Consortium as illustrated in Figure 8 below. The first tier is between minimum requirements for a "standard Qualified Products List (QPL)" (of 90-100 lm/W) and of a "premium QPL" (of 110-120 lm/W).

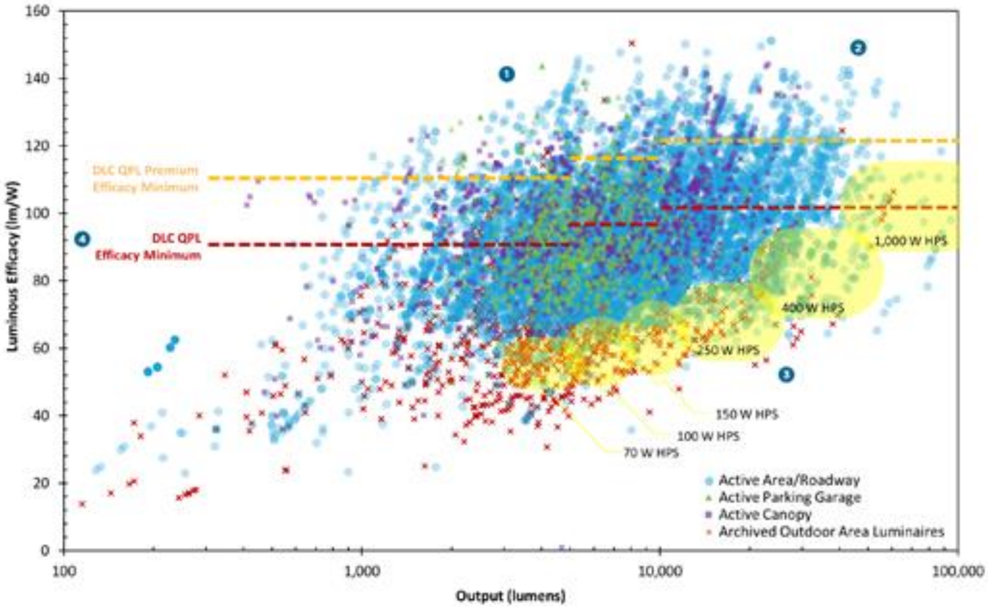


Figure 8. US DOE Lighting Facts database (2016) of road lighting luminaires with luminaire output (lumens) versus luminaire efficacy (source DOE, 2016)

Figure 8 shows that while the typical luminaire efficacies of HPS lamps (indicated in yellow areas) depends on the lumen output and wattage, the LED data for area/roadway lighting (blue points) is effectively independent of power rating and lumen output – except perhaps when output drops below 500 lumens. The DLC have recognised some minor relationship between luminous efficacy and lumen output for LED by stepping the minimum requirements for luminaires to appear on their Qualified Products List in 2016 by setting minimum requirements of:

- 90 lm/W up to 5000 lumen output,
- 95 lm/W for 5000-10000 lumen output
- 100 lm/W for >10000 lumen output

Figure 8 also highlights how much LED-based luminaires for road lighting (blue points) can exceed HPS-based luminaires (yellow areas) in terms of luminous efficacy for outputs between 3000 and 30000 lumens. This increase in efficacy of HPS-based luminaires as the output increases is clear from Figure 8. This tendency was well reflected for all HID type lamps in the current GPP criteria published in 2012. However, with LED technology there is no technical reason to introduce weaker requirements for luminaires with a lower wattage and/or road illuminance. When comparing the minimum requirements for the DLC QPL (Qualified Products List), it is clear that only high power (1000W) HPS lamps could meet the requirements.

Stakeholders generally acknowledged that any fixed minimum requirement for energy efficiency in GPP criteria would need to be reassessed as LED technology continues to rapidly improve. Due to the fact that GPP criteria are fully revised every 5 to 6 years but not periodically updated, the best way to do this would be to introduce a tiered approach to the PDI or luminous efficacy reference values, which could then be increased in a tiered approach.

__Stakeholder proposal based on Lighting Facts database__

Three tiers of luminaire efficacy were proposed based on LED luminaire efficacy data trends between 2012 and 2017 and with the intention of targeting the top 75% of LED luminaires on the market for core level and the top 50% for comprehensive level.

An analysis of luminaire efficacy data from the US DOE (Department of Energy) database was submitted by one stakeholder to justify the tiered approach. The data covered around 5600 street light luminaires for models on the market from 2012 to 2016.

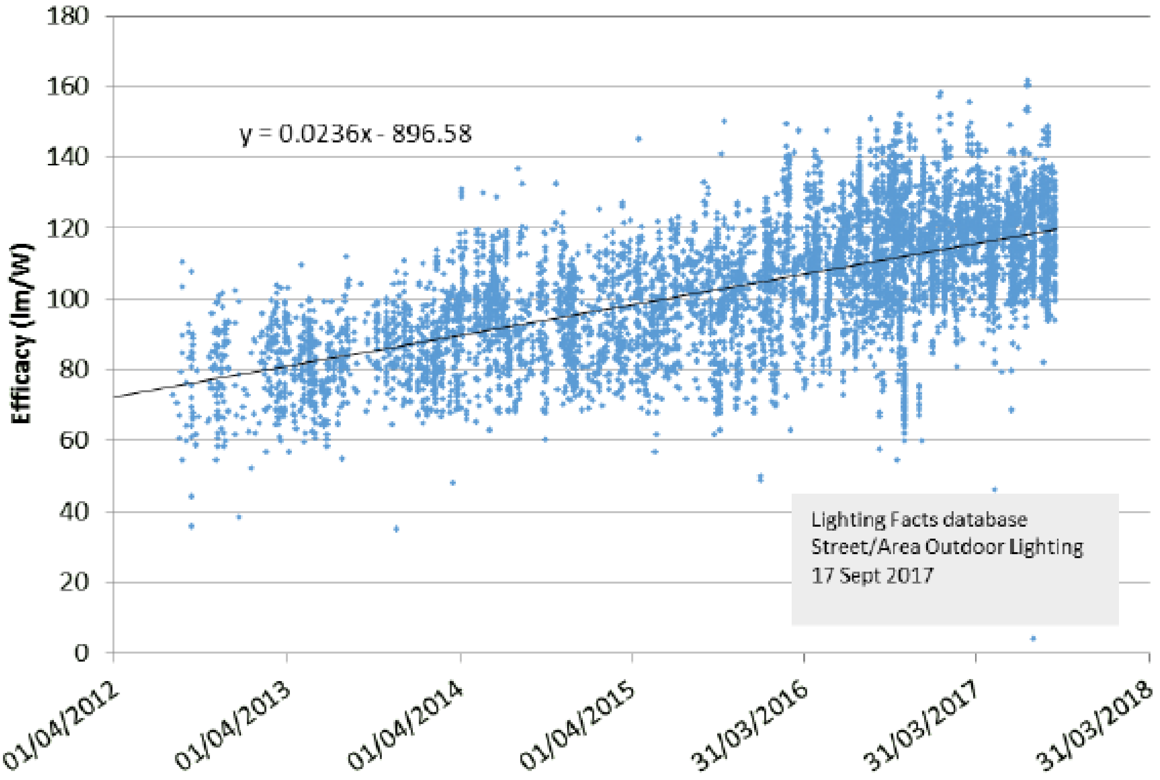


Figure 9. Scatter plot of luminaire efficacy data from 2012-2017 in the Lighting Facts database.

The trendline shows an increase in average efficacy of 8.6 lm/W each year between 2012 and 2016 and by 8.6 lm/W between 2016 and 2017. This confirms that the trends assumed in TR 2.0 when proposing the tiered approach to the ambition level for luminaire efficacy continue to be valid.

The ambition level was set based on 2016 data and the % of all roadway lighting products in the Lighting Facts database that are capable of meeting the efficacy requirements. This led to the following observations:

- 96% meeting 80 lm/W
- 75% meeting 102 lm/W
- 50% meeting 112 lm/W

The stakeholder proposal was therefore to set core criteria ambition level to 102 lm/W and the comprehensive level criteria to 112 lm/W *__if the criteria were to be published in 2016__*. However, since the criteria are expected to be published by the end of 2018, accounting for the continued market improvements, it was proposed that the ambition level be set to 120 lm/W (core) and 130 lm/W (comprehensive) and run until 2020. After that, the ambition level would increase by 17 lm/W and in 2022, it would increase by another 17 lm/W. It was agreed that any reference values for luminous efficacy should be set at the level of the luminaire, so that any optical losses from luminaires and power losses from ballasts and control gear are accounted for.

On the other hand, some stakeholders expressed concern that too high a level of ambition might essentially exclude low wattage HPS and warm LED as possible options. It was also commented that in historic areas in city centres, it is possible that luminaires have a decorative function which would limit their luminous efficacy. This led to a further analysis of the Lighting Facts database to determine to what extent luminaire efficacy decreased with decreasing CCT (see section 8.1.1). Overall, average data revealed a modest decrease of 3 lm/W per 1000K decrease in CCT.

Concerns about the lower efficacies of lower power LEDs were also expressed and appear to be valid when looking at Figure 8. The results of an assessment of light output plotted versus luminaire efficacy are presented in Figure 10 below.

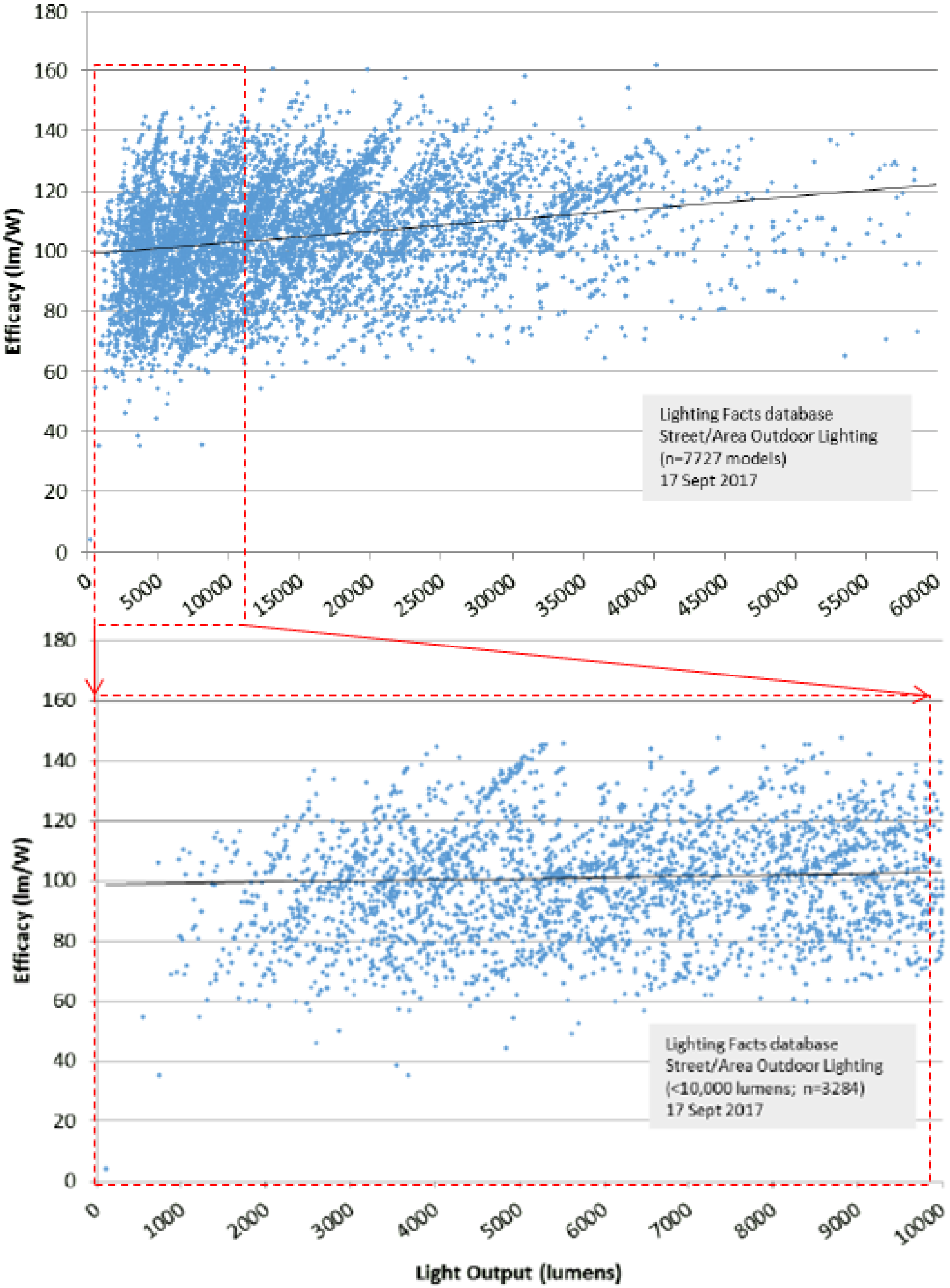


Figure 10. Scatter plot of luminaire efficacy versus total light output from the Lighting Facts database (2017). Over the range 0-60000 lumens (top) and a closer look at the 0-10000 lumens range (bottom).

The data presented in Figure 10 show that the average luminaire efficacy does decrease as light output decreases. The average values ranged from 100 to 120 lm/W, increasing as light output increased.

The JRCs own analysis of the same Lighting Facts data from 2017 tried to break down the luminaire efficacy in blocks based on different ranges of light output (see Table 7 below).

Table 7. Breakdown of Lighting Facts database (2017) efficacy data as a function of light output range

Light output range (lumens)	Number of products	Average efficacy	1st quartile (top 25%)	2nd quartile (top 50%)	3rd quartile (top 75%)
0-1000	10	69.1	81.5	75.5	58.4
0-2000	102	84.8	99.5	84.2	73.0
0-3000	341	90.7	103.1	90.8	78.2
3000-4000	448	95.8	108.2	96.5	84.0
4000-5000	464	100.0	114.5	99.5	84.2
5000-6000	448	97.4	106.0	96.1	83.3
6000-7000	454	98.3	111.2	98.8	85.3
7000-8000	372	102.2	116.0	103.3	89.0
8000-9000	435	101.1	113.5	103.1	85.9
9000-10000	375	102.7	116.3	101.7	89.4
10000-11000	314	103.2	117.8	103.5	88.5
11000-12000	333	103.5	115.2	105.6	90.7
12000-13000	339	107.4	120.3	110.6	93.9
13000-15000	498	107.0	119.2	106.2	94.6
15000-17000	452	108.4	117.5	108.7	98.4
17000-19000	458	109.0	120.4	113.0	99.0
19000-21000	308	110.3	127.2	110.3	97.9
21000-24000	400	108.7	119.1	109.2	98.8
24000-27000	313	112.1	124.8	114.0	100.1
27000-31000	330	112.4	123.1	114.3	102.5
31000-37000	349	111.0	119.9	112.1	103.8
37000-140000	351	112.9	124.4	116.8	100.6

The choice between light output ranges was based on the desire to have a representative number of products listed (i.e. n ≥300). The exception to this was for LED luminaires in the 0-2000 lumen range, where only a few products were available, but that their significantly lower efficacies justified their separate listing.

The same data is also presented as in graphical format, where the columns represent the 2nd quartile data and the error bars are the difference when going to the 1st quartile (bar going up, covering 25% of the products) and when going to the 3rd quartile (bar going down, covering 75% of the products).

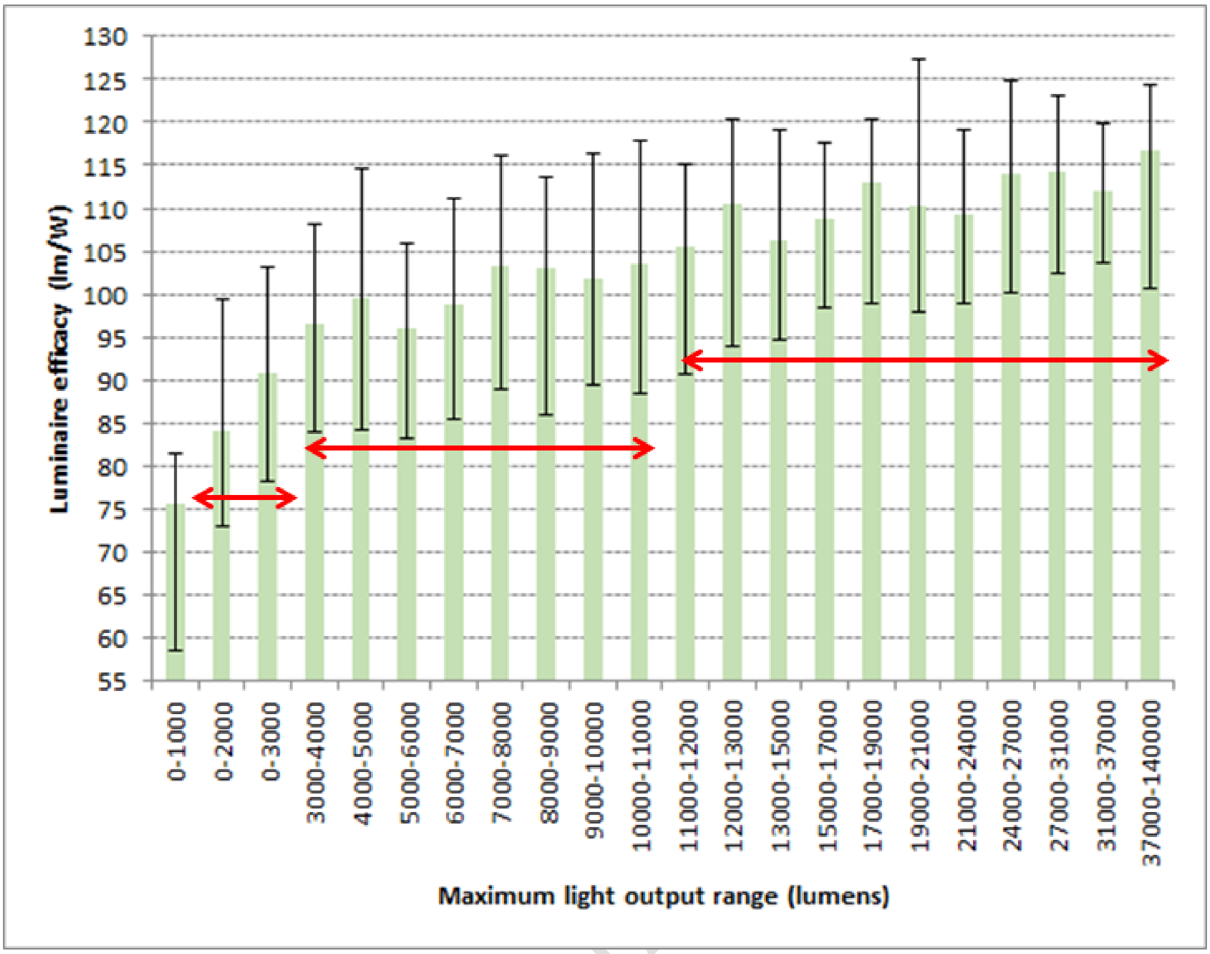


Figure 11. Plot of luminaire efficacies met by 50% of Lighting Facts database (2017) products as a function of light output (top and bottom of error bars represent top 25% and top 75% of products).

The data presented in Table 7 and Figure 11 suggest that a distinction should be made for any requirements for luminaire efficacy depending on whether the total light output is less than 3000 lumens and especially if it is less than 1000 lumens. There is also a potential argument for considering a different ambition level for products in the 3000-11000 lumen range as well. The data suggests that the highest luminaire efficacy requirements should be placed on the most powerful products (>11000 lumens). Grouping the same data together in this way provided the numbers listed below.

Table 8. Grouping of Lighting Facts database (2017) efficacy data into 4 light output ranges

Light output range	Number of products	Average efficacy	1st quartile (top 25%)	2nd quartile (top 50%)	3rd quartile (top 75%)
0-1000	10	69.1	81.5	75.5	58.4
1000-3000	331	91.3	103.1	91.1	78.5
3000-11000	3310	99.8	112.7	100.0	86.2
>11000	4131	109.2	120.9	110.3	98.6

Using the 2017 data in Table 8 as a basis, the core ambition level will be set to the values that 50% of products on the market can be expected to meet in 2018 (i.e. 2017 data plus 8 to 9 lm/W). The comprehensive ambition level will be set to the values that 25% of the products on the market can be expected to meet in 2018 (i.e. 2017 data plus

8 to 9 lm/W). The same projected increase is applied in 2 year steps up until 2023. For clarity, it is repeated here that the rates of increase in efficacy are based on analysis of all LED products listed in the Lighting Facts database during the period 2012-2017 (see Figure 9).

When asked about what type of format the photometric file should be provided in, stakeholders mentioned EU lumdat (.ldt) and (.xls). However, the most important point was that the file format was compatible with common light planning software such as Dialux, Relux or Oxytech freeware. The software called "Lighting Reality" was also mentioned.

7.1.3. Criteria proposals for luminaire efficacy

<table>
<tr><th>Core criteria</th><th>Comprehensive criteria</th></tr>
<tr><td colspan="2">TS1 Luminaire efficacy</td></tr>
<tr>
<td>
<i>(This criterion should apply when light sources or luminaires are to be replaced in an existing lighting installation and no re-design is carried out. Especially with lower light output products (<1000 lumens), procurers should check to ensure that there are sufficient products on the market that meet their efficacy criteria.)</i>

The lighting equipment to be installed shall have a luminaire efficacy higher than the relevant reference value stated below.

<table>
<tr><th>Light output (lumens)</th><th>Year of ITT*</th><th>Efficacy (lm/W)</th></tr>
<tr><td rowspan="3">0-1000</td><td>2018-19</td><td>84</td></tr>
<tr><td>2020-21</td><td>101</td></tr>
<tr><td>2022-23</td><td>118</td></tr>
<tr><td rowspan="3">1000-3000</td><td>2018-19</td><td>100</td></tr>
<tr><td>2020-21</td><td>117</td></tr>
<tr><td>2022-23</td><td>134</td></tr>
<tr><td rowspan="3">3000-11000</td><td>2018-19</td><td>108</td></tr>
<tr><td>2020-21</td><td>125</td></tr>
<tr><td>2022-23</td><td>142</td></tr>
<tr><td rowspan="3">>11000</td><td>2018-19</td><td>119</td></tr>
<tr><td>2020-21</td><td>136</td></tr>
<tr><td>2022-23</td><td>153</td></tr>
</table>
<i>Verification:</i>

The tenderer shall provide a standard photometric file that is compatible with common light planning software and that contains technical specifications of the light source or luminaire, measured by using reliable, accurate, reproducible and state-of-the-art measurement methods. Methods shall respect harmonised international standards, where available.

<i>*Due to the rapid technological developments in</i>
</td>
<td>
<i>(This criterion should apply when light sources or luminaires are to be replaced in an existing lighting installation and no re-design is carried out. Especially with lower light output products (<1000 lumens), procurers should check to ensure that there are sufficient products on the market that meet their efficacy criteria.)</i>

The lighting equipment to be installed shall have a luminaire efficacy higher than the relevant reference value stated below.

<table>
<tr><th>Light output (lumens)</th><th>Year of ITT*</th><th>Efficacy (lm/W)</th></tr>
<tr><td rowspan="3">0-1000</td><td>2018-19</td><td>90</td></tr>
<tr><td>2020-21</td><td>107</td></tr>
<tr><td>2022-23</td><td>124</td></tr>
<tr><td rowspan="3">1000-3000</td><td>2018-19</td><td>110</td></tr>
<tr><td>2020-21</td><td>127</td></tr>
<tr><td>2022-23</td><td>144</td></tr>
<tr><td rowspan="3">3000-11000</td><td>2018-19</td><td>120</td></tr>
<tr><td>2020-21</td><td>137</td></tr>
<tr><td>2022-23</td><td>154</td></tr>
<tr><td rowspan="3">>11000</td><td>2018-19</td><td>130</td></tr>
<tr><td>2020-21</td><td>147</td></tr>
<tr><td>2022-23</td><td>165</td></tr>
</table>
<i>Verification:</i>

The tenderer shall provide a standard photometric file that is compatible with common light planning software and that contains technical specifications of the light source or luminaire, measured by using reliable, accurate, reproducible and state-of-the-art measurement methods. Methods shall respect harmonised international standards, where available.

<i>*Due to the rapid technological developments</i>
</td>
</tr>
</table>

<table>
<tr><td>*luminaire efficacy of LED-based lighting, it is proposed that the reference values stipulated here should increase over the next 6 years, to avoid them becoming obsolete before the EU GPP criteria are due for revision again.*
In certain cases, e.g. use of decorative luminaires in historic city centres, or where a very low (e.g. <2300K) CCT is also specified, the procurer may choose to apply a lower minimum luminous efficacy.</td><td>*in luminaire efficacy of LED-based lighting, it is proposed that the reference values stipulated here should increase over the next 6 years, to avoid them becoming obsolete before the EU GPP criteria are due for revision again.*
In certain cases, e.g. use of decorative luminaires in historic city centres, or where a very low (e.g. <2300K) CCT is also specified, the procurer may choose to apply a lower minimum luminous efficacy.</td></tr>
<tr><td colspan="2">**AC1: Enhanced luminaire efficacy**</td></tr>
<tr><td colspan="2">*(This criterion should apply when light sources or luminaires are to be replaced in an existing lighting installation and no re-design is carried out)*
Up to X points shall be awarded to tenderers who are able to provide light sources or luminaires which exceed the minimum luminous efficacy defined in TS1.
Maximum points (X) will be awarded to the tender with the highest luminous efficacy value and points shall be proportionately awarded to any other tenders whose light sources or luminaires exceed the minimum requirements of TS1 but do not reach the value of the highest efficacy tender.</td></tr>
<tr><td colspan="2">**CPC2: Provision of lighting equipment that complies with efficacy claims**</td></tr>
<tr><td colspan="2">The contractor shall ensure that the lighting equipment (including light sources, luminaires and lighting controls) is installed exactly as specified in the original tender.
If the contractor changes the lighting equipment from those specified in the original tender, explanations must be provided in writing for this change and the luminous efficacy of the luminaire shall be at least equal to or better than the original (according to EN 13032-1 or EN 13032-4).
In either case, the contractor shall deliver a schedule of the actually installed lighting equipment together with manufacturer invoices or delivery notes in an appendix.
If alternative lighting equipment is installed, test results and reports or certificates for luminous efficacy from the manufacturer(s) of any new light sources and luminaires shall be provided.</td></tr>
</table>

7.2. Dimming controls

7.2.1. Background research and supporting rationale

Dimming the light output of a road lighting installation saves energy. The relationship between dimming and power consumption is almost directly proportional for LED-based luminaires.

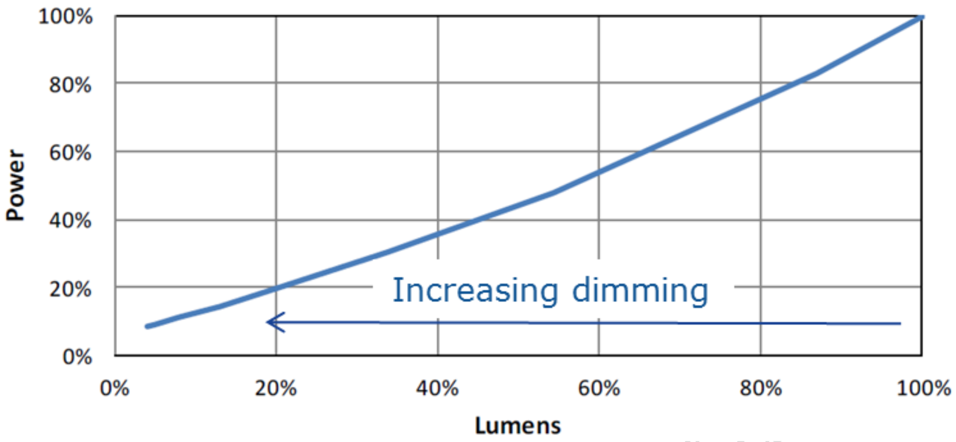


Figure 12. Relationship between power consumption and dimming of light output (Source, NEMA, 2015)

Many dimming controls can easily go down to 10% of maximum light output and some can even go to 1%. However, as the dimming levels increase, the basic low-level power consumption of the drivers and control units becomes increasingly significant, as can be demonstrated when the plotting luminaire luminous efficacy for the same luminaire under different dimming conditions.

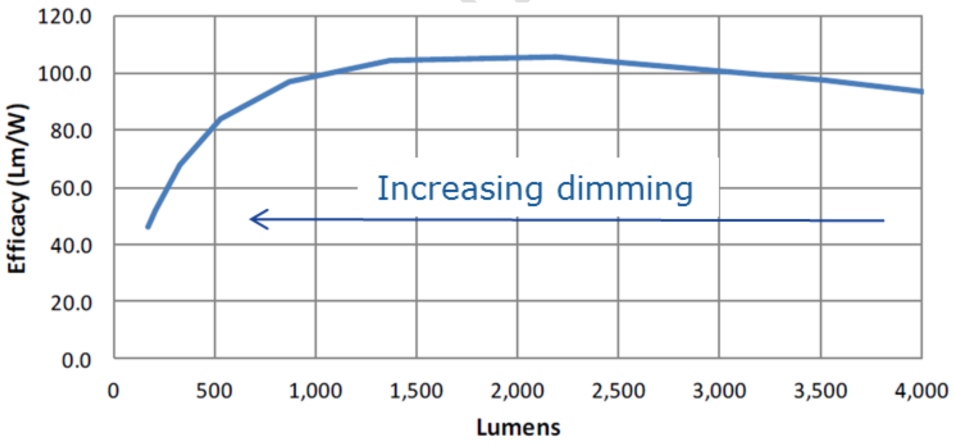


Figure 13. Relationship between luminaire efficacy and dimming of light output (Source, NEMA, 2015).

When considering the data from Figure 12 and Figure 13, it is clear that all dimming is beneficial in terms of reduced costs and environmental impacts related to energy consumption. However, it should be noted that when dimming to extremely low levels (i.e. dimming to less than 20% of maximum light output), the luminous efficacy of the luminaire will reduce.

Another benefit of dimming is that it is possible to minimise light pollution on demand. In some cases, where a more efficient lamp has been retrofitted without the control drivers and ballast being modified or replaced accordingly, it is possible that the new lamp uses the same power input to simply generate more light, even if this is more than was desired. Dimming controls can correct for this.

Existing EU GPP criteria

Annex VII of Ecodesign Regulation EC/245/2009, which provides benchmarks for luminaires, states that:

"*Luminaires are compatible with installations equipped with appropriate dimming and control systems that take account of daylight availability, traffic and weather conditions, and also compensate for the variation over time in surface reflection and for the initial dimensioning of the installation due to the lamp lumen maintenance factor*."

The same wording is used as a comprehensive level award criterion in the current GPP criteria (published in 2012). It is worth noting that the criterion only requires "compatibility" with dimming and not the installation of dimming controls as such.

Without dimming controls, it is possible that lighting installations are either over-designed to produce excessive lighting at the beginning (before lumen output depreciation) or that they will sooner fail to meet the initially designed lighting levels (again due to lumen output depreciation).

The gradual depreciation in lumen output is a common issue for all lighting technologies and is related to both decreased output due to the light source itself (can only be addressed by reduced dimming or light source replacement) and also due to dirt gathering on the luminaire (can be addressed by increased cleaning cycles).

Operational profile

In order to reduce costs, local authorities are increasingly looking at the possibility of dimming during curfew hours (i.e. periods of low road use, typically midnight to 6am). The recognition of dimming is reflected in the EN 13201-5 standard (Road lighting Part 5 – Energy Performance Indicators), which defines the term "*operational profile*".

The operational profile refers to how long the lighting installation is powered up on a daily basis. With the possibility of dimming controls, the alteration of the level of power creates the possibility for many different operational profiles. Some examples of operational profiles are provided in Figure 14 below.

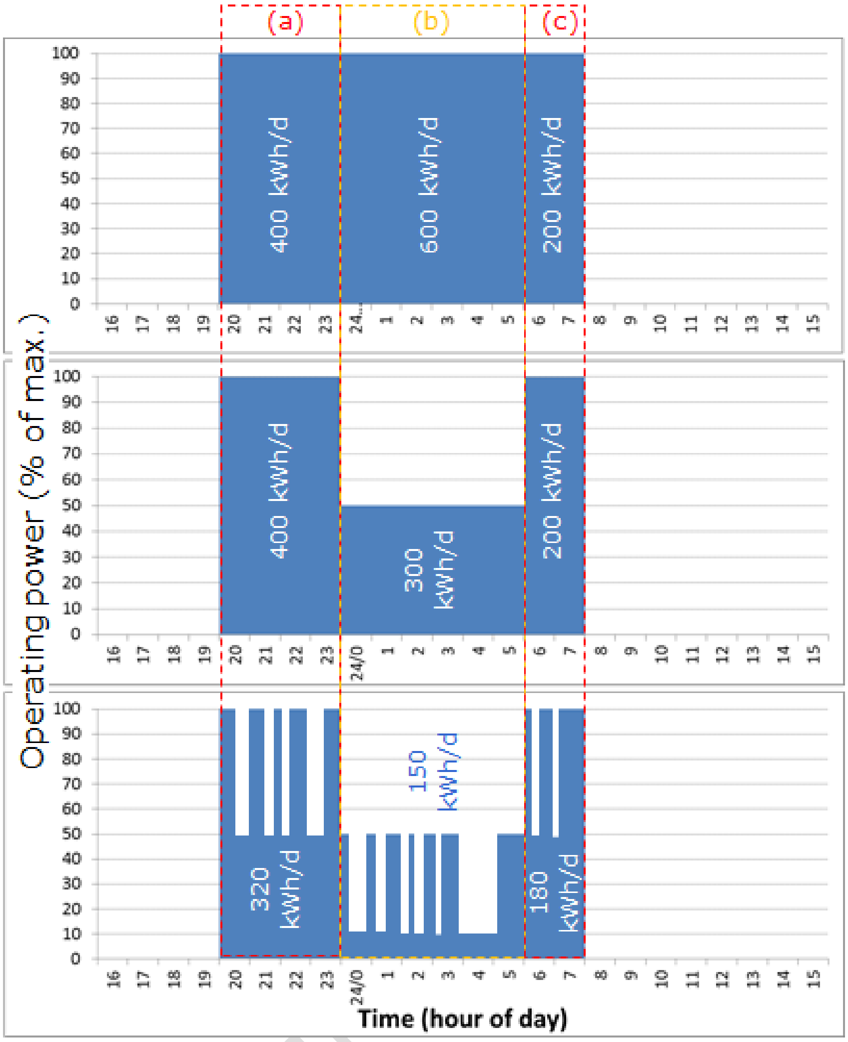


Figure 14. Examples of different operational profiles for road lighting installations during period a) evening peak hours, b) off-peak hours and c) morning peak hours (adapted from EN 13201-5). Consumption figures included refer to a 100kW installation

The top profile in Figure 14 refers to a simple on/off scenario for a lighting installation where the start and end time are programmed – this is typical of most existing installations and in this particular case, would consume 1200 kWh/d.

The middle profile in Figure 14 shows the implementation of a dimming scenario, where light output is reduced by 50% during the expected hours of low use (in this case from 0000 to 0600) – resulting in a consumption of 900 kWh/d – 25% less than the same undimmed installation.

The lower profile refers to a situation where the default light output is the same as in the middle profile, but only when sensors indicate that road use is above a certain minimum level. If road use is lower than this defined level, the lighting output will be automatically decrease from the default lighting level (from 100% to 50% during peak times or from 50% to 10% during off-peak times). Although the exact energy savings will vary from day to day, the road traffic pattern used in the assumption for Figure 14 resulted in a consumption of 650 kWh/d – almost 30% less than the simple curfew dimmed installation and almost 46% less than the same undimmed installation.

Possible cases where dimming control might not payback

Given the major operational cost savings that are possible with dimming controls, it seems unlikely that such an investment would not pay for itself. However, attention must be paid to the capital costs of dimming controls and the power rating of the luminaire. As the power rating decreases, the capital costs become more significant.

One example is with a low wattage luminaires where the extra cost for dimming controls (estimated around 50 euro) does not outweigh the savings. A quick calculation shows that for a 20W luminaire, the cost saving by reducing average energy consumption by 30% through dimming for 20 years is similar to the extra cost of the controls:

$$0.3\ x\ 20W\ x\ 4000h.yr^{-1}\ x\ 20yr\ x\ 0.11€.kWh^{-1} = 52.80€$$

The factor 0.3 corresponds to an easily achievable 30% energy saving due to implementing an operational profile that accounts for a 50% dimming during curfew hours (e.g. midnight to 6am) and prevents over-lighting of the newly installed luminaire which was specified to allow for gradual reductions in lumen output.

Future increases in electricity prices and future decreases in the costs of dimming controls will make dimming control more attractive from an investment perspective. In order to be able to take advantage of these potential future trends, and especially considering that many LED luminaires installed today will be expected to continue to operate for 10-20 years without any replacement, it is recommended that all installed luminaires and light sources are at least compatible with dimming controls.

Before deciding on whether to invest in dimming controls or not, procurers are encouraged to use the preliminary check based on LCC costing prior to launching any ITT.

7.2.2. Stakeholder discussion

Stakeholders were in general in favour of dimming controls being promoted, even in core criteria, where the installation of simple controls based on an astronomical clock could be specified. However, opinions differed about how exactly dimming should be promoted in the criteria.

In the proposal in TR 1.0, degrees of dimming were addressed indirectly simply by adjusting the CL factor in the equation that was proposed to measure the AECI. A CL factor of 1.1 was proposed for LED-based lighting in order to account for initial over-design to account for lumen output depreciation. It was proposed to reduce this factor from 1.1 to 0.85 (core) or to 0.75 (comprehensive). In order to maintain a constant AECI value, this would essentially require dimming of around 23% and 32% for core and comprehensive criteria respectively.

The assumptions behind the indirect dimming ambition levels were questioned by one stakeholder. Different opinions were expressed about the degree of dimming that would be allowable in certain situations. However, it is possible that procurers will already have clear ideas about what dimming scenarios they wish to implement (if any) and this could be specified in the Invitation to Tender (ITT) as a dimming ratio for the average illuminance with dimming divided by the average illuminance if no dimming was applied (e.g. E,m_{dim} / E,m_{nodim}). A similar idea was also suggested about the desire to see procurers specify AECI values with and without dimming.

For the purposes of calculating the impact of dimming on energy consumption tenderers should ideally provide the power curve for the luminaire with light output plotted against power consumption. The relationship is generally proportional except in high dimming scenarios where standby power consumption by control gear would become important.

Due to the fact that nearly all installations can benefit from dimming, for example to provide constant light output regulation (CLO) independent of the flux depreciation over time a requirements for dimming shall be included in the EU GPP criteria. The proposal in TR 1.0 about dimming was perhaps not so visible to procurers, so stand-alone criteria are proposed in TR 2.0. The installation of simple dimming controls based on an astronomical clock is provided as a basic requirement.

