Implementing energy-efficient street lighting

In a nutshell

SUMMARY
It is best practice to: • carry out an audit of the street lighting system; • improve the luminaires to avoid upward lighting and intrusive lighting and maximise useful lighting; • reduce lighting levels to actual needs (i.e. avoid over lighting); • replace lamps selecting highly energy-efficient technologies (e.g. LED) taking into account durability, colour rendering index and colour temperature of the light; • implement night dimming (i.e. reduced lighting late at night); • introduce intelligent street lighting (e.g. using sensors to temporarily increase the lighting levels when the presence of people is detected).
Target group
Local authorities
Applicability
This best practice is applicable to all public administrations directly or indirectly (through a public or private company) managing the provision of street lighting. The investments required to implement the measures listed may, in some instances, be a limitation and affect the choice of specific measures to implement, but are generally outweighed by the energy savings and result in reasonable payback times.
Environmental performance indicators
• Annual energy use for street lighting per inhabitant (kWh/inhabitant/year) • Annual energy use for street lighting per kilometre of street lit (MWh/km/year)
Benchmarks of excellence
Street lighting energy use per kilometre is lower than 6 MWh/km/year

Description

Street lighting accounts for a small share of the total final energy consumption of a country (for instance, it accounts for 2% of the electricity consumption in Italy[1]) but is an important area of action for municipalities for three reasons:

1. Street lighting is often responsible for a large share of the direct energy bill of a municipality (for instance, 55% and 64% in two medium-sized cities according to Fiaschi et al., 2012; about 50% of the direct electricity consumption of municipalities on average in France in 2005 – ADEME, 2007).

2. Street lighting is an area where interventions are relatively easy to plan and implement (Lorenzoni et al., 2006): information on technology used, number of lighting points, power, energy consumption, maintenance costs, etc. is often readily available within the municipality; the service is usually under direct control or contracted by the municipality.

3. Street lighting can often offer a relatively large potential to reduce its energy consumption (with savings up to 60-86%[2]) with proven solutions and reasonable returns on investment. Moreover, with over 90 million street and roadway lamps in place only in IEA member countries[3] and a global energy consumption of about 114 TWh (IEA, 2006), a widespread deployment of the best technologies and management practices can have a considerable impact on energy consumption.

Street lighting is aimed at meeting two important societal needs: ensuring safety for road users (cars, motorbikes, bikes, pedestrians) and improving security for all citizens, during the hours of darkness. As human activity during the day extended beyond the hours of daylight, street lighting became essential and it is nowadays a very important service, mostly provided by municipalities. It has a very high visibility, because citizens can judge its effectiveness by direct experience and because it can be considered (indirectly) responsible for accidents and crimes.

It is thus of utmost importance to obtain the maximum benefits, and not only in terms of energy efficiency, when planning any upgrade of an existing street lighting system or a new installation.

The main benefits that should be sought are:

- Reducing costs

Reducing or minimising the energy consumption of street lighting is a major factor in reducing the lifetime costs of such a system. Indeed, the energy bill represents a very large share of the lifetime cost of a luminaire (e.g. 69% in Baenziger, 2002).

However, maintenance costs are also a key aspect to be considered. Lamps have a limited lifetime and can also fail because of malfunctions of the system or accidents. The frequency of the need for replacement is a considerable contribution to maintenance costs, although the need for luminaires cleaning or other operations should also be considered. Maintenance costs do not only include the costs for repair and cleaning, but also those related with checking that the system is correctly in operation (e.g. checking if/which lamps need to be replaced).

- Improving street lighting quality

There is very often scope to improve the quality of the public lighting service. Pursuing such an objective can make it much easier to obtain public acceptance for interventions in this field. In the meanwhile, better public lighting means better mitigation of the safety and security risks it addresses, and, therefore, indirectly, saving human lives.

There are a number of dimensions in which the quality of the service provided can be improved: (i) the reliability of the system, (ii) the uniformity of the lighting, (iii) the colour of the light, (iv) the directionality of the light.

1. Reliability

Improving the reliability of a street lighting system is essentially reducing the amount of time the system as a whole or individual lighting points do not work. One common example of outage of a lighting point is a lamp burning out. Improving reliability is about being able to act as soon as possible after such a failure, or, better, foreseeing the failure through monitoring and being able to replace a lamp (just) before it would burn out, and/or limiting the number of such failures, e.g. thanks to better power quality or to the choice of lamps with longer lifetime.

2. Uniformity

Human eyes take a certain time to adapt to different lighting conditions. A good street lighting installation should thus avoid the alternation of brighter and darker zones. In technical terms, if we call E the illuminance (measured in lux), a good indicator for uniformity is the $E_{min}/E_{average}$ ratio. An increase of the ratio (i.e. a ratio closer to 1) indicates a street lighting installation with higher uniformity, i.e. less difference between the illuminance of the darkest areas (E_{min}) and the average illuminance ($E_{average}$).

3. Light colour

Different lighting technologies emit light at different wavelengths (or frequencies). For instance, Figure 1 shows the distributions of wavelengths (or emission spectra) for natural light compared with some lighting technologies. The emission spectrum for each lighting technology is often referred to as the colour temperature, given that how much light is emitted at the different wavelengths depends on the temperature of the body emitting the light.

Spectra of various light sources

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Figure 1: Emission spectra of natural light from the sun and the sky and of artificial light from incandescent bulbs at different temperatures, from a mercury vapour lamp and from a multi-vapour lamp. (Source: http://www.light-measurement.com/spectra/)

Different kinds of lamps and lighting technologies can thus be classified according to their *Correlated colour temperature* (CCT). For instance, incandescent light bulbs have a CCT of 2700 - 3000 K as this is their normal operating temperature range (about 2400 ºC – 2700 ºC), while mercury vapour lamps, have a CTT of 2900 - 4200 K. In general, lamps with CTT around 2700 K offer "warm white" light (more yellowish), while lamps with CTT over 4000 K have "cold white" (more blueish).

Compact LED bulb with warm light Compact LED bulb with cold light

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Figure 2: A light bulb with a CCT of 2700K ("warm white") on the left and one with a CTT of more than 4000K ("cold white") on the right. (Source: http://ec.europa.eu/energy/lumen/overview/howtochoose/packaging/packaging_en.htm)

The CCT and the distribution of the intensities in the spectrum determine the colour of the light that is emitted (i.e. which colour components are more important) and, as a consequence, the ability for the human eye to distinguish colours under such kind of lighting. The parameter that describes this behaviour is called *Colour rendering index* (CRI). Incandescent light bulbs, with CRI = 100, allows to perfectly distinguish colours, while mercury vapour lamps, with CRI = 45, can only be used in applications where a correct perception of colours is unimportant, due to their very strong green-blue component.

Changing type of lamps means very often changing light colour, i.e. changing CTT and CRI. Such an intervention can thus offer a good opportunity to improve street lighting quality as far as light colour is concerned.

However, depending on the purpose of each lighting installation, different light colours may be appropriate.

For instance, a high CRI can be important in the historical centre of a town but not on countryside roads. Conversely, it may be important to avoid a strong blue component in areas where this can be an important source of disturbance for wildlife or human health (Falchi et al., 2011).

4. Directionality

The purpose of street lighting is illuminating the streets, i.e. their surface, but also the vehicles, people, animals, trees, objects on them or on their border. However, in most cases, a considerable share of the light is dispersed in other directions: towards the sky, towards buildings, private land or other areas where street lighting is not needed. This can be referred to as "wasted lighting". Conversely, the share of the light actually reaching the surface that it is intended to illuminate is called "useful lighting".

