SUSTAINABLE STREET LIGHTING

A Guide to Efficient Public Street Lighting for Lebanon

A UNDP-CEDRO Publication

December 2015

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SUSTAINABLE STREET LIGHTING:

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Edited by
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This study is implemented by the UNDP-CEDRO Project; Phase 4

This project is funded by the European Union

CEDRO phase 4 (2014–2016) is funded by the European Union

ACKNOWLEDGEMENT

The UNDP-CEDRO Project would like to thank the European Union for the donation of funds that enabled the CEDRO project's current forth phase. This study has been funded through their kind contribution.

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Note: The information contained within this document has been developed within a specific scope, and might be updated in the future.

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LIST OF ACRONYMS & ABBREVIATIONS

ADT	Average Daily Traffic
AGM	Absorbed Glass Mat
ANSI	American National Standards Institute
BSI	British Standards Institute
Cd	candela
CDR	Council of Development and Reconstruction
CEDRO	Community Energy Efficiency & Renewable Energy Demonstration Project for Lebanon
CFL	Compact Fluorescent Lamp
CRI	Color Rendering Index
EDL	Electricite du Liban
$E_{sc,min}$	Minimum semi-cylindrical illuminance
$E_{v,min}$	Minimum vertical illuminance
GLS	General Lighting Service
HPMV	High Pressure Mercury Vapor
HPS	High Pressure Sodium
HVAC	Heating, Refrigerating and Air Conditioning
HZ	Hertz
IENSA	Illuminating Engineering Society of North America
IES	Illuminating Engineering Society
Lav	Average illuminance over whole of used surface
LCEC	Lebanese Center for Energy Conservation
LED	Light Emitting Diode
LPMV	Low Pressure Mercury Vapor
LPS	Low Pressure Sodium
MEW	Ministry of Energy and Water
MOB	Municipality of Beirut
MOIM	Ministry of Interior and Municipalities
MPW	Ministry of Public Works
PSL	Public Street Lighting
PV	Photovoltaic
SR	Surround Ration
STC	Standard Test Conditions
TFL	Tubular Fluorescent Lamp
TI	Threshold increment
TWh	Terawatt Hour (109 kWh)
U_L	Longitudinal uniformity of illuminance
U_o	Uniformity of illuminance
Voc	Open Circuit Voltage
VRLA	Valve-Regulated Lead-Acid