7.2.3. Criteria proposals for dimming

Core criteria	**Comprehensive criteria**
TS2: Dimming control compatibility	
(This criterion applies to all calls for tender, whether simply for relamping purposes, for re-design of existing lighting installations or the design of new lighting installations). All light sources and luminaires shall be compatible with dimming controls. *Verification:* The tenderer shall provide documentation from the manufacturer(s) of the light sources and luminaires that are proposed to be used by the tenderer are compatible with dimming controls. In cases where controls are not integrated into the luminaire, the documentation should state what control interfaces can be used for dimming. The documentation shall also state what dimming methods are compatible, for example: • Dimming based on pre-set curfew hours of low road use intensity. • Initial dimming of over-designed lighting installations to compensate for gradual decreases in lumen output. • Variable dimming to maintain a target illuminance in variable weather conditions	
TS3: Minimum dimming performance	
(This criterion is especially recommended when higher light levels are required during peak hours. The dimming scenario below is just one possible suggestion – procurers should have their own ideas and mention these in their ITT). All light sources and luminaires shall be installed with fully functional dimming controls that are programmable to compensate for lumen output depreciation and for setting 1 level of curfew dimming which should be as low as 50% of maximum light output. *Verification:* The tenderer shall provide documentation from the manufacturer(s) of the light sources and luminaires that are proposed to be used by the tenderer showing that they are compatible with dimming controls. The documentation shall also state what dimming controls are incorporated, for example: • constant light output to compensate for lumen depreciation, • pre-set curfew dimming or • variable dimming based on weather conditions or traffic volume.	*(This criterion is especially recommended when higher light levels are required during peak hours. The dimming scenario below is just one possible suggestion – procurers should have their own ideas and mention these in their ITT).* All light sources and luminaires shall be installed with fully functional dimming controls that are programmable to compensate for lumen output depreciation and for setting 2 levels of curfew dimming which should be as low as 50% (level 1) and 10% (level 2) of maximum light output. *Verification:* The tenderer shall provide documentation from the manufacturer(s) of the light sources and luminaires that are proposed to be used by the tenderer showing that they are compatible with dimming controls. The documentation shall also state what dimming controls are incorporated, for example: • constant light output to compensate for lumen depreciation, • pre-set curfew dimming or • variable dimming based on weather

The documentation shall also clearly provide a power curve of light output versus power consumption, state the maximum dimming possible and provide instructions about how to programme and re-programme the controls.	conditions or traffic volume. The documentation shall also clearly provide a power curve of light output versus power consumption, state the maximum dimming possible and provide instructions about how to programme and re-programme the controls.
CPC3: Dimming control	
(Applicable to TS2 and TS3) If, for whatever reason, the contractor changes the light sources and/or luminaires from those specified in the successful tender, the new light sources and/or luminaires shall be at least • equally compatible with dimming controls as the originals, • have the same programmable flexibility, • be able to achieve at least the same maximum dimming and • have a similar power curve. Agreement on this matter shall be settled by the provision of similar documentation from the manufacturer(s) of the new light sources and/or luminaires that would justify the selection of the new luminaires and/or light sources.	

7.3. Annual Energy Consumption Indicator (AECI)

7.3.1. Background research and supporting rationale for AECI

When a new design is carried out for a lighting installation, either because it is a new site or a complete refurbishment of an existing site, it is possible to specify in the tender some design details such as the Power Density Index (PDI) and, by knowing the illumination level required, the AECI. In TR 2.0, two criteria were set for these situations, one for a maximum PDI and one for a maximum AECI.

One major criticism of the approach in TR 2.0 was that procurers will not easily understand the standard calculations for PDI and AECI and that a simpler approach is needed. In the same way, it was questioned if procurers really needed to specify any PDI value, since this only forms a part (albeit a very important one) of the AECI calculation.

The AECI (expressed in Wh.m^{-2}) is considered as a more intuitive indicator for procurers to understand than PDI or luminaire efficacy since it can easily be converted to kWh or kWh.km^{-1}) to effectively express the final electricity consumption of a particular road lighting installation. The AECI takes into account over-lighting and dimming.

Consequently, the approach in TR 3.0 focuses purely on a single criterion for AECI and the aim of the background research is to explain how this calculation can be broken down into distinct factors and directly linked to PDI.

The same explanation of how to calculate PDI that was provided in TR 2.0 has been moved to Technical Annex I. In a separate excel spreadsheet, tables of different PDI reference values have been included that are directly related to the factors that determine PDI (luminaire efficacy, maintenance factor and utilance). The PDI tables are included in Technical Annex II and form the basis of the AECI criterion. However, the spreadsheet will also be available to stakeholders for comment during the written consultation period.

The one variable that is not specified in the AECI criterion is the illumination level, which is something that the procurer must define (illumination should also take into account any dimming). For reference only, we have also included some indicative AECI reference values for C and P class roads (in Technical Annex II).

Comparison of standard and simplified calculations

The EN 13201-5 standard calculation is defined in the text box below.

Calculating AECI (W/(m2.yr)

The standard calculation defined in EN 13201-5 is not directly linked to the PDI calculation and so does not consider lighting levels or PDI, only power consumption, taking into account all the periods when power consumption is different:

$$D_E = AECI = \frac{\sum_{j-1}^{m}(P_j\ x\ t_j)}{A}$$

Where P_j is the operational power required (in W) in the j^{th} period of operation, t_j is the length of time (in hours) during a one year period that the j^{th} period is in operation, A is the area that is lit (m^2) and m is the number of periods with different operational power.

When trying to examine what is a suitable ambition level for the AECI, it is arguably better to calculate AECI in such a way that the PDI is directly included in the calculation and that the influence illumination has on the AECI can be clearly seen:

$$AECI = PDI\ x\ E_m\ x\ F_D\ x\ T\ x\ 0.001$$

Where, AECI is in units of kWh.m^{-2}.yr^{-1}

PDI is in units of W.lx^{-1}.m^{-2}

E_m is the maximum maintained illuminance (lx),

F_D is the dimming factor for any programmed dimming.

T is the operating time ($h.yr^{-1}$)

0.001 is the number of kW in 1W

It is clear that the higher the average light level or the longer the lights are on, the higher will be the AECI.

A closer look at the PDI variable

The PDI is the other major variable and, as initially described in TR 2.0, a breakdown of the factors that affect PDI values is provided so that readers can understand why a fixed PDI value for all roads cannot be used:

$$PDI_{ref}(W.lx^{-1}.m^{-2}) = \frac{1}{\eta_{lum}\ x\ F_M\ x\ U}$$

Where:

- η_{lum} is the luminaire efficacy (in lm/W).
- F_M is the maintenance factor (accounting for both lamp lumen depreciation and dirt on the luminaire housing, i.e. F_{LLM}xF_{LM}).
- U is the utilance (expressing the % of total light output that lands on the target areas).

Luminaire efficacy

With regards to luminaire efficacy, the reader is referred to the background research carried out for TS 7.1 (see section 7.1.1). The main points are that the LED technology is improving at such a rate that it would be necessary to increases the ambition level every 2 years.

Factors that affect the luminaire efficacy for LED are the year it was produced (as rapid developments continue) and also the maximum light output of the lamp.

Maintenance Factor

A maintenance factor of 0.85 (subtracting 0.10 for lamp lumen depreciation, F_{LLM} and 0.05 for dirt accumulation, F_{LM}) is suggested here but this can be altered by the procurer. The maintenance factor can be considered as the combined effect of all factors that decrease the light output from the luminaire such as lamp lumen output depreciation and dirt accumulation on the luminaire. The latter factor will be influenced by the degree of atmospheric pollution (especially particulate matter), the type of luminaire casing material and the cleaning frequency. Local authorities have often used general calculation tables to estimate the maintenance factor.

Table 9. Example of a table to estimate the maintenance factor for road lighting (Sanders and Scott, 2008).

Cleaning interval (months)	**Luminaire maintenance factor (F_{LM})**								
	IP2X			**IP5X**			**IP6X**		
	High pollution	Medium pollution	Low pollution	High pollution	Medium pollution	Low pollution	High pollution	Medium pollution	Low pollution
12	0.53	0.62	0.82	0.89	0.90	0.92	0.91	0.92	0.93
24	0.48	0.58	0.80	0.87	0.88	0.91	0.90	0.91	0.92
36	0.45	0.56	0.79	0.84	0.86	0.90	0.88	0.89	0.91
48	0.42	0.53	0.78	0.76	0.82	0.88	0.83	0.87	0.90

High pollution is generally considered to occur in large urban or heavily industrialised zones. Medium pollution is attributed to semi-urban, residential or light industrial zones and low pollution is attributed to rural areas.

It is clear from Table 9 that the Ingress Protection rating will also have a major effect, at least between IP2X and IP5X. Other GPP criteria mentioned later (see TS12) recommend a minimum IP5X in some cases and IP6X in the majority of cases.

However, the traditional rules of thumb for luminaire maintenance factors in the UK were shown to be overly conservative by Sanders and Scott (2008). A more appropriate approach was to consider mounting height and to split areas into different "environmental zones".

Table 10. Actual observed data of maintenance factor for IP65 luminaires in UK

Cleaning interval (months)	E1: national parks, areas of outstanding natural beauty		E2: generally outer urban and rural residential areas		E3: generally urban residential areas		E4: generally urban areas having mixed residential and commercial use with high night time activity	
	≤6m	≥7m	≤6m	≥7m	≤6m	≥7m	≤6m	≥7m
12	0.98	0.98	0.98	0.98	0.94	0.97	0.94	0.97
24	0.96	0.96	0.96	0.96	0.92	0.96	0.92	0.96
36	0.95	0.95	0.95	0.95	0.90	0.95	0.90	0.95
48	0.94	0.94	0.94	0.94	0.89	0.94	0.89	0.94

The data collected by Sanders and Scott reveals that in general, the lumen depreciation due to dirt accumulation is much lower than previously assumed. This may be due to improved emission control on vehicles, decreased industrial activity in the UK or other factors. Interestingly, the data also revealed that mounting height had no effect on luminaire maintenance factors in areas of low pollution but did have an effect in areas of higher pollution.

Regardless, the main purpose of showing these tables is to explain that the choice of maintenance factor is important. While the F_{LLM} is confirmed by the lighting equipment manufacturer, the F_{LM} is very much up to the procurer to define and may use overly conservative rules of thumb that led to overdesign in the lighting installation.

Factors that influence the MF include: local environment, luminaire housing, pole height and cleaning frequency.

The Utilance Factor

The utilance is determined according to road width. The utilance factors that have been used to calculate the reference PDIs listed in Technical Annex II are as follows:

Table 11. Utilance factors as a function of road width and ambition level

Road width	Core level	Comprehensive level
≥ 9m	0.7	0.7
8-9m	0.63	0.7
7-8m	0.56	0.6
6-7m	0.49	0.5
5-6m	0.42	0.5
≤ 5m	0.35	0.5

This is the general guide to follow unless the procurer decides to choose their own utilance based on site specific freedoms or restrictions for optimising the lighting design. For reference, the highest utilance that can be realistically considered today would be around 0.78, and that is only when there are no constraints on the placement of poles and mounting heights of luminaires. In sites where there are lots of constraints on optimising the optical design, a utilance of 0.35 may be justifiable even for roads that are wider than 5m.

Factors affecting utilance are the road width, luminaire optics and pole positioning.

7.3.2. Stakeholder discussion

Comments about AECI vs PDI

There was considerable discussion about whether or not criteria should be set for PDI. The main argument against PDI was that it was an additional complexity that procurers might not understand properly. The main argument in favour of PDI criteria is that it ensures that the design delivers enough light to the road for a certain amount of power consumption. Increasing spilled light will increase power consumption but not light on the road, so it would increase the PDI. Consequently, the PDI enables any subsequent AECI value to be contextualised correctly because it is linked to a certain illuminance or luminance level on the road.

One stakeholder stated that the usefulness of the PDI criterion really depends on how interested the procurer is in minimum lighting levels and design performance – which can vary depending on the nature of the road. For example:

- Where details of road layout, lighting level or dimming are not specified by the procurer in sufficient detail and there is little or no flexibility in the design, the calculation of PDI is not so valuable and only AECI linked to a defined reference PDI would be necessary.
- When sufficient details are provided and flexibility in the design is possible, there is a real opportunity to optimise PDI (and thus AECI) by good design. So in this case, a PDI criterion could be specified and allowed to be used in the AECI calculation.

However, other stakeholders felt that so long as the influence of PDI was clearly demonstrated on AECI, the simplest approach would be to set AECI ≤ PDI_{ref} x E,m. Then it would simply be up to the procurer to define either the AECI they want (the tenderers then have to play with the light and with dimming) or the E,m that they want (the tenderers have to play with luminaire efficacy, maintenance factors and utilance).

For this new approach to work, it is necessary to justify a series of PDIref values that can be used as a basis. As mentioned earlier, there are many variables affecting PDI (all the factors affecting luminaire efficacy, maintenance factor and utilance).

For consistency, when constructing the PDI reference tables in Technical Annex II, the same numbers for luminaire efficacy that are stated in section 7.1.3 have been used. A single maintenance factor of 0.85 has been used for all situations (procurers may change this if they wish when setting minimum PDI_{ref} values). The utilance factor is defined as a function of road width (higher utilance for higher road widths) but the assumed utilance is also more ambitious in the comprehensive level requirements.

7.3.3. Criteria proposals for AECI

<table>
<tr><th>Core criteria</th><th>Comprehensive criteria</th></tr>
<tr><td colspan="2">TS4 Annual Energy Consumption Indicator (AECI)</td></tr>
<tr><td colspan="2"><i>(Applies when a new lighting installation is being designed or when a re-design is required due to renovation of an existing lighting installation. Procurers should pay particular attention to the numbers submitted for the maintenance factor and utilance from the designer/tenderer and make sure that they are realistic and justifiable).</i>
The procurer shall provide technical drawings of the road layout together with the areas to be lit and the illuminance/luminance requirements.
For M class roads, the procurer shall define the surface reflectivity coefficient of the road which tenderers should use in luminance calculations.
To aid tenderers in their assumptions for design maintenance factors, the procurer should define with what frequency the luminaires will be cleaned.
For the average maintained illuminance/luminance defined by the procurer, the maximum AECI of the design shall comply with the equation below:
$$\mathrm{AECI}_{design} \leq \mathrm{PDI}_{ref} \text{ x } E_m \text{ x } F_D \text{ x } T \text{ x } 0.001$$
<i>Where:</i>
<i>PDI is in units of</i> $W.lx^{-1}.m^{-2}$
E_m <i>is the maximum maintained illuminance (lx),</i>
F_D <i>is the dimming factor for any programmed dimming.</i>
<i>T is the operating time</i> $(h.yr^{-1})$
<i>0.001 is the number of kW in 1W</i>
The PDI_{ref} value used shall depend on the road width and the road lighting class as listed in Technical Annex II.
<i>Verification</i>
The tenderer shall state what lighting software has been used to calculate the PDI value and provide a clear calculation, where the values for luminaire efficacy, maintenance factor and utilance factor of their proposed design are visible. The calculation results will include the measurement grid and calculated illuminance/luminance values.</td></tr>
<tr><td colspan="2">AC2: Enhanced AECI</td></tr>
<tr><td colspan="2"><i>(Applies when TS4 has been applied in an Invitation to Tender (ITT).</i>
Up to X points shall be awarded to tenderers who are able to provide designs that result in a lower AECI than the maximum limit defined in TS4.
Maximum points (X) will be awarded to the tender with the lowest AECI value and points shall be proportionately awarded to any other tenders whose designs are lower than the maximum requirements of TS4 but do not reach the value of lowest energy consuming tender.</td></tr>
</table>

7.4. *Metering*

7.4.1. Background research and supporting rationale

As shown in the Preliminary report (PR) the operational costs of electricity are the major source of environmental impacts. The purchase of electricity is a major contributor to the total cost of ownership of road lighting installations and can represent a significant fraction of total energy costs for municipalities.

As mentioned in the PR (section 3.3.3), more and more cities understand that a metering system for a road lighting network may play a strategic role in energy consumption and CO_2 emission reduction measures. A metering system could potentially be added to the existing road lighting system, even if non-LED technologies are in place.

The electricity has to be billed and purchased for road lighting, but in a lot of cases there are no meters to count the electricity consumption. In those cases it usually means that the bill to pay is estimated by the lamp power and the operation time without considering the real consumption, which may vary especially if dimming and CLO drivers are used. With traditional HID lamp technologies and operating practices, this was not a major issue because lamps only came in a limited number of power ratings (e.g. 50W, 70W, 110W), the same type of ballasts were used and operational profiles did not account for CLO, curfew dimming or user volume-based dimming.

However, with the rise of LED technology, lamps are available in a much wider range of power ratings. The use of CLO drivers to avoid excessive power consumption and over-lighting of installations during initial operation is increasingly being considered. For municipalities and road authorities under budgetary pressure or wishing to reduce light pollution, the ability to dim light output during defined periods of low use is essential.

If dimming control programs that are activate different dimming levels based on real life, in-situ variations in daylight or traffic are used (see bottom option in Figure 14), it will be impossible to accurately predict electricity consumption. In these cases especially, the metering of electricity consumption at the luminaire level, or at least at the level of the installation responding to these dimming controls, is the only way to ensure that the billing for electricity is accurate and to also know how these dynamic dimming controls perform compared to simpler fixed curfew dimming controls.

Metering at the level of the luminaire could provide valuable information about the lifetime performance of the light source and control gear and, if reported remotely, would also identify any abrupt failures. Such data could also be valuable if attempting to identify the cause of abrupt failures (e.g. during storm periods, accidents or pinpointing and act of vandalism). Long term metering data could provide valuable feedback to manufacturers as well, to compliment the laboratory data they already have.

Reference to the Measuring Instruments Directive (MID) was made in the criteria proposed in TR 1.0 and such a reference is maintained in the TR 2.0 and TR 3.0 proposals. However, due to the costs and effort involved in complying with the requirements of the MID, this condition should only apply to a meter installed at the sub-station for a lighting installation and not to individual luminaire level meters.

7.4.2. Stakeholder discussion

The interest in metering was highlighted by a request to consider the creation of a database with the real electricity consumption of the road lighting by authorities in each city. The best quality data would be based on lighting installations and networks that are metered. However, it would still be possible to report data based on the MWh consumption that is billed and the number of lighting points covered in that bill. If possible, the number of kilometres of road covered should be defined too.

Stakeholders confirmed that metering of electricity consumption in road lighting installations is not common practice. Consumption is often estimated for billing purposes by multiplying the number of luminaires by the typical luminaire power consumption and factoring in any dimming scenarios. Some extreme examples in the UK were cited where billing for electricity consumption was simply based on a fixed cost per luminaire and did not account for any lower consumption due to higher efficacy light sources or dimming. It was questioned if metering was actually a "green" criterion although it would be very useful in the aforementioned extreme cases and also in verifying operational performance (and costs) relating to energy efficiency for any road lighting installation. It would also provide real data and provide direct positive feedback to road network managers on any measures taken to improve energy efficiency.

A distinction was made between metering at the level of the installation and at the level of the individual luminaire. The main problems with installing metering systems for installations were related to the need to comply with different regulations, additional costs and, in urban areas at least, limited space for new electrical cabinets and/or limited space in existing cabinets. At the individual luminaire level, it is possible to specify control gear that is at least compatible with metering and that remote reporting of electricity consumption offers significant potential in monitoring operational performance, especially if linked to constant light output controls but also to detect abrupt failures in some or all of the light sources in a particular luminaire. Considering the potential to embrace smart lighting principles, some stakeholders were in favour of introducing individual luminaire reporting compatible with remote systems as an award criterion, since it would entail additional costs.

7.4.3. Criteria proposals for metering

Core criteria	**Comprehensive criteria**
TS5 - Metering	
(Recommended for all tenders where a new lighting installation is being installed or where an existing installation is being refurbished and no meter is already in place for that installation) The procurer shall state any specific technical requirements for the metering system in the ITT. The tenderer shall provide details of the proposed metering equipment and any ancillary equipment required in order to monitor electrical consumption at the lighting installation level for the same lighting installation that is the subject matter of the ITT. ***Verification:*** The tenderer shall provide the technical specifications of the metering and measurement system and provide clear instructions on how to operate and maintain this system. A calibration certificate compliant with the Measuring Instruments Directive 2004/22/EC (MID) shall be provided for each control zone.	*(Recommended for all tenders where a new lighting installation is being installed or where an existing installation is being refurbished and no meter is already in place for that installation)* The procurer shall state any specific technical requirements for the metering system in the ITT. The tenderer shall provide details of the proposed metering equipment and any ancillary equipment required in order to monitor electrical consumption at the lighting installation level for the same lighting installation that is the subject matter of the ITT. The metering device must be capable of logging data on a 24 hour basis that can later be manually or remotely downloaded. ***Verification:*** The tenderer shall provide the technical specifications of the metering and measurement system and provide clear instructions on how to operate and maintain this system. A calibration certificate compliant with the Measuring Instruments Directive 2004/22/EC (MID) shall be provided for each control zone.

7.5. Contract performance clauses relating to energy efficiency

7.5.1. Background research and supporting rationale

A CPC was proposed to ensure the correct functioning of any specified controls (e.g. timers, daylight controls, CLO drivers etc.) that relate to routine operation and dimming of the installation. The correct operation of these controls will have a direct impact on energy consumption (i.e. PDI and AECI values).

As with the CPC for luminaire efficacy (CPC2), the contractor is obliged to provide the originally installed lighting equipment as specified in the design used in the successful tender except in cases where equivalent or better performing equipment can be provided at no extra cost to the procurer. The need for this CPC is to prevent the contractor from substituting the originally specified lighting equipment for inferior (and cheaper) products. However, if cheaper products are available on the market that are of equivalent or superior performance, then this CPC also allows for this so long as it is clearly communicated to the procurer and adequate supporting evidence is provided of the performance of the alterative lighting equipment.

A comprehensive level CPC has been proposed, which only applies to contracts where a re-design or a new design has been carried out. The CPC requires that a road area selected by the procurer, free of obstructions such as trees, bus-stops and parked vehicles and as free as possible from interference from other background light sources such as advertising boards and buildings, is tested for actual lighting levels and compared with the actual power consumption of the relevant luminaires.

7.5.2. Stakeholder discussion

Stakeholders were cautious about any promotion of specific control systems at the installation level because this is highly unlikely to be requested when network wide control systems are already in place. Regarding presence detectors, one stakeholder referred to a project where 1 in 5 presence detectors were found to be performing inadequately after only 1 year of operation, resulting in increased energy consumption. Consequently, it would not be recommended to install these types of controls without metering of electricity consumption (ideally at the level of individual luminaires linked to remote data recording systems). Further research into possibilities to specify "self-commissioning" luminaires in EU GPP criteria was requested. Such self-commissioning would involve automatic in-situ checks against a defined set of operational parameters that can be defined and adjusted if needed.

The comprehensive level CPC6 proposal goes further by requiring a randomly chosen road segment to be assessed for photometric performance by field measurements of illuminance and energy efficiency (PDI and AECI values over a 1 week period) to check that they are sufficiently close to or even exceed design performance. For verification of the PDI the measurement grid and calculated illuminance values should be provided by the designer and they can be verified by an illuminance meter (+/- 10 %). Nonetheless, it was pointed out that such measurements are complicated due to uneven road surfaces, which requires a self-levelling photometer and increased measurement time. Taking measurements from a point 10 cm above the road surface was not recommended due to interference by reflected light.

Stakeholders had strong opinions about this of post-completion monitoring of energy efficiency performance. It was emphasised that although it was very useful and obliges the contractor to comply, this would introduce additional costs and should only be used in contracts that cover larger installations. In smaller installations or installations using only traditional HID lamps, CPC4 and CPC5 would be sufficient.

It was also considered important to distinguish between "urban" and "non-urban" road lighting when considering the use of CPC6. Due to potential interference with light measurement in urban areas due to blocking by balconies and trees or background light from windows, cars and advertisements, it was recommended to only consider applying the comprehensive level CPC to non-urban lighting installations.

Another distinction was made between traditional lamp technologies (no follow up measurement recommended) and LED lighting (follow up measurement recommended). The reason for this was due to the fact that LED can vary significantly in terms of wattage and optics.

The option to measure illuminance instead of luminance was supported because it is possible that the reflectance of the real road differs significantly from the assumed reflectivity used in photometric calculations.

When considering onsite verification of light levels and energy consumption, the work of CEN TC 169 regarding verification steps should be considered and acceptable tolerances should be considered in terms of Annexes E and F of EN 13201-4.

One key question that arose with the comprehensive level CPC was "what happens in cases of non-compliance"? Ultimately this should be defined by the procurer and clearly stated in the ITT. Options would be either to remedy the works at no additional cost or the application of financial penalties in proportion to the discrepancy between claimed energy efficiency and photometric performance. There is also the option to provide bonuses in the case of superior performance.

7.5.3. Criteria proposals

Core criteria	**Comprehensive criteria**
CPC4: Commissioning and correct operation of lighting controls	
The successful tenderer (contractor) shall ensure that new or renovated lighting systems and controls are working properly. • Any daylight linked controls shall be calibrated to ensure that they switch off the lighting when daylight is adequate. • Any traffic sensors shall be tested to confirm that they detect vehicles, bicycles and pedestrians, as appropriate. • Any time switches, CLO drivers and dimming controls shall be shown to be able to meet any relevant specifications defined by the procuring authority in the ITT. If after the commissioning of the system, the lighting controls do not appear to meet the relevant requirements above, the contractor shall be liable to adjust and/or recalibrate the controls at no additional cost to the procuring authority. The contractor shall deliver a report detailing how the relevant adjustments and calibrations have been carried out and how the settings can be used. ***Note:*** *For large utilities it may be required that the new or renovated installation is simply compatible with the existing control systems used for the wider lighting network. In this situation, this CPC would also refer to compatibility of controls with the existing control system.*	
CPC5: Provision of originally specified lighting equipment	
The contractor shall ensure that the lighting equipment (including light sources, luminaires and lighting controls) is installed exactly as specified in the original tender. If the contractor changes the lighting equipment from those specified in the original tender, explanations must be provided in writing for this change and the luminous efficacy of the luminaire, the parasitic power consumption of lighting controls and the degree of flexibility in programming of lighting controls shall be at least equal to or better	

<table>
<tr><td colspan="2">than the originals.
In either case, the contractor shall deliver a schedule of the actually installed lighting equipment together with manufacturer invoices or delivery notes in an appendix.
If alternative lighting equipment is installed, test results and reports for luminous efficacy from the manufacturer(s) of any new light sources and luminaires shall be provided as well as relevant documentation stating the performance of any new lighting controls.</td></tr>
<tr><td colspan="2">**CPC6: Compliance with actual energy efficiency and lighting levels with design claims**</td></tr>
<tr><td></td><td>*(Only recommended for large installations with a significant amount of installed power)*
Where relevant, a suitable non-urban road sub-area shall be selected by the procurer where the luminaire positioning is in line with the PDI photometry study for in-situ photometric measurements (according to EN 13032-2) and energy consumption measurements (according to EN 13201-5) during an agreed period of one week.
The selected sub-area must be free of significant interference to lighting caused by trees, bus-stops or parked vehicles and from background light levels caused by advertising boards or buildings.
For roads with luminance requirements, it will be acceptable to provide illuminance data so long as the road surface reflectivity assumed in the design calculations for PDI has previously been stated.
The parameters influencing the uncertainty in illuminance measurements mentioned in Annex F of EN 13201-4 should be considered. It is advisable to use automated illuminance measurement systems and to agree on the illuminance and data point tolerances before the project (±10% is suggested).
During the same one week period peak power [W] and energy consumption [kWh] shall be measured and/or calculated for the relevant light points.
The in-situ measured values of PDI and AECI shall be ±10% of the design AECI value and ± 15% of the design PDI value.
Note: The consequences of non-compliance with the design values for PDI and/or AECI should be defined in the ITT. Options could include:
• *Remedial works to be undertaken at no additional cost to the procurer.*
• *Financial penalties in proportion to the degree of non-compliance (perhaps related*</td></tr>
</table>

	to foreseeable additional electricity costs over a defined period caused by the poorer performing installation). *In cases where non-compliance is disputed, the contractor may repeat the measurements on the same sub-area or, if it can be argued that the sub-area was not suitable for measurement, select another sub-area. The procurer shall not be liable for the cost burden of any additional measurements.* *If the performance is actually better than the design predictions, then no penalties should apply.*

8. Light pollution criteria

As mentioned in the Preliminary report, light pollution is one of the environmental impacts associated with road lighting that is not captured by LCA analysis. Broadly speaking, light pollution can have diverse adverse impacts of artificial light on the environment due to any part of the light from a lighting installation that:

1. is misdirected or that is directed on surfaces where no lighting is required
2. is excessive with respect to the actual needs
3. causes adverse effects on human beings and the environment"

Some strong opinions were expressed by certain stakeholders about this topic, with the most extreme arguments stating that the most environmentally friendly road lighting system is the one that was never built in the first place.

Although the aforementioned argument is technically correct and perfectly valid, it must be emphasised that the EU GPP criteria does not intend in any way to influence the decision to light a road or not. The way EU GPP criteria should fit into procurer decisions is illustrated in Figure 15.

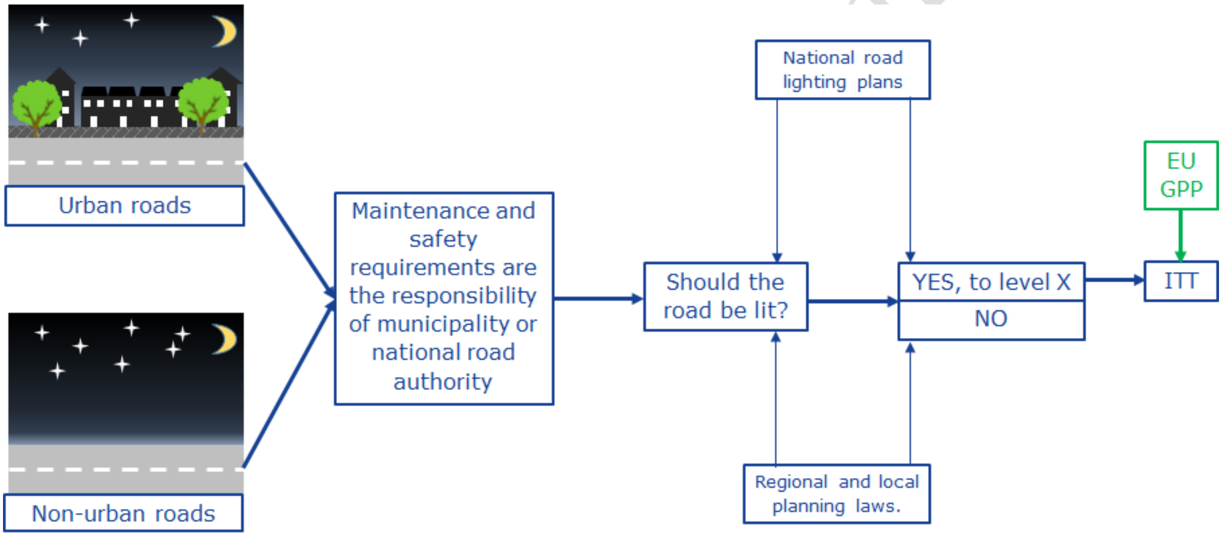


Figure 15. Role of EU GPP criteria in planning process for road lighting installations

From Figure 15, it is clear that the decision making process of whether or not to light a road is the responsibility of the relevant public authority and that the decision will ultimately be determined by provisions made in national, regional and local planning procedures. Only once the decision to light a road has been taken and an Invitation to Tender (ITT) is drafted, would EU GPP criteria potentially apply.

One example of national planning guidelines for limits on upward light pollution is that of the UK, which is based on technical guide CIE 126:1997. In a similar manner, Catalonia (DECRETO 190/2015) (Spain) has developed its own planning law for public lighting.

Table 12. Upward light limits as a function of environmental zone in UK, Catalonia and CIE 126

Environmental Zone	Maximum R_{ULO} (%)		
	CIE 126	UK (ILE, 2002)	Catalonia non-curfew/curfew
E1: Areas with intrinsically dark landscapes: national parks, areas of outstanding natural beauty	0	0	2 / 1
E2: Areas of low district brightness: generally outer urban and rural residential areas	5	2.5	5 / 2
E3: Areas of medium intrinsic brightness: generally urban residential areas	15	5	10 / 5
E4: Areas of high district brightness: generally urban areas having mixed residential and commercial use with high night time activity	25	15	25 / 10

Another example of a standard approach is the Low Impact Lighting (LIL) which has especially been promoted by German, Italian and Slovenian members of the European Environmental Bureau. The standard sets out the following requirements:

- Specific energy consumption of 15 kWh/pe/yr for all outdoor public lighting.
- CCT <2200K with less than 6% of total emissions in the <500nm range (except when average illumination is <5 lx, CCT can rise to 2700K and <500nm emission can rise to 10%).
- ULOR of 0.0% both when new and when dirty.
- Ban on lighting on any roads, exits and junctions outside of settlements.
- Pole distance must be at least 3.7x the pole height.
- Maximum luminance allowed is 0.5 cd/m^2 (i.e. no brighter than an EN 13201 compliant M5 road).
- Curfew dimming to at least 10% with adaptive technology or to at least 50% with non-adaptive technology.
- Mean time between failure of luminaires must be at least 100000 hours or 25 years.
- Luminaire efficacy must be: >50lm/W for lighting less than 1900K, >95lm/W for lighting of 1900-2200K or > 100lm/W for lighting of 2200-2700K CCT (exemptions may apply when mechanical shielding is added to prevent unwanted lighting or when the pole distance:pole height ratio exceeds 6:1).
- Utilisation factor of at least 70% (i.e. 0.70) must be achieved except in cases of narrow cycle or pedestrian paths, where it can be at least 40%.
- Illumination on residential windows cannot exceed 0.01 – 0.50 lx depending on how close the window is to the illuminated public place.

The LIL standard has rules that would not follow the recommendations set out in EN 13201, so procurers interested in such an approach should take care that there is no national or regional legislation that would oblige them somehow to implement the EN 13201 recommendations. The LIL standard clearly prioritises light pollution over energy efficiency but, by advocating lower light levels and curfew dimming, would have a significant beneficial impact on overall electricity consumption of a particular lighting installation – especially when compared to the direct implementations of EN 13201 recommendations for the same area.

The concept of light pollution can broadly be considered as the alteration of natural light levels by human activities, including the emission of artificial light. Light pollution may undermine enjoyment of the night sky (phenomenon skyglow), be harmful to species or be a source of annoyance to people (glare and obtrusive light).

8.1. Ratio of Upward Light Output (R_{ULO} / ULOR)

8.1.1. Background research and supporting rationale

Skyglow

The central argument for having criteria that limit the upward light output ratio is to reduce the artificial brightening of the night sky (skyglow) and also help limit obtrusive light in built-up urban areas.

For obvious reasons, one of the first stakeholder groups to raise concerns about skyglow from light pollution was astronomers. The Royal Astronomical Society (RAS) in the UK found that 80% of their members could not, or could barely see the Milky Way, having to travel 5-50 miles before being able to find suitable viewing conditions.

LED luminaires typically include glass envelopes, lenses, optical mixing chambers, reflectors and/or diffusers to obtain the desired light distribution. This makes them better suited to deal with ambitious R_{ULO} requirements. With traditional HID cobra-heads there was a trade-off when choosing between drop refractor type lenses and flat glass lenses. Drop lens units were typically used for wider pole spacings and more uniform lighting patterns. Flat glass units usually have less upward light output, better control of light trespass into residential windows, and lower high angle glare. However, flat glass also reduces the total light output or efficiency of the luminaire due to increased internal reflections. Internal reflections can be attenuated by using anti-reflective coatings.

From the point of view of environmental impact and products available on the market there are no grounds to discriminate R_{ULO} requirements according to EN 13201-2 road classes. It should be noted that P classes only occur in residential areas and therefore they could be subjected to less strict requirements.

Thanks to the use of satellite mounted cameras and sensors, it is possible to have an idea of the actual levels of light pollution across the whole of Europe.

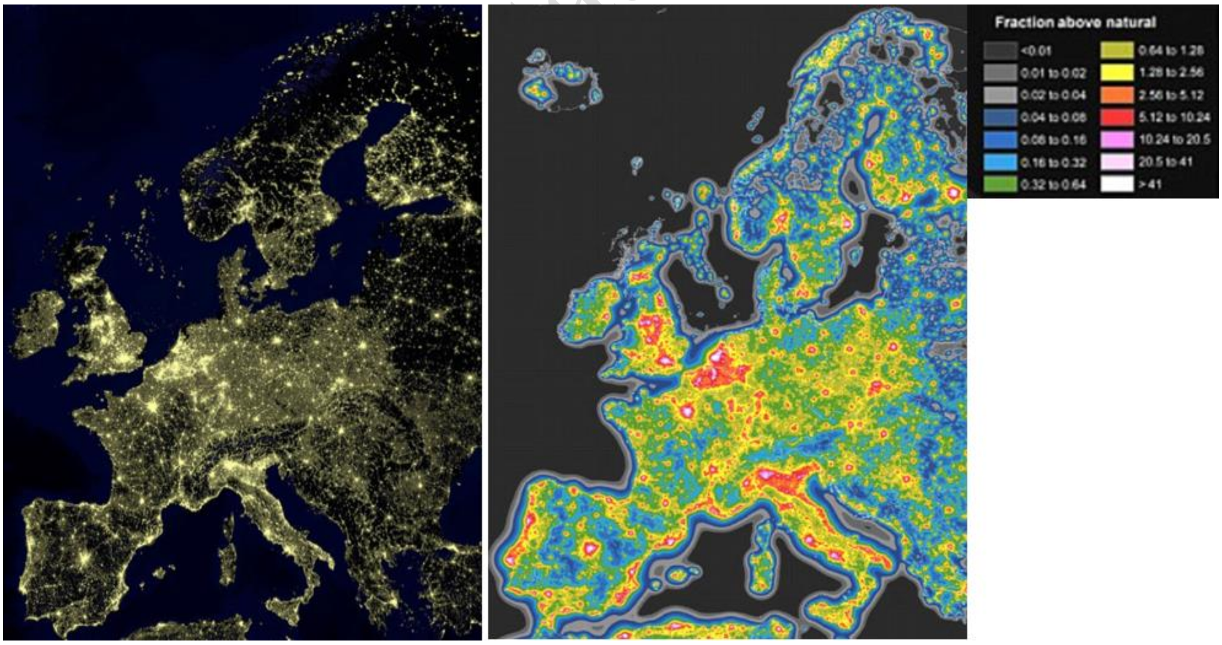


Figure 16. Light pollution in Europe: "Earthlights 2002" published by NASA (left) and a map of skyglow from Falchi et al., 2016 based on VIIRS DNB data from the Suomi NPP satellite (right).

From the images in Figure 16 it is clear that Europe has significant levels of light pollution. The particular impact of major cities can be seen in the cases of Madrid, Paris, London and Rome compared to surrounding areas. The largest areas of consistently high light pollution are in northern Italy, the “low countries” (Belgium and the Netherlands), Western England and on the coastline between Lisbon and Porto.

According the data presented by Falchi et al., (2016) around only around 7% of the land in Europe suffers from light pollution levels that are high enough to prevent viewing of the Milky Way. However, unfortunately around 60% of the European population live in these polluted areas. Concern was expressed by the authors about a significant amount of light pollution being missed in the future as the many lighting installations shift to LED. The problem with LED is that, unlike traditional sodium lamps, it emits a significant portion of its light output in the 400-500nm range. The sensitivity of the satellite mounted VIIRS DNB (Visible Infrared Imaging Radiometer Suite Day Night Band) sensor is only useful between 500 and 900nm. So one consequence of a shift to more energy efficient, LED-based street lighting could possibly be that there is a perceived drop in light pollution levels measured by VIIRS DNB that may or may not be true.

Blue light can hinder naked eye astronomic observations by increasing skyglow because it scatters more in the atmosphere and the eye is more sensitive to it at low light levels.

Existing criteria and ambition level

The existing EU GPP criteria, published in 2012, make a distinction between road classes (ME1-ME6, CE0-CE5, S1-7 and roads split by use type (functional or amenity lighting). UOR requirements were much higher, ranging from 3 to 25%.

The best benchmark recommended in EC 245/2009 is to have ULOR at a maximum of 1% for all road luminaires. Because the GPP criteria are voluntary and have the aim of increasing awareness of environmental criteria that can apply in ITTs, it is proposed that all luminaires have a ULOR of 0% when tested in the laboratory. A distinction is made between scenarios where light points are flexible (luminaires must be installed horizontally) ad where existing light points must be used (exceptions made for retrofitting existing installations). This last point is due to the fact that light poles are most often installed at some distance from the road and in order to direct the light on the road they are inclined (typically 5 to 15°).

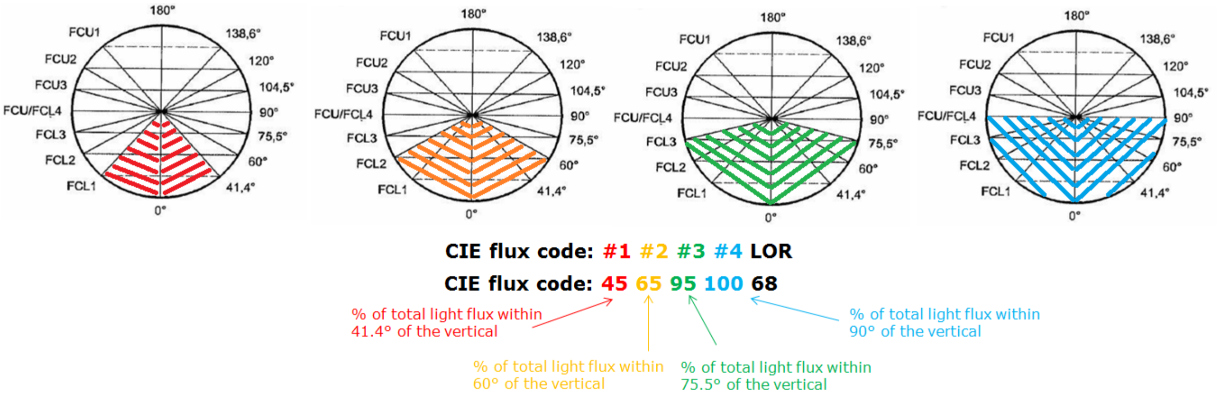
8.1.2. Stakeholder discussion

Stakeholders highlighted the major benefits that were possible in reducing light pollution from road lighting due to reduced upward light output from luminares, better directed optics using LED technology and curfew dimming. It was pointed out that municipalities would also have to be pro-active in other areas beyond the scope of EU GPP criteria for road lighting if they wanted to minimise light pollution as much as possible. Examples of other areas where action would be required included: lighting of monuments, buildings, parks, advertisements, commercial and private properties.