Public_lighting

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Figure 3: Useful lighting

The share of "useful lighting" can be substantially increased by improving the directionality of the luminaires, i.e. choosing luminaires that direct most of their light downwards. This depends mainly on the shape of the luminaire, but also on whether the lamp is visible or hidden and on the materials used.

To obtain the best results, changing the positions of the luminaires and thus a whole re-thinking of the installation taking directionality into account may be needed.

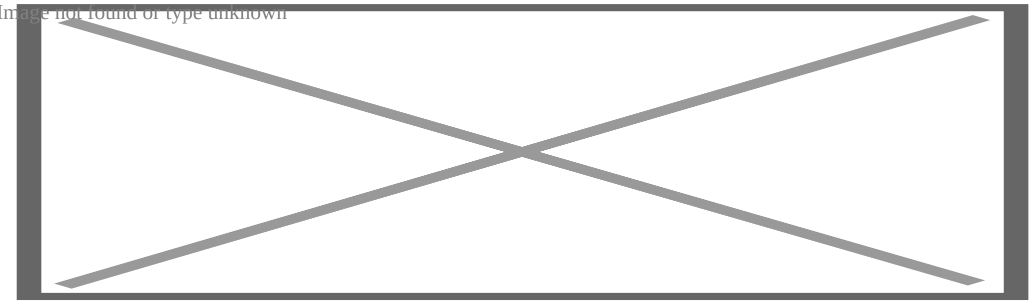

Figure 4: Directionality of the lighting (Source: Bruxelles Environnement, 2011 – where the stated source is ASCN : http://www.astrosurf.com/anpcn/)

Improving the directionality of the street lights and thus increasing the share of useful lighting has three benefits: first, lamps with lower illuminance levels can be used to provide the same level of lighting on the areas to illuminate, resulting in energy and costs savings; secondly, the so-called obtrusive lighting or trespass, i.e. the light from street lighting entering into buildings, gardens, etc. and potentially disturbing their occupants, can be drastically reduced; thirdly, this aspect is crucial in minimising glare. Glare is the reduction in visibility caused by the presence of intense light sources in the field of view.

- Decreasing light pollution

Light pollution is an environmental issue that has so far received relatively limited attention (Lyytimaki et al., 2012). The term refers mainly to the veiling effect upon celestial objects of light emitted with an upward component from luminaires on the ground, on buildings or on infrastructures (Mizon, 2002). This light illuminating the sky at night is known as skyglow and is caused by upward light, scattered and reflected by particles such as aerosols in the atmosphere, and, when it is relatively intense, such as in the case of large towns, its effects are visible tens of kilometres away. Moreover, according to Holker et al. (2010a), artificial lighting of the night has been growing worldwide by around 6% per year.

The concern for this form of light pollution, especially in the context of astronomy, has been raised for several years. It is caused by a number of sources of lights, such as illuminated buildings, infrastructures, factories, but also vehicles or gas flaring, all of which are likely to be locally significant and can have disproportionate effects compared to their aim. However, since it is very widespread, often operated all night long and sometimes rather intense, street lighting plays a major role in contributing to light pollution. The main mitigation measures suggested are: avoiding upward lighting, limiting the extension of the lighted areas; reducing lighting levels to what is necessary; and turning off the lights when not needed.

Concerning the upward lighting, it is important to mention that the light causing the skyglow is, in most cases, wasted lighting (i.e. light that was not directed upwards intentionally), and that light does not need to be emitted vertically to cause skyglow: in fact, light emitted at a shallow angle above the horizontal will cause more skyglow since it will encounter more particles and droplets from which to be scattered (Mizon, 2002).

A simple method to evaluate the contribution to skyglow of a luminaire is its ULOR. This acronym stands for "upward light output ratio" and it is the ratio between the light output that is emitted at an angle above the horizontal and the total light output of a luminaire. In order to reduce the contribution of street lighting to skyglow, the ULOR of its luminaires should be zero. However, ULOR of a few percentage points can sometimes be accepted in urban areas for lamps of limited luminous power. Conversely, if a municipality is really determined to mitigate the contribution to skyglow, it should not only achieve a ULOR of zero but no light should be emitted also within the first 10º below the horizontal (Brunet, 2011).

In order to fully consider the properties of a luminaire concerning directionality and contribution to skyglow a more comprehensive system was elaborated by the Illuminating Engineering Society under the name of a luminaire classification system for outdoor luminaires (IES, 2011). This system includes the so-called BUG rating, where BUG stands for Backlight, Uplight and Glare. Backlight indicates the light emitted at the back of the luminaire, usually causing obtrusive lighting. Uplight is the light emitted above the horizontal and glare is an indication of the light emitted at a shallow angle below the horizontal. The space around the lamp is divided into a number of solid angles and the lighting flux in each of those angles is taken into consideration to determine the rating of the luminaire in terms of backlight, uplight and glare.

As mentioned before, however, light pollution does not only refer to skyglow. Another very relevant aspect is the impact of continuous lighting and of the absence of darkness during night time on animals, plants and ecosystems, as well as on human health. This can be easily understood considering that most organisms, including humans, have evolved circadian clocks controlled by day-night cycles and a substantial proportion of global biodiversity is nocturnal, with 30% of all vertebrates and over 60% of all invertebrates (Holker et al., 2010b).

Although there is an important need for further research in this field (Holker et al., 2010a), Lyytimaki et al. (2012) list a considerable number of recent studies about the detrimental effects of light pollution on animals, plants, ecosystems and human health. Davies et al. (2012) provide evidence that street lighting has an impact at higher levels of biological organisation than a single organism, such as changing the abundance of species within communities, with still unknown impacts on the functioning of the ecosystems.

Other recent studies highlight the crucial importance of the spectral composition of the light. As species differ in the wavelengths to which their visual systems are most sensitive and responsive, and as organism behaviour can be dependent on the presence of certain wavelengths of light, Gaston et al. (2012) state that lighting technologies that emit a narrow spectrum of light, such as LPS lighting, are likely to have less ecological impact compared with broader spectrum or "whiter" light sources, such as LED and metal halide lamps. According to Falchi et al. (2011), even when all the measures against light pollution mentioned above are implemented, there is a residual light pollution that should be mitigated by avoiding or limiting emissions of light at wavelengths shorter than 540 nm, corresponding to the blue component of light, which is the one with the most severe consequences for the environment and human health.

In order to seek the objectives of reducing costs, improving street lighting quality and decreasing light pollution, while also addressing the primary objective of reducing the energy consumption of street lighting, it is best practice to implement the following measures.

- Carry out an audit of the street lighting system

Before any upgrade of an existing street lighting installation can be planned, it is crucial to assess the current situation, understand needs and problems and be able to prioritise interventions.

This should include making an inventory of the technology currently in use, analysing the current energy consumption as well as the local needs and how well these are met.

However, street lighting auditing can go much further. For instance, in August 2012, Viteos (2012a, 2012b, 2012c), a public electricity company owned by the municipalities of Neuchatel, Chaux-de-Fonds and Locle, in Switzerland, and responsible for the provision of street lighting in these cities, held an aerial street lighting audit. Thanks to a nocturnal helicopter flight together with measures on the ground taken at the same time to calibrate the aerial data, the levels of illumination of the whole territory could be surveyed in a few hours. Moreover, thanks to a second survey carried out during the same flight with the public lighting being switched off, also the residual lighting caused by other lighting sources (such as building, lights in gardens, etc.) was measured, in order to study its importance and understand even better the role played by the street lighting. The analysis of the data allowed to both check the effectiveness of different new technological solutions implemented in different areas of the municipalities and identify under and over-illuminated areas requiring interventions.