Basic Definition of Terms

Candela (cd)	Luminous intensity in a given direction (1 cd = a body that emits a monochromatic radiation at 540 x 1012 Hz and has an intensity of radiation in that direction of 1/683 W per steradian)
Color Rendering Index	The ability of a light source to render colors of surfaces accurately. It is based on the accuracy with which a set of test colors is reproduced by the lamp of interest relative to a test lamp, perfect agreement being given a score of 100. Rendering groups and index shown in Table 1.
Color Temperature	The color appearance of the lamp and its light expressed in Kelvin scale (K). It is an indication of how warm, neutral, or cool the light source is. The lower the temperature is, the warmer the lighting source. **Unit: K**
Glare	Light that either reduces the comfort or directly reduces the vision. Maximum requirements are set for street lighting installations.
Illuminance	The metric unit of measure to illuminate a surface. It is the average of different lux levels at various points and is equivalent to one lumen per square meter. Formula: Lumen / Area **Unit: Lux**
Installed Load Efficacy	The average maintained illuminance on a horizontal plan per circuit watt with general lighting of an interior. Installed Load Efficacy ratio is the ratio of target load efficacy and installed load. **Unit: Lux/W/m^2**
Intelligence	Built-in electronics in the luminaire that can measure and control the luminiare and make two-way communication possible and thereby achieve adaptive lighting, also called intelligent lighting.
Light Pollution	Pollution caused by very high levels of lighting. It is defined as the direct or indirect entry of artificial light into the environment. It leads to the degradation of nighttime ambience and alters the nature of urban areas and environments.
Lumen	The luminous flux emitted within a unit solid angle by a point source with a uniform luminous intensity of one candela. It is the photometric equivalent of the watt, weighted to match the eye response of the "standard observer". 1 watt = 683 lumens at 555 nm wavelength. It is referred to as the luminous flux per square meter of a sphere with a 1 meter radius and a 1 candela isotropic light source at the center. Formula: $4\pi \times$ luminous intensity **Unit: lm**
Luminaire	The lighting unit with all parts and components including lamps as well as support, power supply, light diffusion, positioning, and protection components.
Luminance	Density of reflected or emitted light from a surface in a specific direction, per unit area. It is very important in street lighting. **Unit: Cd / m^2**
Luminous Intensity (I)	The luminous flux, which falls on each square meter of a sphere one meter in radius when a 1-candela isotropic light source is at the center of the sphere. Formula: Lumen / 4π **Unit: Candela**
Mounting Height	The height of the fixture or lamp above the working plane
Photopic Vision	Eye vision under well-lit conditions. It allows color perception, mediated by cone cells, and a significantly higher visual acuity and temporal resolution than available with scotopic vision.
Rated Luminous Efficacy	The ratio of rated lumen output of the lamp and the rated power consumption.
Room Index	The ratio relating plan dimensions of the room to the height between the working plane and the plane of the fittings.
Scotopic Vision	Eye vision under low-lit conditions. It is produced exclusively through rod cells, which are most sensitive to wavelengths of light around 498 nm and insensitive to wavelengths longer than about 640 nm.
Target Load Efficacy	The value of Installed Load Efficacy considered being achievable under best efficiency. **Unit: Lux/W/m^2**
The Inverse Square Law	The law that defines the relationship between luminance from a point source and distance, with intensity of light per unit area being inversely proportional to the square of distance from source. **Formula: $E = I / d^2$**
Uniformity	Relative number that indicates the relation between the lowest luminance level present and the average luminance level present in a defined measuring field. Minimum requirements are given for street lighting installations.
Utilization Factor (UF)	The measure of the effectiveness of lighting that is the proportion of the luminous flux of the lamp reaching the working plane.
Veiling Luminance	A luminance superimposed over the eye›s retinal image, produced by stray light within the eye. The veiling luminance ratio is a ratio of maximum veiling luminance to average pavement luminance.

EXECUTIVE SUMMARY

This present publication provides an analysis and evaluation of the possible public street lighting designs that can be found in Lebanon and/or can be installed in the foreseeable future. Public street lighting is one of the key public services governments and municipalities offer, and it is a strong indicator of a nation's development level and progress in infrastructure provision. The major importance of public street lighting is its impact on enhancing safety conditions, reducing road accidents, and encouraging social activity.

The Lebanese roads feature various types of public street lighting systems mainly ranging from grid powered with simple operation to PV powered with advanced control, therefore a survey of the available street lighting designs was completed. A detailed description of the possible systems and features to be included in street lighting designs, include: lamp types and their technical characteristics, energy sources, and control options. Interviews have been conducted with few municipalities as to provide the end user's feedback on the performance of the applied systems in their villages. In order to assess the effectiveness of the available systems and technologies, as well as the possibility of retrofitting currently installed streetlights, a techno-financial analysis is performed comparing options that are available in the Lebanese market.

Results show that options with LED lamps are more cost-effective than ones with the widely used High Pressure Sodium (HPS) and Inductive lamps. As for the energy source and control system, grid powered implementations with advanced control presented the most cost – effective solution followed by grid powered with basic control and PV power with advanced control.

Financial analysis for energy efficient options, compared to business as usual HPS lamps, show high internal rate of returns (IRR), reaching up to more than fifty percent for some applications. This depends on the operating hours, lamp power, dimmability potential, and other luminance requirements.

The selection of the best street lighting option depends on a number of variables that should be given special attention during the design phase, with main design considerations to maximize the coefficient of utilization, prevent direct light upward emissions, avoid excess lighting levels, implement adaptive lighting, avoid short wavelengths, use proper luminaire distribution design, follow proper spacing, and select technical reliable material and equipment.