About R_{ULO}

In the TR 1.0, it was proposed that R_{ULO} should be less than 1% for all road classes and lumen outputs for both the core and comprehensive ambition level.

The initial proposal was criticised by stakeholders from several different perspectives. One simple criticism was that the terminologies and acrynoms should be updated to reflect recent changes in terminology in international standards (EN 12665:2011 could be considered as a case in point). It was pointed out that R_{ULO} (percentage of total light output above 90°) might address diffuse light pollution to the night sky but does nothing for addressing obtrusive light into adjacent areas. In order to address obtrusive light, procurers should be able to stipulate requirements for certain CIE flux codes at 80° and 70° to the vertical. It was stated that light emitted near the horizontal can scatter for 100km if unobstructed. To better understand these requirements, flux codes should be considered in the context of the flux diagram provided in EN 13032-2. A closer look at what the flux codes actually mean is illustrated in Figure 17.



CIE flux code: #1 #2 #3 #4 LOR

CIE flux code: 45 65 95 100 68

% of total light flux within 41.4° of the vertical

% of total light flux within 60° of the vertical

% of total light flux within 75.5° of the vertical

% of total light flux within 90° of the vertical

Figure 17. Illustration of illuminated zones applicable to CEN flux codes.

The CIE flux codes are reported in a series of 5 numbers, all of which relate to a certain percentage of the total luminous flux from the light source. First it is worth explaining the last number in the sequence (i.e. 68 in the example above). The number 68 refers to the LOR (Light Output Ratio) and basically means that of all the light produced by the light source, 68% of it actually leaves the luminaire.

The other 4 numbers all relate to the fraction of that 68% of light leaving the luminaire and within what range of angles to the vertical it falls.

An example requirement for a flux code would be FCL3 >99 for comprehensive level (meaning that 99% of total light output is within the downwards 75.5° angle). When dealing with R_{ULO}, it is basically a requirement on FCL4. For example, FCL4 ≥99 is equivalent to a maximum R_{ULO} of 1% while FCL = 100 is equivalent to a R_{ULO} of 0%.

The initial 1% R_{ULO} proposal was considered as unambitious by some stakeholders who added that 0% was particularly easy to achieve for correctly installed LED luminaires. However, it was added by another stakeholder that some degree of upward light output (e.g. 1%) may be desirable in road lighting in old city centre locations with historical buildings. Another comment suggested that a R_{ULO} of 15% could be suitable in areas where vertical illumination is required. One considerable advantage of 0% R_{ULO} was that it prevents the deposition of dirt via the carriage by water droplets during the life of the luminaire. This could also have a positive impact on the maintenance factor of the luminaire.

Another stakeholder in support of the appropriate use of flux codes commented that for every 1° tilt upwards in the range of 30° below to horizontal to 30° above the horizontal, luminance to the sky doubles. Regardless, any measurements of R_{ULO} should be based on luminaire data from accredited laboratories (Article 44 of Directive 2014/24) in accordance with the photometric intensity tables in EN 13032-1:2004+A1:2012 and EN 13032-4:2015. Specifically for LED luminaires, measurements according to Annex D of IEC 62722-1 should be considered. It was added that field measurements of R_{ULO} are not practical.

In Italy, one stakeholder made reference to light pollution laws that require fully shielded fixtures for public road lighting.

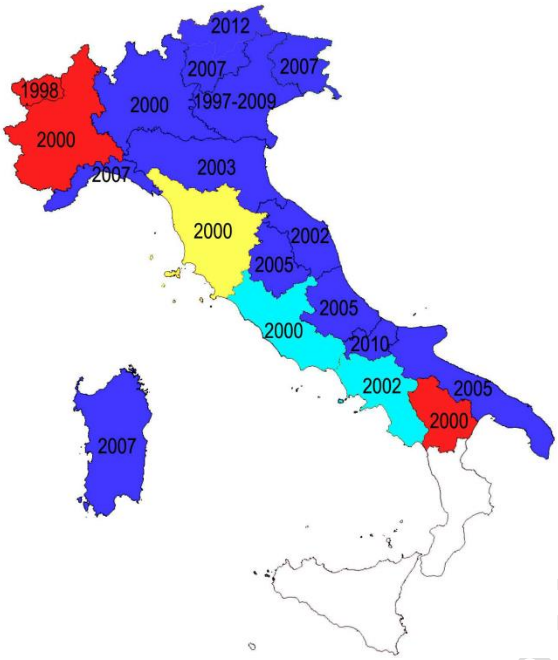


Figure 18 . Regions in Italy where 0% R_{ULO} is required (depicted in blue).

The same stakeholder added that the advantage of 0% R_{ULO} is that it was the one value that can be (relatively) easily verified in-situ although other stakeholders wished to point out that any scientific assessment of R_{ULO} in-situ would need to account for interference of reflected light and direct light from other sources.

One potential problem with restrictions for R_{ULO} was that it might lead to unintended impacts on the energy efficiency (requiring more light points) or, where no extra light points are introduced, on the level of uniformity. Some stakeholders added that they were accustomed to working with glare classes instead of R_{ULO}, although these two considerations do not fully overlap in terms of road lighting design. However, any implementation of GPP criteria related to G classes would be more complex and require additional guidance. Despite this additional complexity, it was stated that Italian GPP criteria currently take G classes into account.

Other stakeholders complained that 0% R_{ULO} will still not prevent skyglow because light will also be reflected off the road surface. While asphalt generally has a reflection of less than 8%, other surfaces such as grass and especially concrete, have significantly higher reflection rates. The problem is exacerbated for any blue light that is reflected, because it will scatter much more than higher wavelength light (scattering is a function of the reciprocal 4th power of the wavelength). However, it was countered that such reflection cannot be avoided, that the surface to be lit is not part of the same subject matter of lighting procurement contracts and that in any case, reflected light will represent a less significant contribution to skyglow than directly emitted upward light.

8.1.3. Criteria proposals for R_{ULO} (or ULOR) and CEN flux code

<table>
<tr><th>Core criteria</th><th>Comprehensive criteria</th></tr>
<tr><td colspan="2">TS6 Ratio of Upward Light Output (R_{ULO}) and CEN flux code 3</td></tr>
<tr><td colspan="2"><i>(Applies to all contracts where new luminaires are purchased and applies equally, irrespective of road class or lumen output. In situations where vertical illumination is required from shorter poles, procurers should consider if 0% R_{ULO} is still appropriate. In situations where illuminance is >15 lux, procurers should consider specifying a requirement for C3 flux codes to reduce the risk of glare.)</i>
All luminaire models purchased shall be rated with a 0.0% R_{ULO} and with a C3 flux code of ≥95% according to photometric data.
In cases of new lighting installations, the luminaires shall be installed horizontally to ensure that 0.0% R_{ULO} is achieved on the road. The boom angle shall not exceed 10° unless this can be justified for energy efficiency reasons.
In cases of existing lighting installations, luminaires will have a boom angle correction if the boom angle is above 15°
<i>Verification:</i>
The photometric file shall be provided including the photometric intensity table from which the R_{ULO} is calculated according to EN 13032-1, EN 13032-2, EN 13032-4, Annex D of IEC 62722-1 or other relevant international standards.
In cases where luminaires are not installed horizontally, the photometric file shall prove that there is no significant upward light emission within the installation angle.</td></tr>
</table>

8.2. Ecological light pollution

8.2.1. Background research and supporting rationale

The most important aspect of light pollution is the potential harm it may cause to species. Many thousands of years of evolution in harmony with natural photic environments has been disrupted by human settlement and activity. Levels of artificial lighting have increased dramatically in developed countries to the extent that light pollution levels can even be considered as an indicator of economic activity (Henderson et al., 2012). The nature of the photic environment can play an important role on mating behaviour, ease of predation, ease of predator evasion, nesting and foraging behaviours. A growing body of evidence in the academic literature is leading to the conclusions that night time light can seriously disrupt the nocturnal behaviour of many species. The degree of impact on the behaviour of different species and their potential to adapt to artificial lighting may vary significantly. One recently published article (Knop et al., 2017) highlighted the disruption that Artificial Light At Night (ALAN) creates for pollinators (both nocturnal and diurnal) and subsequently on plant reproductive success.

The effect of light on insect behaviour and survival is especially relevant since they play a vital role in food pyramids in all ecosystems. Insects that are attracted by lights can be subjected to different effects, which Eisenbeis (2006) described as:

- The "fixated or capture effect", where insects are drawn to the light and so fixated by it that they effectively do not feed, reproduce or attempt to evade predators. They may flight directly to the light, suffering traumas due to burns, overheating, dehydration, wing damage or, if lighting in on bridges, possible drowning.
- The "crash barrier effect", where a row of road lights may act as an effective barrier preventing the passage of insects to potentially important food sources and breeding habitats.
- The "vacuum cleaner effect", where areas of 50 to 600m may be devoid of certain insect species due to the strength of the draw of artificial light sources.

Two examples worth mentioning are moths and mayflies. Moths are well known to suffer from the "fixated effect", flying towards lights and remaining there all night, losing opportunities for feeding and reproduction. Light sources can mask the dim moonlit glows of natural flowers that moths have evolved to feed on. Once distracted by artificial light, moths are less prone to carrying out evasive manoeuvres to avoid predation by bats (Frank, 2006). The attraction of moths to artificial lights greatly increases predation opportunities for bats, birds and spiders but, in the context of road lighting, all of these species are brought closer to the road, were collisions with road traffic would be fatal.

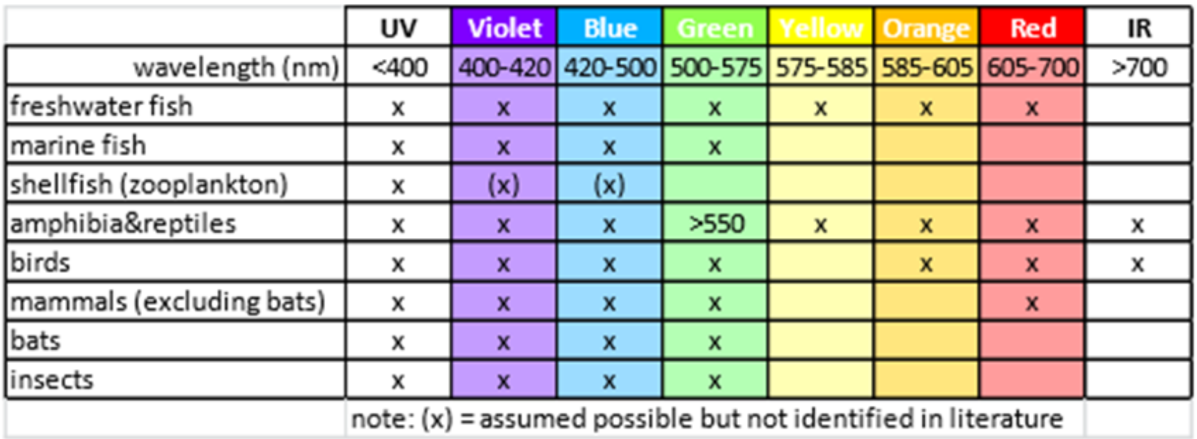
Mayflies, and very important food source for fish in many ecosystems, spend most of their lives underwater but after their final moult, they develop wings and live for as little as 30 minutes or as long as a few days. During this short period, mating occurs and females will lay their eggs on the first surface they land on. The draw to artificial lights will end up with eggs being laid in inadequate locations on many occasions.

The effect of artificial light at night has been shown to affect the migratory routes of birds (La Sorte et al., 2017). Light-induced grounding and mortality of sea-birds is an especially serious issue that has been observed in petrel and shearwater families, and shown to affect already endangered sea bird species (Rodriguez et al., 2017).

Exposure of loggerhead sea turtles to yellow and orange lights (but not red light) has been shown to cause a reduction in nesting attempts, delay the nesting process of attempts that were made and cause notable disruption and disorientation in sea finding behaviour (Silva et al., 2017). Disruption to sea finding behaviour is especially an issue for sea turtle hatchings. The reflection of moonlight on the sea naturally attracts the hatchlings to the sea. In a recent Brazilian study (Simoes et al., 2017), low moonlight levels alone are sufficient to complicate sea finding for sea turtle hatchlings but that they still moved in the general direction of the sea. When artificial light was present, more than half of the deviations in hatchling trajectory were actually away from the sea and towards the artificial light source.

In cases where lighting is deemed necessary for human activity, the only potential role EU GPP criteria could perhaps play is to encourage dimming as far as possible and/or consider the choice of spectral output from the artificial light source. Although there is much research still to be carried out in this area, a literature review of ecological impacts of light pollution on different types of species has led to the following guidance table (Biodiv, 2015):

Table 13. General guide to effect of different spectral bands of light on different species



	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							

In general, the table above implies that blue light is more disruptive for ecosystems. Blue light is also a concern that has links to the human circadian system (see section 8.2.3). With the general shift to LED lighting, it is worth noting that the emission spectra can contain high proportions of blue light, although this can vary significantly from one LED model to another (see Figure 19 below).

In areas of high ecological value, dimming or even complete extinction during curfew hours should be considered for road lighting for both ecological and energy efficiency reasons.

Blue rich light

Apart from the much greater skyglow effect of blue light due to Rayleigh scattering, there has been considerable debate about potential health effects of blue light on humans and nocturnal species.

Much recent debate, both in scientific circles and in public news, has referred to impacts on human circadian rhythm (AMA, 2016). This is related to the recently discovered intrinsically photosensitive retinal ganglion cells (ipRGCs), which are crucial for delivering light information to parts of the brain controlling the biological clock. Potential health effects on humans are specific to certain wavelengths and not necessarily to broader sections of the blue light region. The Scientific Committee on Health, Environmental and Emerging Risks (SCHEER) recently (July 2017) published its preliminary opinion on potential risks to human health of LEDs (SCHEER, 2017). According to SCHEER, significant further research is needed before it can be determined if the effects of certain short wavelength light on circadian rhythms can be linked to adverse human health effects or not.

However, for road lighting in particular, the exposure time of people is relatively short compared to indoor light sources and so this is a much more relevant discussion for indoor lighting. Of course, this does not apply to wildlife, especially to nocturnal species and, as implied in Table 13, blue light is in general more harmful for ecosystems.

Generic terms such as "*blue light*," "*blue-rich LEDs*," and "*blue content*" used with lighting are not very specific and in fact can be misleading (DOE, 2017). Actual emissions of "*blue light*" require a knowledge of the full spectral distribution of a light source. The general public perception is that white light from LED is associated with a significant proportion of "blue light" in its emission. Today (April 2017) this assumption is generally true because many white LEDs are based on phosphor converted blue light and consequently many of the high efficacy white LEDs have a relative high amount of blue light in their colour spectra.

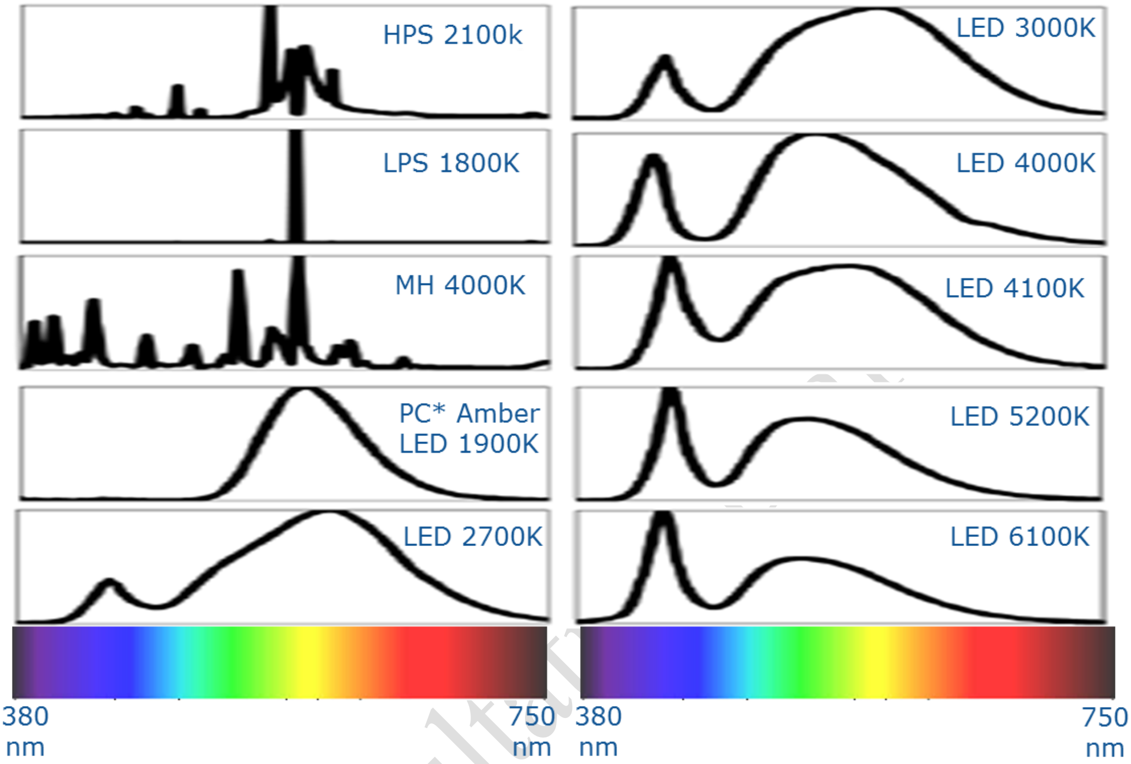


Figure 19. Spectral Power Distributions (SPDs) of different light sources commonly used in road lighting (DOE, 2017b). *PC stands for Phosphor Converted.

As shown in Figure 19, traditional HID lamp technologies can be entirely free of blue light (LPS), have very low "blue light" output (HPS) or have significant output in the blue wavelength ranges (MH). With LED technology, it is possible to tailor the relative outputs of "blue light" and those in the green-yellow-red light ranges. However, the only way to eliminate the blue light output altogether is to down convert the blue light emitted from diodes into longer wavelength light (still in the visible spectrum) using a phosphor.

However, even for a light source emitting blue light, depending on the other relevant wavelengths emitted, the human eye may perceive it as white or as other colours. There are different blends of white light defined. The perceived "colour" of a white light source by the human eye is most often expressed as the Correlated Colour Temperature (CCT). The term CCT is expressed in units of Kelvin and corresponds to the temperature that a "black body" would need to have in order to emit light corresponding to the same appearance as the light source in question.

In this context, the CCT is an approximate and unreliable metric for gauging the potential health, ecological impact and Rayleigh scattering of a light source, but is a reasonable reflection of human perception. Confusingly, the higher the CCT, the "colder" is the appearance of the light (i.e. more white-blue). So a "warm LED" would actually have a lower CCT than a "cold LED". This is illustrated in Figure 20. To put the numbers in context, it should be noted that an overcast daylight is typically 6500 K.

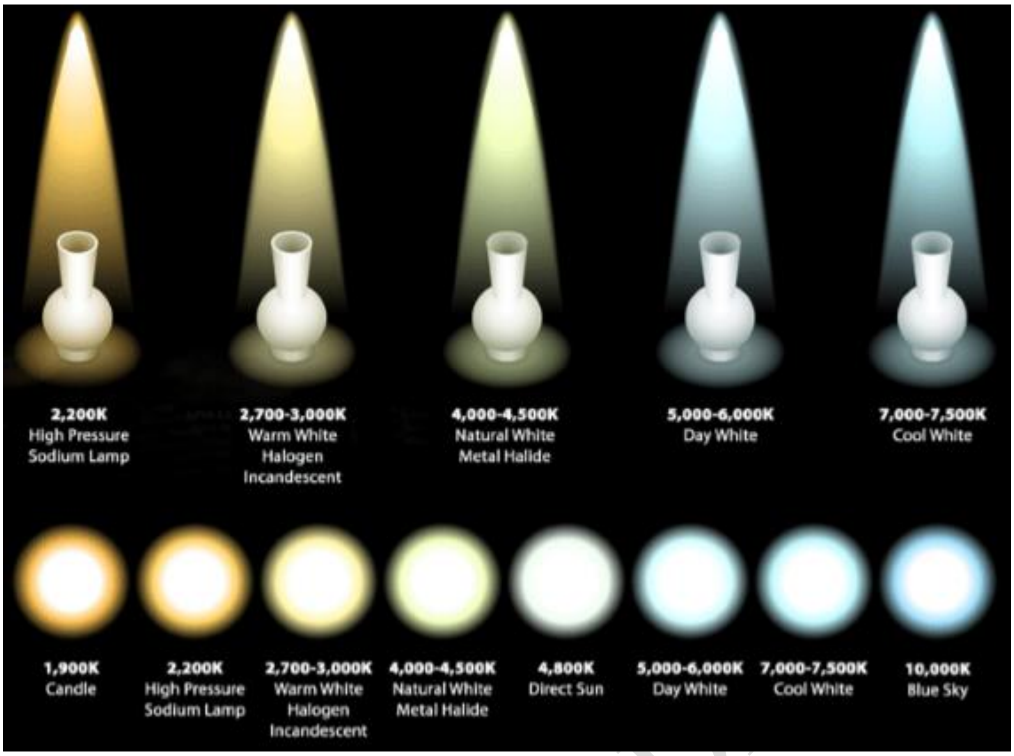


Figure 20. Illustration of different correlated colour temperatures (CCTs).

An advantage of “blue light” is that at very low light levels the human eye is more responsive to blue light due to so-called scotopic vision in comparison to photopic vision (DOE, 2017). The area between or combination of photopic and scotopic vision is called mesopic vision.

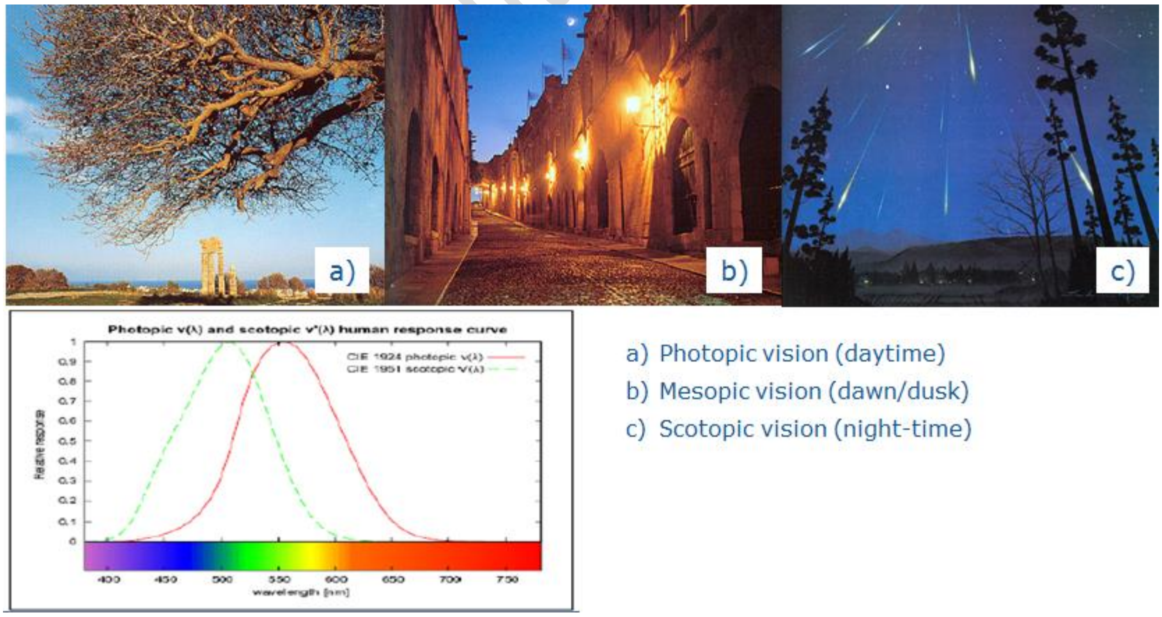


Figure 21. Illustration of the differences in photopic, mesopic and scotopic vision (a-c) and in the response of human photoreceptors in photopic and scotopic environments (Source: presentation titled "Lighting fundamentals").

Cool white (e.g. 5000 K) tend to have more blue in their spectra compared to warm white (e.g. 3000 K). Hence there are advocates to promote cool white light sources with so-called increased mesopic vision. This is not recognised in EN 13201-2:2016 but is acknowledged in the US standard IES TM-12 'Spectral Effects of Lighting on Visual Performance at Mesopic Lighting Levels'.

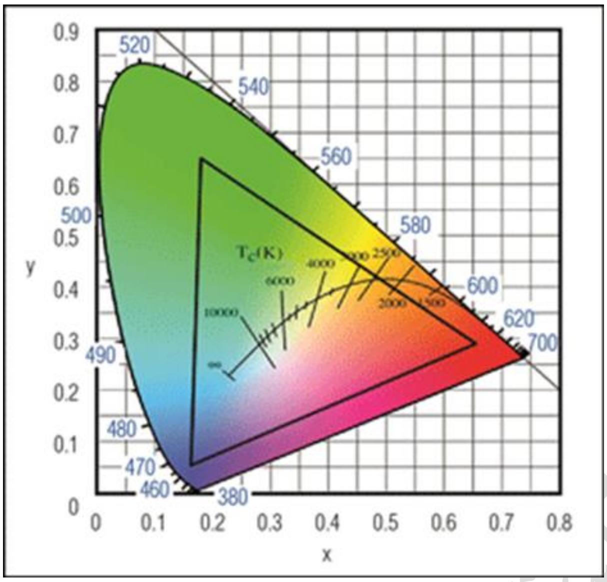


Figure 22. The CIE 1931 x,y chromaticity space showing the colour temperature locus and CCT lines: the lower the CCT, the more red light (Image sourced from [this webpage](#)).

Some general recommendations can be made regarding this topic:

- Do not use the term blue light in any GPP criteria unless relating to spectral emission within a defined wavelength range.
- Only use CCT if the criterion is related to aesthetic requirements relating to light perceived by humans (rather than light perceived by other species).
- Do not justify criteria on blue light restrictions or CCT in road lighting due to potential human health effects because, although long term effects are unknown, exposure times are much smaller when compared to indoor exposure.
- Instead, any blue light restrictions should be justified based on concerns about potential impacts on wildlife and skyglow.

8.2.2. Stakeholder discussion

When prompted, a split opinion was received from stakeholders about photobiological safety of LED light sources. One group felt that this should be addressed by EU GPP criteria while the other group felt that this should be addressed by other means. Reference was made to the IEC 62471-1, CIE 62778, EN 60598-1 and EN 60598-2-3 standards, which cover this issue. One suggestion was to state that EU GPP criteria require that any LED luminaire be compliant with Risk Group 0 or Risk Group 1 limits for light hazards. It is important to clarify that this bears no relation to chronodisruption, but rather to the risk of tissue damage in the human optical system.

An intermediate proposal (between TR 1.0 and TR 2.0) that was discussed amongst a sub-group of the most active stakeholders in the group was to consider light pollution in different ways. For example, one criterion for skyglow (R_{ULO}) and another criterion for the visual quality of the light for humans and nocturnal species (CCT and CRI) impacts of road lighting. However, this intermediate approach did not account for the specific concerns (e.g. higher Raleigh scattering for skyglow and higher ecological impact on wildlife) that are directly related to blue light output.

Concerns were expressed about any requirements for lower CRI values, as it may result in higher emissions of “blue light” and/or higher levels of illuminance to achieve a given visual acuity for humans.

Some stakeholders were highly critical of justifying higher CCT values in the comprehensive level criterion on the basis of impact on nocturnal species since much research still needs to be done in this area and potential impacts could vary greatly from species to species. A further review of research related to the impact of light on nocturnal species such as birds, bats, insects and aquatic species was requested. Despite these concerns there was some support for criteria related to CCT, but with the nuance that CCT alone will not address concerns about light pollution.

One of the arguments against proposals for low CCT values was that lower CCT LEDs had lower energy efficiency. This prompted an analysis of US data by one stakeholder who kindly provided the results of their analysis (see below).

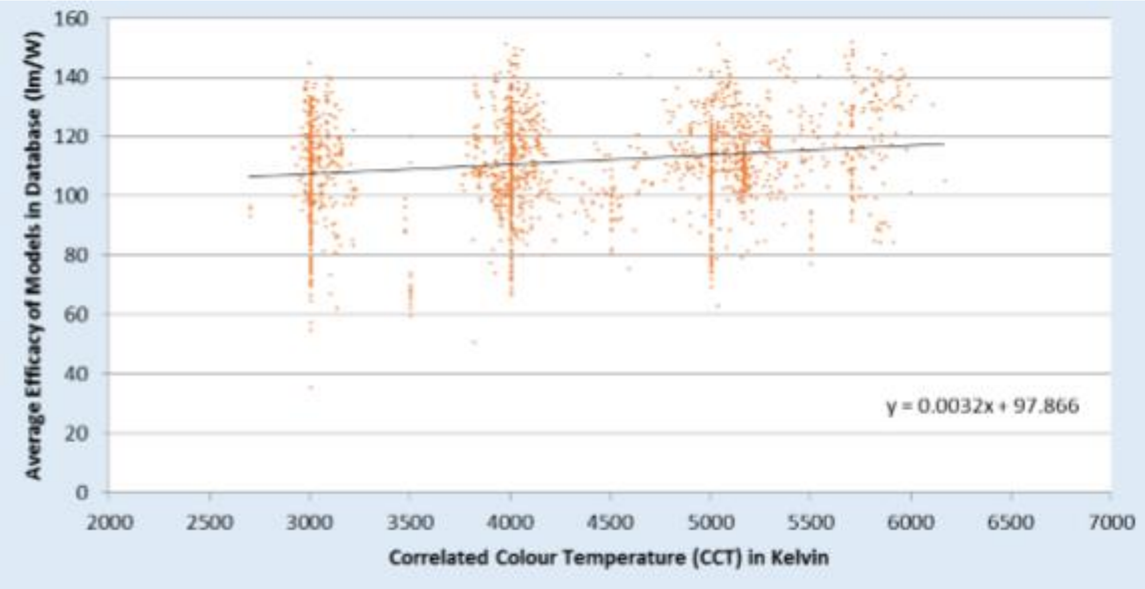


Figure 23. Effect of CCT on luminaire efficacy of 2016 models in the Lighting Facts database of the US DOE.

The data in Figure 23 reveal only a modest decrease in luminaire efficacy of around 3lm/W, per 1000K change within the typical LED CCT range of 2500 to 5500K. This is equivalent to around a 3% decrease in luminaire efficacy and is not considered sufficient as to justify it as a significant trade-off (i.e. lower CCT results in lower energy efficiency).

When asked if the criteria for CRI and CCT should be applied always or only in certain situations, most stakeholders agreed that this should be decided by the tenderer. The interpretation of guideline CIE 126 (1997) for identifying areas where light pollution is a concern will not be applied in an identical way across different Member States.

It was also added that requirements for lower CCT values is an indirect way of reducing concerns about the emission of blue light from cooler LED lighting. Some stakeholders were in favour of CCTs <3000K being specified in EU GPP criteria while others were opposed to the idea. Those against disputed this assumption that blue light output and CCT are correlated. This prompted one stakeholder to share the graph below.

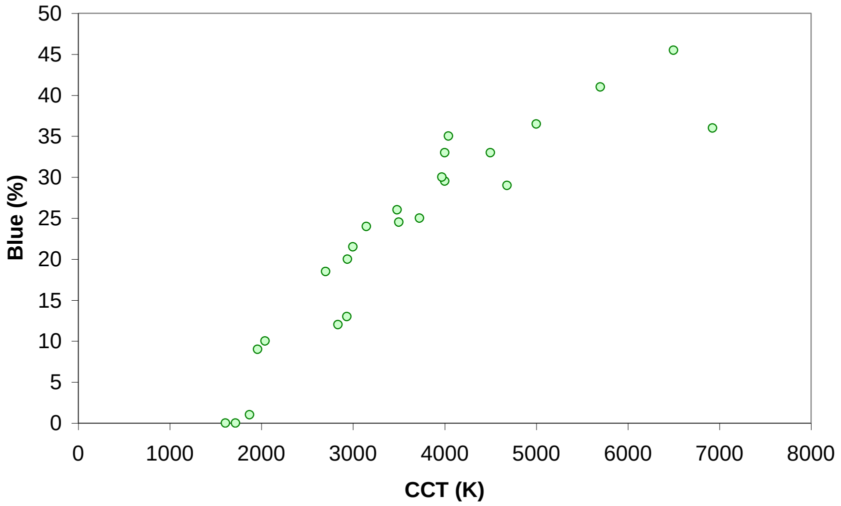


Figure 24. Correlation plot of blue light spectral power output versus CCT for different light sources.

Despite the general correlation shown above, it was repeated that there is no fixed relationship between CCT and the fraction of light output in the "blue" wavelength range.

Even though some stakeholders were against the specification of CRI and CCT in light pollution criteria, any requirements stipulated in the criteria should be linked to standard methods defined in CIE 13.3:1995 and CIE 15:2004 for CRI and CCT respectively. These parameters are also mentioned in IEC 62717 and IEC 62722 (parts 1 and 2).

Regarding the subject of photobiological safety of road lighting, a mixed response was received with some stakeholders wanting this to be addressed in EU GPP criteria and others not. Those in favour referred to a requirement that assessment according to IEC 62471 should reveal luminaires to fall into risk groups 0 or 1 only. Other relevant standards included IEC 62778:2012 (for assessment of blue light hazard) and EN 60598 (general requirements for luminaires).

Annoyance, glare and obtrusive light

Light is a relatively subjective quality and as public authorities have shifted towards more energy efficient LED road lighting, this has led to a “whitening” of road lighting. There are numerous examples in the news of citizens complaining about the change in “atmosphere” in a residential or historic city centre location after sodium lamps have been changed to LED-based light sources.

Common complaints are that the change creates a “hospital or prison-like” feel to the lighted area despite the fact that other aspects such as energy efficiency and facial recognition are improved. Procurers should be sensitive to the potential reaction of local residents to any LED-based substitution of HPS or LPS lamps. In cases where objections can be expected or have already been voiced (e.g. historic city centre and residential zones), criteria should relate to CCT (e.g. <3000K) in certain environmental zones.

There is a standard approach for assessing the glare from road lighting is set out in the recent EN 13201-2:2016, which defines intensity classes for the restriction of disability glare and control of obtrusive light G*1, G*2, G*3, G*4, G*5 and G*6 in Annex A. In general, as the glare class becomes more stringent, less light is permitted on the ground coming directions higher than 70°, 80° and 90° below the horizontal.

Light pollution from obtrusive light to humans and the methods for reduction are discussed in guideline CIE 150:2003 'Guide on the limitation of the effects of obtrusive light from outdoor lighting installations'.

8.2.3. Discussion relating to human health effects of blue light

Such a strong input was received from stakeholders following the 2nd AHWG meeting that it was considered necessary to dedicate a sub-section to the points that were raised about the potential human health effects of blue light. The information detailed below is broadly based on SCHEER, 2017. Although the SCHEER preliminary opinion is predominantly based on exposure to blue light from computer screens and indoor lighting, the same potential health effects should also apply to outdoor lighting with the main difference being the lower exposure of people to optical radiation to outdoor lighting. One study suggests that exposure to dim light at night (10 lux) may decrease cognitive performance although 5 lux did not seem to be problematic (Kang et al., 206).

One specific concern with outdoor road lighting is that it is generally more powerful than indoor light sources and short term exposure to very intense visible radiation (i.e. light) can induce cell damage or cell death due to free radical formation via photoreactive pigments such as lipofuscin (Chamorro et al., 2013; Kuse et al., 2014). These effects can apply to exposure to any light in principle.

The higher energy, shorter wavelength light (400-600nm) is capable of penetrating into cell organelles and producing reactive oxygen species in mitochondria, which may lead to apoptosis (Roehlecke et al., 2009) or phototoxic effects (Godley et al., 2005).

The concerns with blue light are more pronounced with older people, due to the accumulation of photoreactive pigments in the epithelium with age, and also with aphakic individuals (who have no lens/lenses to help filter shorter wavelength light).

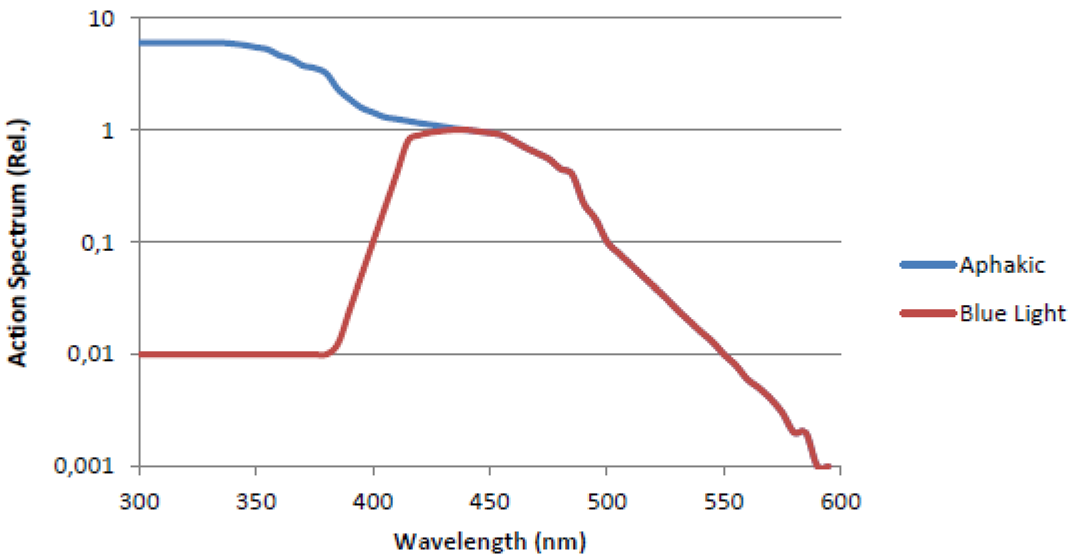


Figure 25. Blue light spectra compared to action spectra for aphakic eyes (from ICNIRP).

The data in Figure 25 clearly show that aphakic members of the population are especially sensitive to the shorter wavelengths of visible radiation (light) and that LED light sources emitting in blue light range would be much more harmful for them than traditional HID type lamps.

While the effects of immediate, short term exposure can be readily demonstrated in scientific studies, it is much more difficult to demonstrate more chronic effects that accrue with gradual exposure over time. Other effects of blue light exposure on human health, especially due to artificial light at night, may relate to disruption of the circadian rhythm (biological clock). The degree of influence that light may have on the circadian rhythm depends on a number of factors:

- Timing

- Intensity
- Duration
- Spectrum of the light stimulus
- Previous light exposure

Effects can be observed at relatively low intensities (<100 lux) and even for durations of the order of minutes or less (Glickman, Levin et al., 2002; Duffy and Czeisler, 2009; Lucas, Peirson et al., 2014).

The fourth point in the list above is particularly relevant and concerns with blue light are centred on the relatively recent identification of melanospin (within the last 15 years) as the key protein in intrinsically photosensitive Retinal Ganglion Cells (ipRGCs) for carrying out non-image forming functions and for sending signals to various parts of the brain, particularly the suprachiasmatic nucleus, which ultimately affect the production of the hormone melatonin from the pineal gland (Schomerus and Korf, 2005). The melatonin hormone is well known as an important regulator of the human body clock (circadian rhythm).