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Figure 5: Examples of the result of the data acquisition by aerial photometry. Source: ALTILUM, 2013

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Figure 6: Example of the final output of the analysis (after data processing to calculate illumination levels and its inclusion in a GIS system). Source: ALTILUM, 2013

The cost of this aerial auditing was about 40,000-50,000 CHF for a total of 11,482 lighting points, which corresponds to about 4 CHF (or 3,30€) per luminaire (Dreyer, pers.comm., 14 September 2012). This was considered a good investment by the company, given the usefulness of the detailed information obtained and how this would have allowed increasing the efficacy of the new investments on upgrading the street lighting system in terms of energy savings but also street lighting quality and light pollution.

- Improve the luminaires to avoid upward lighting and intrusive lighting and maximise useful lighting

A large share of the luminaires on operation are rather old and inefficient. For instance, ADEME (2012a) estimates that in France over 40% of luminaires are over 25 years old and mainly bowl type luminaires with very high ULOR values.

A 2004 study by Euroelectric reported that the average luminaire efficiency in Europe for the different lighting technologies was between 25 and 45% (IEA, 2006). This means that the average luminaire in Europe in 2004 wasted at least 55% of the light emitted by the lamp it contained, either by emitting light in unwanted directions or by trapping it in the luminaire itself.

Improving the luminaires allow thus reducing the installed power of each lighting point guaranteeing the same (or even better) illuminance on the ground.

The best luminaires have a good reflective coating around the lamp and such a shape so that all the light is emitted downwards and towards the area to be lighted (see information on directionality and light pollution above).

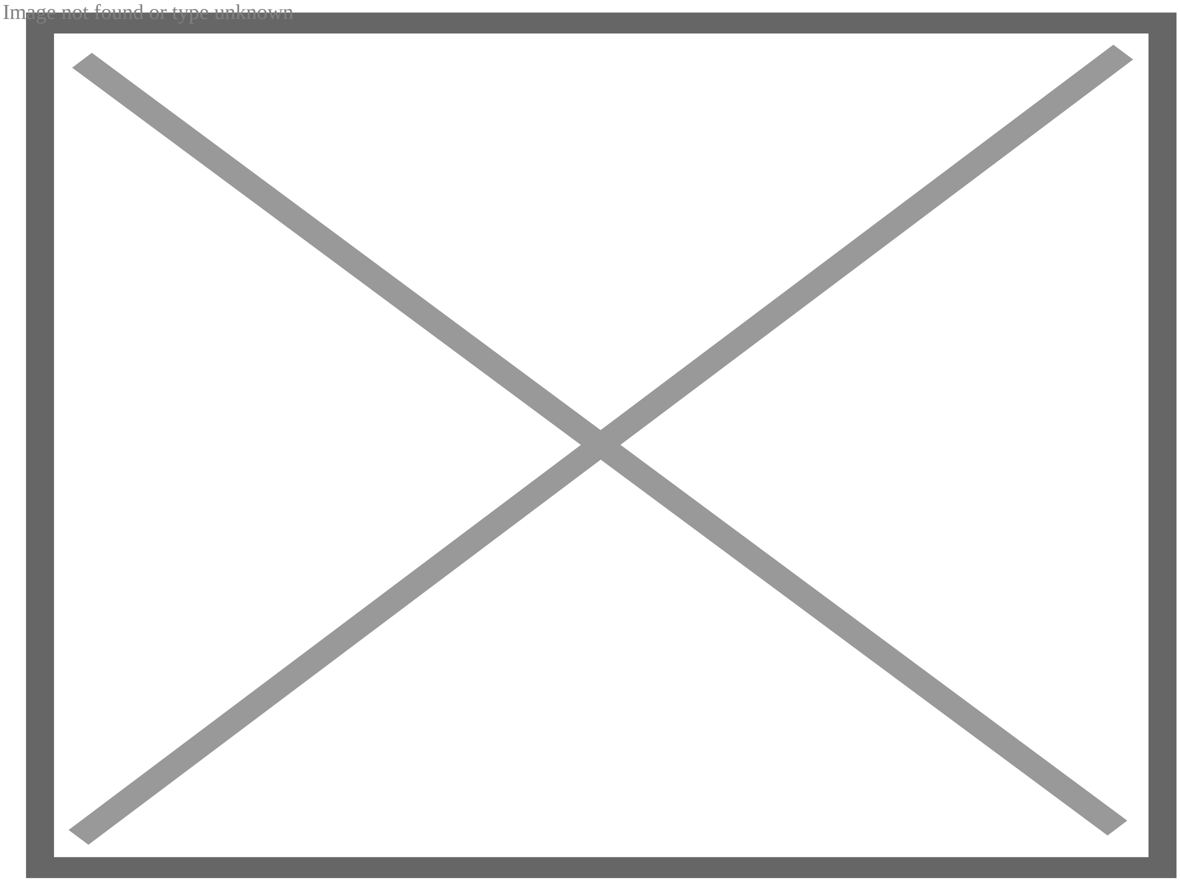

Figure 7: Luminaires with ULOR=0 in the bottom part of the picture and emitting light upwards in the top part. (Source: Philips, Hicksgate case study)

<u>- Reduce lighting levels to actual needs (i.e. avoid overlighting)</u>

There are many examples of areas that are illuminated more than needed. In these cases, permanently reducing the luminous flux can be an effective option to maximise the energy savings. This is very important to consider when planning a lamp replacement or any more thorough upgrade of the public lighting system.

For instance, 250 W mercury high pressure lamps can be replaced by either 150 W sodium high pressure lamps, reducing power by 40% and increasing the luminous flux by 23%, or by 100 W sodium high pressure lamps with a 60% reduction of power but also a 24% reduction of luminous flux (Menga and Grattieri, 2009). If this reduction of luminous flux is acceptable, the additional energy savings mentioned can be obtained at negative additional costs (a lamp with lower power is likely to be cheaper).

The best way to choose the appropriate level of lighting is considering standards and applicable laws as well as indicators such as lm/km, but also working together with the citizens to understand their real needs and how to cater for them.

An example is the project for the street lighting upgrade of Parco Madonie, in Italy (Bruni, 2012), where a large portion of the savings is determined by the choice of substituting high-pressure mercury lamps with LED lamps with a rather lower light output but still sufficient to meet the lighting needs of the area.

<u>- Replace lamps selecting highly energy-efficient technologies (e.g. LED) taking into account durability, colour rendering index and colour temperature of the light</u>

Upgrading the lamps used in street lighting with more modern and efficient technologies is the most common measure implemented to reduce the energy consumption of street lighting.

Table 1 presents the main characteristics of the main lighting technologies currently used for street lighting.

Table 1: Key characteristics of different street lighting technologies. Data from: Elvidge et al., 2010; Lorenzoni et al., 2006; Bruxelles Environnement, 2011; Eurelectric and UIE, 2004; Enel Sole, 2012.