Proper selection of street lighting designs and selection of cost-effective options could save hundreds of Megawatt hours (MWhs) and reduce the electrical load. In addition, it would reduce greenhouse gas emissions and help achieve national targets of GHG emissions should they be put in place in the near future for Lebanon.

This report aims to provide the major criteria and technical considerations upon selection of public street lighting for Lebanon, including a techno-financial appraisal of the various options outlined.

INTRODUCTION

Public street lighting (PSL) is a major consumer of electricity. It serves as an indispensable social and economic objective of reducing crime, increasing road safety, and enhancing social interactions within towns and villages. In Europe, for example, public street lighting accounts for about six percent of the tertiary sector electricity consumption, varying from one country to another depending on the density of light points and the lamp technologies used. In some European countries, it reaches 12% of the tertiary sectors' electricity consumption (Fleiter et al., 2010). More importantly however, is the share of total electricity consumption of various towns and villages' public facilities, and this can reach 30-50% of total electricity consumption of municipalities (EPEC, 2015). In Lebanon this is not difference, and street lighting constitutes a burden for many municipalities' already restricted budgets.

Total annual electricity consumption for PSL in Lebanon is difficult to estimate, given a lack of data availability and centralized registry with respect to this sector, particularly due to the involvement of various public institutions in the installation, operation and maintenance of PSL. Furthermore, there is a lack of harmony or standardization in the use of PSL among these institutions, and the use of PSL can be considered, to date, relatively inefficient and/or inefficient in its operation (e.g. PSL operating during the day).

There is sufficient room for improvement in this sector, and concerned ministries and official bodies have already done considerable work and are seeking to provide effective PSL in various regions of Lebanon and to reduce PSL consumption through demonstration projects, proposed regulations, and awareness raising. This report provides an introduction about the different lighting options and their applications, while emphasizing on public lighting. Different lighting technologies are assessed from a technical, financial and environmental perspective, providing a better understanding of the parameters taken into account while designing public street lighting.

Why street lighting?

Being one of the key public services provided by municipalities and other public authorities, public street lighting is an important indicator of a nation's development and progress level. Street lighting enhances the appeal of cities and neighborhoods and provides a relatively more modernized perception of communities' infrastructure availability and efficacy. It plays a major role in highlighting attractive landmarks and accentuating the ambiance during night.
But the major motive behind street lighting is improving road safety and protecting human lives. Proper and well-designed lighting is thereby essential since it contributes to safe roads, reduction of car accidents, and an increase in drivers' and pedestrians' levels of comfort.

As soon as the sun goes down and the lights go off, it becomes essential to light up the streets and provide motorists, cyclists, and pedestrians with enough visibility to increase safety levels and to avoid accidents that lead to injury or mortality.
Studies conducted in this sector show that pedestrian accidents are reduced by around fifty percent as a result of proper street lighting (Box, 1970). Pedestrian accidents normally occur due to poor visibility levels where pedestrians are hit by cars under a variety of circumstances. Research indicates that pedestrian fatalities increase by 3 to 6.7 times in the dark compared to daylight (Commission Internationale de l'Éclairage, 1992), and that lighted intersections and highway interchanges tend to be characterized with a considerably lower rate of accidents than those that do not have such lighting elements (Scienceline, 2006).

Another important aspect of proper street lighting is its role in reducing crime and vandalism by enhancing the sense of personal safety and improving the security of properties. Street lighting helps in making residents and pedestrians feel safe to walk at night. This issue becomes even more important in regions, cities, towns and villages that are experiencing disruption due to, for example, an influx of refugees or other disruption, as is the case in Lebanon in since 2011 up to the publication of this report (2015).

LIGHTING TECHNOLOGY, STANDARDSAND REQUIREMENTS

The electromagnetic spectrum varies with wavelength from one in thousands of nanometers to billions. The visible light is a small portion of these electromagnetic waves present in space, located between infrared heat and ultraviolet light as shown in Figure 1.