While *in vitro* experiments clearly show the peak spectral sensitivity of melanospin to be around 480nm (Bailes and Lucas, 2013), the *in vivo* effects are much more complex and may be context dependent (Lucas, Peirson et al., 2014). Nonetheless, it can be generally concluded that the circadian rhythm is most affected by light in the wavelength range 460-490nm (Duffy and Czeisler, 2009; Benke and Benke, 2013). It is worth noting that this coincides almost exactly with the blue peak emission of most LED light sources depicted in Figure 19.

Melatonin is a particularly useful biomarker for monitoring the circadian rhythm and levels can be monitored by analysing saliva, serum or urine. Circadian rhythms do not only affect sleeping and waking cycles but also cognition, immune system and repair mechanisms and numerous physiological processes such as metabolism, endocrine functions and protein expression (Takahashi, 2017).

Research to date has predominantly focussed on circadian disturbance due to indoor light exposure and possible effects on cancer, metabolic health effects and cognitive function (IARC, 2010; Wang, Armstrong et al., 2011; ANSES, 2016; Mattis and Sehgal, 2016). One interesting point is that when looking at the potential broader effects of artificial light at night on human health, it is impossible to know to what extent "social jetlag" might affect results – e.g. the need for individuals to wake up and have breakfast when it is still dark in order to get to work on time. There is also the need to consider the differences between sleep quality and sleep quantity (Joo, Abbott et al., 2017; Magee, Marbas et al., 2016).

Considering all of these complex interactions and the general lack of comparable studies in the literature, it is unsurprising that the preliminary opinion of SCHEER is that:

"The Committee concludes that there is no evidence of direct adverse health effects from LEDs in normal use (lightening and displays) by the general healthy population..."

And

"…Light sources that emit more short-wavelength light, as do some types of LEDs, will have a larger effect on the circadian rhythms at equal optical radiance, duration and timing of exposure. At the moment, it is not yet clear if this disturbance of the circadian system leads to adverse health effects."

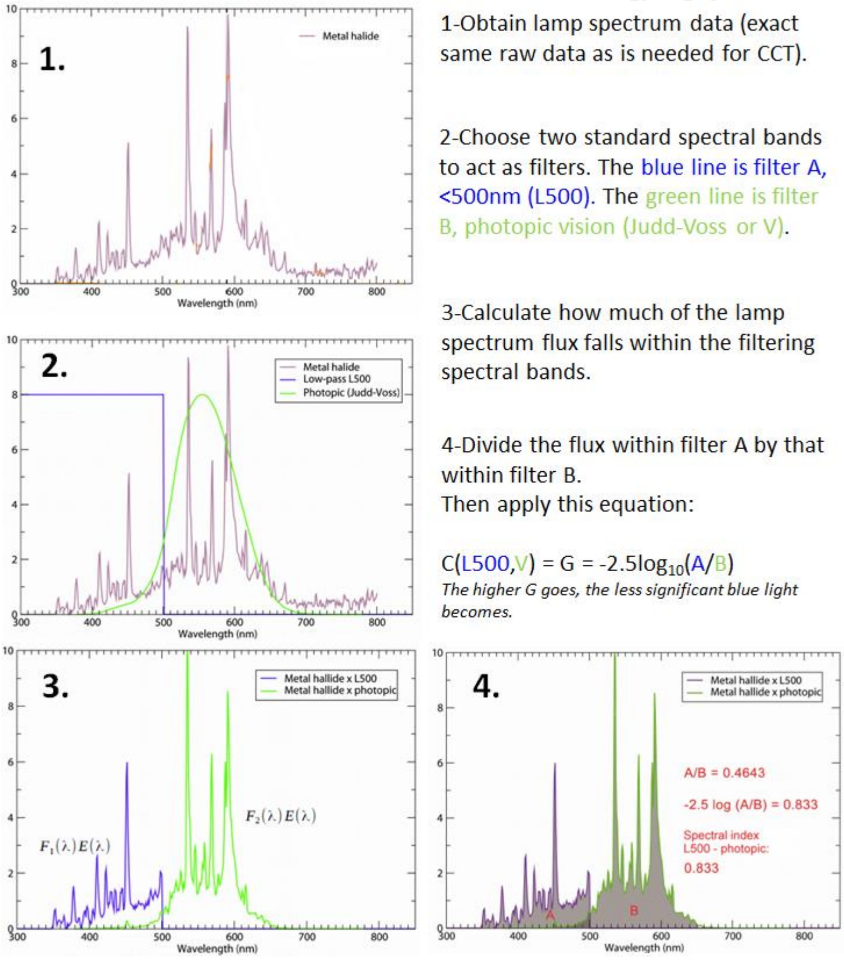
Considering these comments quoted above, it must be emphasised that the rationale for any EU GPP criteria that restrict the blue light emission from lamps is not primarily based on the desire to reduce human health impacts. To some extent, the precautionary principle could be justified for limiting blue light emission. However, there are already other arguments than human health to justify limiting blue light emission. Examples include impacts on nocturnal species, increased potential contribution to skyglow and possible complaints from local residents based.

8.2.4. Discussion about how to quantify blue light output (and limits)

Significant discussion took place regarding the proposals in TR 2.0 relating to limits that were set for CCT and specifically for blue light output. It was already understood that CCT is not a perfect indicator of blue light output (see Figure 24) but it was also argued that this is a metric that many people seem to be able to grasp.

One of the main arguments against CCT was that it only roughly describes the spectra of lamp light output by assuming that the lamp behaves as a black body. While this may have been relevant for incandescent bulbs, it is not relevant to LED technology.

An alternative method was proposed that allows the same data that is needed to calculate CCT to be used to calculate a spectral index which expresses the relative importance of light in two bands or wavelength intervals. If these bands are A and B, the related spectral index may be noted in the most general way as C(A,B). For the evaluation of blue light content, it has been suggested to use A as all emissions of wavelength lower than 500nm (L500), and B as the standard curve of photopic vision (Judd-Voss version, for example, V). The resulting C(L500,V) index is already being implemented in some regulations and, following the Andalucian Regulation, it was proposed to label it as the "G index" (in spite of possible minor confusion with glare classes). An example of how the G index is calculated is illustrated below.



1-Obtain lamp spectrum data (exact same raw data as is needed for CCT).

2-Choose two standard spectral bands to act as filters. The blue line is filter A, <500nm (L500). The green line is filter B, photopic vision (Judd-Voss or V).

3-Calculate how much of the lamp spectrum flux falls within the filtering spectral bands.

4-Divide the flux within filter A by that within filter B.
Then apply this equation:

$C(L500,V) = G = -2.5\log_{10}(A/B)$

The higher G goes, the less significant blue light becomes.

Figure 26. Example of how the spectral index C(L500,V), or G index, works.

The proponents of the G index cited some of its advantages, which included:

- Simpler basic principles than CCT.

- The index is unit-independent, so the units on the y-axis of any spectral data are irrelevant because the calculation is based only on that same spectrum.
- No external reference sources or standards needed for comparison.
- The G-index units are "magnitudes", the same units that are used in astronomy – directly relevant when considering skyglow.

The approach to calculating the G-index for lamps has already been consulted widely with Spanish stakeholders representing the industry, governments and academia and is also presented by Galadi-Enriquez in a recent journal article. Computationally, its value is easier to derive than CCT, and from the same kind of spectral data. The Andalusian representatives have very recently made available an online calculator or spreadsheet where the input of lamp spectrum data can be directly inserted and the G-index calculated straight away.

In order to better understand how the G-index might compare to CCT data for different lamps, a number of spectra have been analysed for both CCT and the G-index.

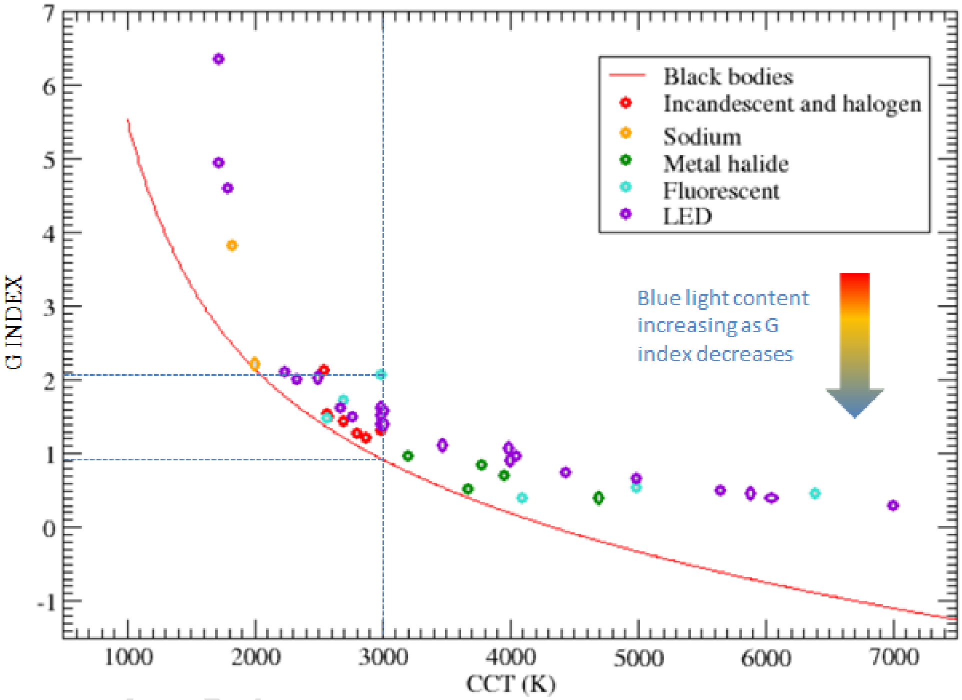


Figure 27. Correlation between CCT and G-index values for different lamps (specific comparison at 3000K highlighted).

The data in Figure 27 show that while the real lamp data, when plotted as G-index versus CCT, generally follows the black body curve, it is far from a perfect fit.

In fact, looking specifically at CCT = 3000K, which is an important threshold that has been much quoted in public debate, there is actually a significant difference in actual blue light content (the G-index can range from around 0.9 for a true black body to 2.1 for a fluorescent lamp. Just looking at 3000K LED lamps, the range was also from 1.3 to 1.6.

It is also worth comparing the G-index approach with the requirements of the Low Impact Lighting (LIL) standard that was summarised at the beginning of section 8. The LIL standard is asking for a very similar thing, but expresses blue light as a % of all light output (not just light within photopic range) and does not formally translate the results into an index value. Although not directly comparable, because the second filter is different (bolometric instead of photopic) the LIL standard would ask for:

- a C(L500,bol) index of >3.05 when blue light should be <6% or
- a C(L500,bol) index of >2.50 when blue light should be <10%.

Due to concerns that the LIL approach may favour light sources that also emit outside of the photopic vision range and into the infra-red region, it is considered more appropriate to continue with the (L500,V) index when setting actual EU GPP criteria.

8.2.5. Criteria proposals for ecological light pollution and annoyance

Core criteria	**Comprehensive criteria**
TS7 Ecological light pollution and annoyance	
(It is recommended to preferentially use the G index as the specification. However, because this is a new development, procurers are encouraged to familiarise themselves with an online calculator that calculates the G-Index from standard spectral output data for light sources. In case this is not possible or practical for whatever reason, procurers should specify the CCT value instead.).* When deemed necessary due to specific local ecological impact, light levels shall be dimmed to less than 50% during curfew hours. The G-Index shall be ≥1.5 or, The CCT of road lighting at full design light output in urban areas shall be ≤3000 K. ***Verification:*** If requested, the tenderer shall provide the light spectra of all lamps to be provided. The tenderer shall provide measurements of CCT reported in accordance with CIE 15 and, when relevant, also include the measurement of the G-Index. With dimming, the tenderer shall provide details of the proposed dimming controls and the range of dimming capabilities, which shall at least permit dimming based on an astronomical clock. For LED lighting, results shall be considered in the context of IEA 4E SSL recommendations. **Link to be provided later*	*(It is recommended to preferentially use the G index as the specification. However, because this is a new development, procurers are encouraged to familiarise themselves with an online calculator* that calculates the G-Index from standard spectral output data for light sources. In case this is not possible or practical for whatever reason, procurers should specify the CCT value instead.).* When deemed necessary due to specific local ecological impact, light levels shall be dimmed to less than 30% or even switched off during curfew hours The G-Index shall be ≥2.0 or, The CCT of road lighting at full design light output in urban areas shall be ≤2700 K. ***Verification:*** If requested, the tenderer shall provide the light spectra of all lamps to be provided. The tenderer shall provide measurements of CCT reported in accordance with CIE 15 and, when relevant, also include the measurement of the G-Index. With dimming, the tenderer shall provide details of the proposed dimming controls and the range of dimming capabilities, which shall at least permit dimming based on an astronomical clock. For LED lighting, results shall be considered in the context of IEA 4E SSL recommendations. **Link to be provided later*

9. Lifetime

A lighting installation may perform well from an energy efficiency perspective and may deliver the desired quantities and qualities of light after installation but this is irrelevant if the installation is not able to maintain such performance for very long. Problems with the reliability and durability of lighting installations will have direct economic impacts and less direct environmental impacts.

All the criteria in this section are in one way or another related to guaranteeing a minimum useful lifetime of the lighting equipment that is procured. Longer life products that can be repaired or even upgraded to extend their useful life are an important part of European efforts to shift towards a circular economy.

9.1. Provision of instructions

9.1.1. Background research and supporting rationale

As lamps and luminaires will probably have to be replaced or repaired at least once in their lifetime, it is important that the procurer has the knowledge on how this should be done in order to carry out replacement and repair operations in a correct and timely manner.

When controls are provided with the system, the procurer has to know exactly how to operate and calibrate them. Periodic recalibration of controls may be necessary as part of maintenance strategies. Besides extending the useful lifetime of the lighting equipment, correct maintenance and repair will also ensure that real-life energy consumption (AECI) can be maintained within the original design window.

9.1.2. Stakeholder discussion

In the proposals in TR 1.0, it was recommended to define a Contract Performance Clause (CPC) requiring the provision of instructions for key aspects related to the lifetime (disassembly of luminaire, replacement of light sources and minimum specifications for replacement light sources) and operation (of lighting controls, including timer or daylight level linked switches) of luminaires.

Stakeholders generally acknowledged the importance of adequate instructions but highlighted the fact that when the contract relates to only one part of a larger lighting network, the requirements for lighting controls will probably already be defined by procurers in technical specifications so that they fit in with the pre-existing centralised control scheme. In any case, it is still useful to have instructions at the level of the individual luminaire in case of the need for in-situ repair or adjustment.

9.1.3. Criteria proposals for provision of instructions

Core criteria	**Comprehensive criteria**
TS8 Provision of instructions	
(Applies in cases where the equipment and/or controls in the particular lighting installation are different from the normal equipment installed elsewhere on the wider lighting network operated by the procurer). The tenderer shall provide the following information with the installation of new or renovated lighting systems: • Disassembly instructions for luminaires • Instructions on how to replace light sources (where applicable), and which lamps can be used in the luminaires without decreasing the energy efficiency. • Instructions on how to operate and maintain lighting controls. • For daylight linked controls, instructions on how to recalibrate and adjust them. • For time switches, instructions on how to adjust the switch off times, and advice on how best to do this to meet visual needs without excessive increase in energy consumption. ***Verification:*** Confirmation that written instructions will be provided to the contracting authority. ***Note:*** *For large utilities these instructions can be part of the tender requirements, hence in this situation a statement of compliance with the tender requirements is sufficient.*	

9.2. *Waste recovery*

9.2.1. Background research and supporting rationale

Most procurement contracts in EU countries will relate to the renovation or relamping of existing lighting installations. This will result in the generation or waste lamps, ballasts, luminaires and other auxiliary controls. The disposal of waste electronic and electrical equipment (WEEE) has historically been a problem and a loss of potential valuable raw materials which are present in small amounts in each individual component or product.

Large scale organised collection of WEEE will maximise opportunities to recover valuable raw materials and is one of the main drivers behind the WEEE Directive (2012/19/EU). Under the Directive, Member States are obliged to create systems and infrastructure for the collection and recycling of WEEE.

The main aim of any criterion on WEEE compliance for tenderers is to basically ensure that they know where to take the WEEE and commit to doing so if awarded the contract. In a review of the implementation of the WEEE Directive across Europe, it was found that only 4 of the EU-28 countries were collecting more than 50% of the estimated WEEE generated.

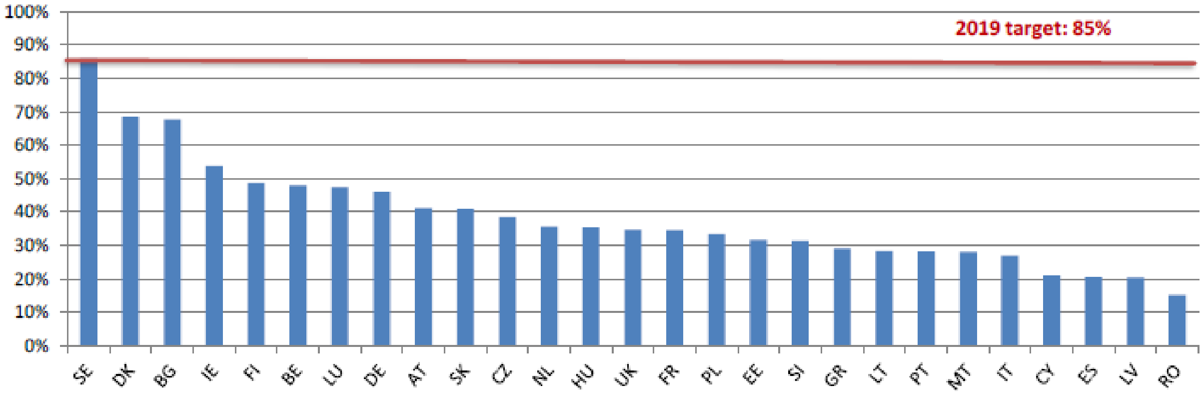


Figure 28. WEEE collection rate in different Member States in 2010 (Source: Eurostat) *to be updated*.

In order to improve WEEE collection and disposal rates in line with the targets of 85% set for 2019 Member States will have to overcome the following problems:

- High rates of unaccounted collection (e.g. due to mislabelling of scrap).
- Improper disposal in household waste
- Limited enforcement and monitoring capacities (e.g. illegally shipped outside of EU).

The same report cited above indicated that there was a significant potential for improving the collection rates of "Category 3 WEEE" (i.e. lamps) although it must be noted that this was a catch-category for both interior and exterior lights for both roads, vehicles and buildings.

9.2.2. Stakeholder discussion

In TR 1.0, CPCs were proposed for the contractor to commit to collecting, sorting and disposing of waste lamps, luminaires and lighting controls for recycling and, where relevant, to facilities accepting WEEE (Waste Electrical and Electronic Equipment). The comprehensive level CPC introduced the additional requirement to produce a bill of materials for a number of specified metals in the waste stream.

Stakeholders were generally of the opinion that a commitment to respecting the requirements of the WEEE Directive was sufficient and that requirements relating to bills of materials would represent additional costs and be of doubtful value when it comes to renovation at least 10-20 years in the future. Furthermore, it was pointed out that the specific information requested in the proposed comprehensive level CPC in terms of the quantities of the specific metals listed does not reflect current practice. How requirements for this CPC apply to different situations need to be clarified, i.e. (i) disposal of waste from a renovation project during the initial execution of the contract and (ii) design for recyclability for a potential future disposal of the new lighting equipment installed during the execution of the contract. Regardless, the scope of the CPC should be clarified (e.g. luminaires, light sources, control equipment, cabinets etc.).

One stakeholder added that the future recyclability of lighting equipment may be hampered by the presence of hazardous materials such as mercury. It could be justified that EU GPP could set criteria for mercury free lamps to be used on the basis that it may enhance the future recyclability of the waste lamp. LED lighting is mercury free and although high pressure mercury lamps have effectively been phased out by Regulation (EC) 245/2009 since 2015, it is still possible for many other different HID-based lamps still on the EU market to contain mercury (IMERC, 2015).

A mixed response from stakeholders was received about the potential ban on mercury-containing lamps. It was recognised that this would essentially ban the procurement of new HID-type lamps in any ITT containing this criterion as a technical specification. However, at the same time, procurement of new lamps is now dominated by LED lamps that would already comply.

In order to back up any benefit of using mercury-free lamps at the End-of-Life, it was considered useful to guarantee that they are labelled as Hg-free.

9.2.3. Criteria proposals for waste recovery

<table>
<tr><th>Core criteria</th><th>Comprehensive criteria</th></tr>
<tr><td colspan="2">TS9 Waste recovery</td></tr>
<tr><td colspan="2">The tenderer shall implement appropriate environmental measures to reduce and recover the waste that is produced during the installation of a new or renovated lighting system.
All waste lamps and luminaires and lighting controls shall be separated and sent for recovery in accordance with the WEEE directive*. Any other waste materials that are expected to be generated and that can be recycled shall be collected and delivered to appropriate facilities.
<i>Verification:</i>
The tenderer shall provide details of the waste handling procedures in place and identify suitable sites to which WEEE and other recyclable materials can be taken to for separation, recycling and heat recovery, as appropriate.
<i>*Directive 2012/19/EU of the European Parliament and of the Council of 4 July 2012 on waste electrical and electronic equipment (WEEE).</i></td></tr>
<tr><td colspan="2">CPC7 Commitment to waste recovery and transport to suitable sites</td></tr>
<tr><td colspan="2">The contractor shall provide a schedule of the wastes collected during the project and provide details of any sorting that has been applied prior to transport to suitable sites identified in the original tender or to other suitable sites where wastes can be sorted, processed, recycled and, if relevant, subject to heat recovery.
Delivery invoices shall be submitted as proof of delivery.</td></tr>
</table>

9.3. Product lifetime

9.3.1. Background research and supporting rationale

Apart from the potential to improve energy efficiency, one of the main advantages of LED lighting is the significantly longer lifetime of the light source compared to most other road lighting lamp technologies. Operation times of 100000 hours, equivalent to 20 years operation of road lighting, are commonly claimed.

Extension of the lifetime of luminaires and its components reduces the overall environmental impacts caused by shorter lifespans, raw material extraction and manufacturing processes. It also partly justifies the higher initial investment in more efficient road lighting installations. An extension of the warranty period would be an addition to the requirements on lifetime and would decrease the frequency of early failures.

All lamp technologies suffer a decrease in lumen output for a given power consumption (i.e. a decrease in luminous efficacy) with time. This has been referred to as the factor of lamp lumen maintenance (F_{LLM}) and can be combined with potential losses of light output caused by dirt collecting on the luminaire (F_{LM}).

However, the lifetime of LED lighting is not so simple to guarantee. There are many different components that may contribute to the failure of an LED component, such as the driver, overheating, poor electrical connections etc. The reliability of a particular LED-based luminaire should be considered as the product of all the failure rates of the individual critical failure mechanisms.

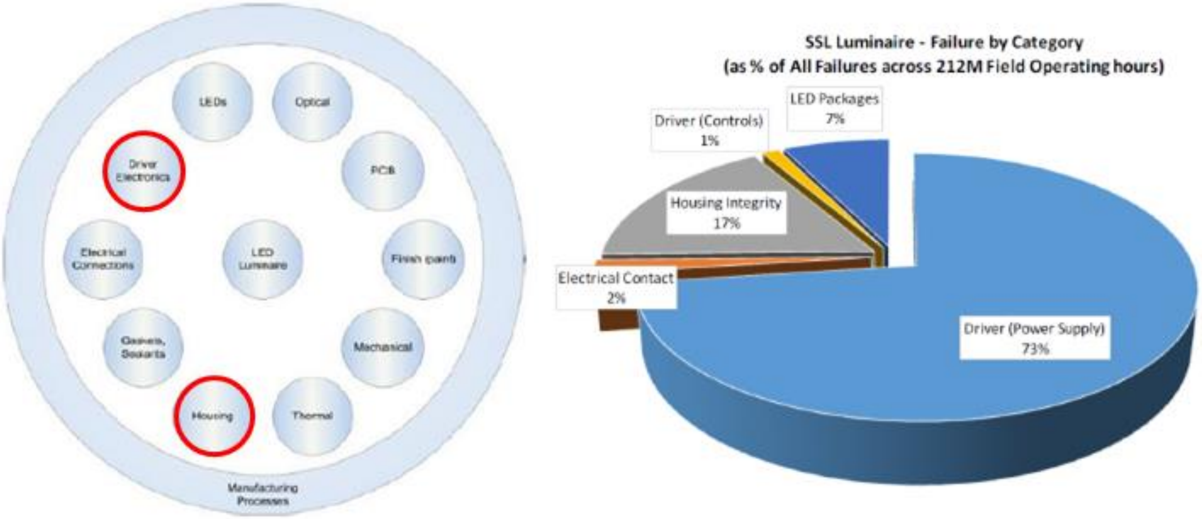


Figure 29. Examples of potential causes of LED failure (left) and statistics about the most common causes of failure (right). Source: LSRSC, 2014.

The relevant parameters relating to LED luminaire life times are LxCz and LxBy which are both defined in EIC 62717 and equivalent to the Lamp Survival Factor and Lamp Lumen Maintenance Factors for traditional HID lamps respectively. The former terms can be explained as follows:

- LxBy relates to gradual reductions in lumen output where x is the % of original lumen output still maintained after a defined operating time and y is the % of units that no longer meet the x % of original lumen output at that same time. For example, L70B10 at 50000 hours means that overall lumen output is at least 70% of the original output and less than 10% of the fixtures are <70%. It is common practice to term the "rated life" of an LED light source as the point when its luminous efficacy reaches 70% of the original efficacy.

- LxCz relates to abrupt failures at the end of rated life. Abrupt failures happen with no set pattern in time. Consequently, linking to the LxBy value above, a LxCz value of L0C10 at 50000 hours would mean 10% of the LED modules suffer abrupt failure during the rated life – and that the failure rate is effectively 0.2% per 1000 hours operation.

Due to the long lifetimes involved and the rapid development of LED lighting technology, there is not a sufficient evidence base of long term test data to verify lifetime claims. Even if there was, it would be relatively obsolete since the technology would have evolved significantly in the meantime.

In the US, the Illuminating Engineering Society of North America (IESNA) has an approved method (TM-21-11) taking LM-80 data and making useful LED lifetime projections, according to what has been reported in the stakeholder meeting a European standard is under elaboration and will be based in that. In Europe, recent developments have been made in 2017 which are detailed in the stakeholder discussion session.

9.3.2. Stakeholder discussion

An initial proposal in TR 1.0 was made for lumen maintenance to be L92B50 at 16000 hours (core) and both L92B50 at 16000 hours and L80B50 at 50000 hours (comprehensive).

Most stakeholders were agreed about the importance of the criterion, especially to those responsible for maintenance of the lighting installation and especially in harsh environments with large temperature fluctuations. However, there was a split opinion about whether maintenance factor specifications should extend beyond 6000 or 16000 hours. Those against longer term maintenance factors cited the current uncertainty in Europe regarding the extrapolation of laboratory data for LED light sources to longer lifetime expectancy claims. However, since then "*IEC 63013:2017 LED packages - Long-term luminous and radiant flux maintenance projection*" has been officially published.

Stakeholders in favour of longer term lifetime projections being included in criteria generally felt that the ambition level should be raised. It was pointed out that luminaires that meet L92B50 at 16000 hours would also tend to meet L80B50 at 50000 hours – so there is no great distinction between the original proposals for core and comprehensive levels. One stakeholder proposed to increase the comprehensive requirement to L80B10 and L80C08 at 50000h. Lighting Europe are currently considering the application of LxBy values for 100000 hours (i.e. 20 years operation) and such an approach may be interesting for comprehensive level criteria.

Regarding standard methods for assessing LxBy and LxCz in the laboratory, one stakeholder opined that IEC 62722 should be used instead of a combination of IESNA LM80 and TM21. If abrupt failure is to be specifically addressed in lifetime criteria (i.e. LxCz values) then it would be worth referring to IEC 62861:2017, which will include optical materials, interconnectors, electronic subassemblies, cooling systems and construction materials used in LED light sources or luminaires. Another option is to simply have a criterion on the maximum acceptable failure rate for control gear (since this is the most common cause of failure as shown in Figure 29 above). However, any specific requirements for abrupt failure rates will always be questionable since they are based on predictions with a certain amount of statistical uncertainty and are not always published by manufacturers.

The truth is that long term performance can be estimated but never known for certain. For this reason, the idea of requesting extended warranties for LED light sources was raised. Mixed opinions from stakeholders were evident. While some stakeholders were against the idea of extended warranties, others felt that an example of 32000 hours operation (i.e. 8 years) would be a reasonable request and that reputable manufacturers would be more likely to commit to extended warranties. It was claimed that warranties of

3-5 years were already common practice and warranties up to 10 years could reasonably be requested but would likely have a cost impact for the procurer. However, longer warranties need to be backed up with clear CPCs otherwise they may simply represent a meaningless commitment.

9.3.3. Criteria proposals for product lifetime and warranty

Core criteria	**Comprehensive criteria**
TS10 – LED lamp product lifetime, spare parts and warranty	
Any LED-based light sources shall have a rated life at 25°C of: • L92B10 at 6000 hours and • L70B50 at 50000 hours (projected) • L0C0 at 3000 hours or L0C10 at 6000 hours. The repair or provision of relevant replacement parts of LED modules suffering abrupt failure shall be covered by a warranty for a period of 5 years from the date of installation. ***Verification:*** Test data regarding the maintained lumen output of the light sources shall be provided by an ILAC (International Laboratory Accreditation Cooperation) accredited laboratory that is in accordance with: IEC 62722 for actual data and IEC 63013 for projected data or, IES LM-80* for actual data and IES TM-21* for projected data. The tenderer shall provide a copy of the minimum 5 year warranty that would be signed in case the tender should be successful. The contractor shall provide a copy of the warranty that would be applicable should the tender be successful and provide the necessary contact details (phone and email as a minimum) for dealing with any related queries or potential claims. For clarity, the warranty shall, as a minimum, cover the repair or replacement costs of faulty LED module parts within a reasonable time period after notification of the fault (to be defined by the procurer in the ITT) either directly or via other nominated agents. Replacement parts	Any LED-based light sources shall have a rated life at 25°C of: • L96B10 at 16000 hours (projected) and • L70B50 at 100000 hours (projected) • L0C0 at 3000 hours or L0C10 at 6000 hours. • L0C50 at 50000 hours (projected). The repair or provision of relevant replacement parts of LED modules suffering abrupt failure shall be covered by a warranty for a period of 7 years from the date of installation. ***Verification:*** Test data regarding the maintained lumen output of the light sources shall be provided by an ILAC (International Laboratory Accreditation Cooperation) accredited laboratory that is in accordance with: IEC 62722 for actual data and IEC 63013 for projected data, or IES LM-80* for actual data and IES TM-21* for projected data. The tenderer shall provide a copy of the minimum 7 year warranty that would be signed in case the tender should be successful. The contractor shall provide a copy of the warranty that would be applicable should the tender be successful and provide the necessary contact details (phone and email as a minimum) for dealing with any related queries or potential claims. For clarity, the warranty shall, as a minimum, cover the repair or replacement costs of faulty LED module parts within a reasonable time period after notification of the fault (to be defined by the procurer in

should be the same as the originals but if this is not possible, equivalent spare parts that perform the same function to the same or to a higher performance level may be used. The warranty shall not cover the following: a) Faulty operation due to vandalism, accidents or other extreme weather events. b) Lamps or luminaires that have been working for a significant time under abnormal conditions (e.g. used with the wrong line voltage) insofar that this can be proven by the contractor. **To be updated to LM-84 and TM 28 when these versions are published.*	the ITT) either directly or via other nominated agents. Replacement parts should be the same as the originals but if this is not possible, equivalent spare parts that perform the same function to the same or to a higher performance level may be used. The warranty shall not cover the following: a) Faulty operation due to vandalism, accidents or other extreme weather events. b) Lamps or luminaires that have been working for a significant time under abnormal conditions (e.g. used with the wrong line voltage) insofar that this can be proven by the contractor. **To be updated to LM-84 and TM 28 when these versions are published.*

AC3 Extended Warranty

X points shall be awarded to tenderers that are willing to provide initial warranties, whose cost is already included in the bid price, that go beyond the minimum warranty periods stated in TS10. Points shall be awarded in proportion to how long the warranty exceeds the minimum requirements as follows:

- Minimum +1 year: 0.2X points
- Minimum +2 years: 0.4X points
- Minimum +3 years: 0.6X points
- Minimum +4 years: 0.8X points
- Minimum +5 years or more: X points

Tenderers may also optionally provide quotations for extended warranties that are not included in the bid price, although points shall not be awarded for this. In such cases, it shall be made clear that no payment for any extended warranty is required until the final year of the initial warranty and then annual payments would be made by the procurer to the successful tenderer at the beginning of each year of the extended warranty.

It shall also be clear that the procurer has the option to initiate or leave the offer of the any extended warranty right up until the final year of the initial warranty and that the costs of the extended warranty would be those initially proposed plus any inflation.

9.4. *Reparability*

9.4.1. Background research and supporting rationale

Reparability is one of the key principles that products need to embrace to ensure the transition to a circular economy. In general, products that can be repaired will retain their residual value for the second-hand market and are set up to have extended product lives.

For road lighting, reparability is of particular value to the manufacturer when the products are under warranty in cases where repair due to a simple fault could prevent the need to replace the entire product. Reparability is also of value to the procuring authority if the installation is managed by an in-house maintenance team.

9.4.2. Stakeholder discussion

Stakeholders felt that reparability was an important issue and stated that it was already being considered in mid to high tier products. It was considered important that the LED module and ballast are designed so that they can be replaced independently. A series of 4 reparability classes for LED luminaires that has been established by Synergrid (specification C4/11-3) was described as follows:

- Class 1-LED module and auxiliaries can be removed and replaced in-situ at the luminaire mounting height;
- Class 2 – Auxiliaries can be removed and replaced in situ at the luminaire mounting height;
- Class 3 – luminaire has to demounted before removal and replacement of the LED module or auxiliaries;
- Class 4 – The luminaire is sealed and must be discarded in the case of failure of the LED module or any internal auxiliaries.

Another important aspect to consider in GPP criteria was that of "upgradeability" for LED light sources in existing luminaires. Upgrade could simply mean more energy efficient components, a lower energy consumption for a given photometric output or improved control and functionality. Upgradeable luminaires may offer significant economic and material savings when compared to the complete replacement of luminaires.

9.4.3. Criteria proposals for reparability

Core criteria	**Comprehensive criteria**
TS11 Reparability	
The tenderer shall make sure that the light source (lamp or LED module) and auxiliaries of the luminaire are easily accessible and replaceable and that the replacement can be performed on site (i.e. at luminaire mounting height) and with one of the following types of screwdrivers: - Standard, Pozidrive, Philips, Torx, Allen keys or Combination wrenches ***Verification:*** A manual shall be provided by the tenderer which shall include an exploded diagram of the luminaire illustrating the parts that can be accessed and replaced. It shall also be confirmed which parts are covered by service agreements under the warranty. The tenderer shall provide a declaration that original or equivalent spare parts will be made available to the contracting authority or through a service provider. A spare part list with references shall be provided.	

9.5. *Ingress Protection*

9.5.1. Background research and supporting rationale

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. Light quality is in particular affected by the amount of dirt and water getting inside the luminaire and should be reduced as much as possible. This can be easily measured according to the IP rating system. According to CIE 154:2003, the IP rating (dust and moisture protection) has also a direct impact on the luminaire maintenance factors.

IP is a two digit code. 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. The second digit indicates the protection of the equipment inside the enclosure against harmful ingress of water.

For all road lighting it is necessary that no ingress of dust is allowed and protection against water is guaranteed. Benchmark values are provided in Ecodesign Regulation EC/245/2009:

- IP65 for road classes ME1 to ME6 and MEW1 to MEW6
- IP5x for road classes CE0 to CE5, S1 to S6, ES, EV and A

IP65 rating means "No ingress of dust; complete protection against contact" and "Water projected by a nozzle against enclosure from any direction shall have no harmful effects".

9.5.2. Stakeholder discussion

In TR 1.0, a technical specification was proposed for the ingress protection rating of luminaires in M or C class roads of 65 or 66 (depending on local conditions) and of 55 for luminaires used in P class roads.

Some stakeholders were against the imposition of minimum requirements for IP ratings for luminaires in GPP criteria. The main argument against this was that the correct application of IEC 60598-1 standard (specifically clause 9) is considered appropriate for deciding what IP rating is required. Any over specification of IP rating was claimed to simply add cost but no environmental benefits.

However, it was argued that a good IP rating is an essential component of ensuring a good product lifetime. A general requirement for IP 65 for all road lighting was proposed by one stakeholder. Another specific suggestion was to require IP66 for road classes M1 to M6 and IP55 for road classes C0 to C5, P1 to P6, ES, EV and A. Another stakeholder added that IP65 was the minimum requirement in Belgium.

9.5.3. Criteria proposals for Ingress Protection

<table>
<tr><th>Core criteria</th><th>Comprehensive criteria</th></tr>
<tr><td colspan="2">TS12 Ingress Protection (IP rating)</td></tr>
<tr><td colspan="2">Luminaires for M and C class roads shall have an optical system that has an ingress protection rating of at least IP65, depending on the local conditions.
Luminaires for P class roads shall be at least IP55, depending on the local conditions
<i>Verification:</i>
The tenderer shall provide the technical specifications demonstrating this criterion is met according to IEC 60598-1 clause 9.
<i>Note: The tests for the ingress of dust, solid objects and moisture specified in IEC 60598-1 are not all identical to the tests in IEC 60529 because of the technical characteristics of luminaires. An explanation of the IP numbering system is given in Annex J of the standard.</i></td></tr>
</table>

9.6. *Failure rate of control gear*

9.6.1. Background research and supporting rationale

The control gear is often a weak spot in the (LED) luminaire life time. This is typical for the potential weakness of complex electronic controls but it can also be applied to magnetic control gear that has proven its robustness.

As discussed in the Preliminary report (section 3.4.1.2.2) high-quality drivers provide a service life of more than 50000 hours with a failure rate of 0.2% per 1000 hours. Low-performance devices come with a service life of 30000 hours and failure rates of 0.5% per 1000 hours. Therefore, the core criteria are set at the standard for high quality drivers while the comprehensive criteria go a step further.

9.6.2. Stakeholder discussion

In TR 1.0, minimum technical specifications were made for maximum acceptable failure rates of 0.2 per 1000h and a 5 year warranty (core level) and 0.1 per 1000 with a 7 year warranty (comprehensive level).

Stakeholders accepted that the failure rates were well chosen although lower failure rates associated with better quality control gear would result in increased costs. Reputable suppliers will already have failure rate test data from industry quality control testing. Stakeholders were not aware of any international standards for assessing failure rates for control gear. When prompted about possible requirements in GPP criteria for higher protection levels in control gear due to dielectric strengths, stakeholders felt that this would be difficult to verify and should not be specified as it was still under discussion in the IEC technical committee.

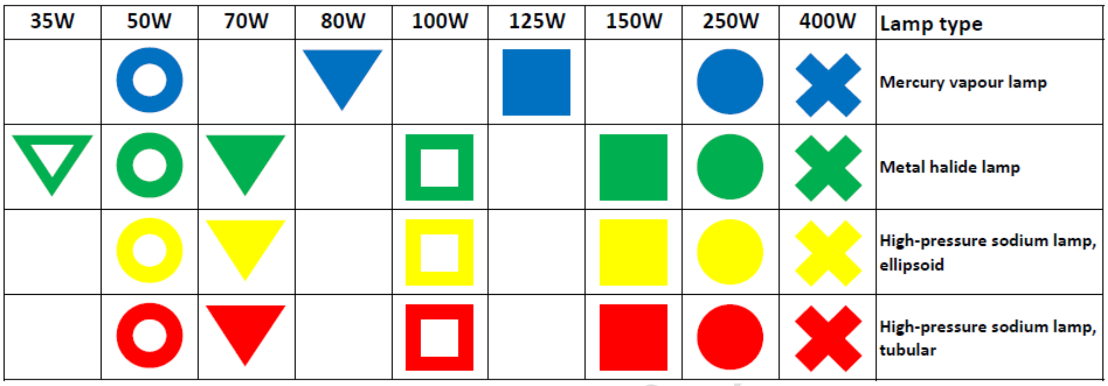
9.6.3. Criteria proposals for control gear failure rates

Core criteria	**Comprehensive criteria**
TS13 Failure rate of control gear	
The specified control gear failure rate shall be lower than 0.2% per 1000 h. Specific warranty for control gear of 8 years ***Verification:*** The tenderer shall provide a declaration of compliance with the above failure rate for any control gear they intend to supply. The declaration shall be supported by relevant industry standard testing procedures.	The specified control gear failure rate shall be lower than 0.1% per 1000 h. Product warranty of 10 years ***Verification:*** The tenderer shall provide a declaration of compliance with the above failure rate for any control gear they intend to supply. The declaration shall be supported by relevant industry standard testing procedures.