	Luminous efficacy	Average lifetime	Light colour (CTT)	CRI	Notes
Incandescent	12-20 lm/W	1000-1500 h	Warm white (2700-3000 K)	100	Almost phased out because of the very low luminous efficacy.
Halogen	15-33 lm/W	2000-4000 h	White		
Fluorescent	50-92 lm/W	10,000-20,000 h	Cold white	5-82	
High-pressure mercury (HPM)	34-70 lm/W	10,000-20,000 h	Cold/blueish white (2900-4200 K)	45	About 4 minutes needed to switch on and off. Not dimmable. Relatively low luminous efficacy.
Low-pressure sodium (LPS)	68-177 lm/W	16,000 h	Orange monochromatic light (1807 K)		8-15 minutes to reach full power. Not dimmable. Extremely bad colour rendering.
High-pressure sodium (HPS)	59-150 lm/W (average 100-110 lm/W)	12,000-22,000 h	Yellow/orange (2000-2500 K)	7-32	5 minutes to reach full power.
Metal halide (MH)	62-100 lm/W	5000-10,000 h	White (2874-4600 K)	64-100	Higher sensibility to tension fluctuations.
Light emitting diodes (LED)	28-100 lm/W		White (1739-8357 K)	65-100	

The indicator used to describe the efficiency of different lighting technologies in generating light with a certain input of energy (or, in other terms, in generating a same lighting output with a lower power) is called luminous efficacy and it is measured in lumen/Watt (lm/W). As it can be seen from the table, it varies substantially between different technologies.

While the use of incandescent light bulbs for street lighting is today rather limited and declining, mercury vapour lamps, among the most inefficient, represent still a large share of the public lighting installations (e.g. about a third of all the lighting points in France according to ADEME, 2012b). In addition, also fluorescent lamps and old sodium lamps can have pretty low efficiencies.

There is thus a large potential to save energy by replacing these lamps with those with the highest luminous efficacy: the most efficient discharge lamps (mainly high-pressure sodium lamps and, in some cases, metal halide) and LEDs. Of course, the other characteristics of these lighting technologies (see Table 1) should be carefully taken into account when selecting what kind of lighting to install as well as a certain particular product.

a. Installing LED

This is an option that is growing in popularity in the last few years. For instance, most of the new street lighting installations or refurbishment by Philips are for the installation of LED lighting (Koster, pers.comm., 14 September 2012).

The main positive aspects are: the rather high luminous efficacy, the highest average lifetime, very little need of maintenance minimising thus maintenance costs, plenty of flexibility in terms of control and possibility to dim the light.

There are plenty of examples of successful implementation of LED lighting. For example, the municipality of Stadt Langen (DE) upgraded all of its street lighting (2551 conventional fluorescent luminaires) with LED, obtaining energy savings of 60% and winning the GreenLight Award 2012. Other examples are some the winners of the German energy efficient street lighting competition *Energieeffiziente Stadtbeleuchtung Bundeswettbewerbs* (Berliner Energieagentur, 2012).

The main resistances against the implementation of LED lighting are: the rather high upfront investment needed (which many municipalities find difficult to finance), the presence on the market of low quality products not fulfilling the foreseen lifetime or light quality, the spectral composition of the light they emit.

Concerning this last point, it should be noted that current LED street lighting technologies use a monochromatic LED emitting blue light and a yellow phosphor coating to convert it into white broad-spectrum lighting. However, there is potential for future developments of LED lights that create light with good colour rendering by mixing coloured light from three or more monochromatic LED sources. Such technology could give a higher degree of control over the wavelengths emitted and allow critical regions of the spectrum to be avoided (Gaston et al., 2012).

b. Replacing existing lamps with most efficient discharge lamps

This has been the most common option for several years and it is still very common. For instance, most street lighting upgrades funded under the French scheme to help small municipalities to adopt energy efficiency street lighting is about the installation of HPS lamps. These, together with MH lamps, are the most common choices.

The advantages are: lower investment costs, very well proven and established technology, and rather high luminous efficacy. MH lamps are slightly more costly and less efficient than HPS lamps but are chosen for some applications because of their better colour rendering.

Supporters of HPS lighting stress that it is currently possible to reach higher luminous efficacy with this technology rather than LED.

c. Changing ballasts

Discharge lamps need ballasts in order to be operated. A ballast is a device which limits the amount of current in an electric circuit.

There are two types of ballasts: conventional ballasts, also called electro-magnetic or induction ballasts, and electronic ballasts.

The first type consumes on average 12% of the energy consumption of the lamp they control, while the more modern, electronic ballasts, less than 10% (Bruxelles Environmment, 2011).

Electronic ballasts also increase the average lifetime of lamps and give much better control in terms of dimming. This last aspect is very often the factor determining the choice to change ballasts.

- Implement night dimming (i.e. reduced lighting late at night)

The implementation of dimming in the field of street lighting refers to reducing the light output during certain hours of the night (often between midnight and 6am). This is usually based on fixed timings and allows saving energy as well as reducing light pollution and intrusive lighting.

This solution is broadly considered much better than switching off one of each two lighting points (a common practice in some municipalities in the past) which had the big disadvantage of heavily affecting uniformity and thus the very essential function of street lighting.

Dimming is possible in LED installations with very large flexibility, as well as with MH or HPS lamps. With a magnetic transformer it is possible to dim HPS and MV lamps up to 50% of their full lighting output, while electronic ballasts can allow dimming up to 50% all discharge lamps and up to only 10% of their full output HPS lamps (Baenziger, 2002). If correctly done, dimming can also allow to obtain lamp life extensions of up to 100% (Baenziger, 2002).

- Introduce intelligent street lighting (e.g. using sensors to temporarily increase the lighting levels when the presence of people is detected)

Intelligent street lighting is the name that it is used to refer to a series of measures that allow reducing the energy consumption of lighting by adapting the lighting output in each point of the installation to the needs over time and according to certain criteria. The most common uses of intelligent street lighting are the reduction of luminance based on traffic density or weather conditions. It is a more sophisticated way of implementing dimming without affecting the service provided by the street lighting to the citizens.

The main features that intelligent street lighting installations can have are, from the simpler ones to the most sophisticated (Andrei et al., 2009):

- switch on/off based on preset schedule
- remote control of switch on/off (communication via wireless or power line communication between the lighting points and a central control centre)
- possibility to dim lights at different levels (from remote)
- monitoring functional parameters (such as current and voltage) from remote
- automatic alert of potential defects
- monitoring energy consumption at the level of each luminaire from remote
- automatic switch on/off depending on level of natural light
- dimming regulated by sensors of ambient lighting (to allow reducing the additional lighting provided by street lighting only to the minimum necessary)
- presence sensors (to increase the lighting levels only when the street is in use),
- weather sensors (to allow to provide more lighting when the weather conditions determine low visibility)
- provide the possibility for the public to control, to a certain extent, the street lighting system (e.g. providing a telephone number to allow the public to switch on or increase the lighting outputs)

According to Baenziger (2002), the implementation of intelligent street lighting has pay back periods within 3-5 years thanks to energy and maintenance savings, with energy savings of 30 to 40%.

Moreover, as already said for dimming, good control means lamp life extension of up to 100% for HPS lamps (Baenziger, 2002).

Another benefit of such a solution is the need for much less on-the-field maintenance, thanks to the possibility to monitor lamp failure and even to replace faulty lamps before they fail. This also increases the reliability of the street lighting installation.

There are however a number of main challenges to the implementation of this best environmental management practices by municipalities that should be taken into account:

- many municipalities do not have a proper street lighting maintenance scheme in place (Baenziger, 2002);

- the people in charge of buying replacement lamps lack knowledge on lamps and lighting and choose the options with cheapest initial costs (Baenziger, 2002);

- part of the savings can be offset by an improvement in street lighting quality (for instance, in Vilnius high-pressure mercury lamp luminaires were replaced by high-pressure sodium lamp luminaires reducing installed capacity by 50% but energy consumption only by 16% - Balsys et al., 2002).