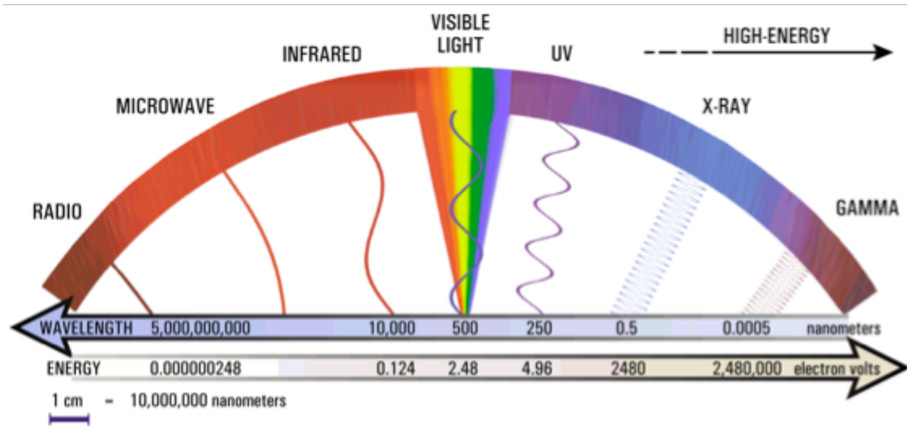


Figure1: Electromagnetic spectrum and visible radiation (Steinle, 2010)

In principle, light is emitted from a body due to one of four phenomena:

1- Incandescence: when bodies are heated to temperatures of 1000°K
2- Electric discharge: by atoms and molecules when electric current passes through a gas
3- Electro luminescence: by semiconductor-like bodies when electric current passes through them
4- Photoluminescence: by solids reemitting absorbed radiation at a different wavelength

Different lighting technologies were utilized using these phenomena, presented in Table 1 and Figure 2 and described in the following section on the evolution of street lighting.

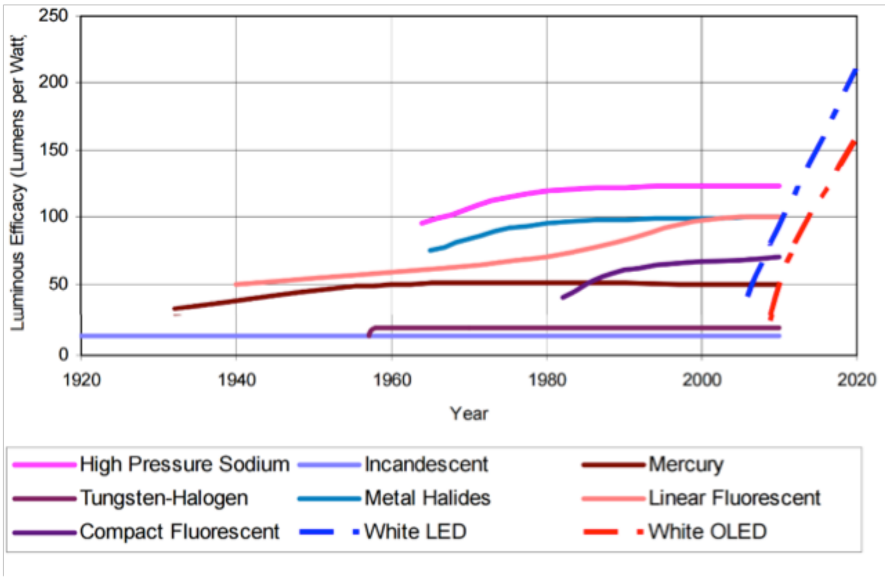


Figure 2: Major lamps development for general lighting (Krames, 2007)

Figure 2 shows the performance of various lighting technologies in terms of luminous efficacy (i.e., lumens per watt), both in the past and expected in the future. Notable is the expected future performance of light-emitting diode (LED) technology. Table 1 compares these lighting technologies accordingly to other parameters such as lifespan, ability to dim, and upfront costs (capex) and running costs (opex).