9.7. *Labelling of LED luminaires*

9.7.1. Background research and supporting rationale

This potential criterion is of direct relevance to road lighting in particular. If metering is not in place, which is currently a common situation according to stakeholder feedback, it is extremely difficult to estimate the current electricity consumption of the lighting installation. When it comes to replacing lamps, it is extremely important to know the relevant input voltages. These issues are also relevant to traditional lamp technologies, as illustrated by the labelling scheme that provided in Finnish Transport Agency guidelines.



35W	50W	70W	80W	100W	125W	150W	250W	400W	Lamp type
	○		▼		■		●	✖	**Mercury vapour lamp**
▽	○	▼		□		■	●	✖	**Metal halide lamp**
	○	▼		□		■	●	✖	**High-pressure sodium lamp, ellipsoid**
	○	▼		□		■	●	✖	**High-pressure sodium lamp, tubular**

Figure 30. Example of labelling system recommended in Finland for traditional lamp technologies (FTA, 2016).

With traditional lamp technologies, labelling was to some extent simpler because the lamps were only supplied with certain standard power ratings (e.g. 35W, 50W, 100W, 250W etc.). However, with LED lamps, the rate of technological advance is so fast that there is not yet any industry standard power rating that can apply. This fact, coupled with the possibilities for dimming, make it extremely difficult to assess the actual energy performance of existing road lighting installations, which in turn makes it more difficult to accurately assess the potential for energy savings by retrofitting the installation with new and more efficient lamps.

An example of labelling requirements specifically for LED installations is provided in the Synergrid technical specification used in Belgium (Synergrid). The specifications for labelling include the following:

- Wiring diagram.
- Manufacturer's name, code, serial number and date of manufacture.
- Type of lighting appliance.
- Nominal input voltage (or range).
- Nominal input current (or range).
- Total input power (or range).
- Light flux emitted at ambient temperature (25°C).
- LED current in mA.
- Colour temperature and colour rendering index.
- Indication of the dimming control technology (if applicable).
- Mercury free or mercury-containing

9.7.2. Stakeholder discussion

Some requests were made for an EU GPP criterion that requires a certain amount of key information to be available on the luminaire. The main reason for this is because LED technology is advancing so quickly, that it is important that procurers can remain aware of the actual equipment that they have installed and be well informed when the time comes to replace the existing LED lamps or luminaires. In theory, all of this information should be kept in records of the public authority. However, in reality such records can be lost or populated incorrectly.

Traditional HID lamp technologies tend to come in one of 3 or 4 standard power ratings but LED lamps can have a much broader range of power ratings. Such a situation can make it impossible to accurately estimate the AECI of the lighting installation.

The most important information that was mentioned in discussions were: power rating; luminous flux; Upward Light Ratio (ULR); CIE flux codes and CCT.

No objections were received by stakeholders to including this information although no particularly preferable way of providing this information was described either. The main options are: stickers with QR codes; stickers with information printed on top or engravings into metal plates.

9.7.3. Criteria proposals for labelling of LED luminaires

<table>
<tr><th>Core criteria</th><th>Comprehensive criteria</th></tr>
<tr><td colspan="2">TS14 Labelling of LED luminaires</td></tr>
<tr><td colspan="2">(<i>Recommended whenever new LED luminaires are installed</i>)
The luminaires proposed to be installed by the tenderer shall carry, as a minimum, the following technical information:
• Manufacturer's name, code, serial number and date of manufacture.
• Input power rating
• Luminous flux at ambient temperature.
• Upward Light Ratio
• CIE flux codes
• Correlated Colour Temperature (CCT)
• Indication of the dimming control technology (if applicable).
The information should be included in the luminaire and, where possible, also in a part of the light pole that is accessible from ground level. The tenderer should specify how exactly this information shall be contained (e.g. label with QR code, label with written information or metal plate with engravings).
<i>Verification:</i>
The tenderer shall describe how the example label that would accompany the lighting equipment they propose to provide if their tender is successful.</td></tr>
<tr><td colspan="2">CPC8 Labelling of LED luminaires</td></tr>
<tr><td colspan="2">The contractor shall commit to providing labels for the luminaires they supply that contain at least the minimum information specified in TS14.</td></tr>
</table>

10. Traffic signals

Although not strictly the same subject matter, criteria for traffic signals are included together with the broader criteria-set for road lighting. There is no other relevant EU GPP product group for traffic signals since it is not included within the scope for "*EU GPP Road Design, Construction and Maintenance*" and there is no stand-alone product group such as "*Traffic Management Systems*".

10.1. Life Cycle Cost

10.1.1. Background research and supporting rationale

The existing EU GPP criteria for traffic signals focus exclusively on energy efficiency and set maximum operating wattages of 9 to 12W (core) or 7 to 9.5W (comprehensive depending on the diameter of the roundel, the colour of the light and whether the display was a full ball or just an arrow.

The criteria proposed in TR 1.0 (October 2016) were identical to the comprehensive ambition level set in the 2012 criteria for energy efficiency. The only additional aspect was that a minimum lamp lumen maintenance factor (L92B50 at 16000 hours) and a minimum lamp survival factor of L92C08 at 16000 hours were set.

In both the existing EU GPP criteria and the TR 1.0 proposal, there is a lack of data about the energy consumption of pedestrian signals – which will also be highly relevant to the contractual subject matter in the majority of intersections.

Energy efficiency and lifetime data can be quite neatly combined with a life cycle cost framework over a defined period. Better energy efficiency results in lower electricity costs and better lifetime results in reduced maintenance costs. An added advantage of longer life is that there will be less disruption to traffic caused by traffic signal maintenance.

It is uncertain whether the energy efficiency criteria are ambitious enough and what range of performance is available on the market. The market front-runner performance appears to be of the order of just 1-2W (Siemens, 2016). This performance can only be achieved by replacing load resistors and switching elements with digital LED driver modules.

Due to the fact that front-runner performance could be 4-9 times better that the EU GPP requirements and doubts about how widely available front-runner products are and how much more expensive such technology is, it is considered most appropriate to propose a criterion for traffic signals based on life cycle cost.

Chicago case study (C4O Cities, 2011)

In 2011, the city of Chicago reported on an ambitious $32 million project, running from 2004-2014, to retrofit traffic signals with LED technology at 2900 intersections. The new LED traffic signals consume 85% less energy and save $2.55 million per year. It was unclear if the cost savings referred to once all 2900 intersections had been replaced or to the 1000 intersections that had been replaced at the time of the report. Regardless, the worst-case payback period was less than 13 years.

In terms of relative importance in Chicago, installed power for traffic signals was 6MW while road lighting was 70MW.

Graz case study (COMPETENCE)

Graz has around 260 traffic signal intersections and is promoting the replacement of traffic signals with LED technology whenever the existing lamp needs to be replaced. The assessment assumed an energy consumption of 75W for the traditional lamp and 10W for the replacement LED lamp. In terms of lifetime, the traditional lamps were replaced every 6 months as per a fixed maintenance schedule (an annual maintenance cost of

€960,000). The replacement schedule can be extended by a factor of 6 (i.e. up to 3 years instead of every 6 months) when using LED lamps.

At the time of publication (year unknown), LED lamps for traffic signals were 2-3 times higher than traditional lamps but it could be realistically expected that this would be paid back within 2 years simply by the longer lifetime.

In terms of relative importance in Graz, electricity consumption for traffic signals was 1.7 million kWh/yr while (ca. €220,000) road lighting was 8.5 million kWh/yr (ca. €1.1 million).

For comparison, the same document citing the Graz case study provided details of the 2001 retrofit of traffic signals in Stockholm in 2001 (530 intersections). A total additional LED-related investment of €3 million was paid back in 4-5 years thanks to annual savings in electricity (€471,000/yr) and maintenance (€243,000/yr).

Early US experience (RPN, 2009)

Even back in 2009, LED was the standard approach for any new traffic signal installations in the US. The replacement of traditional incandescent lamps with LED lamps results in energy savings of around 93%. In 2009 the reported difference in lamp costs was typically $3 for incandescent bulbs and $150 for LED bulbs – a factor of 50 difference!

Despite the major differences in capital costs, savings on electricity and maintenance are so high that payback periods of 0.5 to 3 years for retrofitting traffic signals with LEDs are the norm.

The energy saving potential of retrofitting an individual traffic signal will depend on the duty cycle (i.e. red-amber-green). The US study found that, in general, the retrofitting of red signals should be prioritised over green signals and that amber signals were of least potential energy savings.

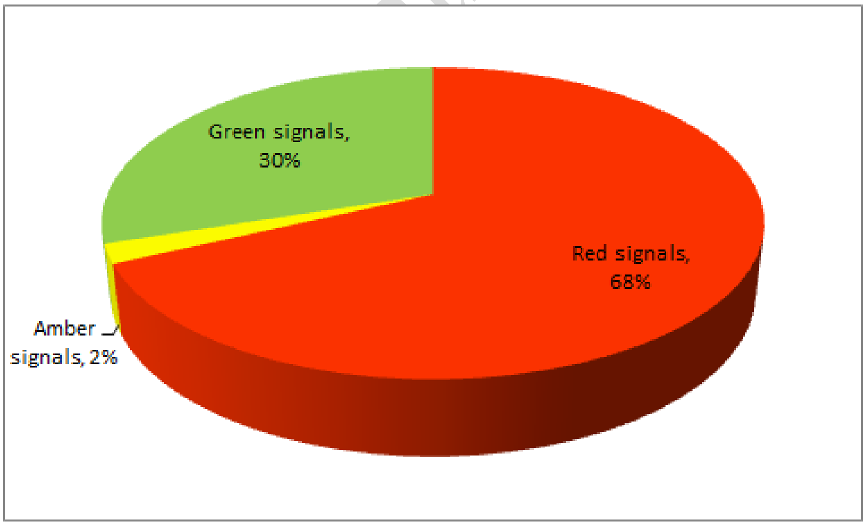


Figure 31. Energy saving potential for different lights in traffic signals (Source RPN, 2009)

The authors of the 2009 RPN guide also illustrated the specific savings that are possible for different traffic light fixtures.

Table 14. Energy and cost savings of incandescent vs. LED traffic signals

	Incandescent wattage (Annual energy consumption, kWh)	LED Wattage (Annual energy consumption, kWh)	Annual electricity savings per LED*
12 inch red ball (55% duty cycle)	150 (723)	10 (48)	$67.50
12 inch red ball (90% duty cycle)	150 (1183)	7 (55)	$112.80
12 inch green ball (45% duty cycle)	150 (591)	11 (43)	$54.80
12 inch green arrow (10% duty cycle)	150 (131)	7 (6)	$12.50
Stop hand display	67 (528)	8 (63)	$46.50
Walking figure display	67 (59)	8 (7)	$5.20

*assuming an electricity cost of $0.10/kWh

Specific examples of municipalities implementing the replacement of traffic signals were provided:

- Denver, CO (1996): Replacement of >20,500 traffic signals (150W incandescent with 14W LED or 69W incandescent with 8W LED) saving $276,000 per year in electricity and $154,000 per year in maintenance. Payback period was less than 4 years.
- Salt Lake City, UT (2001-2007): Replaced red and green bulbs with LEDs and reduced electricity consumption by 70% (almost 2 million kWh/yr) and electricity costs by $115,000/yr.
- Portland, OR (2001): Replaced 6900 red and 6400 green incandescent bulbs with LEDs at a cost of $2.2 million and reduced electricity consumption by 4.9 million kWh/yr, reduced electricity costs by $335,000/yr and reduced maintenance costs by $45,000.

Considering the notable increases in electricity costs in the last 10-15 years and the simultaneous drastic decrease in the cost of LED lamps, it is clear that the financial benefits of investing in LED-based traffic signals has increased significantly and must today be the stand-out candidate in any ITT that considers lifetime costs. Today the main competition is likely to be between one LED-product and another LED-product.

There is clearly a lot of experience in calculating life cycle costs and payback periods for justifying investments in LED traffic signals although the precise details of how this is done are not well published and are likely to vary from one project to another and from one public authority to another. This could be due to factors such as the use of in-house or contracted maintenance staff and electricity tariffs.

10.1.2. Stakeholder discussion

Very little discussion took place about criteria relating to traffic signals. Some mixed comments were raised about the wattage requirements initially proposed in TR 1.0 with one stakeholder stating that the limits were already too ambitious and another stating that the ambition limits were acceptable.

Further doubts were raised about the 1W traffic signal front-running technology in terms of capital cost and the need for ancillary equipment that would rule out simple retrofits.

In general, support was expressed for lifetime criteria.

10.1.3. Criteria proposals for Life Cycle Cost

Core criteria	**Comprehensive criteria**

TS1 – Life Cycle Cost

A life cycle cost shall be calculated based on the specifications set by the procurer, which should include:

- Time period (e.g. 8 years).
- Inventory of traffic signals required (e.g. red ball signals, amber ball signals, green ball signals, green arrow signals, pedestrian stop signals and pedestrian go signals).
- Average duty cycle of each traffic signal (e.g. red signal 55%, amber signal 2%, green signal 43%).
- Electricity rate (e.g. €/kWh).

The tenderer shall provide the following details in order to complete the life cycle cost assessment:

- Period of time that bulbs are covered by warranty for abrupt failure.
- Rated lifetime of lamp (i.e. the time when lamp lumen output is expected to fall to 70% of original output.
- Purchase cost for lamps (both at the beginning and for any necessary replacement during the defined time period).
- Purchase cost for any ancillaries.
- Purchase cost for any poles, foundations and new electrical connections.
- Installation cost (hours of labour multiplied by labour rates plus any costs for lifting equipment etc.).

Verification:

The procurer shall provide the tenderers with a common spreadsheet-based Life Cycle Cost calculator in which the information required from the procurer has already been entered.

The tenderer shall submit a copy of the completed spreadsheet together with a declaration confirming that these costs are valid at least for a defined period that would cover the original timescale planned for the execution of the contract after selection of the successful tenderer.

AC1 Lowest Life Cycle Cost

A maximum of X points shall be awarded to the tenderer whose proposal is shown to have the lowest life cycle cost.

Points shall be awarded to other tenderers in proportion to how their life cycle cost compares to the lowest cost using the following formula:

$$Points\ awarded = X\ x \left(2 - \left(1 - \frac{lowest\ LCC\ \left(\frac{Euros}{yr}\right)}{actual\ LCC\ \left(\frac{Euros}{yr}\right)} \right) \right)$$

Negative points cannot be awarded. The lowest number of points awarded using the above formula shall be 0 (which would apply to any actual LCC that is at least twice as high as the lowest LCC).

Verification:

Once all tenders have been received, the procurer shall be able to determine which tender provides the lowest life cycle cost and use this to determine how many points (if any) should be applied to each tender.

10.2. Warranty

10.2.1. Background research and supporting rationale

The justification for a criterion relating to product warranty for traffic signals is broadly similar to the arguments presented for warranties for street lighting in section 9.3. The superior longevity of LED lamps and their lower incidence of abrupt failure when compared to incandescent lamps results in less frequent replacement cycles and maintenance interventions.

One notable difference between traffic signals and street lights is that the former are constantly switching running through short duty cycles of the order of seconds while the latter tend to have one signal and continuous duty cycle for 10-12 hours per day and then are switched off. As a result, lamps used in traffic signals need to be replaced more frequently than lamps based on the same technology when used in street lighting. This fact should also be reflected in shorter warranty periods for traffic signals.

Despite the superior longevity of LED-based lamps compared to incandescent lamps, there is a range of performance within LED technology alone. As illustrated in Figure 29 in section 9.3.1, a number of factors can contribute to a reduced lifetime of LED lamps. A sufficiently long warranty is an indirect way of ensuring that the contractor will take extra care to minimise the possible factors that could shorten lamp lifetime. Such factors include:

- overheating of electronics due to inadequate heat sinks/cooling mechanisms,
- the use of good quality LED chips,
- the use of durable capacitors and drivers that can accurately regulate currents within design specifications.

The need for a warranty going beyond the standard 2 year period is also necessary in order to back up claims and assumptions made in the life cycle cost assessment.

10.2.2. Stakeholder discussion

Since this is a new proposal, no previous stakeholder discussion has taken place about this criterion in particular for street lighting.

The main motivation for including such a criterion is that if it is relevant for street lighting it should be even more relevant for traffic signals, given the more acute potential safety impact.

10.2.3. Criteria proposals for traffic signal warranty

Core criteria	**Comprehensive criteria**
TS2 – LED lamp product lifetime, spare parts and warranty	
Any LED-based light sources shall have a rated life of: • L92B50 at 16000 hours (projected) and • L80B10 at 60000 hours (projected) The repair or provision of relevant replacement parts of LED modules suffering abrupt failure shall be covered by a warranty for a period of 5 years from the date of installation. ***Verification:*** Test data regarding the maintained lumen output of the light sources shall be provided that is in accordance with IEC 62722 for actual data and IEC 63013 for projected data. The tenderer shall provide a copy of the minimum 5 year warranty that would be signed in case the tender should be successful. The contractor shall provide a copy of the warranty that would be applicable should the tender be successful and provide the necessary contact details (phone and email as a minimum) for dealing with any related queries or potential claims. For clarity, the warranty shall, as a minimum, cover the repair or replacement costs of faulty LED module parts within a reasonable time period after notification of the fault (to be defined by the procurer in the ITT) either directly or via other nominated agents. Replacement parts should be the same as the originals but if this is not possible, equivalent spare parts that perform the same function to the same or to a higher performance level may be used. The warranty shall not cover the following: a) Faulty operation due to vandalism, accidents or other extreme weather events. b) Lamps or luminaires that have been working for a significant time under abnormal conditions (e.g. used with the wrong line voltage) insofar that this can be	Any LED-based light sources shall have a rated life of: • L92B50 at 16000 hours (projected) and • L90B10 at 60000 hours (projected) The repair or provision of relevant replacement parts of LED modules suffering abrupt failure shall be covered by a warranty for a period of 7 years from the date of installation. ***Verification:*** Test data regarding the maintained lumen output of the light sources shall be provided that is in accordance with IEC 62722 for actual data and IEC 63013 for projected data. The tenderer shall provide a copy of the minimum 7 year warranty that would be signed in case the tender should be successful. The contractor shall provide a copy of the warranty that would be applicable should the tender be successful and provide the necessary contact details (phone and email as a minimum) for dealing with any related queries or potential claims. For clarity, the warranty shall, as a minimum, cover the repair or replacement costs of faulty LED module parts within a reasonable time period after notification of the fault (to be defined by the procurer in the ITT) either directly or via other nominated agents. Replacement parts should be the same as the originals but if this is not possible, equivalent spare parts that perform the same function to the same or to a higher performance level may be used. The warranty shall not cover the following: a) Faulty operation due to vandalism, accidents or other extreme weather events. b) Lamps or luminaires that have been working for a significant time under abnormal conditions (e.g. used with the wrong line voltage) insofar that this can be

proven by the contractor.	proven by the contractor.

AC2 Extended Warranty

X points shall be awarded to tenderers that are willing to provide initial warranties, whose cost is already included in the bid price, that go beyond the minimum warranty periods stated in TS10. Points shall be awarded in proportion to how long the warranty exceeds the minimum requirements as follows:

- Minimum +1 year: 0.5X points
- Minimum +2 years: 0.75X points
- Minimum +3 years or more: X points

Tenderers may also optionally provide quotations for extended warranties that are not included in the bid price, although points shall not be awarded for this. In such cases, it shall be made clear that no payment for any extended warranty is required until the final year of the initial warranty and then annual payments would be made by the procurer to the successful tenderer at the beginning of each year of the extended warranty.

It shall also be clear that the procurer has the option to initiate or leave the offer of the any extended warranty right up until the final year of the initial warranty and that the costs of the extended warranty would be those initially proposed plus any inflation.

11. Technical Annex I: Calculating PDI.

The PDI value, in W/(lx.m^2) essentially tells us how much power is consumed to provide a certain amount of maintained average illuminance (lx) over one square metre. Generally speaking, the lower the PDI value, the better the lighting system energy efficiency. It is relative to the installed illumination and therefore does not take into account over-lighting.

The PDI value is technology neutral and should include power consumption from all components of a luminaire with light source installed. For this reason, there is no need to set overlapping requirements for individual types of lamps and ballasts.

Calculating PDI[W/(lx.m^2)] or [W/lm]

The Power Density Indicator is calculated according to EN 13201-5:2016 as follows:

$$PDI = D_P = \frac{P}{\sum_{i=1}^{n}(E_i \; x \; A_i)}$$

Where P is the system power, Ei is the average maintained horizontal illuminance of sub-area A. and n is the number of sub-areas. Any one particular sub-area may have illuminance classes defined as luminance requirements, L,m (e.g. M-class road sections) or illuminance, E,m or illuminance requirements E,hs (e.g. C or P class road sections). The following conversion formulas for switching from luminance and illuminance are provided in EN 13201-5:2016:

- *Illuminance (E,m) = Luminance (L̄,m) / 0.07 (where 0.07 is a general "rule of thumb" coefficient for a reference asphalt surface, in cd/(m^2.lx. For greater accuracy, in-situ measurements of the asphalt road surface reflectivity should be taken (especially if not asphalt!) and results generated via a specialised lighting program)*.
- *Illuminance (E,m) = Hemispherical illuminance (E,hs) / 0.65*

It should be noted that 1 W/(lx.m^2), i.e. the unit of PDI, is equivalent to 1 W/lm which is the reciprocal value of the installation efficacy in lm/W. The PDI indicator does not take into account dimming and/or over-lighting.

As indicated above, it is important to be aware of the target area to be lit, A, and this in turn requires knowledge about the road profile. It is important to be aware of the road profile and the target area to be lit when calculating the PDI.

Road profile

The road profile describes the layout of the road sections to be lit, lighting points, any adjacent pedestrian areas intended to be lit and any vegetated areas or central reservations not intended to be lit, see Figure 32 below.

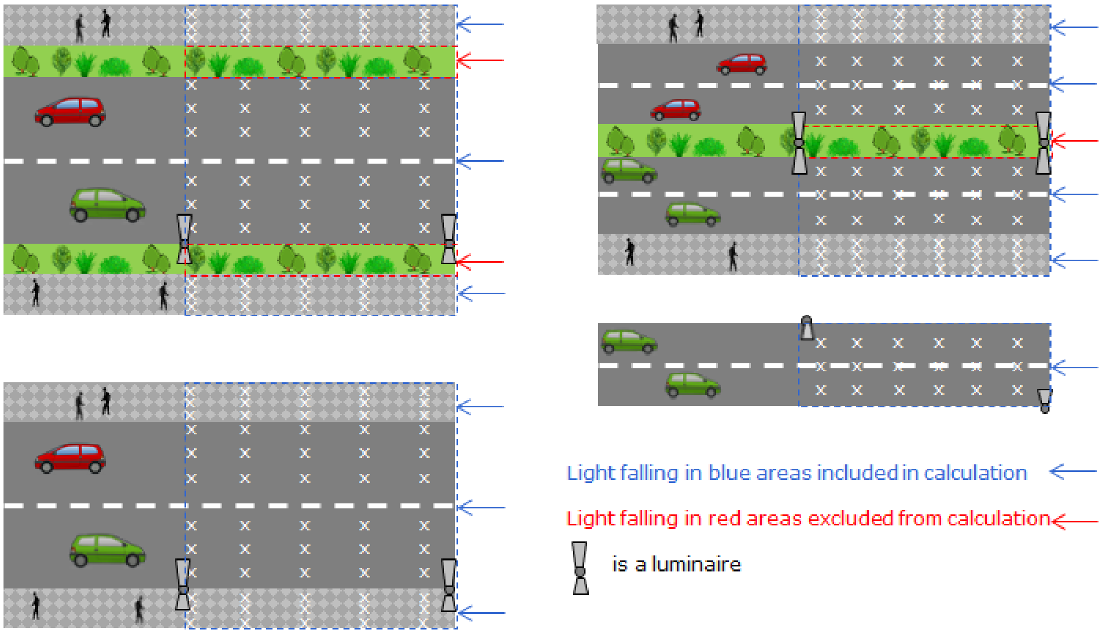


Figure 32. Examples of different possible road profiles and the associated areas to be included in any PDI calculations (adapted from EN 13201-5)

The results for PDI and AECI will be influenced by light output that is essentially "spilled" onto non-target areas. Consequently, a clear understanding of the road profile is important to ensure that different designs are comparable. In certain circumstances, where there is a degree of freedom about the placement of luminaires, the road profile will need to be considered in detail to deliver the optimum energy efficiency without creating problems due to glare or a lack of uniformity. Note that road classes M1-M6 have Edge Illumination Ratio (EIR) and if the carriageway of a road is not surrounded by other areas, the surrounding areas used for calculating EIR are not included in the calculation of power density indicator. As a consequence this can lower the PDI.

Example calculations with real data – (i) road only (Synergrid-b)

The following example is for a road where the ***target average maintained luminance is 1.00 cd/m***^{2}. To minimise the potential for over-lighting, the target luminance also must not be exceeded by more than 25% (i.e. luminance must be between 1.00 and 1.25 cd/m^2 - the lower within this range the better). The EN 13201-5:2016 standard is less stringent in this respect, allowing average luminance to be exceeded by up to 50%.

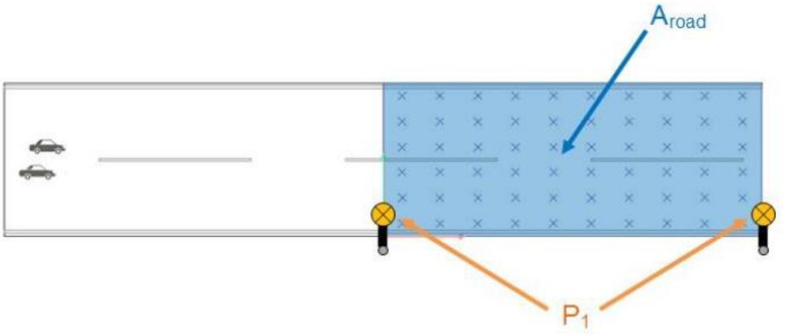


Figure 33. Target area for the calculation of PDI in one road sub-area (Source: Synergrid-b).

To calculate PDI, it is necessary to use suitable lighting calculation software and the photometric file of the light source and luminaire. A real example of the main data needed to calculate PDI include:

- Road width = 7m

- Distance between light poles = 36m
- Sub area, A_{road} = 252m^2
- Height of luminaires = 8m
- Power consumption of the two luminaires (P1) = 115 W (HPS lamp 110W on electronic ballast)
- Luminous flux of the lamp = 10000 lm
- Maintenance factor = 0.92 (IP66, glass cover)

From these data, the average maintained illuminance on A_{road} can be calculated to be 14.4 lx (including the maintenance factor). Once the illuminance is known, the PDI can be calculated as follows:

$$PDI = D_P = \frac{P_1}{E_{road}\ x\ A_{road}} = \frac{115W}{14.4lx\ x\ 252m^2} = 0.032\ W.lx^{-1}.m^{-2}$$

A final check is required to see if the average maintained luminance level is adequate, so it is necessary to convert illuminance into luminance:

$$Illuminance\ (lx)\ x\ surface\ reflectivity\ coeff. = Luminance\ (cd.m^{-2})$$

$$= 14.4lx\ x\ 0.0722cd.lx^{-1}.m^{-2} = 1.04cd.m^{-2}$$

The final luminance result was indeed compliant with the example (i.e. between 1.00 and 1.25 cd.m^{-2}) and the PDI was calculated as 0.032 W.m^{-2}.lx^{-1}.

<u>Example calculations with real data – (ii) road with sidewalk</u>

In cases where the road profile requires different lighting levels for at least 2 different areas, the calculation of PDI is more complex and another example (again from the Synergrid technical specification document) is provided below:

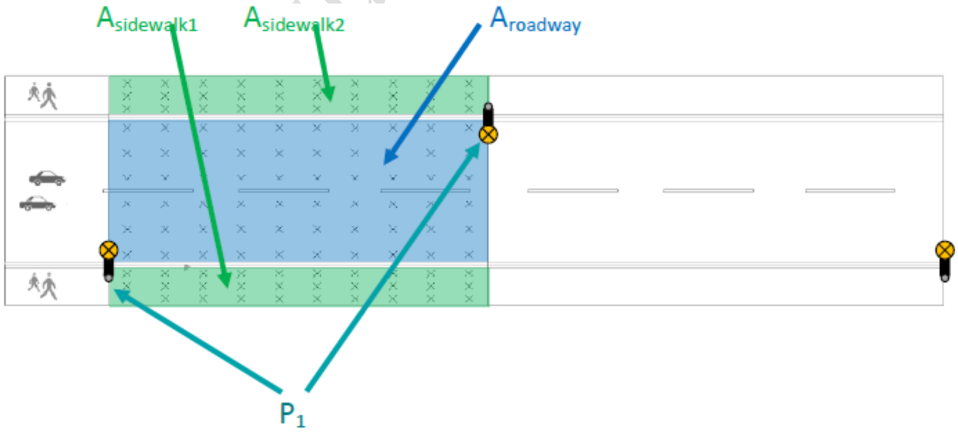


Figure 34. Target areas for calculation of PDI where two lighting classes are required in one sub-area (Source: Synergrid-b).

The following details can be used in lighting software to calculate the average maintained illuminance on the road and on the sidewalks:

- Width of roadway = 7m
- Width of the sidewalk = 2m (on each side)
- Distance between the light poles = 25m
- Sub area A_{road} = 175m^2
- Sub area $A_{sidewalk1}$ = 50m^2

- Sub area $A_{sidewalk2}$ = $50m^2$
- Power rating of luminaire P1 = 103W (90 W MHHP with electronic ballast)
- Maintenance factor = 0.87 (MHHP lamp, IP 66, glass cover)
- Luminous flux = 10500 lm
- Height of the luminaire = 8m

This results in an average maintained illuminance on road of 17.4lx (including the maintenance factor and on the sidewalks of 12.2lx (again including the maintenance factor)

The clearest explanation of the PDI calculation is by following the "absolute method" described in the Synergrid specification. It is necessary to read of the percentages of light output from the luminaire that fall on each of the target areas, as illustrated in Figure 35.

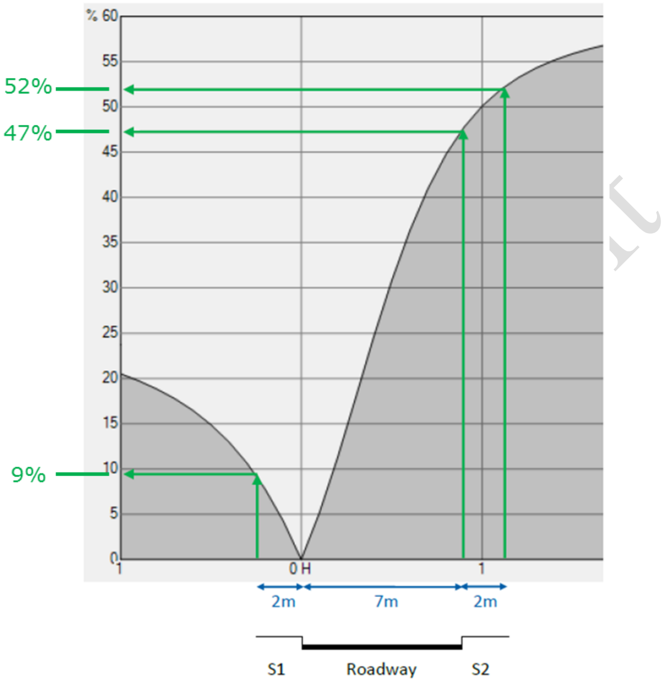


Figure 35. Reading of the "utilance" of luminous flux from luminaire (Source: Synergrid).

The extrapolation of data reveals that 9% of the luminous flux lands on sidewalk 1, 47% lands on the road and 5% (i.e. 52% - 47%) lands on sidewalk 2 – resulting in an overall utilance of 61%, or 0.61.

For the calculation of PDI to be true, it is also necessary to account for the energy that is spent on light that does not reach the target areas. So percentage of power used to illuminate the road is essentially 77% of the 103W (i.e. 47%/61% x100), on sidewalk 1 it is 14.8% of the 103W (i.e. 9%/61% x 100) and on sidewalk 2 is it 8.2% of the 103W (i.e. 5%/61% x100). This two sidewalk values can be combined (i.e. taking 23% of the power) since, due to the staggered layout of lighting points shown in Figure 34, they will receive the same total luminous flux overall.

So the PDI calculations now become:

$$PDI = D_{Proadway} = \frac{0.77\ x\ 103W}{17.4lx\ x\ 175m^2} = 0.026\ Wm^{-2}lx^{-1}$$

And

$$PDI = D_{Psidewalk1+2} = \frac{0.23\ x\ 103W}{(12.2lx\ x\ 50m^2) + (12.2lx\ x\ 50m^2)} = 0.0194\ Wm^{-2}lx^{-1}$$

For ease of comparison with different designs, the PDI for the road, sidewalk 1 and sidewalk 2 can also be aggregated into a single value so long as the average (and maximum) maintained luminance/illuminance levels are specified equally and are complied with by all designs.

Limitations of PDI

Although the PDI is a useful measure of the energy efficiency of the installation, it is not so easy to understand for procurers, who will be most interested in the electricity bill. As the term suggests, PDI, is only an indicator of energy efficiency and not a direct measure of energy consumption.

Because PDI is relative to the installed illumination, it does not take into account overlighting. For example, it is possible for a road to have a very low PDI value even when in reality the lighting levels on the road, and thus the energy consumption, could be much higher than they needed to be. This is why it is necessary to have some check that luminance or illuminance levels do not exceed targets by more than a certain amount (e.g. 25%). The PDI can potentially be weighted to factor in constant light output (CLO) and dimming scenarios by adjusting the system power value but how this number is arrived at is not so transparent in the standard PDI calculation.

PDI should not be used as a stand-alone requirement for energy efficiency. In order to avoid potential perverse outcomes, it is very important that the procurer specifies the average and maximum maintained lighting levels required for each sub-area of the road.

12. Technical Annex II: Reference PDI tables.

Table 15. PDI reference tables for M-class roads

Road class (2018 luminaire efficacy base)	Year	Road width (to be lit)											
		Core ≤5m	Comp ≤5m	Core 5-6m	Comp 5-6m	Core 6-7m	Comp 6-7m	Core 7-8m	Comp 7-8m	Core 8-9m	Comp 8-9m	Core ≥9m	Comp ≥9m
M1 (119 or 130 lm/W)	2018-19	0.028	0.018	0.024	0.018	0.020	0.018	0.018	0.015	0.016	0.013	0.014	0.013
	2020-21	0.025	0.016	0.021	0.016	0.018	0.016	0.015	0.013	0.014	0.011	0.012	0.011
	2022-23	0.022	0.014	0.018	0.014	0.016	0.014	0.014	0.012	0.012	0.010	0.011	0.010
M2 (119 or 130 lm/W)	2018-19	0.028	0.018	0.024	0.018	0.020	0.018	0.018	0.015	0.016	0.013	0.014	0.013
	2020-21	0.025	0.016	0.021	0.016	0.018	0.016	0.015	0.013	0.014	0.011	0.012	0.011
	2022-23	0.022	0.014	0.018	0.014	0.016	0.014	0.014	0.012	0.012	0.010	0.011	0.010
M3 (108 or 120 lm/W)	2018-19	0.031	0.020	0.026	0.020	0.022	0.020	0.019	0.016	0.017	0.014	0.016	0.014
	2020-21	0.027	0.017	0.022	0.017	0.019	0.017	0.017	0.014	0.015	0.012	0.013	0.012
	2022-23	0.024	0.015	0.020	0.015	0.017	0.015	0.015	0.013	0.013	0.011	0.012	0.011
M4 (108 or 120 lm/W)	2018-19	0.031	0.020	0.026	0.020	0.022	0.020	0.019	0.016	0.017	0.014	0.016	0.014
	2020-21	0.027	0.017	0.022	0.017	0.019	0.017	0.017	0.014	0.015	0.012	0.013	0.012
	2022-23	0.024	0.015	0.020	0.015	0.017	0.015	0.015	0.013	0.013	0.011	0.012	0.011
M5 (108 or 120 lm/W)	2018-19	0.031	0.020	0.026	0.020	0.022	0.020	0.019	0.016	0.017	0.014	0.016	0.014
	2020-21	0.027	0.017	0.022	0.017	0.019	0.017	0.017	0.014	0.015	0.012	0.013	0.012
	2022-23	0.024	0.015	0.020	0.015	0.017	0.015	0.015	0.013	0.013	0.011	0.012	0.011
M6 (100 or 110 lm/W)	2018-19	0.034	0.021	0.028	0.021	0.024	0.021	0.021	0.018	0.019	0.015	0.017	0.015
	2020-21	0.029	0.019	0.024	0.019	0.021	0.019	0.018	0.015	0.016	0.013	0.014	0.013
	2022-23	0.025	0.016	0.021	0.016	0.018	0.016	0.016	0.014	0.014	0.012	0.013	0.012

The differences in PDI values for different years are based on a tiered increase in luminaire efficacy that is expected to be delivered by the LED industry or 17 lm/W every two years between the periods 2018 and 2023. The 2018 bases refer to core or comprehensive values.

A simplified calculation of the PDI reference values has been made where PDI = 1 / (luminaire efficacy x Maintenance Factor x Utilance)

For all PDI reference values a maintenance factor of 0.85 is assumed. The utilance values vary as a function of road width and criterion ambition level as follows:

Core level: width ≤5m (U=0.35); width 5-6m (U=0.42); width 6-7m (U=0.49); width 7-8m (U=0.56); width 8-9m (U=0.63); width ≥9m (U=0.70)

Comp. level: width ≤5m (U=0.50); width 5-6m (U=0.50); width 6-7m (U=0.50); width 7-8m (U=0.60); width 8-9m (U=0.70); width ≥9m (U=0.70)

Table 16. PDI reference tables for C and P class roads

Road class (2018 luminaire efficacy base)	Year	Road width (to be lit)											
		Core ≤5m	Comp ≤5m	Core 6m	Comp 6m	Core 7m	Comp 7m	Core 8m	Comp 8m	Core 9m	Comp 9m	Core ≥10m	Comp ≥10m
C0 (119 or 130 lm/W)	2018-19	0.028	0.018	0.024	0.018	0.020	0.018	0.018	0.015	0.016	0.013	0.014	0.013
	2020-21	0.025	0.016	0.021	0.016	0.018	0.016	0.015	0.013	0.014	0.011	0.012	0.011
	2022-23	0.022	0.014	0.018	0.014	0.016	0.014	0.014	0.012	0.012	0.010	0.011	0.010
C1 (119 or 130 lm/W)	2018-19	0.028	0.018	0.024	0.018	0.020	0.018	0.018	0.015	0.016	0.013	0.014	0.013
	2020-21	0.025	0.016	0.021	0.016	0.018	0.016	0.015	0.013	0.014	0.011	0.012	0.011
	2022-23	0.022	0.014	0.018	0.014	0.016	0.014	0.014	0.012	0.012	0.010	0.011	0.010
C2 (119 or 130 lm/W)	2018-19	0.028	0.018	0.024	0.018	0.020	0.018	0.018	0.015	0.016	0.013	0.014	0.013
	2020-21	0.025	0.016	0.021	0.016	0.018	0.016	0.015	0.013	0.014	0.011	0.012	0.011
	2022-23	0.022	0.014	0.018	0.014	0.016	0.014	0.014	0.012	0.012	0.010	0.011	0.010
C3 / P1 (108 or 120 lm/W)	2018-19	0.031	0.020	0.026	0.020	0.022	0.020	0.019	0.016	0.017	0.014	0.016	0.014
	2020-21	0.027	0.017	0.022	0.017	0.019	0.017	0.017	0.014	0.015	0.012	0.013	0.012
	2022-23	0.024	0.015	0.020	0.015	0.017	0.015	0.015	0.013	0.013	0.011	0.012	0.011
C4 / P2 (108 or 120 lm/W)	2018-19	0.031	0.020	0.026	0.020	0.022	0.020	0.019	0.016	0.017	0.014	0.016	0.014
	2020-21	0.027	0.017	0.022	0.017	0.019	0.017	0.017	0.014	0.015	0.012	0.013	0.012
	2022-23	0.024	0.015	0.020	0.015	0.017	0.015	0.015	0.013	0.013	0.011	0.012	0.011
C5 / P3 (108 or 120 lm/W)	2018-19	0.031	0.020	0.026	0.020	0.022	0.020	0.019	0.016	0.017	0.014	0.016	0.014
	2020-21	0.027	0.017	0.022	0.017	0.019	0.017	0.017	0.014	0.015	0.012	0.013	0.012
	2022-23	0.024	0.015	0.020	0.015	0.017	0.015	0.015	0.013	0.013	0.011	0.012	0.011
P4 (100 or 110 lm/W)	2018-19	0.034	0.021	0.028	0.021	0.024	0.021	0.021	0.018	0.019	0.015	0.017	0.015
	2020-21	0.029	0.019	0.024	0.019	0.021	0.019	0.018	0.015	0.016	0.013	0.014	0.013
	2022-23	0.025	0.016	0.021	0.016	0.018	0.016	0.016	0.014	0.014	0.012	0.013	0.012
P5 (84 or 90 lm/W)	2018-19	0.040	0.026	0.033	0.026	0.029	0.026	0.025	0.022	0.022	0.019	0.020	0.019
	2020-21	0.033	0.022	0.028	0.022	0.024	0.022	0.021	0.018	0.018	0.016	0.017	0.016
	2022-23	0.028	0.019	0.024	0.019	0.020	0.019	0.018	0.016	0.016	0.014	0.014	0.014
P6 (84 or 90 lm/W)	2018-19	0.040	0.026	0.033	0.026	0.029	0.026	0.025	0.022	0.022	0.019	0.020	0.019
	2020-21	0.033	0.022	0.028	0.022	0.024	0.022	0.021	0.018	0.018	0.016	0.017	0.016
	2022-23	0.028	0.019	0.024	0.019	0.020	0.019	0.018	0.016	0.016	0.014	0.014	0.014

The differences in PDI values for different years are based on a tiered increase in luminaire efficacy that is expected to be delivered by the LED industry or 17 lm/W every two years between the periods 2018 and 2023. The 2018 bases refer to core or comprehensive values.