The main steps to be followed are thus:

- Prioritise areas for interventions
    - e.g. start by addressing most inefficient solutions, such as globe shaped luminaires with mercury vapour lamps
- Run a lighting study to understand the real needs and how to meet them in the most effective and efficient way
- Explore which way can be the most suited to finance the implementation of the solution

[1] Italian electricity statistics report a consumption for street lighting of 6201.8 GWh in 2011 out of a total consumption of 313 792.1 GWh (Terna, 2012)

[2] 60% in Huenges Wajer et al., 2009; 50-75% in MEDDTL, 2012; 62-86% in UBA (2011a, 2011b, 2011c, 2011d, 2011e, 2011f, 2011g).

[3] In 2006 the following countries were IEA members: Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Japan, Republic of Korea, Luxembourg, The Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, United Kingdom, and the United States (IEA, 2013).

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1. Street lighting is often responsible for a large share of the direct energy bill of a municipality (for instance, 55% and 64% in two medium-sized cities according to Fiaschi et al., 2012; about 50% of the direct electricity consumption of municipalities on average in France in 2005 – ADEME, 2007).

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3. Street lighting can often offer a relatively large potential to reduce its energy consumption (with savings up to 60-86%[2]) with proven solutions and reasonable returns on investment. Moreover, with over 90 million street and roadway lamps in place only in IEA member countries[3] and a global energy consumption of about 114 TWh (IEA, 2006), a widespread deployment of the best technologies and management practices can have a considerable impact on energy consumption.

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It is thus of utmost importance to obtain the maximum benefits, and not only in terms of energy efficiency, when planning any upgrade of an existing street lighting system or a new installation.

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Reducing or minimising the energy consumption of street lighting is a major factor in reducing the lifetime costs of such a system. Indeed, the energy bill represents a very large share of the lifetime cost of a luminaire (e.g. 69% in Baenziger, 2002).

However, maintenance costs are also a key aspect to be considered. Lamps have a limited lifetime and can also fail because of malfunctions of the system or accidents. The frequency of the need for replacement is a considerable contribution to maintenance costs, although the need for luminaires cleaning or other operations should also be considered. Maintenance costs do not only include the costs for repair and cleaning, but also those related with checking that the system is correctly in operation (e.g. checking if/which lamps need to be replaced).

- Improving street lighting quality

There is very often scope to improve the quality of the public lighting service. Pursuing such an objective can make it much easier to obtain public acceptance for interventions in this field. In the meanwhile, better public lighting means better mitigation of the safety and security risks it addresses, and, therefore, indirectly, saving human lives.

There are a number of dimensions in which the quality of the service provided can be improved: (i) the reliability of the system, (ii) the uniformity of the lighting, (iii) the colour of the light, (iv) the directionality of the light.

1. Reliability

Improving the reliability of a street lighting system is essentially reducing the amount of time the system as a whole or individual lighting points do not work. One common example of outage of a lighting point is a lamp burning out. Improving reliability is about being able to act as soon as possible after such a failure, or, better, foreseeing the failure through monitoring and being able to replace a lamp (just) before it would burn out, and/or limiting the number of such failures, e.g. thanks to better power quality or to the choice of lamps with longer lifetime.

2. Uniformity

Human eyes take a certain time to adapt to different lighting conditions. A good street lighting installation should thus avoid the alternation of brighter and darker zones. In technical terms, if we call E the illuminance (measured in lux), a good indicator for uniformity is the $E_{min}/E_{average}$ ratio. An increase of the ratio (i.e. a ratio closer to 1) indicates a street lighting installation with higher uniformity, i.e. less difference between the illuminance of the darkest areas (E_{min}) and the average illuminance ($E_{average}$).

3. Light colour

Different lighting technologies emit light at different wavelengths (or frequencies). For instance, Figure 1 shows the distributions of wavelengths (or emission spectra) for natural light compared with some lighting technologies. The emission spectrum for each lighting technology is often referred to as the colour temperature, given that how much light is emitted at the different wavelengths depends on the temperature of the body emitting the light.

Spectra of various light sources

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Figure 1: Emission spectra of natural light from the sun and the sky and of artificial light from incandescent bulbs at different temperatures, from a mercury vapour lamp and from a multi-vapour lamp. (Source: http://www.light-measurement.com/spectra/)

Different kinds of lamps and lighting technologies can thus be classified according to their *Correlated colour temperature* (CCT). For instance, incandescent light bulbs have a CCT of 2700 - 3000 K as this is their normal operating temperature range (about 2400 ºC – 2700 ºC), while mercury vapour lamps, have a CTT of 2900 - 4200 K. In general, lamps with CTT around 2700 K offer "warm white" light (more yellowish), while lamps with CTT over 4000 K have "cold white" (more blueish).

Compact LED bulb with warm light

Compact LED bulb with cold light

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Figure 2: A light bulb with a CCT of 2700K ("warm white") on the left and one with a CTT of more than 4000K ("cold white") on the right. (Source: http://ec.europa.eu/energy/lumen/overview/howtochoose/packaging/packaging_en.htm)

The CCT and the distribution of the intensities in the spectrum determine the colour of the light that is emitted (i.e. which colour components are more important) and, as a consequence, the ability for the human eye to distinguish colours under such kind of lighting. The parameter that describes this behaviour is called *Colour rendering index* (CRI). Incandescent light bulbs, with CRI = 100, allows to perfectly distinguish colours, while mercury vapour lamps, with CRI = 45, can only be used in applications where a correct perception of colours is unimportant, due to their very strong green-blue component.

Changing type of lamps means very often changing light colour, i.e. changing CTT and CRI. Such an intervention can thus offer a good opportunity to improve street lighting quality as far as light colour is concerned.

However, depending on the purpose of each lighting installation, different light colours may be appropriate.

For instance, a high CRI can be important in the historical centre of a town but not on countryside roads. Conversely, it may be important to avoid a strong blue component in areas where this can be an important source of disturbance for wildlife or human health (Falchi et al., 2011).

4. Directionality

The purpose of street lighting is illuminating the streets, i.e. their surface, but also the vehicles, people, animals, trees, objects on them or on their border. However, in most cases, a considerable share of the light is dispersed in other directions: towards the sky, towards buildings, private land or other areas where street lighting is not needed. This can be referred to as "wasted lighting". Conversely, the share of the light actually reaching the surface that it is intended to illuminate is called "useful lighting".

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Figure 3: Useful lighting

The share of "useful lighting" can be substantially increased by improving the directionality of the luminaires, i.e. choosing luminaires that direct most of their light downwards. This depends mainly on the shape of the luminaire, but also on whether the lamp is visible or hidden and on the materials used.

To obtain the best results, changing the positions of the luminaires and thus a whole re-thinking of the installation taking directionality into account may be needed.

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Figure 4: Directionality of the lighting (Source: Bruxelles Environnement, 2011 – where the stated source is ASCN : http://www.astrosurf.com/anpcn/)

Improving the directionality of the street lights and thus increasing the share of useful lighting has three benefits: first, lamps with lower illuminance levels can be used to provide the same level of lighting on the areas to illuminate, resulting in energy and costs savings; secondly, the so-called obtrusive lighting or trespass, i.e. the light from street lighting entering into buildings, gardens, etc. and potentially disturbing their occupants, can be drastically reduced; thirdly, this aspect is crucial in minimising glare. Glare is the reduction in visibility caused by the presence of intense light sources in the field of view.

- Decreasing light pollution

Light pollution is an environmental issue that has so far received relatively limited attention (Lyytimaki et al., 2012). The term refers mainly to the veiling effect upon celestial objects of light emitted with an upward component from luminaires on the ground, on buildings or on infrastructures (Mizon, 2002). This light illuminating the sky at night is known as skyglow and is caused by upward light, scattered and reflected by particles such as aerosols in the atmosphere, and, when it is relatively intense, such as in the case of large towns, its effects are visible tens of kilometres away. Moreover, according to Holker et al. (2010a), artificial lighting of the night has been growing worldwide by around 6% per year.