Table 1: Lighting technologies comparative table

Lamp	Lm/ Watt	Color rendering index (CRI)	Lifespan (hrs)	Dimmability	Capex	Opex	Applications
GLS	5-15	○✪✪✪✪	1,000	Excellent	+	✷	General lighting
Tungsten Halogen	12-35	○✪✪✪✪	2,000 – 4,000	Excellent	+	✶	General lighting
Mercury vapor	40-60	○○✪✪✪	12,000	Not possible	✹	✹	Outdoor lighting
CFL	40-65	○○○✪✪	6,000 – 12,000	Special lamps	+	+	General lighting
Fluores-cent Lamp	50-100	○○✪✪✪	10,000 – 16,000	Good	+	+	General lighting
Induction Lamp	60 - 80	○○✪✪✪	60,000 – 100,000	Not possible	✶	+	Difficult maintenance applications
Metal Halide	50 - 100	○○✪✪✪	6,000 – 12,000	Not practical	✶	+	Commercial buildings
HPS (standard)	80-100	○○○✪✪	12,000 –16,000	Not practical	✶	+	Outdoor street lighting, warehouse
HPS (color improved)	40-60	○○✪✪✪	6,000 – 10,000	Not practical	✶	+	Outdoor, commercial interior lighting
LPS	80-180	○○○○○	10,000 – 18,000	Not practical	✶	+	Outdoor lighting
LED	20-120	○○✪✪✪	50,000 – 100,000	Excellent	✶	+	All in near future

Legend:

○○○○○ Very Poor

○○○○✪ Poor

○○○✪✪ Fair

○○✪✪✪ Good

○✪✪✪✪ Very Good

✪✪✪✪✪ Excellent

+ Low

✹ Moderate

✶ High

✷ Very high

EVOLUTION OF STREET LIGHT

Outdoor (e.g. garden lighting) and street lighting started a few centuries back. Even before Edison first introduced his commercial lamp, light was invented and the need for outdoor lighting was identified, passing through different phases and stages until it reached the current models of public street lighting.

Arc Lighting

Based on the concept of carbon rods in a closed electric circuit with carbon separated, the arc lamp was the first lamp ever used. It was later developed in 1876 by Charles Brush, who invented the open carbon arc that was the first street lighting lamp ever (Maurath, 2012).

This technology appeared to be effective but didn't seem to become popular, especially with the need for trimming (a maintenance requirement done to arc lamps to change the carbons) and the frequent replacement of electrodes, in addition to the presence of unwanted combustion byproducts.

There were two major types of Arc lights, the first being the open arc which was operated with carbon electrodes openly exposed to the atmosphere, while the second was the enclosed arc light that was developed in the mid-1890s and limited to operating inside a glass globe, which played a major role in increasing the electrodes' life to reach almost 125 burning hours.
Compared to carbon-filament street lighting that was present in those days, Arc street lighting was considered a blessing in terms of efficiency and color quality.

Incandescent Series Lamps

Arc lighting did not survive long, especially when tungsten-coiled series street lighting was introduced. In 1912 "Mazda C", the first gas-filled tungsten filament lamp, was introduced, offering whiter light, increased efficiency, and improved lamp life. This led to a rapid decline of Arc lighting and the widespread use of incandescent for street lighting (Maurath, 2012).

Incandescent lighting passed through various stages throughout the years, developing from a couple of hundred lumens to 6,000 and 8,000 lumens in the twentieth century. The modern look of incandescent lamps started in the early years of the past century, evolving as shown in Figure 3.

1915 1920 1930

Figure 3: Evolution of incandescent street lights

Incandescent Multiple Lamps

Multiple lamps have significant variations compared to series-type lamps since they operate directly from the voltage supplied by the utility distribution circuit. Although this method was present in the early 1900s, it was not actually given much attention until the late 1940s, especially with photo-electric control being introduced and becoming more affordable.
Multiple fixtures were usually operated by a separate control on the pole, while some were operated in groups from one photo-control that can handle higher amounts of current. Then in the 1950s, integral photo-controls started to be more popular, especially when they became cheaper years later.