A simplified calculation of the PDI reference values has been made where PDI = 1 / (luminaire efficacy x Maintenance Factor x Utilance)

For all PDI reference values a maintenance factor of 0.85 is assumed. The utilance values vary as a function of road width and criterion ambition level as follows:

Core level: width ≤5m (U=0.35); width 5-6m (U=0.42); width 6-7m (U=0.49); width 7-8m (U=0.56); width 8-9m (U=0.63); width ≥9m (U=0.70)

Comp. level: width ≤5m (U=0.50); width 5-6m (U=0.50); width 6-7m (U=0.50); width 7-8m (U=0.60); width 8-9m (U=0.70); width ≥9m (U=0.70)

Table 17. Translation of PDI reference values in Table 16 into indicative AECI values for defined maximum illuminances (4015 operating hours/year)

Road class	Year	AECI Ref values in kWh.m-2.yr-1 (as a function of the road width and ambition level)											
		Core ≤5m	Comp ≤5m	Core 6m	Comp 6m	Core 7m	Comp 7m	Core 8m	Comp 8m	Core 9m	Comp 9m	Core ≥10m	Comp ≥10m
C0 (50lux)	2018-19	*No recommendations made specifically for C0 and C1 class roads. If such high illumination is required, the specifications and design should be adjusted via the use of better optics (higher utilance), better luminaire housing (higher maintenance factor) and increased dimming to ensure that these roads can meet the AECI requirements set below for C2 class roads (20 lux).*											
	2020-21												
	2022-23												
C1 (30 lux)	2018-19												
	2020-21												
	2022-23												
C2 (20 lux)	2018-19	2.268	1.057	1.890	1.057	1.620	1.057	1.418	0.881	1.260	0.755	1.134	0.755
	2020-21	1.985	0.935	1.654	0.935	1.418	0.935	1.240	0.779	1.103	0.668	0.992	0.668
	2022-23	1.764	0.833	1.470	0.833	1.260	0.833	1.103	0.694	0.980	0.595	0.882	0.595
C3 / P1 (15 lux)	2018-19	1.874	0.859	1.562	0.859	1.339	0.859	1.172	0.716	1.041	0.613	0.937	0.613
	2020-21	1.619	0.752	1.350	0.752	1.157	0.752	1.012	0.627	0.900	0.537	0.810	0.537
	2022-23	1.426	0.669	1.188	0.669	1.018	0.669	0.891	0.558	0.792	0.478	0.713	0.478
C4 / P2 (10 lux)	2018-19	1.250	0.573	1.041	0.573	0.893	0.573	0.781	0.477	0.694	0.409	0.625	0.409
	2020-21	1.080	0.502	0.900	0.502	0.771	0.502	0.675	0.418	0.600	0.358	0.540	0.358
	2022-23	0.950	0.446	0.792	0.446	0.679	0.446	0.594	0.372	0.528	0.319	0.475	0.319
C5 / P3 (7.5 lux)	2018-19	0.937	0.429	0.781	0.429	0.669	0.429	0.586	0.358	0.521	0.307	0.469	0.307
	2020-21	0.810	0.376	0.675	0.376	0.578	0.376	0.506	0.313	0.450	0.269	0.405	0.269
	2022-23	0.713	0.335	0.594	0.335	0.509	0.335	0.446	0.279	0.396	0.239	0.356	0.239
P4 (5 lux)	2018-19	0.675	0.312	0.562	0.312	0.482	0.312	0.422	0.260	0.375	0.223	0.337	0.223
	2020-21	0.577	0.270	0.481	0.270	0.412	0.270	0.360	0.225	0.320	0.193	0.288	0.193
	2022-23	0.504	0.239	0.420	0.239	0.360	0.239	0.315	0.199	0.280	0.170	0.252	0.170
P5 (3 lux)	2018-19	0.482	0.229	0.402	0.229	0.344	0.229	0.301	0.191	0.268	0.164	0.241	0.164
	2020-21	0.401	0.193	0.334	0.193	0.286	0.193	0.251	0.161	0.223	0.138	0.200	0.138
	2022-23	0.343	0.166	0.286	0.166	0.245	0.166	0.214	0.139	0.191	0.119	0.172	0.119
P6 (2 lux)	2018-19	0.321	0.153	0.268	0.153	0.230	0.153	0.201	0.127	0.179	0.109	0.161	0.109
	2020-21	0.267	0.128	0.223	0.128	0.191	0.128	0.167	0.107	0.148	0.092	0.134	0.092
	2022-23	0.229	0.111	0.191	0.111	0.163	0.111	0.143	0.092	0.127	0.079	0.114	0.079

**For core level, no dimming assumed (i.e. F_D = 1.00), for comprehensive level, dimming to 50% for 6 of 11 daily operational hours assumed (i.e. F_D = 0.73).*

13. Technical Annex III. Examples of PDI specs in IT and BE

Italian approach to PDI requirements

One stakeholder provided details about the approach to PDI in Italy, where the term "IPEI" (defined as the Parameterized Energy Index for Lighting Systems) has been designed to give a broad evaluation of lighting installation energy efficiency in a comparable manner. IPEI is related to the ratio between PDI (or Dp) and a fixed reference value (PDI_{ref} or Dp,r) that is defined for each road lighting class as per the definitions in EN 13201 (i.e. M-class, C-class and P-class roads).

Table 18. IPEI (reference PDI values) for different Italian road classes

Road class	PDI (IPEI) (W/lux.m^2)		
	Road lighting	Area lighting, roundabout, parking lot	Pedestrian area, bike lane
M1	0.035		
M2	0.037		
M3	0.040		
M4	0.042		
M5	0.043		
M6	0.044		
C0		0.03	0.039
C1		0.032	0.042
C2		0.034	0.044
C3 (P1)		0.037	0.048
C4 (P2)		0.039	0.051
C5 (P3)		0.041	0.053
P4		0.043	0.056
P5		0.045	0.059
P6		0.047	0.061
P7		0.049	0.064

The reference PDI_{ref} is less demanding for classes with lower luminance/illuminance requirements - which is justified since these will use lower wattage lamps that may have lower inherent luminaire efficacies. Denominated road types are: '*road lighting (M classes)*', '*area lighting, roundabout, parking (C&P classes)*' and '*pedestrian or bike lane' (P classes)*'. Depending on the IPEI ratio energy efficiency labels are given to lighting installations (G to A5+). The IPEI labels serves as a benchmark in public tenders in Italy.

Belgian approach to PDI requirements

One stakeholder made reference to a Belgian standard (Synergrid C4/11-2, 2016 version) that defines the minimum energy efficiency requirements (PDI and AECI) for M class roads and that these requirements have indeed been linked to road width as shown in the table below.

Table 19. Maximum PDI values permitted for Belgian M-class and C-class roads

Road width	Lighting class (M2-M5 and C2-C4) Maximum PDI values permitted (in W/lx.m^2))						
	M2	M3	M4	M5	C2	C3	C4
4m	0.035	0.05	0.05	0.05	0.06	0.065	0.07
5m	0.035	0.045	0.045	0.045	0.05	0.055	0.06
6m	0.035	0.04	0.04	0.04	0.04	0.045	0.05
7m	0.03	0.035	0.035	0.035	0.03	0.035	0.04
8m	0.025	0.03			0.03	0.035	0.04
9m	0.02	0.03			0.03	0.035	0.04
10m	0.02	0.03			0.03	0.035	0.04
11m	0.02	0.03					

The data in Table 19 reveal that as the road width decreases, the maximum permitted PDI value increases. This is consistent with the general idea that it is more difficult to efficiently light narrower roads due to light spilling over the target area (i.e. the "utilance" factor decreases).

The PDI requirements also become more relaxed as the lighting level required decreases (i.e. moving from M2 to M5 or C2 to C4) because these will require lower wattage lamps that may result in inherent lower luminaire efficacies. While this reasoning holds true for HID type lamps, it is not really the case for LED-based lamps, whose efficacies are much less dependent on operating power.

The Belgian requirement is very pragmatic but is only applicable in regions where there is a common approach to classifying the required lighting levels for roads. Since this is not common across the EU, it is not recommended to refer to road classes at all in the criteria but instead to the average maintained luminance or illuminance level specified by the procurer.

14. Technical Annex IV. Examples of LCC

Life cycle costing is a hugely relevant topic for road lighting. The dominant life cycle cost for traditional HID technologies has always been electricity consumption during the use phase. LED technologies are more efficient but also more expensive to buy - although the cost has rapidly decreased during the last 5 years. Consequently, it is necessary for public authorities to be able to make objective assessments of what is the best decision for them from an economic perspective. This matter is especially sensitive since the conversion of a road lighting installation from HPS to LED typically requires a high capital outlay which exceeds the annual budget of the public authority for road lighting. Consequently, the demonstration of lower life cycle costs may actually be a pre-requisite for obtaining financing for converting to a LED installation.

There are a number of life cycle cost comparisons that have been carried out in US cities and towns, where LED uptake began. Some examples are briefly described below:

- The City of Portland invested $18.5 million in the replacement of 45,000 HPS light points with LED that had 50% lower energy consumption – leading to savings of $1.5 million per year in reduced energy and maintenance costs – a payback period of 8 years when accounting for discount rates (Portland, 2015).
- The City of Los Angeles invested $57 million in the replacement of 140,000 HPS light points with LED that had 3% lower energy consumption (Los Angeles, 2013). The energy savings were initially expected to be around 40% but advances in LED technology prior to the implementation of the project resulted in greater savings. The study also noted rapidly falling unit costs (e.g. between March and September 2012, the cost fell from $495 to $309). Annual savings of $2.5 million in maintenance costs alone are expected due to the lower failure rate of LED (0.2% for LED versus 10% for HPS). Together with $7.5 million savings in electricity costs, the total annual savings of $10 million should result in a payback period of 5-6 years. Caution was urged in this study when procuring LED solutions when it was found that on 84 of 244 LED units met the quality specifications set out by the Bureau of Street Lighting website (BSL, 2018).
- Charlotte County considered the costs in 2016 of changing their 2145 light points from HPS to LED lighting. Their existing maintenance costs were assumed to be between $28 and $55 per light point, depending on the type. The power cost of an HPS light was around $12/month and a LED light assumed to be $6/month (50% reduction). Current energy and maintenance costs (for HPS) are $310,000 and $80,000 respectively. The costs they quoted for different types of luminaire were as follows: cobra head (HPS $345, LED $780) and decorative head (HPS $1200, LED $1800). It was assumed that an HPS lamp would be replaced every 5 years, the LED power module ($150) would be replaced every 5 years and the LED optical module ($750) would need to be replaced every 20 years. They concluded that costs for HPS and LED were similar over a 20 year period but that continued decreases in LED costs would soon make it the more economical option.
- In Minnesota (City of Chanhassen) in 2012, simple payback periods of 8-12 years were estimated for converting from HID to LED lighting (Swanson and Carlson, 2012). Lifetimes of 6 years (21000h) and 22 years (78000 hours) were estimated for HID and LED lamps respectively (based on 3550 hours operation per year). The authors found that the pricing for LED luminaire purchase varied significantly depending on the efficacy required, the size of the order and the length of the

supply chain. For batches of 500 luminaires, the prices ranged from $250 to $1325 per LED luminaire. A new HPS lamp was estimated to cost $11 and a new pole, $800. To install a new HPS lamp or a new LED luminaire was estimated to cost $110 and the installation of a new pole, $1500. A 60% saving in energy consumption was assumed for LED and total service costs of LED over 22 years estimated to be $220. Different discount rates of 2%, 4% and 8% were applied, an electricity rate of $0.046/kWh assumed and three different leasing rates were considered. In almost all cases, the LED option was cheaper than the HID option from an LCC perspective. The higher the discount rate, the less attractive the LED option.

- In Phoenix, the conversion of almost 95000 HPS light points to LED was considered in 2013 (Silsby, 2013). Over a period of 10 years, they considered HPS and LED with the following characteristics: energy cost per light per year (HPS $72.36, LED $32.88); fixture cost (HPS $250, LED $475); fixture installation (HPS $29, LED $29); lamp life (HPS 20000h, LED 50000h). In conclusion, the found that LED was around 20% cheaper over a period of 10 years which, applied to the City of Phoenix, equated to around $5 million per year once the whole system is converted. For a $1 million investment in LED, a 9 year simple payback period was calculated.

Using the LCC calculator from the Swedish National Agency for Public Procurement, a number of scenarios are calculated to demonstrate the influence of different variables on LCC of any particular design solution. The tool requires the following input parameters from the procurer and the supplier:

Table 20. Input parameters required for calculating LCC with the Swedish tool (note that 1 SEK is roughly equal to 0.1 EUR)

Procurer	Supplier	
Usage time (years)	Investment costs	Number of luminaires and price per luminaire (SEK/luminaire).
Discount rate (%)		Material and labour cost per luminaire installation (SEK/luminaire).
Electricity price (SEK/kWh)		Number of poles and foundations and price per pole and foundation
Annual electricity price change (%/year)		Material and labour cost per pole installation and foundation (SEK/pole or foundation).
Operating time (hours per year)		Cost of any external control devices and start up
Operating hours at full power, at level 1 (dimming) and level 2 (more dimming), all in hours/year	Operating costs	Power consumption at full power, at power level 1 and at power level 2 (in Watts)
	Maintenance costs	Light source replacement capital cost (SEK/piece)
		Light source replacement labour cost (SEK/piece)
		Light source replacement intervals (hours)
		Electrical ballast / control driver replacement capital cost (SEK/piece)
		Electrical ballast / control driver replacement labour cost (SEK/piece)
		Electrical ballast /control driver replacement interval (hours)
		Luminaire lifespan (years)
		Pole lifespan (years)
Note that the maintenance costs in the right hand column may be able to be defined by the procurer if they also manage the lighting installation and have competent and qualified staff.		Inspection cost (SEK/piece)
		Inspection interval (year)
		Surveillance cost (SEK/piece)
		Surveillance interval (year)

It is recommended that any LCC study cover a period of at least 20 years, possibly longer. Given the very low economic growth and inflation during the last 10 years in Europe, it is recommended to use a low discount rate of 1-2%. With regards to possible increases in electricity prices during the period of the LCC, Eurostat data was consulted as shown below.

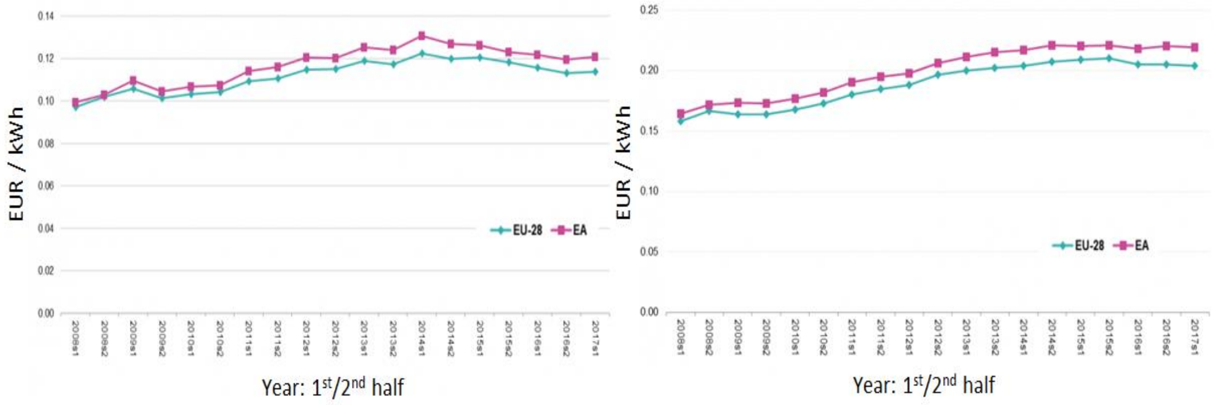


Figure 36. Electricity price increases for non-household customers (left) and household customers (right). Source: Eurostat.

The data in Figure 36 reveal that the average annual increase in electricity during the period 2008-2017 was 2% for non-household rates and 2.5% for household rates. It should be noted that non-household rates were considered as those customers consumption 500-2000 MWh/year. For the purposes of road lighting, the non-household rate of 0.12 EUR/kWh shall be used together with a presumed 2% annual increase in electricity price.

Another aspect to consider is whether the luminaires should be cleaned periodically or not. With traditional HID light sources, cleaning is typically carried out every 5 years, at the same time as lamps needed to be replaced. However, with LED lamps it may be that replacement only needs to occur every 10, 15 or 20 years. This raises the question of whether or not cleaning, as a standalone maintenance operation, should be carried out. For the purposes of these LCC calculations, it is assumed that needs for cleaning are greatly reduced by the use of 0.0% upward light output luminaires and so cleaning interventions are not considered.

Example scenario 1: New installation (HPS versus LED over 30 years).

The following example assumes a new installation and compares the LCC of using light sources that are either: HPS, cheaper LED (LED-1) or more expensive LED (LED-2). A total of seven different options were included: 1 for HPS (no dimming), 3 for lower quality LED (3 dimming scenarios) and 3 for higher quality LED (3 dimming scenarios). When considering dimming scenarios, 1 level dimming was when 50% of the time, light output was dimmed to 50% and 2 level dimming was when 25% of the time, light output was dimmed to 50% and 25% of the time, light output was dimmed to 10%. An electricity cost of €0.12/kWh was assumed as well as an annual increase in electricity cost of 2% and a discount rate of 1%. The installation operates for 4000 h/yr. The other main input cost elements were as described below.

Table 21. Input costs and assumptions for the 7 different scenarios new installation costing over a 30 year period

	Option 1 HPS no dimming	Option 2 LED-1 no dimming	Option 3 LED-1 1 level dimming	Option 4 LED-1 2 level dimming	Option 5 LED- 2 no dimming	Option 6 LED-2 1 level dimming	Option 7 LED-2 2 level dimming
No. luminaires	500 units	500 units	500 units	500 units	500 units	500 units	500 units
Price per luminaire*	€280	€500	€500	€500	€800	€800	€800
Labour cost per luminaire	€89	€89	€89	€89	€89	€89	€89
No. poles and foundations	500 units	500 units	500 units	500 units	500 units	500 units	500 units
Price per pole and foundation	€3240	€3240	€3240	€3240	€3240	€3240	€3240
Labour cost per pole and foundation	€1215	€1215	€1215	€1215	€1215	€1215	€1215
Cost of external control device/system	€0	€0	€0	€0	€0	€0	€0
Luminaire power consumption (50% of time)	150 W	100 W	100 W	100 W	80 W	80 W	80 W
Reduced power level 1 (25% of time)	150 W	100 W	50 W	50 W	80 W	40 W	40 W
Reduced power level 2 (25% of time)	150 W	100 W	50 W	10 W	80 W	40 W	8 W
Light source replacement price	€9	€200	€200	€200	€300	€300	€300
Light source replacement labour cost	€89	€89	€89	€89	€89	€89	€89
Light source replacement interval	20000 h	50000 h	50000 h	50000 h	100000 h	100000 h	100000 h
Ballast/driver replacement price	€160	€160	€160	€160	€160	€160	€160
Ballast/driver replacement labour cost	€89	€89	€89	€89	€89	€89	€89
Ballast/driver replacement interval	80000 h	50000 h	50000 h	50000 h	100000 h	100000 h	100000 h
Luminaire lifespan	30 yrs	30 yrs	30 yrs	30 yrs	30 yrs	30 yrs	30 yrs
Pole lifespan	30 yrs	30 yrs	30 yrs	30 yrs	30 yrs	30 yrs	30 yrs

**includes light source and ballast/control drivers*

The output of the LCC is illustrated below in Figure 37.

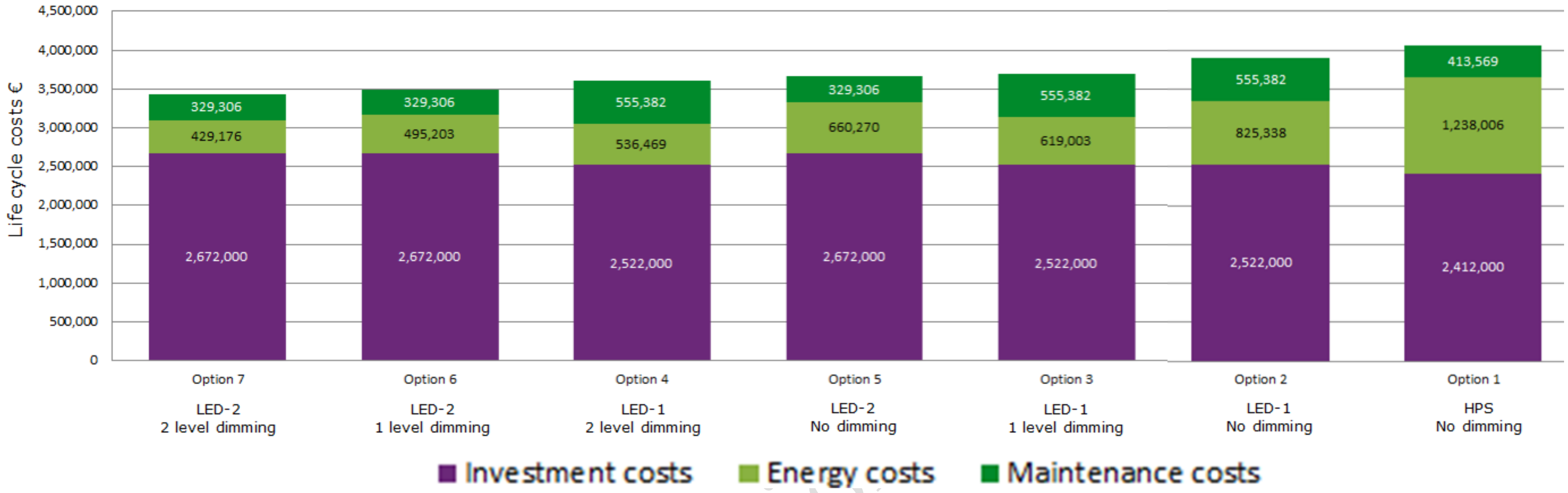


Figure 37. Graphical presentation of LCC results for the 7 options described in Table 21.

The data presented in Figure 37 show some very interesting conclusions. Due to the fact that the installation is new, investment costs dominate the overall LCC for all options. Even though investment costs are slightly cheaper for the HPS luminaires and that significant maintenance cost reductions were possible due to the low cost of HPS light sources, this was not sufficient to compensate for the need to change these light sources more frequently and the fact that LED-1 and LED-2 offer power consumption reductions of 33% and 47%.

Comparing HPS, LED-1 and LED-2 for the no dimming scenarios (i.e. options 1, 2 and 5), the following conclusions can be drawn:

- The investment costs increased by €110,000 going from HPS → LED-1 and by a further €150,000 going from LED-1 → LED-2.
- The energy costs decreased by €410,000 going from HPS → LED-1 and by a further €165,000 going from LED-1 → LED-2.
- The maintenance costs increased by €140,000 going from HPS → LED-1 but then decreased by €225,000 going from LED-1 → LED-2. In this case, the longer lifetime (100,000h) of the LED-2 light source more than compensated for its higher replacement cost compared to the other light sources.

The effect of dimming (i.e. comparing options 2, 3 and 4 or comparing options 5, 6 and 7) had clear and directly proportional benefits on the fraction of LCC relating to energy costs. Dimming by 50% for 50% of the time (i.e. curfew) reduced energy costs by 25%. Going further (i.e. dimming to 50% for 25% of the time and to 10% for 25% of the time) resulted in energy cost reductions of 35%. It is extremely important to highlight that equally significant savings can also be achieved simply by procuring more energy efficient luminaires in the first place in order to achieve a given light level or even more simple, by considering if a lower light level would be acceptable in the first place even during peak hours.

Example scenario 2: Existing installation (HPS replacement versus LED retrofit over a period of 10, 20 or 30years).

A much more common scenario in Europe will be where an existing lighting installation needs to be refurbished. The public authority will basically have two choices: (i) simply replace the HPS lamps with new HPS lamps or (ii) retrofit the existing poles with LED luminaires. The main issues with the second option are that it has a significantly higher capital outlay and that not all LED luminaires are equal. Consequently, the aim of this analysis is explore the effect of different types of LED luminaire (that get progressively more expensive, but more durable and more energy efficient at the same time) and also the effect of the choice of life cycle period. The input data used is given below (again the electricity cost was €0.12/kWh, the electricity annual price increase was 2% and the discount rate was 1%).

Table 22. Input costs and assumptions for the 5 different scenarios for an existing installation over a 10, 20 or 30 year period

	Current facility	Retrofit LED-1 no dimming	Retrofit LED-1 With dimming	Retrofit LED-2 With dimming	Retrofit LED-3 With dimming
No. luminaires	500 units	500 units	500 units	500 units	500 units
Price per luminaire	€9**	€500	€500	€750	€1000
Labour cost per luminaire	€89	€89	€89	€89	€89
No. poles and foundations	500 units	500 units	500 units	500 units	500 units
Price per pole and foundation	€0	€0	€0	€0	€0
Labour cost per pole and foundation	€0	€0	€0	€0	€0
Cost of external control device/system	€0	€0	€0	€0	€0
Luminaire power consumption (50% of time)	150 W	100 W	100 W	80 W	65 W
Reduced power level 1 (25% of time)	150 W	100 W	50 W	40 W	32.5 W
Reduced power level 2 (25% of time)	150 W	100 W	50 W	40 W	32.5 W
Light source replacement price	€9	€200	€200	€350	€500
Light source replacement labour cost	€89	€89	€89	€89	€89
Light source replacement interval	20000 h	50000 h	50000 h	100000 h	100000 h
Ballast/driver replacement price	€160	€160	€160	€200	€250
Ballast/driver replacement labour cost	€89	€89	€89	€89	€89
Ballast/driver replacement interval	80000 h	50000 h	50000 h	100000 h	100000 h
Luminaire lifespan	30 yrs	30 yrs	30 yrs	30 yrs	30 yrs
Pole lifespan	30 yrs	30 yrs	30 yrs	30 yrs	30 yrs

**includes light source and ballast/control drivers*

***to account for 1st replacement of HPS lamp instead of retrofitting*

****dimming was assumed to be to 50% of normal lighting during 50% of the operational hours (i.e. curfew)*

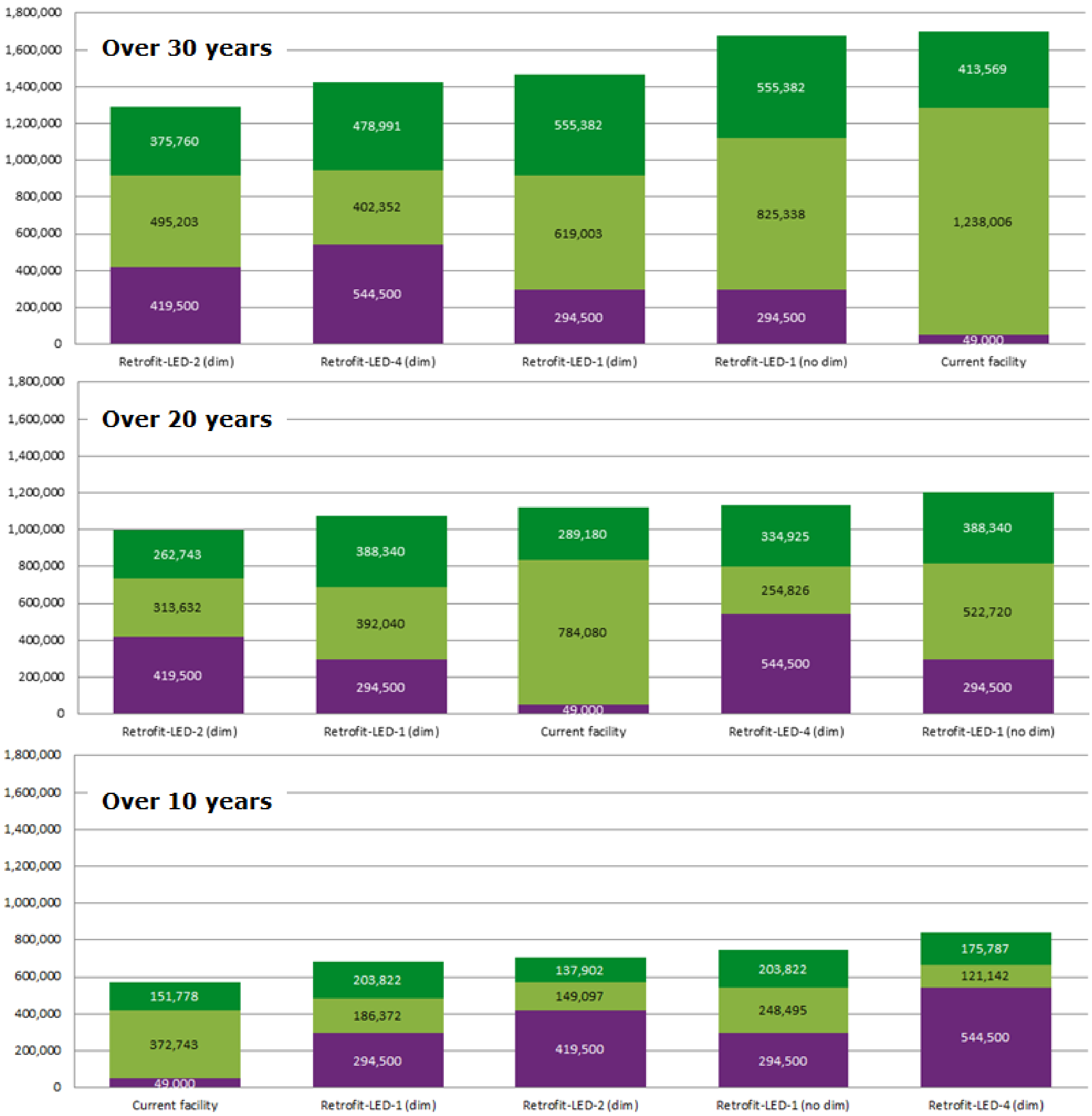


Figure 38. Comparison of LCC for different retrofitting options and periods

The data presented in Figure 38 are particularly interesting because they highlight the importance of the period that the LCC covers on the final result. When assessing costs over 10 years only, simple replacement of HPS lamps was the most economical option despite the fact that energy costs were double or triple those or some other options. There is a real possibility that public authorities will choose to wait until the LED road lighting market matures (and costs decrease even further) before deciding on massive refurbishment programmes. Another major influence on such decisions will be whether or not government subsidies or other financial incentives are available for LED-retrofitting.

When looking at the LCC over 30 years, simple relamping was the least economical option although it must be added that the key benefits for LED-retrofitting was the ability to dim light output.

When looking over a period of 20 year, simple relamping was the 3rd most economical option, only being beaten by the cheaper LED options where dimming was carried out.

15. References

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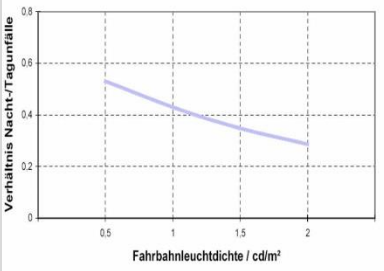
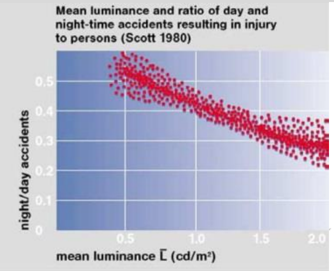
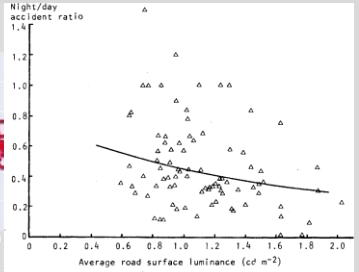
16. Table of Comments: Stakeholder feedback following 2nd AHWG meeting

Topic	Comment	JRC Response
EN 13201 and light levels	The implementation of the recommendations of CEN/TR 13201 increases the emission artificial light at night significantly and therefore also increases the environmental damage in regard to human health, biodiversity and the environmental performance of nocturnal land- and cityscapes. For this reason GPP for Street Lighting and Traffic Signals explicitly does not support the implementation of EN13201 at all. Delete the paragraph "The European standard EN 13201-2:2016 contains performance requirements for different classes (M1….M6, C1….C5, P1….P6), they will have a positive impact on light pollution because they set requirements on uniformity and glare reduction. Herein, class M1 requires much higher light levels compared to class M6, see figure 1: EN 13201-2 road classes and their required light levels"	The wording has been modified in such a way as to reflect your concerns but without negating the fact that the EN 13201 standards do provide guidelines on these technical parameters.
EN 13201 and light levels	The following standards are relevant to reduce the negative environmental effect of Street Lighting and Traffic Signals: DIN ISO 26000 Guidance on social resonsibility (avoiding light pollution) Standards of Low Impact Lighting of the Light Pollution Expert Coalition within European Environmental Bureau (https://www.licht-und-natur.eu/lpec-in-eeb/standards-of-low-impact-lighting/) Propose to replace EN 13201 with these standards in the "Relevant Standards" section.	Section 3.2 "Relevant Standards" is a summary of another report that has already been published, so we cannot simply remove reference to EN 13201. In any case, it is still a relevant standard, especially for referring to the concepts of PDI and AECI. We have introduced some description of the LIL standard in section 8.
EN 13201 and light levels	For its strong adverse effects on nocturnal environment, ANPCEN opposes the citation of the EN13201 standard in any public procurement (Press release: Paris, June 30th, 2016 https://www.anpcen.fr/docs/20160630205641_kn7ixi_doc190.pdf : attached file "20160630205641_kn7ixi_doc190.pdf"). The citation of the EN13201 is not pertaining for, fortunately for the nocturnal environment, it is not applied in major countries of the Union. The non-application of the EN13201 standard can be seen through the wide disparities of illuminance in the streets of comparable European towns. The attached file (European-towns.pdf) is a record of the max illuminance in streets of European towns, performed for the French NGO ANPCEN. It is seen that a high percentage of streets in Vienna (Austria), and in German towns, do not meet the EN13201 requirements. Moreover, these data do not render the illuminance high non-uniformity observed in German towns; again a breach in the EN13201 illuminance uniformity requirements. Requiring the application of the EN13201 standard in Germany would lead to a considerable increase in light pollution and power consumption.	We understand the concerns shared by many stakeholders relating to EN 13201. However, this does not change the fact that it was mentioned in the Preliminary Report and the reference to it here in the Technical Report is in the chapter that summarises the main points of the Preliminary Report. In any case, although not mandatory, EN 13201 does introduce the concepts of PDI and AECI which are used in our criteria. The lighting levels is another matter – which is up to the procurer to decide. The JRC will produce some draft guidance about lighting levels in a separate document.
EN 13201 and light levels	The paragraph (about ALARA) should continue as: Particularly, they should be aware that even the full moon illuminates at the 0.1 lx level mostly (1/4 lx being the possible maximum for horizontal illuminance by the Moon when it is high in the sky), and that this is often regarded as enough light by pedestrians and cyclists. The levels recommended by EN 13201 shown in the table above are orders of magnitude higher, and this EN provides no scientific arguments for that. Moreover, the light level produced by full moon in bedrooms is regarded as disturbing the sleep already by a significant fraction of the population, so artificial lighting should illuminate windows of flats less than that, including light reflected from the lit ground, after curfew at least.	We have added the level of moonlight from a full moon to the table EN 13201 in section 3.2 in order to give some context to the illumination levels.
EN 13201 and light levels	I don't quite understand what ALARA means in practice, but my experience from talking with communities is that many are fearful of lighting below the EN 13201 specification, and end up installing way more light than is necessary. Many Bavarian communities have recently increased in total light output (as measured by satellite) by factors of 3-4, which will greatly worsten light pollution, and may not even end up having	Noted. These are all reasonable points but ones which are better addressed in the guidance document rather than the actual

	much of a reduction in energy consumption. Is it possible to provide a very clear statement that in many countries (including Germany) there is no legal requirement to light according to the norm? If the GPP results in communities installing far more lighting than they need, then (in my opinion) it has failed in its goal.	criteria.
EN 13201 and light levels	From my perspective, there is a problem with linking the GPP so closely to EN 13201, which as far as I understand is based on a community of practice rather than actual modern accident analysis (i.e. in the last few years). For example, it doesn't seem to make any sense to specify P1 require 15 lux, when **Narendran et al. (2015)** have established that there is effectively no difference from a user perspective when increasing from an average of 7 to 15 lux. Similarly, **Fotios et al. (2017)** found that there is no difference for drivers in going from 1-2 Cd/m^2, so why do M1 and M2 require such high values? Furthermore Fotios et al. found barely any difference at all between 0.1 and 1 Cd/m^2, so perhaps the entire range of values all the way from M1-M6 is an order of magnitude or more too bright? While EN 13201 is officially a "Norm", it is by no means "normal" in Europe. German communities, for example, are lit far below the norms, yet do not have appreciably different traffic safety from countries such as Italy where the norms are more normally applied. If EN 13201 is specifying lighting levels that are way higher than reasonably necessary (which seems to be the case), then having the GPP document implicitly endorse it is effectively greenwashing. Cities will think they are being environmentally friendly, when in fact they are wasting a massive amount of energy for light that has no actual impact on traffic safety. Narendran: Energy and user acceptability benefits of improved illuminance uniformity in parking lot illumination Fotios: The transition between lit and unlit sections of road and detection of driving hazards after dark	We accept that there is no conclusive cause-effect relationship between lighting levels and road safety. With EN 13201, all we can do is try to put the EU GPP criteria into some sort of context. Some Member States closely follow the standard, and consequently end up with very high light levels on many roads. The EU GPP criteria are now linked to AECI criteria and we are promoting the reward of tenderers who get AECI as low as possible (within the procurer specifications). In our guidance document we will continue to promote ALARA without dictating what light levels should be specified.
	This comment is part of an excessively long comment The levels suggested by AEN 13201 are too high and not based on science: see the fake graphs of figure 1 and 2 that are 'based' on the original data seen in figure 3. Note also that even the data in figure 3 don't show a lowering trand of accident night/day ratio with raising luminance. Moreover, where are the data of the no-lighted roads?    Figure 1. from: M. Eckert, H.-H. Meseberg: Straßenbeleuchtung und Sicherheit (street illumination and security), ISBN 3-927787-16-7 (http://www.litg.de/publik/mitte.html Figure 2. From: Heft 3 " Licht.Wissen Straßen, Wegen, Plätzen", ISBN 3-926 193-03-4, http://www.licht.de/fileadmin/shop-downloads/h03.pdf engl. version: No. 03 "Licht.Wissen Roads, Paths and Squares", ISBN 3-926 193-16-6, http://www.licht.de/fileadmin/shop-downloads/h03_engl.pdf Figure 3. From: Hargraves and Scott (1979): Measurements of Road Lighting and Accidents – The Results, Public Lighting Dec. 1979, 213-212	Thank you for providing us with this information. As explained several times before, it is not the aim of EU GPP criteria to dictate light levels to procurers, that is their decision. However, what we can do is explain clearly in an accompanying guidance document what the effect of choosing different lighting levels has on operating costs and light pollution. We hope that you can offer your input into the guidance document. One criticism of Figure 3 would be that the data is very old and cars are completely different now in terms of safety and handling.
EN 13201 and light levels	*This comment is part of an excessively long comment* Some cities like Graz, Wien are around 20 kWh/person/year. With a small increase in efficiency and in late night light level reduction or switch	We have investigated further this indicator (see section 7) although it is not suitable for