The concern for this form of light pollution, especially in the context of astronomy, has been raised for several years. It is caused by a number of sources of lights, such as illuminated buildings, infrastructures, factories, but also vehicles or gas flaring, all of which are likely to be locally significant and can have disproportionate effects compared to their aim. However, since it is very widespread, often operated all night long and sometimes rather intense, street lighting plays a major role in contributing to light pollution. The main mitigation measures suggested are: avoiding upward lighting, limiting the extension of the lighted areas; reducing lighting levels to what is necessary; and turning off the lights when not needed.

Concerning the upward lighting, it is important to mention that the light causing the skyglow is, in most cases, wasted lighting (i.e. light that was not directed upwards intentionally), and that light does not need to be emitted vertically to cause skyglow: in fact, light emitted at a shallow angle above the horizontal will cause more skyglow since it will encounter more particles and droplets from which to be scattered (Mizon, 2002).

A simple method to evaluate the contribution to skyglow of a luminaire is its ULOR. This acronym stands for "upward light output ratio" and it is the ratio between the light output that is emitted at an angle above the horizontal and the total light output of a luminaire. In order to reduce the contribution of street lighting to skyglow, the ULOR of its luminaires should be zero. However, ULOR of a few percentage points can sometimes be accepted in urban areas for lamps of limited luminous power. Conversely, if a municipality is really determined to mitigate the contribution to skyglow, it should not only achieve a ULOR of zero but no light should be emitted also within the first 10º below the horizontal (Brunet, 2011).

In order to fully consider the properties of a luminaire concerning directionality and contribution to skyglow a more comprehensive system was elaborated by the Illuminating Engineering Society under the name of a luminaire classification system for outdoor luminaires (IES, 2011). This system includes the so-called BUG rating, where BUG stands for Backlight, Uplight and Glare. Backlight indicates the light emitted at the back of the luminaire, usually causing obtrusive lighting. Uplight is the light emitted above the horizontal and glare is an indication of the light emitted at a shallow angle below the horizontal. The space around the lamp is divided into a number of solid angles and the lighting flux in each of those angles is taken into consideration to determine the rating of the luminaire in terms of backlight, uplight and glare.

As mentioned before, however, light pollution does not only refer to skyglow. Another very relevant aspect is the impact of continuous lighting and of the absence of darkness during night time on animals, plants and ecosystems, as well as on human health. This can be easily understood considering that most organisms, including humans, have evolved circadian clocks controlled by day-night cycles and a substantial proportion of global biodiversity is nocturnal, with 30% of all vertebrates and over 60% of all invertebrates (Holker et al., 2010b).

Although there is an important need for further research in this field (Holker et al., 2010a), Lyytimaki et al. (2012) list a considerable number of recent studies about the detrimental effects of light pollution on animals, plants, ecosystems and human health. Davies et al. (2012) provide evidence that street lighting has an impact at higher levels of biological organisation than a single organism, such as changing the abundance of species within communities, with still unknown impacts on the functioning of the ecosystems.

Other recent studies highlight the crucial importance of the spectral composition of the light. As species differ in the wavelengths to which their visual systems are most sensitive and responsive, and as organism behaviour can be dependent on the presence of certain wavelengths of light, Gaston et al. (2012) state that lighting technologies that emit a narrow spectrum of light, such as LPS lighting, are likely to have less ecological impact compared with broader spectrum or "whiter" light sources, such as LED and metal halide lamps. According to Falchi et al. (2011), even when all the measures against light pollution mentioned above are implemented, there is a residual light pollution that should be mitigated by avoiding or limiting emissions of light at wavelengths shorter than 540 nm, corresponding to the blue component of light, which is the one with the most severe consequences for the environment and human health.

In order to seek the objectives of reducing costs, improving street lighting quality and decreasing light pollution, while also addressing the primary objective of reducing the energy consumption of street lighting, it is best practice to implement the following measures.

<u>- Carry out an audit of the street lighting system</u>

Before any upgrade of an existing street lighting installation can be planned, it is crucial to assess the current situation, understand needs and problems and be able to prioritise interventions.

This should include making an inventory of the technology currently in use, analysing the current energy consumption as well as the local needs and how well these are met.

However, street lighting auditing can go much further. For instance, in August 2012, Viteos (2012a, 2012b, 2012c), a public electricity company owned by the municipalities of Neuchatel, Chaux-de-Fonds and Locle, in Switzerland, and responsible for the provision of street lighting in these cities, held an aerial street lighting audit. Thanks to a nocturnal helicopter flight together with measures on the ground taken at the same time to calibrate the aerial data, the levels of illumination of the whole territory could be surveyed in a few hours. Moreover, thanks to a second survey carried out during the same flight with the public lighting being switched off, also the residual lighting caused by other lighting sources (such as building, lights in gardens, etc.) was measured, in order to study its importance and understand even better the role played by the street lighting. The analysis of the data allowed to both check the effectiveness of different new technological solutions implemented in different areas of the municipalities and identify under and over-illuminated areas requiring interventions.

Photometry1

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Photometry2

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Figure 5: Examples of the result of the data acquisition by aerial photometry. Source: ALTILUM, 2013

Photometry3

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Figure 6: Example of the final output of the analysis (after data processing to calculate illumination levels and its inclusion in a GIS system). Source: ALTILUM, 2013

The cost of this aerial auditing was about 40,000-50,000 CHF for a total of 11,482 lighting points, which corresponds to about 4 CHF (or 3,30€) per luminaire (Dreyer, pers.comm., 14 September 2012). This was considered a good investment by the company, given the usefulness of the detailed information obtained and how this would have allowed increasing the efficacy of the new investments on upgrading the street lighting system in terms of energy savings but also street lighting quality and light pollution.

- Improve the luminaires to avoid upward lighting and intrusive lighting and maximise useful lighting

A large share of the luminaires on operation are rather old and inefficient. For instance, ADEME (2012a) estimates that in France over 40% of luminaires are over 25 years old and mainly bowl type luminaires with very high ULOR values.

A 2004 study by Euroelectric reported that the average luminaire efficiency in Europe for the different lighting technologies was between 25 and 45% (IEA, 2006). This means that the average luminaire in Europe in 2004 wasted at least 55% of the light emitted by the lamp it contained, either by emitting light in unwanted directions or by trapping it in the luminaire itself.

Improving the luminaires allow thus reducing the installed power of each lighting point guaranteeing the same (or even better) illuminance on the ground.

The best luminaires have a good reflective coating around the lamp and such a shape so that all the light is emitted downwards and towards the area to be lighted (see information on directionality and light pollution above).