Mercury Vapor

Mercury vapor was something totally new introduced to street lighting. The concept of mercury lamps is based on an electric discharge tube containing mercury vapor and put under pressure. The vapor density decides on the color output and lamp efficacy, while the first can be modified using different methods such as the use of phosphorous (Maurath, 2012).
Mercury vapor lamps were used extensively for street lighting applications with wattage of 100 and above, but suffered from poor color rendering which required the development of different types of mercury vapor lamps such as phosphorus-coated lamps, yellow mercury lamps, deluxe white lamps, and caution yellow lamps.

Low Pressure Sodium

Known as sodium illumination before the 1960s when high-pressure sodium was introduced, low-pressure sodium (LPS) was considered a state-of-the-art technology reaching up to fifty lumen per watt with approximately 18,000-hour lifespan. This was considered a great achievement in those days. Its capacity was double that of incandescent streetlights.
The 180W 10,000-lumen and the 145W 6,000-lumen LPS lamp were the most widely used street lighting lamps for highways and bridges, especially in Europe. The major drawback was color distortion making things appear a bit yellowish. But LPS remains advantageous in foggy regions because it doesn't scatter light.
Fluorescent Lamps

General Electric (GE) was the leader in manufacturing fluorescent lamps back in the late-1950s, introducing it as a street lighting application that was widely used in those days especially in the United States in the 1960s. Fluorescent lamps had the advantages of higher efficiency, increased lifespan, and excellent color rendering.

However fluorescent street lighting didn't last much and by 1980 you could rarely find any of them because they stopped being installed in the early 1970s (Maurath, 2012).
High-Pressure Sodium

GE also led the introduction of high-pressure sodium (HPS) back in the 1960s with the first 400W HPS street lamp. A couple of years later, more wattage were introduced offering more flexibility, especially for secondary streets' applications.

HPS lamps are characterized by their high efficacy, long life, and good color rendering compared to LPS and other technologies used at that time. It is still being considered as one of the most used lighting technologies for street lighting.

Metal Halides

The first commercially available metal halide lamp was introduced in 1965 with a 400 wattage offering 80 to 90 lumens per watt with around 6,000 hours lifespan (Maurath, 2012).
These lamps are usually enclosed in elliptical envelopes and very similar in appearance to mercury vapor lamps. In order to reduce glare and improve color rendering, some lamps are internally coated with phosphor.
Metal halides are not widely used in street lighting applications; this is mainly due to the presence of high performance HPS lamps that offer better options than metal halides.

Light Emitting Diode

LED lighting is currently the most efficient and growing application for public street lighting due to its improving technology, high lumen per watt ratio, and wide variety of shapes and applications.

LED offers higher efficacy and a good color rendering compared to other technologies that are currently being used. However, much care needs to be taken when designing LED public street lighting applications to make sure proper lighting requirements are met such as lux levels, color rendering, color temperature, and uniformity.

STREET LIGHTING STANDARDS & REQUIREMENTS

There are several standards and codes followed in the design of street lighting to guarantee energy performance and safety requirements. A number of standards and codes are currently in place, varying from one country to another. In principle, these standards consider various variables and influencing parameters that affect light requirements. These variables are:

1. Speed:	Vehicle and pedestrian flow rate, speed limit, and composition
2. Geometry:	Type of junctions, intersection density, conflict areas, etc…
3. Traffic use:	Flow of vehicles and pedestrians, parked vehicles, crime risk, etc…
4. Environmental:	Complexity of visual field, ambient luminance, weather type, color rendition
5. Visual guidance:	Including traffic control

The main and most commonly adopted standards, along with a link from which they are published, are presented in Table 2 and further elaborated on below.