	off we get 15 kWh/person/year. Milan claims to have obtained 40 kWh/person/year with its change to LED in 2013. Considerable further reductions are possible implementing lower lighting levels (in roads now overlighted) in rush hours and, expecially, after rush hours. Of course to get this values the EN 13201 as is now cannot be used. The main problem in getting to 15 kWh/person/year is due to the fact that in most countries they are using too many light where not needed and too bright light, for no reason guided by real safety issues (see the papers of Paul Marchant on the quality of the works supporting the use of light as a way to reduce accidents and/or crime.	use in GPP in our opinion (ambition level will depend on too many site-specific conditions like population density, proximity of strategic roads and local planning laws.
EN 13201 and light levels	*This comment is part of an excessively long comment* Italy has now a norm UNI 11248/2016 (I worked in the group that wrote the norm) that was aimed to lower as much as possible the lighting levels required by EN 13201. This is obtained by lowering the operational category of the roads due to factors such as low traffic, adaptive lighting, no pedestrian/cyclist, and so on. This allows to lower to minus 4 categories in case of adaptive lighting (minus 3 in case of no adaptive lighting). This means that a M1 can be lighted as low as 0.5 cd/m^2 and a M2 down to 0.3 cd/m^2. The problem is that this lowering is demanded to the engeneer designing the light and most of them will not use this fantastic possibility to lower the impact of light on environment. I have a copy of a masterplan of a small city where these reductions are explicitly not used.	This is very interesting and seems to fit well with our proposed criterion on dimming in section 7.2.3.
EN 13201 and light levels	*This comment is part of an excessively long comment* ISTIL asks JRC to search for sound statistical evidence that lighting increase safety and in a way that in the most cost effective. The eventual advantage due to artificial lighting (during the night) should be weighted with the deaths, injuries and simple incidents due to collisions (during the 24/7) with the tens of millions of lighting poles in Europe. If the re is still an advantage in lighting vs no lighting (o poles), then the cost against other road accidents prevention should be considered (e.g. better signals, more controls by police).	This is well beyond the scope of this project and will not be investigated.
EN 13201 and light levels	*This comment is part of an excessively long comment* ISTIL asks JRC to find out the original scientific research(es) on which are based the suggested lighting levels of EN 13201. Then request the original data to make a new scientific and statistical analysis of the data.	This is well beyond the scope of this project and will not be investigated. The lighting level is for the procurer to decide.
EN 13201 and light levels	*This comment is part of an excessively long comment* PR EN 13201 2013 asks for too high lighting levels (luminance, illuminance, uniformity) compared to levels used in countries such as USA and Germany. A widespread use of the recommended levels will produce an unsustainable cost for municipalities, as is already occurring in Italy. These too high costs drain resources for new installations and so will shift money from the lighting industry to the energy industry. Moreover, the lighting levels, being all the rest unchanged, are directly proportional to the negative effects of artificial light at night (ALAN) on the environment and on human health.	We understand your concerns and hope that procurers are actually interested in saving money as well as reducing light pollution.
EN 13201 and light levels	*This comment is part of an excessively long comment* A direct comparison with IESNA classes is not possible, but anyway it is evident that IESNA prescribes far lower lighting levels and uniformities. Let's compare the highest requirements in IESNA (for a typical R2 asphalt): Average Illuminance: 17 lux Uniformity U0: 0.33 and EN 13201: Average Illuminance: 50 lux Uniformity U0: 0.4 Now the lowest in IESNA: Average Illuminance: 3 lux Uniformity U0: 0.17 and in EN 13201: Average Illuminance: 7.5 lux Uniformity U0: 0.4 The EN 13201 illuminance requirements are 2.5 to 2.9 times higher. The EN 13201 uniformity requirements are 1.2 to 2.4 times higher.	Point accepted but as mentioned on multiple occasions already, it is for the procurer to decide on the light levels that they want.
EN 13201 and light levels	*This comment is part of an excessively long comment* Using the suggested parameters to select lighting classes it is very difficult to arrive to M5 and M6 classes that, on the contrary, should be the vast majority of all the roads. This mirrors in an unjustified increase of recommended lighting levels. **ISTIL asks for a whole rethinking of the suggested lighting levels, as also explained in point 1, in order to make M5 and M6 the workhorse of**	We can in principle agree to this up to a point and even recommend this in guidance however it will not change the fact that it is up to the procurer to decide what lighting

	the lighting classes.	level they want.
General - guidance	The actual purchase of road lighting equipment plus installation or maintenance services are only one important step where environmental considerations need to be taken into account. That is why the EEB recommends to the JRC to complement its GPP criteria proposal with some more guidance and clarity on additional considerations needed e.g. regarding adequate lighting levels, dimming, lifetime and upgradability of the installations, performance-based contracting before launching a call for tender based on the GPP criteria proposal.	Noted. We have released a very initial draft guidance document for feedback.
General - guidance	We recommend that the proposal could be further improved or complemented regarding the following points of concerns: Provide additional guidance on how to lower lighting levels when switching from existing more yellow light sources towards warm white road lighting with LEDs; Provide additional guidance on how to maximise the benefits from dimming as the most adequate means to both mitigate energy consumption and light pollution; Provide additional guidance how to best ensure longer lifetime and upgradability of road lighting installations; Provide examples of how to include these aspects in the least Life-Cycle-Cost calculations; Provide additional guidance on how to support new business models around performance-based contracting to help small municipalities who may not have a lot of technical depth and/ or financial means for renovating their roadway lighting systems to allow for gradual improvements and optimsation over time; and Provide more clarity on potential applications and implications of amber and low power LEDs or outlines conditions where you might still opt for non-LED solutions.	Noted. We have released a very initial draft guidance document for feedback.
General - guidance	We recommend that the JRC provides more clarity on potential applications and implications of amber or low power LEDs and conditions where you might still opt for non-LED solutions.	Noted. We have released a very initial draft guidance document for feedback.
General - guidance	We also recommend that the JRC provides additional guidance on lower lighting levels needed when switching from more yellow light sources towards warm white LEDs. The EEB would also like to highlight the need for support of new business models around performance-based contracting to help small municipalities who may not have a lot of technical depth and/ or financial means for renovating their roadway lighting systems to allow for gradual improvements and optimisation over time.	Noted. We have released a very initial draft guidance document for feedback. We are especially reliant on stakeholders to share experience with alternative business models.
General - guidance	The JRC should develop additional guidance on how to maximise the benefits from dimming as the most adequate means to mitigate energy consumption and light pollution. The JRC should provide examples of how to include these aspects in the least Life-Cycle-Cost (LCC) calculations.	Noted. We have released a very initial draft guidance document for feedback.
General	The purpose of Green Public Procurement for Street Lighting and Traffic Signs is to avoid or at least to minimize the adverse health effects, the harmful impact on biodiversity and the negative influence of artificial light at night on security. Furthermore it enables public entities to reduce energy consumption and to unburden public budged in regard to lighting at night. **Proposal for modification:** The should be a clear statement what GPP is intended to achieve. Text of comment should be added to the report.	We agree in principal to introducing such a statement, which could appear in the abstract of this report and perhaps elsewhere too.
General	The most recent comprehensive studies on the influence of CCT (and lighting levels, including curfews) in traffic collisions and crime show no correlation with these factors. See. e.g. Steinbach R, Perkins C, Tompson L, et al., The effect of reduced street lighting on road casualties and crime in England and Wales: controlled interrupted time series analysis, J Epidemiol Community Health doi:10.1136/jech-2015-206012	We can accept that the link between road lighting and crime or traffic accidents is extremely difficult to demonstrate. At no point does the JRC recommend lighting for these reasons, that is the procurers decision.
General	*This comment is part of an excessively long comment*	We actually felt that the ambitious and

	The current draft would not only allow the existing business-as-usual to go on, but it would mark increase of light amounts from today levels to much higher ones as "Green". Its scope, limited almost completely to electricity consumption, could hardly help anybody, as an effort to save electricity is nothing alien to public authorities, because it results in saving money. In contrast, improvements in protecting people and nature from harmful light are not easy to evaluate financially, and GPP criteria, if aimed at light, could be very useful. But the "1st draft" goes no way in that direction. It has to be either abandoned, or, very much rewritten with help of the best experts in light pollution mitigation. To achieve that, I endorse the 12 minimum requirements given below [copy paste from the Low Impact Lighting standard]. Most target the light itself, but 3 aim directly at electricity and infrastructure costs, rooting from the well experienced best practice in Italian provinces and Slovenia.	future-proofed ambition levels for luminaire efficacy, the promotion of dimming and metering and the requirement for 0% RULO were all significant deviations from business as usual (in a way that is good for the environment). The Low Impact Lighting standard has been briefly discussed now in the section 8.
General	Product related definitions should be in-line with the EN standards and these standards should also be listed on page 13 where the application standards are mentioned (EN 12665).	We shall update any product related definitions according to the latest standards when this project finishes.
General	In the market analysis only the LED package price trends are included. This price represents only ~ 10- 15% of the cost of a street lighting luminaire. Showing LED package price only can be misleading and can create unfounded expectations as cities buy LED luminaires, not LED packages.	This has been clarified now.
General	this is just a typo, it should be '100 lm/W for >10000 lumen output'	Corrected.
General	Light planning software, like Dialux, is usually not distributed under an Open Source license agreement, although in many cases they can be downloaded and used free of charge. The term 'open source' should be replaced by 'common light planning'.	Correction made.
General - labelling	Previous to any metering, core and comprehensive criteria of the GPP should require some label be sticked on the pole of luminaires (sticker, QR code, engraving,…), indicating light flux and electrical power, and possibly any other informative specifications of the luminaire: ULR, CCT, CIE flux codes. All the more with the advent of the LED technology for which all combinations of technical specifications are made available. We must deplore that public lighting does not exhibit this key information, as it is available for any other devices (home appliances,…) That way, the public information on the energy efficacy of public lighting will be made available. Without this declarative sticker, the luminaire should not be ecolabeled.	We can in principle agree to this (see the new section 9.7) but it will depend on how the industry stakeholders respond and what can realistically be asked for. We understand that you are asking for the following information: power rating; luminous flux; ULR, CIE code #3 and CCT. We also ask that you do not use the term "ecolabelled" because this might cause confusion with another of the Commission's sustainable product policies (and which is not applicable to road lighting).
General – Preliminary Report	This data based on the "Revision of the EU Green Public Procurement Criteria for Street Lighting and Traffic Signals, Preliminary report: Final version. june 2017" is wrong. At least the Spain data 84% higher, so minimun energy comsumption will be 37,5 TWh. Regarding the file: Revision of the EU Green Public Procurement Criteria for Street Lighting and Traffic Signals, Preliminary report: Final version. june 2017: Page 42. section 3.3.2 Road lighting luminaires per capita and stock growth. Table 12. The estimation for Spain is clearly wrong, check[1]. Should be saying at least ~8.800.000 street lights. Other numbers look suspicious. ¿Finland has duplicated their stock? ¿The Netherlands has increased by 50%?. Those numbers look that there is something potentially wrong or problems on the source of the statistics. From [2] can be estimated homogeneously the energy consumption of the EU countries using satellite images. With that data is possible to constrain better the possible real number of light points. [1] Sánchez de Vera Quintero(2017) http://www.idae.es/file/11167/download?token=qK_9OxAg (Official source) [2] Sánchez de Miguel, A. (2015). Variación espacial, temporal y espectral de la contaminación lumínica y sus fuentes: Metodología y resultados. (Peer reviewed)	Thank you for pointing this out. However the Preliminary Report has now been published and cannot be modified.

	[3] de Miguel, A. S., Zamorano, J., Castaño, J. G., & Pascual, S. (2014). Evolution of the energy consumed by street lighting in Spain estimated with DMSP-OLS data. Journal of Quantitative Spectroscopy and Radiative Transfer, 139, 109-117. (Peer reviewed)	
General – Preliminary Report	Preliminary Report. Page 26: Section 2.4.1.5. "...and do not pollute the night sky."That claim is wrong, all the introduction of artificial light into the light produce light pollution, because of the reflection on the ground. So, that claim should be corrected to something like "minimize the pollution to the sky" or "do not pollute directly the night sky(but does it indirectly)". Please, if this a quote, I would like to know the source to be fixed.	Thank you for pointing this out. However the Preliminary Report has now been published and cannot be modified.
General – Preliminary Report	Page 38: Section 3.2.2. Electricity prices "...For road lighting and traffic lighting it can assumed that the industrial electricity rates are the most representative. ..." That assumption has been proven to be wrong at least for Spain. http://ec.europa.eu/eurostat/statistics-explained/index.php/File:Disaggregated_electricity_price_data_for_industrial_consumers,_second_half_2016_YB17.png According to Eurostat, the price of the electricity in Spain is 0.108 €/kwh, but the Townhall of Madrid has estimate it on 0.18 €/kwh (2015), the city of Valencia was paying 0,16 €/kwh on 2014 and from the data of the Ministry of Public administration data can be interpretated that the cost is of all the country is 955 M€ that for a Energy consumption of 5,2 to 5,4 TWh mean a minimum rate of 0,17 €/kwh and the IDAE estimate it on 0,15 €/kwh.[1] So, by several independent sources all indicate my higher rate for street lighting than for industrial use. Unless there is more info, I recommend use the industrial rate as lowest possible rate, the household rate as maximum rate, as average as most probable. Page 42. section 3.3.2 Road lighting luminaires per capita and stock growth. Table 12. The estimation for Spain is clearly wrong, check[1]. Should be saying at least ~8.800.000 street lights. Other numbers look suspicious. ¿Finland has duplicated their stock? ¿The netherland has increased by 50%?. Those numbers look that there is something potentially wrong or problems on the source of the statistics. From [2] can be estimated homogeneously the energy consumption of the EU countries using satellite images. With that data is possible to constrain better the possible real number of light points. Page. 48 "Electricity cost of 0.08 €/kwh". Not reliable data, data before of the economic crises. Page 50 Section 3.3.10. Total EU electricity cost of road lighting. As explained, these data are not reliable. Because at least the energy consumption of Spain is 84% higher than on Van Tichelen et al. 2007 said by [1][2] and [3]. For other countries Van Tichelen et al. 2007 can be more reliable, but still not enough data. I suggest you to use as most probable value of 6300 ± 613 M€ and 38.12 ± 1.82 TWh energy consumption for the EU28[2]. **Proposal for modification:** Add information from A. Sanchez de Miguel (2015), summarizes the potential uncertainty on the cost from 3800 M€ to 6300 M€. Mention that more detailed studies are needed it due, the errors found on[1] regarding Spain data, that is the only detailed country studied. [1] Van Tichelen, P., Geerken, T., Jansen, B., Vanden Bosch, M., Van Hoof, V., Vanhooydonck, L., & Vercalsteren, A. (2007). Final report lot 9: Public street lighting. Study for the European Commission DGTREN unit D, 3, 2007. **Rationale / supporting data:** Big assumptions have been made in the previous work without the more basic literature search about the quality of the work of their original base document. Oficial and research peer review paper shows how for Spain, neither electricity rate, energy consumption, and street light numbers are correct. https://scholar.google.es/scholar?cites=13057469436296731069&as_sdt=2005&sciodt=0,5&hl=es	Thank you for pointing this out. However the Preliminary Report has now been published and cannot be modified.
Tenderer	*Would you support a proposal to insert a list of relevant professional bodies and qualifications from different Member States (and help provide*	Noted.

requirements	*examples of such from your own Member States)?* Yes as membership of professional bodies implies that an engineer also does continuing professional development as this tends to be a condition and can be checked up upon. However other experience and qualifications should not be ruled out, for example the UK Lighting Industry Association runs a Lighting Certificate course	
Tenderer requirements	*What are the main lighting design software programs used for road lighting? Should they need to be validated against CIE 171? What is the scale of potential variation caused by using different software for the same designs?* Dialux, Relux, Lighting Reality. For road lighting CIE 171 is not so useful as it concentrates on interior conditions and daylight. This means it does not consider luminance calculations using road surface reflectance tables, threshold increment, etc. which are more road lighting specific. Therefore validating against CIE 171 would have limited use for street lighting.	Noted, but what is the alternative to CIE 171 for road lighting then?
Light pollution – CCT	*This comment is part of an excessively long and unstructured comment* I have 6 years of records from my observatory near the Malvern Hills. Milky Way is at 30% contrast. Increasing light levels by 50% over Europe would reduce contrast to zero. Then No Milky Way visible even in rural areas. Note the CCT colour change to 4500K to 6000K rather than 3000K is mostly responsible, despite better optical control. I have extensively models different types of luminaire with different effective CCT colour temperatures, particularly that for LEDs, Changing from 3000° K through 4500° K to 6000° K equivalent. Using blue rich LEDs will have the potential causing considerably enhance sky brightness through the high blue content. Lower CCT LEDS are now approaching the efficacy levels of high CCT LEDS, so energy efficiency is no longer a reason to adopt them. The overall effect form atmospheric scattering based sky light pollution using the higher CCT is 2 to 3 times for the same visual brightness luminaire.	Thank you for sharing the images and please be aware that we are continuing to promote "3000K" luminaires in section 8.2.5 but that we also have introduced a new way of quantifying the problematic blue light (C-Index)..
Light pollution – CCT	There is a satisfactory correlation between CCT and blue spectral content of light: plotting the data of Table 1 of the attached file “Street Lighting and Blue Light FAQs.pdf” gives the attached plot “Street Lighting and Blue Light FAQs.xls”. The CCT information should be made available through some sticker on the pole of luminaires (as any home appliance displaying its technical specifications). All the more with LED devices for which all combinations of power, light flux, CCT,… are made possible. This declarative information must be part of the TS8 core and comprehensive criteria. If it appears that this sticker delivers wrong information, it would then be some justice concern	While we accept some correlation between CCT and blue light content, we think it is a far from perfect one. Instead, we have proposed that CCT is complimented by (or replaced) by an indicator that focuses on blue light (see section 8.2.4).
Light pollution – CCT	Suggest "non white or very low...", to make it clear that amber LED and PC-amber LED are explicitly excluded.	A CCT of <2300K has now been explicitly mentioned.
Light pollution – CCT	As far as I understand, no one considers CCT to be "perfect", and in fact, it is very frequently criticized. I am pretty sure that lamps with identical CCT can appear to have different colors to humans.	The term "perfect" has been replaced by "reasonable".
Light pollution – CCT	*This comment is part of an excessively long comment* Blue-Light Content Correlated Colour Temperature (CCT) of all luminaires must be equal or lower than 2200 K AND must emit under 500 nm energy flux lower than 6% of the total emitted in the entire visible range. In case of an average illumination level below 5 lx it is allowed to use luminaires with CCT from 2200 K up to 2700 K AND energy flux must be lower than 10% of the total emitted in the entire visible range under 500 nm.	There is nothing stopping procurers from asking for 2200K but please be aware that this greatly restricts the LED products on offer. In the Lighting Facts database, of 13 of almost 8000 luminaires were <2200K and 26 were <2700K. Despite this, we are continuing to promote 2700K at the comprehensive level and 3000K for the core level (there were 793 models <3000K). We also have a new way of looking at blue light (C-Index). Please see section 8.2.4.

<table>
<tr>
<td>Light pollution – CCT</td>
<td>A criterion on the spectral content of light is too complex, and could not be verified.
CCT is an available data in manufacturers' catalogs and software databases, and is ready to comply to a criterion.
CCT is a widely used quantity (particularly concerning display devices: screens, monitors, camera sensors,…). At this stage, there is no reason that the GPP be based on another quantity.</td>
<td>Many stakeholders are not happy with CCT when the logic for it is due to concerns with blue light. We have introduced what is a simple requirement in principle (simpler than CCT) and which uses the same raw data needed to calculate CCT but which quantifies blue light – it is called the C-Index, please see section 8.2.4. for more details..</td>
</tr>
<tr>
<td>Light pollution – CCT</td>
<td> These data confirmed that the trends we had observed in our previous comments are con-tinuing - namely a progression of 8.6 lm/W per year.
 The new data analysis also illustrate that the efficacy improvement trends are consistent across different CCT values: the change in efficacy is only about 3 lm/W per 1000K of CCT. Un-fortunately, the share of models available between 2000 to <3000 K is still very small and rep-resent only 3% of all models included in the dataset.
<table>
<tr><th>CCT (K)</th><th>Model Count (n=)</th><th>Model Count (%)</th><th>Average Efficacy (lm/W)</th></tr>
<tr><td>2000 to <3000</td><td>257</td><td>3%</td><td>106.7</td></tr>
<tr><td>3000 to <4000</td><td>2168</td><td>28%</td><td>101.7</td></tr>
<tr><td>4000 to <5000</td><td>2668</td><td>35%</td><td>104.7</td></tr>
<tr><td>5000 to <6000</td><td>2586</td><td>33%</td><td>107.1</td></tr>
<tr><td>>=6000</td><td>48</td><td>1%</td><td>89.0</td></tr>
<tr><td>Total</td><td>7727</td><td>100%</td><td>104.4</td></tr>
</table>
</td>
<td>The average data seem to confirm that there is no significant negative effect of lowering CCT on energy efficiency at all. In fact, it seems to be that the highest CCT lamps suffer from poorer luminaire efficacy.
However, we do also note the (relatively) small numbers of products on the market in the 2000-3000K and the>6000K ranges.</td>
</tr>
<tr>
<td>Light pollution – CCT</td>
<td>Well, I take note that you do not want to step back from CCT criteria.
I am still quite skeptcial about supposed blue light pollution (please, see my paper about it) and I would suggest to leave core criterion blank and to use CCT limits only as comprehensive criterion.
For spectrum limits, I would not be so sure that a limitation on LED source spectrum could really affect light pollution (please, see figure below). There are so many unknown vartiables that could affect final emission that I would suggest not to use it at all.
[DRAWINGS NOT INCLUDED HERE]</td>
<td>We accept your point and it really emphasises just how important it is to avoid overlighting in the first place and to maximise any dimming potential that is allowed. However, due to the major feedback from other stakeholders, we have tried to propose a new way of specifying a limit on blue light (the C-Index, see section 8.2.4).</td>
</tr>
<tr>
<td>Light pollution - glare</td>
<td>*This comment is part of an excessively long and unstructured comment*
The limitation of glare is not sufficient.
It is now obvious that, especially for the new installations using LED fixtures, a glare problem needs to be solved. One of these is true: (1) the TI index is not enough or (2) most of the new LEDs installations disseminated in Europe does not fulfil the 10 or 15% TI requirement.
ISTIL asks to lower the recommended TI for all road classes
Glare and lighting classes
Vision not impaired by glare require lower lighting levels to perform well. For this reason using G6 fixtures should allow to change the required lighting levels (for example by changing the road class).</td>
<td>We would welcome other stakeholder opinions on the matter of glare as well. Perhaps it is complimentary with the Flux code 3 requirements as well?</td>
</tr>
</table>

	By the way, calling full cut-off the G4 and G5 fixtures is not correct. **ISTIL asks that the use of G6 fixtures must allow the lowering of luminance-illuminance- uniformity parameters as a two steps change in lighting classes (M1 to M3, M2 to M4 and so on).**	
Light pollution – skyglow	*This comment is part of an excessively long and unstructured comment* Blue light is less reflected by asphalts. This is a main argument NOT to use blue light in road lighting, because blue light produces less luminance (due to the lower reflections by the road surface), but nonetheless it produces direct glare in the driver/pedestrian (the more so in the elders). Spectral reflectance of asphalts and concrete data are in: Falchi F, Cinzano P., Elvidge C.D., Keith D.M., Haim A., 2011, Limiting the impact of light pollution on human health, environment and stellar visibility, J. of Environmental Management, 92 (2011) 2714-2722, doi:10.1016/j.jenvman.2011.06.029 Details on the spectral issues, including the different light pollution generated by different lamps and LEDs of various CCT are in: Aubé M, Roby J, Kocifaj M (2013) Evaluating Potential Spectral Impacts of Various Artificial Lights on Melatonin Suppression, Photosynthesis, and Star Visibility. PLoS ONE 8(7): e67798. doi:10.1371/journal.pone.0067798	We need some clarity on this point for the sake of our guidance because there are conflicting views from different stakeholders.
Light pollution – skyglow	Blue light increases skyglow by a considerable factor. Upward directed light, however, is the very worst contributor to skyglow, followed by overlighting. The experience in practice is that replacing ~5% uplight HPS with 0% uplight white LED and some amount of dimming results in little noticable change in skyglow. BUT: if PC amber were used instead of white LED, then the the replacement would cut light pollution by another factor (maybe about 3, I'd have to look it up).	Please do look it up. If there are any clear general rules out there it would be helpful. But site specific factors will no doubt be important too – such as light level, surface reflectivity etc.
Light pollution – skyglow	Yes, 0% ULOR is the best option due to it reduce the light pollution to the minimum.Also, reduce the maintenance cost.	Noted. We do continue to promote 0.0% ULOR.
Light pollution – skyglow	On Fig 12 of Aubé can be seen the effect of the ULOR. How a CObra head(7%) can be ~8 times more pollutant than an Helios(1%) regarding the obstacles. Deu to the physics of the surface tension of the water, any surface that is not perpendicular to gravity vector and does not have convex regions will produce that the water will transport dust and residuals to the lower part of the luminaire. Therefore, 0 %ULOR, guarantee that no light is emitted into the upper hemisphere, that only can be accomplished with the use of convex surfaces or flat glass luminaires.	Thank you for providing this explanation, which could potentially have an impact on the choice of maintenance factor as well for the PDI (and thus AECI) calculation.
Light pollution – skyglow	When looking at the light pollution of the Po Valley from space, and if it is an aim of the GPP to preserve the European nocturnal environment, it appears obvious that the GPP should promote lower figures than the ones derived from the Italian practices (see http://www.blue-marble.de/nightlights/2012).	Thank you for providing this background information.
Light pollution – skyglow	*This comment is part of an excessively long and unstructured comment* Zero tilt is essential but ground reflection is VERY significant... As shown in modelling. Cut off below C=70deg. very important, as is spectral content.. see below. I have been working on this for very many years. DO NOT IGNORE. Adopting your policy will be a disaster for Milky Way visibility. Remedy... lower 70 deg. gamma angle and very sharp cut-off, as is now done by Highways England, BUT also only using CCT 3000K or below.	Noted. However, we are not sure if it will be practical to implement 70 deg. cut-off luminaires as this would either have a detrimental effect on uniformity or require more light points in many cases.
Light pollution – skyglow	*This comment is part of an excessively long and unstructured comment* Even one degree from the horizontal is no longer acceptable by Highways England, and so should be the same across Europe. I am aware that luminaires have to be offset from the road, but they could be designed to be asymmetric throw and still have full cut-off. For every 1° tilt of a luminaire between 30° below the horizontal and 30° above, the luminance to the sky doubles. It was for this reason, that Highways England in 2012, adopted a biased weighting system based on luminance versus gamma angle, against higher angles, which are summed through gamma angles to produce an overall score, used for passing or failing a design. This was based on my modelling work.	We have not had discussions at any meetings about how such an approach could be implemented in EU GPP criteria. We welcome any concise suggestions to adapting the criteria during the written consultation period.

Light pollution - skyglow	*This comment is part of an excessively long and unstructured comment* Direct light the sky is subject to Rayleigh scattering. The sky is blue overhead because the air molecules size are matched are similar in wavelength . Blue light scatters 16 times more than red at twice the wavelength, varying as the reciprocal 4th power of wavelength. It is dominantly forwards and backwards and the rest sideways. Scattering by water droplets and dust (Mie scattering) is mostly in the lower atmosphere and is very directional; nearly all forwards and a little backwards and not wavelength dependent. All light near horizontal scatters for up to 100Km if unobstructed. The overall effect form atmospheric scattering based sky light pollution using the higher CCT is 2 to 3 times for the same visual brightness luminaire	Thank you for the background information.
Light pollution - skyglow	*This comment is part of an excessively long and unstructured comment* Tarmac roads have less than 8% reflectivity, but grass verges have much more, which is spectrally colour dependent, and concrete even more (not colour dependent). Most of the ground reflection, in suburban and rural areas, away from the road is off green verges and vegetation. Grass and other vegetation, due to photosynthesis occurring in the red, is green yellow and does not reflect blue. Providing the luminaire points down on dark roads and green verges, with nothing anywhere near horizontal, as can be achieved with LEDs, then blue content is part filtered out by the reflection and so less gets to the sky.	Thank you for the background information.
Light pollution - skyglow	According to the present degree of knowledge about the ecological (and potential health) effects of artificial light at night, and taking into account the key fact that visual performance can be perfectly assured using light sources of CCT smaller than 3000 K (as a long tradition of using high pressure sodium lamps shows), it seems advisable to apply the CCT<3000 K condition by default, not only in the areas or situations when "cold" lighting would be deemed unnaceptable by the procurer. Consequently, the use of higher CCT sources shall be considered an exception, only applicable in definite particular cases (*).	We can agree to this and now the CCT limits are recommended in all cases and the execptions defined (i.e. low light levels and when good colour rendering deemed necessary).
Light pollution - skyglow	If the procurer requires vertical illumination, the lighting installation should not be eco-labelled If eco-labelling of vertical illumination is desirable, some specific standard has to be issued	We understand that vertical lighting may be needed in urban areas in particular. Just because vertical lighting is required should not mean that all other EU GPP criteria should be ignored.
Light pollution - skyglow	*This comment is part of an excessively long comment* It is highly desirable that the GPP sets criteria on the spatial distribution of light emission, in order to at least, address the aims of three recent French major laws: Loi « Grenelle » n° 2010-788 du 12 juillet 2010 - Chapitre III - Prévention des Nuisances Lumineuses » - Art. L. 583-1 [2]. Décret n° 2011-831 du 12 juillet 2011 relatif à la prévention et à la limitation des nuisances lumineuses - Art. R 583.1 … R 583.4 [1]: (…) « Ces prescriptions peuvent notamment porter sur (…) les grandeurs caractérisant la distribution spatiale de la lumière (…) ». (…) « These requirements may include in particular (...) the quantities characterizing the spatial distribution of light (…) ». Loi de « Transition Energétique » n°2015-992 du 17 août 2015 relative à la transition énergétique pour la croissance verte – Art. 189 [3]: (…) « Les nouvelles installations d'éclairage public sous maîtrise d'ouvrage de l'Etat et de ses établissements publics et des collectivités territoriales font preuve d'exemplarité énergétique et environnementale conformément à l'article L. 583-1 du code de l'environnement (…) ». (…) The new public lighting installations (…) show best energy and environmental performances in accordance with Article L. 583-1 (…) Loi « Biodiversité » n° 2016-1087 du 8 août 2016 pour la reconquête de la biodiversité, de la nature et des paysages – Art. 171 [4]: (…) « garantir la prévention des nuisances lumineuses définie à l'article L. 583-1. » (…) « to secure the prevention of light pollution defined in Article L. 583-1.» [1]https://www.legifrance.gouv.fr/affichTexteArticle.do;jsessionid=1F01B4AA99BC57D8155094A1D2F28B02.tplgfr30s_1?idArticle=JORFARTI000024357941&cidTexte=JORFTEXT000024357936&dateTexte=29990101&categorieLien=id [2] https://www.legifrance.gouv.fr/affichCodeArticle.do?cidTexte=LEGITEXT000006074220&idArticle=LEGIARTI000022479260&dateTexte=&categorieLien=cid	We cannot recommend procurers across the EU to implement certain criteria that are well reflected in the national law of just one Member State.

	[3]https://www.legifrance.gouv.fr/affichTexteArticle.do;jsessionid=6493AA7E26ABFF8AB9F80F2606872FAB.tpdila22v_1?idArticle=LEGIARTI000031048293&cidTexte=LEGITEXT000031047847&dateTexte=20160925 [4]https://www.legifrance.gouv.fr/affichTexteArticle.do;jsessionid=CCA2E6D4223C4DF21E8DBD4226A704AB.tpdila18v_1?idArticle=JORFARTI000033016391&cidTexte=JORFTEXT000033016237&dateTexte=29990101&categorieLien=id	
Light pollution - skyglow	*This comment is part of an excessively long comment* ***Proposal for modification:*** *Core and comprehensive criteria should be distinguished, bringing an additional Technical Specification on the CIE Flux code #3.* *For example, Core criterion : CIE Flux Code #3 > 95%* *Comprehensive criterion : CIE Flux Code #3 > 98%* *The ONG ANPCEN has issued a guide on the "Assessment and Design of the Environmental Performance of Outdoor Public and Private Lighting" (attached file "CDC_ANPCEN.pdf"). In this guide, there is a sample of luminaires (pages 11 to 15) for which are given:* *ULR_alpha=0° :actual ULR of the luminaire on an horizontal support ULR_alpha=15°actual ULR of the luminaire on a 15° tilted support CIE Flux Code #3 (relevant for an horizontal support - figure not given for all luminaires).It must be noticed that number of luminaires offer a high value of the CIE Flux Code #3, that should be inspiring for Technical Specifications*	We have proposed a C3 flux code of >95% as part of the comprehensive requirement for RULO. Let us see what stakeholder feedback is received.
Light pollution - skyglow	Blue light is of course reflected off the road surface. This is why the road appears to be lit with white light! Thus the 0% ULOR does not prevent blue light to be emitted into the nighttime environment.	Noted.
Light pollution - skyglow	In Catalonia, law 6 2001 is of a general nature. Its development is through Decree 190 of the year 2015. In this, specifies the technical characteristics for lighting systems. Its correct denomination is: "Decret 190/2015, del 25 d'agost". Link: http://dogc.gencat.cat/es/pdogc_canals_interns/pdogc_resultats_fitxa/index.html?action=fitxa&documentId=701266&language=ca_ES&newLang=es_ES Number of legal document. DOGC 6944 27-set-2015 In this document, there are ULOR values for diferent Ex protection àrea, with values before and after curfew (please , see annex 2 in attached document). For example, after curfew: E1: 1% ULOR E2: 1% ULOR E3: 5% ULOR E4: 10% ULOR There are also conditions for lamps, where it is specifically mentioned LED lamps, and their limitations in% radiance as function of the protection zone. With the aim of protecting the ecosystem, and the rest in dwellings, it is especially important to take into account the limitations of intrusive light. The same is taken into account in CIE 126. Both in light level in the sensitive area (lux) and in light intensity [cd] to avoid glare. This factor is especially sensitive in LED luminaires, where glare is a factor to be improved in future designs. However: In the case of intrusive light in the most sensitive ecosystems in protected natural areas (E1 zones), the value of 1 lux is known as excessive. And for these "E0" zones it is recommended to reduce to 0 lux of direct intrusive light, as has been quoted in comments from other stakeholders.	Thank you for providing this information. The correct reference has been included together with the Catalonian limits, in section 8.
Light pollution - skyglow	Skyglow researchers (of which I am one) generally write it as a single word, rather than two.	OK, this has been changed throughout.

Light pollution - skyglow	I would recommend to ask photometric labs about 0% RULO, because 0% is a physics nonsense. Also how to measure it and how to correctly asses background noise – as to avoid photometric files to be artifically "cutted" above 90°. I would suggest to limit 0% RULO limit to street lighting classes (M classes); but for other classes an absolute limit valuse (such as maximum lumen, as in Italian GPP or maximum candela).	This concern needs to be discussed in more detail in order to clarify.
Light pollution - skyglow	It's very strange to me "sky glow" in quotes. Skyglow is a scientific term that has been used in hundreds of scientific publications, I don't see any reason to make it appear unusual by putting it in quotes.I also see a problem with "the central argument". Reducing ULOR also results in increased efficiency (not efficacy, but consumption over a year).I would therefore suggest the following:A central argument for having criteria that limit the upward light output ratio is to reduce the artificial brightening of the night sky (skyglow), and also help limit obtrusive light in built-up urban areas. As upward light is of no intrinsic benefit for lighting roadways, eliminating it also decreases overall energy consumption.	Noted. We have made some changes to the wording as per your comment.
Light pollution - skyglow	The right hand panel is not data from VIIRS DNB, it is a map of skyglow from Falchi et al. (2016). We used a radiative transfer model to simulat how the lights observed by VIIRS DNB light the sky throughout Europe.	The correct reference has now been inserted.
Light pollution - skyglow	VIIRS, not VIIR. By the way, it unfortunatley turns out that lighting observed by VIIRS DNB is increasing in most European countries *despite* the blindness to blue light. I have an article in press that I can share with you if you want.	Thanks for this input. Yes, we would be interested to see this article.
Light pollution - skyglow	I am afraid I don't understand this. Does the boom angle imply that the luminaire can be installed at a tilted angle? If that is the case, then requiring 0% uplight doesn't make any sense, as significant light will be emitted upward. I hope I am misunderstanding this, because it makes no sense whatsoever to require lamps to be designed to not emit uplight and then install them in a way that has a massive amount of uplight.	When a luminaire cannot be placed directly over the road it is to light, it can be tilted to face the road. Even when tilted, the aim is to have virtually 0.0% RULO. We will cross-check if there is an acceptable allowance for tilted luminaires.
Light pollution - skyglow	In particular, we welcome the strict requirement for Zero Ratio of Upward Light Output (TS7) in all applications;	Noted
Light pollution - skyglow	*This comment is part of an excessively long comment* ISTIL asks that poles be painted black in order not to waste part the 0% RULO requirement due to the reflections by the poles. ISTIL wonders where the 2 metres tall poles, mentioned in the webinair, are. Can you touch the lamp fixture raising your hand?	Noted – although this would also have environmental, cost and possible safety impacts of its own. Fair point about 2m high poles although 3m seems a lot more reasonable.
Light pollution - skyglow	*Is the potential contribution of blue light to sky glow effectively negated by also requiring 0% RULO? Or is light reflected off the road surface also significant enough?* Reflected light will have an impact but this is also heavily dependent upon the atmospheric conditions and reflectance characteristics of the road surface and surrounding areas. It is therefore adequate to ensure 0% RULO as anything else would be difficult to quantify and measure.	Noted. However, some other comments received are adamant that reflection is a significant issue although we agree that there is no practical way to address that except by lowering light levels overall.
Light pollution - skyglow	*This comment is part of an excessively long comment* The extreme glare due to LED fixtures is somewhat controlled by imposing 0% RULO. In fact, almost always 0% is achieved with flat glass that lower the light transmission at angles of incidence approaching 90°. This is not enough, of course, so ISTIL suggest to control and limit also the light escaping from fixtures at below the horizon plane too, at low angles below the horizon (say, 0-20 degrees below horizon). The alternative is to impose a far lower luminance to the LED fixtures. This may be the more comfortable choice.	This would support the request made by another stakeholder for requirements for flux code 3 >95%. Making that an optional requirement at higher illuminance levels is a good idea.