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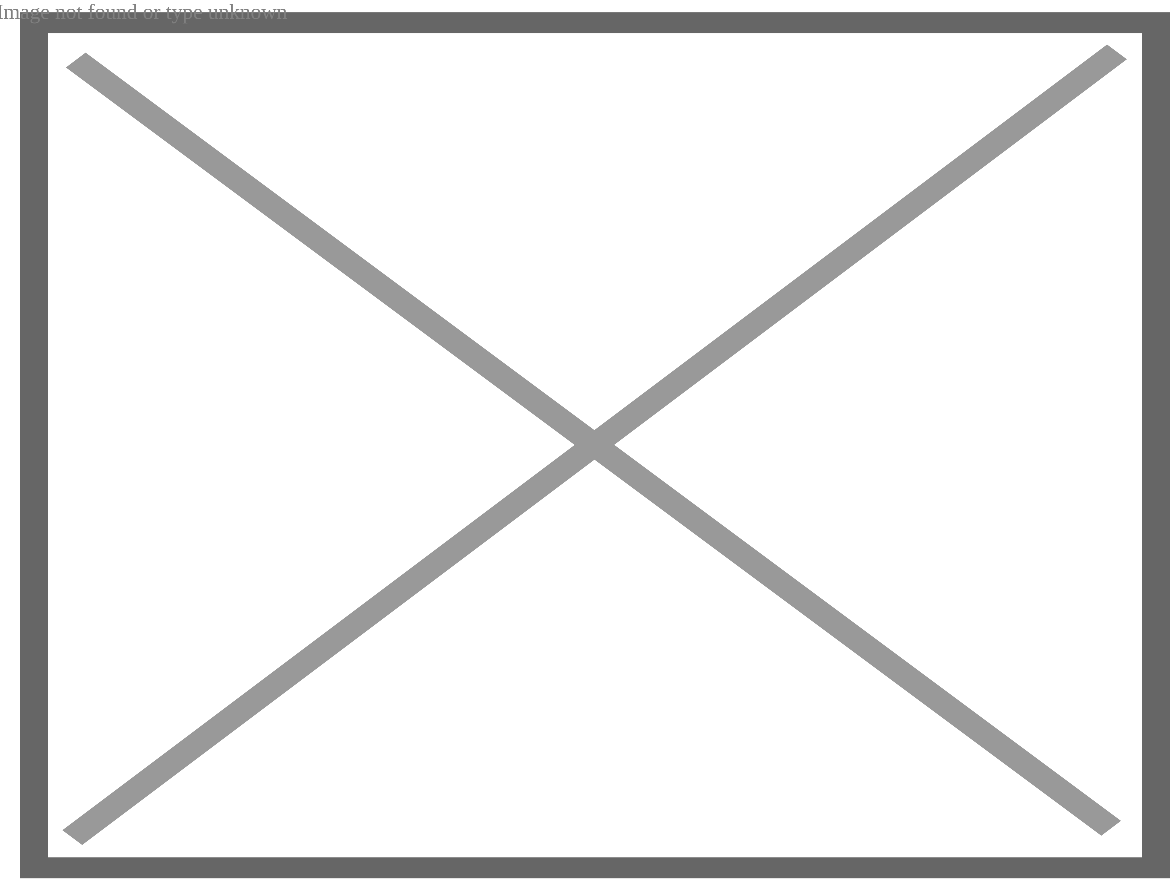

Figure 7: Luminaires with ULOR=0 in the bottom part of the picture and emitting light upwards in the top part. (Source: Philips, Hicksgate case study)

<u>- Reduce lighting levels to actual needs (i.e. avoid overlighting)</u>

There are many examples of areas that are illuminated more than needed. In these cases, permanently reducing the luminous flux can be an effective option to maximise the energy savings. This is very important to consider when planning a lamp replacement or any more thorough upgrade of the public lighting system.

For instance, 250 W mercury high pressure lamps can be replaced by either 150 W sodium high pressure lamps, reducing power by 40% and increasing the luminous flux by 23%, or by 100 W sodium high pressure lamps with a 60% reduction of power but also a 24% reduction of luminous flux (Menga and Grattieri, 2009). If this reduction of luminous flux is acceptable, the additional energy savings mentioned can be obtained at negative additional costs (a lamp with lower power is likely to be cheaper).

The best way to choose the appropriate level of lighting is considering standards and applicable laws as well as indicators such as lm/km, but also working together with the citizens to understand their real needs and how to cater for them.

An example is the project for the street lighting upgrade of Parco Madonie, in Italy (Bruni, 2012), where a large portion of the savings is determined by the choice of substituting high-pressure mercury lamps with LED lamps with a rather lower light output but still sufficient to meet the lighting needs of the area.

- Replace lamps selecting highly energy-efficient technologies (e.g. LED) taking into account durability, colour rendering index and colour temperature of the light

Upgrading the lamps used in street lighting with more modern and efficient technologies is the most common measure implemented to reduce the energy consumption of street lighting.

Table 1 presents the main characteristics of the main lighting technologies currently used for street lighting.

Table 1: Key characteristics of different street lighting technologies. Data from: Elvidge et al., 2010; Lorenzoni et al., 2006; Bruxelles Environnement, 2011; Eurelectric and UIE, 2004; Enel Sole, 2012.

	Luminous efficacy	Average lifetime	Light colour (CTT)	CRI	Notes
Incandescent	12-20 lm/W	1000-1500 h	Warm white (2700-3000 K)	100	Almost phased out because of the very low luminous efficacy.
Halogen	15-33 lm/W	2000-4000 h	White		
Fluorescent	50-92 lm/W	10,000-20,000 h	Cold white	5-82	
High-pressure mercury (HPM)	34-70 lm/W	10,000-20,000 h	Cold/blueish white (2900-4200 K)	45	About 4 minutes needed to switch on and off. Not dimmable. Relatively low luminous efficacy.

Low-pressure sodium (LPS)	68-177 lm/W	16,000 h	Orange monochromatic light (1807 K)		8-15 minutes to reach full power. Not dimmable. Extremely bad colour rendering.
High-pressure sodium (HPS)	59-150 lm/W (average 100-110 lm/W)	12,000-22,000 h	Yellow/orange (2000-2500 K)	7-32	5 minutes to reach full power.
Metal halide (MH)	62-100 lm/W	5000-10,000 h	White (2874-4600 K)	64-100	Higher sensibility to tension fluctuations.
Light emitting diodes (LED)	28-100 lm/W		White (1739-8357 K)	65-100	

The indicator used to describe the efficiency of different lighting technologies in generating light with a certain input of energy (or, in other terms, in generating a same lighting output with a lower power) is called luminous efficacy and it is measured in lumen/Watt (lm/W). As it can be seen from the table, it varies substantially between different technologies.

While the use of incandescent light bulbs for street lighting is today rather limited and declining, mercury vapour lamps, among the most inefficient, represent still a large share of the public lighting installations (e.g. about a third of all the lighting points in France according to ADEME, 2012b). In addition, also fluorescent lamps and old sodium lamps can have pretty low efficiencies.

There is thus a large potential to save energy by replacing these lamps with those with the highest luminous efficacy: the most efficient discharge lamps (mainly high-pressure sodium lamps and, in some cases, metal halide) and LEDs. Of course, the other characteristics of these lighting technologies (see Table 1) should be carefully taken into account when selecting what kind of lighting to install as well as a certain particular product.

Installing LED

This is an option that is growing in popularity in the last few years. For instance, most of the new street lighting installations or refurbishment by Philips are for the installation of LED lighting (Koster, pers.comm., 14 September 2012).

The main positive aspects are: the rather high luminous efficacy, the highest average lifetime, very little need of maintenance minimising thus maintenance costs, plenty of flexibility in terms of control and possibility to dim the light.

There are plenty of examples of successful implementation of LED lighting. For example, the municipality of Stadt Langen (DE) upgraded all of its street lighting (2551 conventional fluorescent luminaires) with LED, obtaining energy savings of 60% and winning the GreenLight Award 2012. Other examples are some the winners of the German energy efficient street lighting competition *Energieeffiziente Stadtbeleuchtung Bundeswettbewerbs* (Berliner Energieagentur, 2012).

The main resistances against the implementation of LED lighting are: the rather high upfront investment needed (which many municipalities find difficult to finance), the presence on the market of low quality products not fulfilling the foreseen lifetime or light quality, the spectral composition of the light they emit.