Table 2: Common internationally adopted standards and codes

Standard	Description	By
CIE-115	Lighting of roads for motor and pedestrian traffic,	CIE (www.cie.co.at)
CIE 180	Road Transport Lighting for Developing Countries	CIE (www.cie.co.at)
BS EN 13201-2:2004	Road lighting. Performance requirements	BSI (www.bsigroup.com)
ANSI/IESNA RP-8	American national standard practice for roadway lighting	ANSI/IES (www.ies.org)

CIE 115

The latest CIE version is CIE 115:2010 that is being followed in several countries, especially in Europe. According to CIE 115:2010, there are different sets of classes applied to lighting, namely:

- **Class M** for motorized traffic
- **Class C** for conflict areas[1]
- **Class P** for pedestrian and low speed traffic areas

These classes are described with the influencing parameters listed in Annex I: Selection Parameters and Design Factors for Lighting Classes in CIE 115:2010.

CIE 180

CIE 180 standard is developed for developing countries where safety is always at risk. It discusses the nighttime value of simple road markings and signs, stressing the importance of retro-reflective materials. This leads to the role of vehicle lighting, with particular emphasis on the need for individual drivers to take responsibility for cleaning and aiming of their vehicle lights.

A chapter in CIE 180 on fixed roadway lighting deals with the basic design of simple installations and explains the many different factors that need to be considered. Because of its importance, maintenance is considered in a separate chapter.

Design requirements for developing countries are presented in Annex 2: Lamination Requirements in CIE 118:2007.

BS EN 13201

The European Norm for Road Lighting (EN13201) provides the basis for specifying lighting quality for a given scheme. It is divided into three norms as follows:
- **BS EN 13201-2:** Performance Requirements
- **BS EN 13201-3:** Calculation of Performance
- **BS EN 13201-4:** Methods of Measuring Lighting Performance

The factors of interest in the norm are: ME (Luminance), S (Illuminance) and CE (Conflict areas). Design requirements are presented in Annex 3: Technical Requirements in EN 31201 Standards.

IESNA RP-8

The IESNA RP-8 standard provides practices for designing new continuous lighting systems for roadways and streets. Roadway and street lighting includes pedestrian and bikeway lighting when it is associated with the public right-of-way.

This standard is adopted in North America. It provides uniformity and veiling luminance ratio (see basic definition of terms, page 4 and 5) for different Road and Pedestrian Conflict Area combinations and considering different pavement classifications (R1, R2, R3, and R4).
Road types are Freeway Class A and Freeway Class B, in addition to Expressway, Major, Collector, and Local with different pedestrian conflict areas (High, Medium, and Low).

Design requirements are presented in Annex 4: Lamination Requirements in ANSI/IESNA RP-8.

[1] Conflict areas are areas where vehicle streams intersect each other or run into areas frequented by pedestrians, cyclists, or other road users, or when the existing road is connected to a stretch with substandard geometry, such as a reduced number of lanes or a reduced lane or road width.

ENERGY EFFICIENCY IN LIGHTING

Lighting (both indoor and outdoor lighting) makes up a significant share of electricity consumption for facilities and buildings, particularly due to the considerable time that they are needed and used. In order to reduce the impact of lighting electricity bills without compromising the quality, availability, or convenience of lighting, several methods, that are discussed below in this section, are being utilized to reduce lighting electricity consumption.
With respect to PSL, the focus of this report, studies have shown that over a period of 35 years, a typical street lighting operation would incur costs split between 85% for maintenance and operation - inclusive of power supply, and as low as 15% for capital cost (EPEC, 2015). According to one study regarding the benefits of switching to more energy efficient street lighting in Europe, it is indicated that the continent could save more than 3 billion Euros in energy costs a year when switching from old to new street lighting technologies.
The below sections summarize the key parameters that can be used for lighting, in general (i.e. both indoor and/or outdoor), to gain efficiency or more of the required light with less power usage.