Light pollution - general	*This comment is part of an excessively long comment* The whole document suffers from a basic misconception, stemming from a completely inadequate understanding of light pollution taken from an old publication “CIE 126:1997” (which is devoted to sky glow only, outdated and fruitless). Light pollution is definitely NOT “a generic term indicating the sum-total of all adverse effects of artificial light”. It is the adding of the light itself (as an act) or the presence of the added light (as an altered state of the environment). See the 4 scientific definitions at https://en.wikipedia.org/wiki/Light_pollution#Definitions and the corresponding 4 references, or the footnote 1 of page http://amper.ped.muni.cz/light/declaration/Declaration.htm#r1 or the paper http://amper.ped.muni.cz/light/declaration/lp_what_is.pdf.	Please note that the other definitions of light pollution which we have included were at the specific request of other stakeholders.
Light pollution - general	All artificial lighting can cause adverse effects on human beings and environment. Compromising the quality and quantity of sleep is the most serious one.	Noted although this is not so well proven for outdoor lighting in studies because in reality it is likely that indoor lighting is much more significant..
Light pollution - general	*This comment is part of an excessively long comment* Pollution is an act of adding a pollutant or a state of the presence of the pollutant. In this case, light is the pollutant. The purpose of GPP is to minimise pollution. The (i) and (ii) approaches are scientifically absurd, and their use was and further is counterproductive. They are outdated and obsolete. How they could be ever formutated? Long ago, hardly anybody had the courage to call light a pollutant. For those in the lighting industry, and even to newcomers to the field of night environment, it is still painful. However, pollution and consequences of pollution are entirely different things. Pollution can be expressed in SI quantities and units, unlike many of its adverse consequences. Just the approach (iii) is to be used further on. A historical remark on the past "non-definitions" (i) and (ii) could be added perhaps.	Please note that the other definitions of light pollution which we have included were at the specific request of other stakeholders.
Light pollution - general	What does "overt" mean? All lamps contribute to skyglow over large (tens of thousands of km^2) territores. Bad lamps near one country's border could easily affect a Dark Sky Park well within another country's boundaries.	This has now been changed. It originally came from another stakeholders suggestion.
Light pollution - general	The EEB appreciates that the JRC proposals also take into account other non-LCA modelled impacts, including sky glow and the wider ecological effects of artificial outdoor lighting during night times. Adding these aspects in the EU GPP criteria will highlight their relevance for the decision making process when municipalities develop their policies (e.g. on adequate lighting levels, limiting blue light content) and plan the future design and layout of the road lighting system that fit their needs for different applications.	Noted.
Light pollution – ecological / health	There is a lack of references and most of the information is out of dated and not per reviewed. Do not consider any effect in plants. The SCHEER source document still preliminary. Cite that CCT is not the right criteria but do not use any of the existing metrics to evaluate. Use claims like "Do not justify criteria on blue light restrictions or CCT in road lighting due to potential human health effects because exposure times are too small compared to indoor exposure." with no justification or data that support that claim. **Proposal for modification:** All the species impacted, also plants should be considered, and also all effects, also Air quality. A new metric like MSI should be used to measure the impact of the street lights. Rewrite to fit on the current research consensus. Remove undocumented claims and in case of lack of information, use the precaution principle. **Rationale / supporting data:** There is no effect cited about pants as the effect on Polinization[5] and other impacts[9], no reviews are cited[6], no LEDs specific ecology papers cited[7] and benefits of HPS[8]. No citation of the effect of the city lights on Air quality[12].This is just a sample of how there is so little information on this document about the ecological impact of the light pollution. If the CCT is a bad metric, other metrics can be used, like the Melatonin Suppression Index(MSI), Stellar Light Index(SLI)[4] u others, like emission above certain wavelength.(i.e. 500 nm). Also, therefore the real impact of an installation should not be considered on candelas or luxes. That value has to be corrected by the hazardous content by multiplying it by the modification of the impact corresponding (MSI, SLI or %blue above 500 nm). There is research that shows how sleeping under light is harmful[10] also, CIE 150[11] recognize how harmful is the light trespass, that is regulated under several laws, like the Energy efficiency Spanish degree. The potential different impact is explained in [4]. [4]Aubé, M., Roby, J., & Kocifaj, M. (2013). Evaluating potential spectral impacts of various artificial lights on melatonin suppression, photosynthesis, and star visibility. PLoS One, 8(7), e67798. (Peer reviewed)	Thank you for providing these references. In order to be concise, only some of the references have been incorporated into the latest draft of the document.

	[5]Knop, E., Zoller, L., Ryser, R., Gerpe, C., Hörler, M., & Fontaine, C. (2017). Artificial light at night as a new threat to pollination. Nature, 548(7666), 206-209. [6]Gaston, K. J., Bennie, J., Davies, T. W., & Hopkins, J. (2013). The ecological impacts of nighttime light pollution: a mechanistic appraisal. Biological reviews, 88(4), 912-927. [6]Inger, R., Bennie, J., Davies, T. W., & Gaston, K. J. (2014). Potential biological and ecological effects of flickering artificial light. PloS one, 9(5), e98631. [7]Pawson, S. M., & Bader, M. F. (2014). LED lighting increases the ecological impact of light pollution irrespective of color temperature. Ecological Applications, 24(7), 1561-1568. ISO 690 [8]Rodríguez, A., Dann, P., & Chiaradia, A. (2017). Reducing light-induced mortality of seabirds: High pressure sodium lights decrease the fatal attraction of shearwaters. Journal for Nature Conservation, 39, 68-72.[9]Bennie, J., Davies, T. W., Cruse, D., & Gaston, K. J. (2016). Ecological effects of artificial light at night on wild plants. Journal of Ecology, 104(3), 611-620.[10]Kang, S. G., Yoon, H. K., Cho, C. H., Kwon, S., Kang, J., Park, Y. M., ... & Lee, H. J. (2016). Decrease in fMRI brain activation during working memory performed after sleeping under 10 lux light. Scientific reports, 6, 36731.[11]CIE 150: Guide on the limitations of the effect of obtrusive light from outdoor lighting installations (2003)[12]Stark, H., Brown, S. S., Wong, K. W., Stutz, J., Elvidge, C. D., Pollack, I. B., ... & Parrish, D. D. (2011). City lights and urban air. Nature Geoscience, 4(11), 730.	
Light pollution – ecological / health	I don't understand what "250µW/lm 10%" is supposed to mean.	This is why we have replaced it with a new indicator (C-Index) which is a standard way of measuring blue light output (see section 8.2.4).
Light pollution – ecological / health	"Biorhythm" is a word often associated to pseudoscientific contents. "Biological rhythms" would be a better choice in the present context. On the other hand, there is a comprehensive body of research showing the negative effects of artificial light at night on a wide variety of biological processes, ranging from gene expression at the molecular level to the disruption of metabolic, reproductive, foraging, displacement and migration processes, affecting individuals, populations and whole ecosystems, not only on the traditionally known as biological rhythms.	Accepted in principle, although the rewording in TR 3.0 meant that the original sentence was no longer needed.
Light pollution – ecological / health	The disruptive effects of artificial light at night are well documented on almost every species studied until now (including marine, and plants), spanning a large number of taxa, so this enumeration seems highly restrictive. A more appropriate text for this paragraph would be perhaps "Ecological impact, in the sense that artificial lighting has been shown to affect a wide range of biological processes including metabolism, foraging, displacement, reproduction, predator-prey dynamics, and migrations, across a large number of taxa"	We have updated the text accordingly.
Light pollution – ecological / health	- "Colour spectrum" > just "spectrum" - "visible (to humans) light level" Light is by definition the electromagnetic radiation able to elicit a visual stimulus in humans. "visible (to humans) light level" is strictly equivalent to "light level". - Please note that for the evaluation of the unwanted effects of light on the environment, the spectral sensitivity of the visual system of many other species has to be taken into account, not only (nor mainly) the human one. - Additionally, no mention is made in this section of the potentially relevant effects of artificial light and night on human health, a factor that should be included in any impact analysis.	We have updated the text accordingly and even included a sub-section about the possible impact of artificial light at night (and blue light) on health..
Light pollution – ecological / health	Please note that this "clear link" may be somewhat blurred if all negative externalities of artificial light at night on the environment are properly taken into account. As a classical example, high CCT LEDs may help to achieve a somewhat higher energy efficiency (by increasing the luminous efficacy of the sources), but at the same time are more disruptive for several species due to the increased blue content. The environmental problems created by street/road lighting are not only due to energy consumption, but also to the disruption of biological processes. Ignoring these hidden costs may lead to an innacurate evaluation of the overall budget.	The analysis of luminaire efficacy data in section 7.1 has shown that there is only a modest energy penalty for lower CCT LEDs (at least going to 2500K anyway). We continue to promote lower CCT but without trying to monetise the ecological impacts.
Light pollution – ecological /	Again, it should be pointed out that this statement is based on a life cycle analysis that excludes the negative externalities associated with the direct effects of artificial light on the environment (and also on intangibe assets as those related to the cultural heritage of humankind, as well	We do not feel that it would be appropriate to try to monetise these types of impacts in

health	as, potentially, on human health). A broader, unified scope, would be advisable for GPP of road lighting systems.	LCC while LCA is not set-up to do this.
Light pollution – ecological / health	In a context of outdoor lighting levels that prevent the possibility of achieving scotopic adaptation this can hardly be deemed a relevant advantage (of blue light).	We simply refer to broader facts based on observations with blue-light rich public lighting.
Light pollution – ecological / health	This recommendation could not be as evident as it seems at first sight. There are at least two relevant factors that should be taken into account: on the one hand, the potential health effects of chronic, long term exposure along the night, to relatively low light levels of outdoor light entering bedrooms, about which some epidemiological and clinical evidence exists (albeit incomplete). On the other hand, the presence in some streets of high-luminance high-CCT LED sources without diffusers (not infrequently used to achieve high vertical illuminances in pedestrian crossings). These sources give rise to high irradiances on localized regions of the retina due to their high luminance and small angular size, and may present non-negligible hazards, especially for those sectors of the population not covered by the EN-62471 norm on photobiological safety (e.g. children below 2 yr or people with age-related macular degeneration, the leading cause of vision loss among people age 50 and older in industrialized countries). Note also that this norm does not address the potential photochemical effects associated with prolonged exposures to light levels smaller than the ones established as thresholds, which are only valid for exposures in the working time. Taking into account that the required visual performace goals can perfectly be achieved using sources of low 'blue' content, the formulation of criteria restricting the 'blue' content / CCT value of the lamps seems a sensible option.	We continue to believe that the potential health effects of indoor lighting are much more significant than outdoor lighting. We have introduced an additional stakeholder discussion section (8.2.3) to explain better our consideration of outdoor lighting on human health.
Light pollution – ecological / health	As with the core criteria, these reasonable conditions (limitations on blue light) should be applied by default, and not only in case of addressing specific local ecological impacts. If these conditions are acceptable for protecting the environment (*), they should also be acceptable for saving energy and reducing the overall density of blue photons at night, which are indeed sensible goals. (*) note that this implicitly acknowledges that they have no significant negative impacts on people safety and wellbeing, e.g. there is no relevant loss of human visual performance.	Please note that we have now proposed a new way of limiting blue light output (C-Index). Please see more details in section 8.2.4.
Light pollution – ecological / health	The TS8 Blue light criterion is highly desirable for it addresses a major environmental and health concern. There are no reported environmental beneficial effects of “cold light” compared to “warm light” (“blue” vs “yellow”). The GPP should include in the core criterion, and thus in the comprehensive criterion, the two following statements: light source <3000K (for, according to manufacturers documentation, the blue light energy efficacy benefit is modest, and blue light environmental adverse effects are numerous) presence of a sticker on the pole indicating power, flux, ULR, CIE code #3, and CCT(this should be an additional transversal criterion throughout the GPP: a declarative environmental performance information about the luminaire, made necessary due to the introduction of the LED technology, for which all combinations of power, flux, CCT,… are made available)	We have continued to promote <3000K CCT (with some exceptions where we believe this is less important). Please also note that we have introduced a new way of quantifying the blue light content (C-Index) – which is explained in more detail in section 8.2.4.
Light pollution – ecological / health	A criterion on the spectral content of light is too complex, and could not be easily verified. CCT is already available (manufacturers catalogues, software databases,...), and is ready to be subjected to a criterion.	CCT is not a guarantee of a lower blue light content so, for this reason we have complimented CCT with a new indicator (the C-Index) see section 8.2.4.
Light pollution – ecological / health	Beside the AMA report on human health blue light harmfulness (reference GPP #31), the health warnings on led light from the institutional French “Agence Nationale de Sécurité Sanitaire de l’Alimentation de l’Environnement et du Travail” (ANSES), should be quoted too: Effets sanitaires des systèmes d’éclairage utilisant des diodes électroluminescentes, ANSES, octobre 2010 (https://www.anses.fr/fr/system/files/AP2008sa0408.pdf, given as attached file). Numbers of testimonials on light pollution incidence on health and environment are given in the 2016 documentary of Claus U. Eckert https://www.youtube.com/watch?v=C8qvPTdC73s	The most recent SCHEER preliminary opinion on human health risks from LED lighting has been used as our main reference point (see section 8.2.3).

Light pollution – ecological / health	It is not to the procurer to state if blue light has adverse effects on the nighttime environment. In fact, blue light has adverse effects anywhere in the nighttime environment. Thus, it is to the GPP to state that light source > 3000K cannot be eco-labelled.	Please do not confuse Ecolabels with GPP, they are two complimentary, but very different sustainable product policy tools.
Light pollution – ecological / health	*Any opinions about the blue light requirement in the comprehensive criterion? Can this be reasonably quantified? Is there much experience with using such a criterion?* Quantifying a limit for blue light would be problematical, even to the point of defining the spectral band considered to be blue light. In reality the effect of street lighting is minimal compared to that of domestic lighting as the levels of illuminance are much lower and the exposure time much reduced compared to light in a domestic environment, including TV and DSE usage. Whilst it is a relatively blunt measure for photobiological impact with many limitations the use of CCT would be a pragmatic approach that could be quantified and verified and for this type of application (as opposed to specifically designed human centric lighting installations) could be justified	Noted. Despite your reservations, we have now promoted the use of an alternative measure (the C-Index) which expresses the quantity of blue light in a spectrum in a relatively simple and reproducible way. It is intended to be used as a compliment to CCT at this stage.
Light pollution – ecological / health	In particular, we welcome the precautionary approach adopted towards ecological light pollution and annoyance (TS8), using CCT values of 2700 and 3000 K as a proxy to improve public acceptance and lower potential impacts on biodiversity (including the option to further limit the blue light content).	Noted. Please also be aware that we have now introduced a proposal to directly limit blue light using what is known as the C-Index (see section 8.2.4 for more details).
Light pollution – ecological / health	*This comment is part of an excessively long comment* In recent years scientific research proved that the blue part of the visible spectrum is the most dangerous for the human health when our body is exposed to light during night time. There is an evident migration toward the use of whiter sources over the last years (MH and, especially, white LED). This increase in the use of sources with substantial blue emissions will mirror in an increase of the damages to human health. Not limiting this in the norm, notwithstanding the new scientific evidences, will make the writers of the new norm responsible for the health consequences of the use of white sources in nigh time lighting. In all the prEN 13201 there is no limitation to the blue part of the spectrum. The use of amber LED or blue deprived LED should be mandatory (at the very least, preferred).	We actually have now proposed a new indicator that relates to blue light (the C-Index). Please see section 8.2.4 for more details.
Light pollution – ecological / health	*This comment is part of an excessively long comment* **ISTIL asks for a strong limitation of the blue part of the spectrum (at least after 20 p.m.).** This is our suggested limit: The wavelength range of the visible light spectrum under 540 nm, corresponding to high sensitivity of the melatonin suppression action spectrum, should be established as a protected range. Lamps that emit an energy flux in the protected range larger than that emitted by the standard High Pressure Sodium lamp on a basis of equal photopic output should not be installed for nighttimes use.	We actually have now proposed a new indicator that relates to blue light (the C-Index). Please see section 8.2.4 for more details. Although we only go to 500nm, not up to 540nm, which is no longer blue light.
Light pollution – ecological / health	*This comment is part of an excessively long comment* ISTIL suggests to ask for photochemical damage risk null for all external lighting. Risk 1 seems to be a good choice, but it is not. In fact, think of a mom with her newborn pupil in a stroll or in a baby carriage. She meets a friend and they stay some minutes under or near a LED light pole. Even if this fixture may be considered ‘safe’ for retinal damage for normal (adult) people that will look away from the glaring light as soon as they feel uncomfortable, the light will not be safe for the baby. In fact, he/she may well look at the bright light for several minutes in a row, with possible permanent damage for the rest of his/her life.	This same principle could apply to the sunlight or to indoor light sources – we are not sure what added value it would provide in reality. How could this be assessed and verified?
Light pollution – ecological / health	*This comment is part of an excessively long comment* ISTIL wants to point out that even if some of the effects of light pollution may be immediately reversed by switching off lights this is false for other consequences such as biodiversity. Once biodiversity is reduced due to light pollution, even switching off all lights will not carry things again to the pre-damage situation. Moreover, due to the consequences in the food network and all species are affected by light pollution, not only nocturnal.	Point accepted. The reference has also been introduced in section 8.2.1.

	Even the pollination is affected by light pollution in a way that disrupt night pollination as well as diurnal, with negative consequences for plant reproductive success (see: http://dx.doi.org/10.1038/nature23288).	
Light pollution – ecological / health	*This comment is part of an excessively long comment* While it is correct that indoor lighting is to be considered more intense in disrupting the circadian rhythms, it is also to be noted that (in our homes) we have complete control of this (e.g. now IKEA sells 2200 K bulbs). The situation is similar to smoke and passive smoking: in public (outdoor) the artificial lighting is imposed, you cannot chose the type nor the timing or the switch off. So, it is duty of public authorities to protect the population from blue light.	But you can choose to close your curtains or blinds or put an eye-mask on when you want to sleep.
Light pollution – ecological / health	Ecological impact is not decided by CCT or quantity of blue light. Therefore, this is of no benefit unless the requirement is that the lighting fulfills the specific ecological rerquirements of the site.	This is not in agreement with a number of other stakeholders.
Lifetime	The suggested LED lifetime of >15 years is not proven. Lifetime significantly depends on temperature and driver current. The resilience of SSL technology in regard to high current potentials due to lighting strokes is poor. The electronic drivers of the LED luminaires are also limited in lifetime and sesitive to temperature and current potentials. The replacement of a broken LED element is much more expensive than the replacement of a HPS/LPS bulb.	Note that HPS/FL lamps today also use electronic control gear and have prover that this life times are possible hence it is not an issue of LED alone.
Lifetime	The LED lifetime of >15 years should probably be revised, according to the most recent evaluations of the industry.	Noted.
Lifetime	At ForumLED last year it was clearly stated by multiple speakers that the manufacturers understand that there is a desire for shorter LED lifetimes, and that in the near future manufacturers will only deliver LEDs will have shorter lifetimes than are currently available. Could the GPP be written in a way that requires an increasing lifetime over the course of the GPP? (E.g. 8 years now, increasing to 9 halfway through the current phase?) Otherwise, where is the incentive to ever develop longer living LEDs?	This is a controversial topic. In theory we could phase in different requirements for lifetime but perhaps it is not such a good idea since LED is still evolving rapidly. Once the technology is mature, then it would be the best time to really push longevity.
Lifetime	*Would an initial lifetime requirement at 6000 hours be preferable to 16000h (i.e. to shorten the time to market for new products)? If so, what would be a suitable LxBy at 6000 hours?* During testing of LED products 6000 hour data is used to project anticipated lifetime. Whsilt testing may continue past 6000 hours, predicted life of 16000 hours is well within acceptable accuaracy for 6000 hour test data and therefore this would have little impact.	Noted, so it is okay to continue with 16000h predictions.
Lifetime	*Should an equivalent minimum maintenance factor (FLLM) also be specified here for HID lamps? If so, what should it be?* This would not be particularly useful as street lighting sales are now almost 100% LED	Noted
Lifetime	*When a claim is made on a warranty, should the claim go to the contractor or to the original manufacturer?* This is a contractual issue and no general rules can be applied	Noted. What is a typical contractual arrangement then? And what are the range of arrangements possible?
Lifetime	IP classification should be application specific as it is related to the environmental conditions and not the road classification.	Is it true that higher IP ratings can also justify higher maintenance factors?
Lifetime	The requested IP rating should depend on the requirements of the environment and not on the road classification or application. Having a higher than required IP rating does not add value or increase sustainability.	Is it true that higher IP ratings can also justify higher maintenance factors?
Lifetime	We ask to have an ingress protection (IP) rating of 65 for all road classes required in TS13. This will help to ensure the lifetime of the luminaire.	This conflicts with other feedback.
Lifetime	Regarding luminous flux, the EEB recommends that the JRC harmonise with the IEA 4E SSL Annex Quality and Performance Tiers published in	We have adjusted the LxBy figures in the

	November 2016 for Street Lighting. Here, the luminous flux maintenance is required to be: At 6,000h, ≥ 95.8% of initial (based on L70 ≥ 50,000h). The test method cited for this measurement should be IES LM-84 and IES TM-28, as this is expected to be adopted widely in 2017 and is the updated standard of the old combination of IES LM-80 and IES TM-21. Please see this link for further information on this criterion.	core criterion to follow to 6000 hour and 50000 hour recommendation suggested and now also recognise the IES test methods as well – although the latest versions still do not yet seem to be available.
Lifetime	We believe that test results must be provided by an accredited laboratory under the International Laboratory Accreditation Cooperation (ILAC) system, but it does not have to be third-party certified. It would be acceptable to be self-reported, as long as the laboratory has accreditation	This has been specifically mentioned now.
Lifetime	The EEB supports the proposed criteria from the JRC on warranty, service agreements and spare parts.	Noted
Lifetime	The EEB firmly agrees that it is important that luminaires are easy to maintain and repair, and not necessarily only with proprietary equipment which can be expensive, but normal tools including those listed in the criteria (TS12).	Noted
Lifetime	The EEB supports the proposed criteria (TS14) on the failure rate of control gear – both the derivation from the preliminary report which identified the higher quality units and then establishing the criteria at a failure rate of <0.2 per 1000 hours for core criteria and <0.1 per 1000 hours for comprehensive criteria.	Noted
Lifetime	LE lifetime metrics should be included (LightingEurope position will be published within a few weeks).	We look forward to discussing these in due course.
Lifetime	GPP should not include a warranty requirement. Additional warranty time and conditions depends on the risk the tender wants to take and therefore may change case by case. A 3 to 5 years warranty is common and in principle it could be extended to 10 years, although currently this is a commercial decision. Manufacturers will have to make provisions for extended warranty periods, which will add to product costs.	Noted. Although the current proposal strikes some balance between a good standard warranty of 5 years with the chance to offer up to an extra 3 years whilst being awarded extra points for that extra cost.
Lifetime	There are currently no industry standard testing procedures available, so the compliance declaration for the control gear failure rates will be based on individual test procedures of the manufacturers.	Understood. Nonetheless, we think this is an important requirement in order to ensure that only reputable suppliers are used.
Mercury	*What would be the impact of an additional criterion excluding Mercury in lamps?* This would enforce refurbishment of some installations that contain HID technologies. Many of these installations are efficient and removing useful product would not be an environmentally friendly approach. Therefore use of efficacy requirements and energy limits such as AECI should be used to push modern technologies in preference to a ban on mercury.	Noted. Although it is understood that EU GPP criteria would only apply to larger contracts where a refurbishment or new installation is required anyway.
Mercury	*What are the additional challenges and costs for disposing of Mercury containing lamps compared to Mercury-free lamps?* Recycling of mercury containing lamps is well-established and the technology is widely used. Therefore recycling costs are reduced as capital costs are lower and have generally already been written off. Non mercury containing technologies have other considerations (use of solder for example) and large-scale recycling is still relatively new due to the smaller quantities of product in the waste chain. Therefore both technologies have pros and cons.	Noted. Although the mercury containing waste streams need special handling conditions and thermal treatment due to the unique properties of Mercury.
Energy consumption	AECI (kWh/m2) < factor × Fdim × E,m (lux) × PDIref (W/lux/m2) × T (h) × 1kW/1000W PDIref should be a parameter set by the GPP according to the used technology (HPS, LPS, LED,…) It is not desirable that the procurer set PDIref, (or the reference luminaire efficacy ηref) For the PDI is a too complex concept, with complex units. And the GPP should aim at simplicity (European norms are regularly blamed for their complexity). For sake of simplicity, the AECI criterion only should be set. Only E,m will be set by the procurer (compliant with EN-13201, or not when not mandatory)	We have set up a series of PDI reference value tables in Technical Annex II and invite stakeholders to comment on them. The ambition levels have been based on the luminaire efficacies used in section 7.1.3.

	Core and comprehensive criteria will depend on the first factor: factor =1.3, factor=1.2,…	
Energy consumption	Paris (France) - Public lighting statistics Some information on public lighting renovation in Paris, from the tenderer EVESA (http://www.evesa.fr/fr/pag-818207-Qui-sommes-nous--.html): 172,000 lighting sources in Paris. The original aim of the contract between the procurer and the tenderer is a -30% power consumption. The -30% power consumption is achieved through a 500,000,000 Euros contract over a 10 years period, and based on the widespread of 4000K LED. (Considering the usual compliance of parisian streets with EN13201, and thus with overlighting (see attached file European-towns.pdf), a -30% power consumption could have been achieved through the replacement of the common 150W HPS lamps with 100W HPS, at the maintenance subscription cost. It should be the aim of the GPP to promote that kind of practice). An interesting fact about the most common LED luminars being deployed in the streets of Paris: they exhibit a modular light source, allowing power increase or decrease if needed in the future, by adding or removing LED chips (attached files One_chip.pdf and Two_chips.pdf).	Thank you for sharing details of this massive lighting contract and other background information.
Energy consumption	France - Public lighting statistics Institutional figures are available at the link: http://www.afe-eclairage.fr/afe/l-eclairage-en-chiffres-26.html To be compared with other countries statistics: public lighting in France is 5.6TWh/year. Considering 65 million inhabitants, it gives 86 kWh/person/year.	Thank you for providing this background information. We have compiled some data about the kWh/pe/yr metric used by the COM (see section 7).
Energy consumption	The Utilance range from 0.7 down to 0.35 is derived from the performance of HID luminaires. This range is too wide, for it is claimed that LED luminaires improve utilance compared to HID luminaires. **Proposal for modification:** The GPP should promote installations with utilance lower bound closer to 0.7. And possibly the utilance upper bound above 0.7.	We would welcome feedback from industry stakeholders about what the most realistic utilance factors are for LED luminaires today.
Energy consumption – luminaire efficacy	*This comment is part of an excessively long comment* Maximum Luminance The luminance of the main roads in cities and towns is not allowed to exceed 0.5 cd/m2. Illumination levels must be below 1 lx Luminaire Efficacy The minimum efficacy of a luminaire at full power needs to be at least: luminaire below 1900K (like amber) 50 lm/W luminaire below 2200K (like PC amber) 95 lm/W luminaire between 2200K and 2700K 100 lm/W A lower luminaire efficacy is allowed when the pole-distance: pole-height ratio exceeds 6:1 or when a mechanical shielding is necessary in order to reduce unwanted illumination of nearby houses or natural environment. Illumination Utilisation Factor At least 70 % of the lumen output must target the road/street/walking area. Lower utilisation factor down to 40 % is allowed in following cases: narrow paved bicycle path narrow paved pedestrian path Protection of People	So a major drop in efficacy is allowed so long as the illumination levels are very low. This trade-off would cancel out nicely in the AECI indicator. Please look at the PDI reference tables for different road classes and see if you think these lower efficacies would still work okay with the PDI tables in Technical Annex II.
Energy consumption - dimming	What about the possibility of REQUIREING controls be included in any lighting under the GPP? This would not only encourage dimming, if a new edition of EN 13201 calls for lower lighting levels this would also make it possible for communities to immediately (and without cost) massively reduce their consumption of energy.	All EU GPP criteria are voluntary, if a procurer chooses to use it as a technical specification, only then does it become mandatory and only for that particular

		invitation to tender.
Energy consumption – luminaire efficacy	I think this concern is very warrented. Consider a community that wants to install lights next to a wetland area with signficant bat activity. Would it make any sense if the GPP required them to buy a white light rather than an amber LED that would have lower ecological impact? A narrow focus on luminous efficacy rather than environmental impact would be a real shame. Once again, subtly encouraging lighting according to EN 13201 in areas that were formerly lite more dimly, while requiring slightly higher luminous efficacy, doesn't seem like much of a win for the environment.	It is a valid point. After a closer look at the luminaire efficacy data, these have been nuanced some more. It was clear that for lower power LEDs (hence lower light level), the efficacy was not as high – so some allowance has now been made for that in section 7.1.3.
Energy consumption - dimming	The capital cost might be larger, but the environmental impact of the light will be smaller with dimming. If this is about green procurement (and not just saving money), doesn't that mean that the reduction in environmental pollution should outweigh the cost?	Procurers should be directed to focus on the biggest potential "win-win" savings and prioritise these over less attractive ones.
Energy consumption – luminaire efficacy	*What are your opinions about the proposed ambition levels and tiered approach (for luminaire efficacy)?* For traffic route lighting where performance optics are used these efficacy levels are not unreasonable. However for amenity areas where the aesthetic and comfort of the product is also very important these levels will tend to be too high. Also consider that colour temperature and special applications requiring higher levels of optical control (in environmentally sensitive areas for example) will reduce efficacy levels. Therefore a single efficacy value is not so useful as it ignores application constraints.	Noted. We welcome your further feedback on the PDI reference value tables and how they can best reflect the range of applications out there.
Energy consumption – luminaire efficacy	*What are your opinions about the proposed ambition levels and tiered approach (for luminaire efficacy)?* I think that levels are way too high for residential ad amenity applications: I would suggest to lover core criteria (comprehensive criteria could be as high as you think they ought to be) and to add some notes about residential and amenity applications.	Noted. We welcome your further feedback on the PDI reference value tables and how they can best reflect the range of applications out there.
Energy consumption – luminaire efficacy	*What are the specific scenarios when lower luminaire efficacy cut-off's could be justified, why and by how much compared to the values in TS1?* For amenity areas where the aesthetic and comfort of the product is also very important and applications using lower colour temperature or special applications requiring higher levels of optical control (in environmentally sensitive areas for example) as these will reduce efficacy levels. For highly aesthetic amenity lanterns this can be to 80-85 lm/W.	Noted. Some of the basic luminaire efficacies that form the basis of PDI ref values are around this level in - 2018 at least.
Energy consumption – luminaire efficacy	*What are the specific scenarios when lower luminaire efficacy cut-off's could be justified, why and by how much compared to the values in TS1?* All scenarios where low glare, high vertical illuminance, smooth lights are needed	
Energy consumption – luminaire efficacy	The Luminaire luminous efficacy levels that the JRC is proposing in the current draft reflect the top 75% of LED models in the market for the core criteria and top 50% of the market for comprehensive criteria. The EEB welcomes these levels of ambition in the proposal and find it appropriate for the products that will be offered on the market during the period when these GPP criteria will be applicable. The EEB is happy to share an updated version of our data analysis including new LED models that became available on the market during the last six months. We uploaded the related Excel spreadsheets plus a PDF file with some further conclusions based on this data in the BATIS Forum for scrutiny by the Commission, their consultants and other stakeholders. These data confirmed that the trends we had observed in our previous comments are continuing The new data analysis also illustrate that the efficacy improvement trends are consistent across different CCT values: the change in efficacy is only about 3 lm/W per 1000K of CCT. Unfortunately, the share of models available between 2000 to <3000 K is still very small and represent only 3% of all models included in the dataset. Looking at 3000K to <4000K, we find the same trend for overall improvement in efficacy over time. We calculate an annual improvement of 8.2 lm/W per year – just 0.4 lm/W slower than the average pace overall between 2012 and 2017. The subset of data covering	It is greatly appreciated that you are willing to share this compiled data with us. A closer look at the data actually revealed that there is a difference in luminaire efficacy ranges depending on lumen output (especially in the range of 0-3000 lumens) and also, to a lesser extent, in the range of 3000-11000 lumens and then >11000 lumens. Using this same database and calculating results as the top 25%, top 50% (i.e. median) and top 75%, it was possible to see how the ambition level could perhaps be nuanced

	3000K to <4000K looks like this: There was a question raised during the webinars about the market availability of low power LED-luminaires for road lighting. Due to the fact that LED road lighting is made up of many small light emitting LEDs, the technology is easily scalable from a luminance point of view, up or down. This can be achieved simply by making larger or smaller LED arrays, by using LEDs with lower flux output (lower drive currents) or of course by dimming the LEDs with intelligent controls. We prepared a plot in the attached PDF file to illustrate the wide availability in the market of the more than 7000 models that we downloaded from the Lighting Facts database in September: And the same graph again, zooming in on the <10,000 lumen light output, which includes over 3000 models in that database. In other words, there is very good availability at the low power range of LED luminaires for road lighting.	based on maximum light output (as well as future tiers based on year of manufacture). We shall share the file with our analysis on BATIS and welcome any comments about this.
Energy consumption – luminaire efficacy	*Do we need a measurement certificate and quality assurance system to avoid overstating performance?* Yes although this could be proof that a measurement laboratory is enrolled with a third-party compliance scheme. Many national standards authorities provide these (OVE in Austria is an example). For quality assurance schemes compliance to internationally recognised standards such as ISO9001 or an industry scheme such as the UK Lighting Industry Association Quality Assurance scheme could be specified.	Noted.
Energy consumption – luminaire efficacy	*Do we need a measurement certificate and quality assurance system to avoid overstating performance?* Yes	Noted
Energy consumption – luminaire efficacy	There was a question raised during the webinars about the market availability of low power LED-luminaires for road lighting. Due to the fact that LED road lighting is made up of many small light emitting LEDs, the technology is easily scalable from a luminance point of view, up or down. This can be achieved simply by making larger or smaller LED arrays, by using LEDs with lower flux output (lower drive currents) or of course by dimming the LEDs with intelligent controls. We prepared the following plot to illustrate the wide availability in the market of the more than 7000 models that we downloaded from the Lighting Facts database in September: [GRAPHS PROVIDED THAT ARE REPRODUCED IN SECTION 7.1.2]	We appreciate this further analysis although we have also looked at the same data and found that there is a real drop in luminaire efficacy when going below 3000 lumens. And also that the range 3000-11000 lumens is slightly lower than >11000 lumens.
Energy consumption - metering	The EEB supports the JRC's criteria proposal on metering.	Noted
Energy consumption - metering	*How significant can the costs of installing metering (either in a junction box for the installation or at the individual luminaire level) be to the overall cost of a particular lighting installation?* For junction box: from 1.000 to 2.000 euros For individual luminaire: from 100 to 200 euros So, if you think about the cost of a street LED luminaire (that range from 300 to 600 euros, individual luminaire installation could be really significant)	Noted
Energy consumption - metering	*Is metering at the luminaire level with remote reporting to centralised systems going to increase in the future?* Only at junction box level	Noted
Energy consumption - dimming	*In which roads classes and scenarios is dimming most/least justifiable?* Dimming is for all road classes justifiable. It is more important to consider the specific application space. A space with problems related to crime or social disorder would be less suitable for dimming compared to a road used less during the early morning. Equally if an area has a large amount of night life (night clubs for example) dimming would not tend to be used whereas urban predominantly residential spaces could safely use dimming. Also, ambient luminance may influence any road lighting operation, so that the dimming function may be required.	Noted.
Energy	*In which roads classes and scenarios is dimming most/least justifiable?*	Noted. An interesting point.

consumption - dimming	Every road – I would suggest also to add a swtich off option	
Energy consumption - dimming	*Would you support award criteria to compensate for more expensive and more sophisticated dimming controls? If so, in what types of road would this be most relevant?* No. The cost of the controls is not relevant, the efficiency of the controls in producing the required lighting levels at a specific time is the relevant criteria. Therefore function as opposed to cost should be used.	Noted. No award criteria for more sophisticated dimming controls has been proposed.
Energy consumption - dimming	*Would you support award criteria to compensate for more expensive and more sophisticated dimming controls? If so, in what types of road would this be most relevant?* No.	Noted
Energy consumption - dimming	*This comment is part of an excessively long comment* The main advantage of Solid State Lighting technology compared to HID lamps is that LEDs are fully dimmable and can be lighted to their full power instantly, when needed. Unfortunately, this new technology is now used as the old HID. An environmentally friend scenario can be this: our cities in later hours at night, when almost none is outdoor, should be lighted to 1/10th or less than the full recommended lighting levels. Only when someone arrives, then the road immediately rises its lighting levels. **ISTIL asks that when using LEDs (or other technologies that allow for this, such as induction lamps) the installations must be equipped with motion-presence sensors that light to its full power only when there are users. Otherwise the roads should be lighted 1/10th or less of the recommended levels during the traffic peak hours.**	We do not agree to motion sensors for road lighting based on some negative experiences with real life trials reported by some stakeholders and also due to the excessive costs that these sensors may entail.
Energy consumption - dimming	The EEB supports the JRC's criteria proposal on dimming control capability and minimum dimming	Noted
Energy consumption - dimming	dimming a street lighting to 10% of its original value cannot be justified by any visual needs, it is not suitable for human vision, it is just signalling light	Surely this depends on what the initial illuminance was? But point accepted for lower initial light levels.
Energy consumption - dimming	*What are the main different options for dimming control and how do they differ in cost and ease and flexibility of programming/reprogramming?* There are many different options for dimming control available. Main criteria for investing in dimming control should be the lowest calculated TCO (total cost of ownership) over a certain period of time.	Noted.
Energy consumption - dimming	*What are the main different options for dimming control and how do they differ in cost and ease and flexibility of programming/reprogramming?* Only few manufacturers are proposing CLO + digital dimming Comments: I would add that 1-10V dimming should be depreciable, and I would encourage digital dimming (such as DALI). At pag. 43, in core criteria, I would change 50% to XX%, because it could not always be possible to dim to that level (for security reasons)	Noted. Just to clarify that we ask for a dimming capability to at least 50% but do not actually tell procurers to use it.
Energy consumption – AECI verification	*What are the main limitations of in-situ measurements of illumination, what degree of accuracy is possible from the instrumentation available and what is the general scale of potential interference from background light or obstacles?* Generally accuracy of measurements will be a tolerance of 10%. A significant problem however is that calculations assume a level road surface, vertical columns and horizontal lanterns. Frequently this is not the case introducing additional variables. Levelling the measurement plane is possible although it introduces additional complexity and therefore increases measurement time. In addition when measuring an	Noted.

	existing installation which has been in place for a period of time extraneous considerations such as vegetation and street furniture and signage need careful consideration. In urban spaces it is practically impossible to remove light from shops, car parks, etc. which impinge on the measurements and whilst generally raising lighting levels also reduce uniformity.	
Energy consumption – AECI verification	*What are the main limitations of in-situ measurements of illumination, what degree of accuracy is possible from the instrumentation available and what is the general scale of potential interference from background light or obstacles?* European standard EN 13201-4 defines methodologies and expected accuracies for these types of measurements. The only problem will be in the measurement of energy use where on the timescale of one week will mean that specific operating conditions within that one week will cause differences with any calculated results, which are the average of all the conditions for one year.	Noted
Energy consumption – AECI verification	*Are there any issues with mobile monitoring of illuminance or luminance using vehicle based instrumentation? Can we ask for measurements 10cm above the road level in order to be more practical?* This is possible, papers demonstrating this principle have been produced and examples have been used in practice. For luminance measurements the results are variable as they depend upon the road surface condition, both in terms of flatness and road surface finish. It is not possible to raise luminance measurements up by 10cm as they measure the light reflected by the road surface. For illuminance unless a self-levelling photometer head is used the same problem of road surface unevenness can cause issues. However a large consideration is capital cost for a vehicle and system that is not used regularly. Technical details are already outlined in EN 13201-4. A practical consideration will be cost of measurement, either in purchase of suitable equipment or periodic rental.	Noted. We also would welcome any input about the actual costs associated with this assessment and verification.
Energy consumption - various	In particular, we welcome the following improvements: The introduction of a tiered approach for Luminaire luminous efficacy (TS1, AC1, CPC2), reflecting the fast-moving development of LED road lighting technology; The enhanced focus on dimming control capability and Minimum dimming performance (TS2, TS3, CPC3) to allow for further reduction of energy consumption and light pollution;	Noted. However, please note that the tiers for luminaire efficacy have changed somewhat after it was noticed that the actual efficacies do seem to vary as a function of lumen output to some extent.
Energy consumption - various	I clearly understand that it is nearly impossible to apply Italian IPEA and IPEI criteria to EU GPP. I would kindly ask if it could be possible to add some sort of “conversion table” from “EU GPP minimum PDI” to “Italian IPEI classes” – so Italian procurers would be allowed to use only one criterion that meet both (in Italy GPP are mandatory and not optional, so I think it could be a good choice to align core criteria). Let me know if you want me to provide you this table.	We would be willing to do this if time permits, but it doesn't make sense to do it yet. This should wait until we have a final agreed set of PDI ref tables for EU GPP.
Traffic signals	The EEB agrees with the chosen approach as LED technology now dominates this market and we do not see the risk of competition with other less efficient technologies.	Noted