Concerning this last point, it should be noted that current LED street lighting technologies use a monochromatic LED emitting blue light and a yellow phosphor coating to convert it into white broad-spectrum lighting. However, there is potential for future developments of LED lights that create light with good colour rendering by mixing coloured light from three or more monochromatic LED sources. Such technology could give a higher degree of control over the wavelengths emitted and allow critical regions of the spectrum to be avoided (Gaston et al., 2012).

Replacing existing lamps with most efficient discharge lamps

This has been the most common option for several years and it is still very common. For instance, most street lighting upgrades funded under the French scheme to help small municipalities to adopt energy efficiency street lighting is about the installation of HPS lamps. These, together with MH lamps, are the most common choices.

The advantages are: lower investment costs, very well proven and established technology, and rather high luminous efficacy. MH lamps are slightly more costly and less efficient than HPS lamps but are chosen for some applications because of their better colour rendering.

Supporters of HPS lighting stress that it is currently possible to reach higher luminous efficacy with this technology rather than LED.

1. c. Changing ballasts

Discharge lamps need ballasts in order to be operated. A ballast is a device which limits the amount of current in an electric circuit.

There are two types of ballasts: conventional ballasts, also called electro-magnetic or induction ballasts, and electronic ballasts.

The first type consumes on average 12% of the energy consumption of the lamp they control, while the more modern, electronic ballasts, less than 10% (Bruxelles Environmment, 2011).

Electronic ballasts also increase the average lifetime of lamps and give much better control in terms of dimming. This last aspect is very often the factor determining the choice to change ballasts.

- Implement night dimming (i.e. reduced lighting late at night)

The implementation of dimming in the field of street lighting refers to reducing the light output during certain hours of the night (often between midnight and 6am). This is usually based on fixed timings and allows saving energy as well as reducing light pollution and intrusive lighting.

This solution is broadly considered much better than switching off one of each two lighting points (a common practice in some municipalities in the past) which had the big disadvantage of heavily affecting uniformity and thus the very essential function of street lighting.

Dimming is possible in LED installations with very large flexibility, as well as with MH or HPS lamps. With a magnetic transformer it is possible to dim HPS and MV lamps up to 50% of their full lighting output, while electronic ballasts can allow dimming up to 50% all discharge lamps and up to only 10% of their full output HPS lamps (Baenziger, 2002). If correctly done, dimming can also allow to obtain lamp life extensions of up to 100% (Baenziger, 2002).

- Introduce intelligent street lighting (e.g. using sensors to temporarily increase the lighting levels when the presence of people is detected)

Intelligent street lighting is the name that it is used to refer to a series of measures that allow reducing the energy consumption of lighting by adapting the lighting output in each point of the installation to the needs over time and according to certain criteria. The most common uses of intelligent street lighting are the reduction of luminance based on traffic density or weather conditions. It is a more sophisticated way of implementing dimming without affecting the service provided by the street lighting to the citizens.

The main features that intelligent street lighting installations can have are, from the simpler ones to the most sophisticated (Andrei et al., 2009):

- switch on/off based on preset schedule
- remote control of switch on/off (communication via wireless or power line communication between the lighting points and a central control centre)
- possibility to dim lights at different levels (from remote)
- monitoring functional parameters (such as current and voltage) from remote

- automatic alert of potential defects

- monitoring energy consumption at the level of each luminaire from remote

- automatic switch on/off depending on level of natural light

- dimming regulated by sensors of ambient lighting (to allow reducing the additional lighting provided by street lighting only to the minimum necessary)

- presence sensors (to increase the lighting levels only when the street is in use),

- weather sensors (to allow to provide more lighting when the weather conditions determine low visibility)

- provide the possibility for the public to control, to a certain extent, the street lighting system (e.g. providing a telephone number to allow the public to switch on or increase the lighting outputs)

According to Baenziger (2002), the implementation of intelligent street lighting has pay back periods within 3-5 years thanks to energy and maintenance savings, with energy savings of 30 to 40%.

Moreover, as already said for dimming, good control means lamp life extension of up to 100% for HPS lamps (Baenziger, 2002).

Another benefit of such a solution is the need for much less on-the-field maintenance, thanks to the possibility to monitor lamp failure and even to replace faulty lamps before they fail. This also increases the reliability of the street lighting installation.

There are however a number of main challenges to the implementation of this best environmental management practices by municipalities that should be taken into account:

- many municipalities do not have a proper street lighting maintenance scheme in place (Baenziger, 2002);

- the people in charge of buying replacement lamps lack knowledge on lamps and lighting and choose the options with cheapest initial costs (Baenziger, 2002);

- part of the savings can be offset by an improvement in street lighting quality (for instance, in Vilnius high-pressure mercury lamp luminaires were replaced by high-pressure sodium lamp luminaires reducing installed capacity by 50% but energy consumption only by 16% - Balsys et al., 2002).

The main steps to be followed are thus:

- Prioritise areas for interventions

- e.g. start by addressing most inefficient solutions, such as globe shaped luminaires with mercury vapour lamps

- Run a lighting study to understand the real needs and how to meet them in the most effective and efficient way

- Explore which way can be the most suited to finance the implementation of the solution

[1] Italian electricity statistics report a consumption for street lighting of 6201.8 GWh in 2011 out of a total consumption of 313 792.1 GWh (Terna, 2012)

[2] 60% in Huenges Wajer et al., 2009; 50-75% in MEDDTL, 2012; 62-86% in UBA (2011a, 2011b, 2011c, 2011d, 2011e, 2011f, 2011g).

[3] In 2006 the following countries were IEA members: Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Japan, Republic of Korea, Luxembourg, The Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, United Kingdom, and the United States (IEA, 2013).

Environmental benefits

According to the European E-Street project (as quoted in Huenges Wajer et al, 2009), up to 36 TWh/year can be saved in Europe by implementing existing technology. If energy efficient street lighting is implemented in a municipality, energy savings up to 60-86% can be achieved with a substantial reduction in the energy bill.

Moreover, improved street lighting results in decreased light pollution, with positive consequences for biodiversity as well as human health.

Side effects

The implementation of this best practice does not lead to any environmental cross-media effect.

Applicability

This best environmental management practice is applicable to all municipalities managing directly or indirectly (through a public or private company) the provision of street lighting.

As explained, not all of the measures described are the best solution for each municipality.

Identifying priority areas of intervention, especially when based on an accurate inventory and auditing of the street lighting stock, is key.

As described in the next section 'economics' the implementation of energy efficient street lighting can be subject to relevant and long-term economic investments and public administration, in light of their specific features compared to the private sector, may face some challenges in this respect.

Economics

Upgrading a street lighting installation as described in this technique makes economic sense, meaning that the costs savings mainly in terms of energy savings and maintenance cost savings can balance the investment costs within relatively short payback periods.

One of the main challenges to the widespread deployment of the best available technology and management practices are the rather large upfront investment often needed (IEA, 2006).

One solution to this problem can be using energy performance contracts for the provision of the street lighting service. This is the approach that a number of cities have adopted recently (Koster, Philips, pers.comm., 14 September 2012). Big cities can also finance feasibility studies for investment in sustainable energy at local level, including public lighting, through the ELENA technical assistance facility or the European Energy Efficiency Fund (EEE-F).

Driving forces for implementation

Energy savings and reduced electricity bills for the municipality are the main driving force to implement this technique.

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Gothenburg (Sweden) – ESOLI project

Langen (Germany) – winner of the European Green Light award 2012

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