Natural Daylight

The objective that should be targeted for any practitioner with energy efficiency in mind is to harvest natural lighting as much as possible. In fact, natural lighting offers the highest level of comfort and provides users with a comforting lighting option.
This option sometimes becomes less convenient in air-conditioned areas where attempts to reduce cooling or heating load is a requirement. Yet, there are modern technologies applied to benefit from natural lighting without having to take the heat that comes with solar radiation. This is done, for example, through the use of skylight systems that channel the light in tubes and transfer the light to the needed areas.
Some methods used to benefit from natural lighting are:

1- Lighting through windows:

This needs to be well designed to avoid glare, and could be incorporated with light shelves to provide disturbance due to glare.

2- Glass strips:

This innovative design eliminates glare and allows the harvested light to blend well with the interiors. Glass strips running across the breadth of the roof can provide good uniform lighting; it is most appropriate in industrial applications.

3- Skylights:

Using skylights with Fiber-reinforced plastic (FRP) material along with transparent or translucent false ceilings reduces glare and avoids the heat generation that adds to the cooling load.

De-lamping

Over-lighting is a major design issue that leads to a considerable waste of electrical energy. Excessive lighting doesn't only waste power, but it also reduces the level of comfort among users. Using a lux meter, and following the standard requirements of lighting levels, the lamp design can be modified to reduce unnecessary lamps especially in industrial and office applications where lighting remains on for more than ten consecutive hours. De-lamping can happen by reducing the number of lamps, splitting the lighting circuit, and isolating unnecessary fixtures.

High Efficiency Lamps

Some lamps are more efficient than others, offering the same levels of lighting but with less electricity consumption. Table 2 summarized the different types of lamps and clearly showed the efficiency levels of different lamps under the column of lumen/Watt. The higher this ratio is, the more efficient the lamp is.

However, there are more parameters that need to be met for effective lighting. These requirements encompass color rendering, cost of retrofit, maintenance requirements, and lifespan of the lamp.

Common lighting retrofits and energy saving potential are presented in Table 3.

Table 3: Potential savings through lamp retrofit

Original Lamp	Replaced by	Potential Saving (%)
Gallium Lanthanum Sulfide Glass (GLS)	CFL	38 – 75
High Pressure Mercury Vapor Lamps (HPMV)	CFL	45 - 54
	Tube light (Krypton)	54 – 61
	Metal Halide	37
	HPS	34 – 57
Metal Halide	CFL	66
	Tube light (Krypton)	48 – 73
	HPS	35
High Pressure Sodium (HPS)	CFL	66 – 73
	Tube light (Krypton)	48 – 84
	LPS	42
Standard tube light (Argon)	Slim tube light (Krypton)	9 – 11
Tungsten Halogen	Tube light (Krypton)	31 – 61
Mercury blended lamp	HPMV	41
LPM	HPS	62
LPS	HPS	42

Feeder Voltage Control

It is possible to reduce a lamps' energy consumption by reducing the feeder voltage, but that would also lead to a reduction in lighting output. As long as this reduction is in the acceptable zone, where lighting level requirements are still met, feeder voltage reduction would be a practical solution.

Table 4 shows the effect of feeder voltage variation on power consumption and lighting output for different types of lamps.

Table 4: Feeder voltage variation effect

	10% Lower Voltage		10% Higher Voltage	
	Light reduction	Power reduction	Light increase	Power increase
Fluorescent	9%	15%	8%	8%
HPMV	20%	16%	20%	17%
Mercury blended	24%	20%	30%	20%
Metal halide	30%	20%	30%	20%
HPS	28%	20%	30%	26%
LPS	4%	8%	2%	3%

Electronic Ballasts

In addition to the electrical power needed to light the lamp, the ballast also adds to the consumption as electromagnetic ballasts are used to provide more voltage to start the light, mainly tube lights. The new electronic ballasts reduce electricity consumption by acting as oscillators and converting the frequency to the range of 20,000-30,000 hertz. This can be applied to fluorescent tube lights, CFLs, LPS, and HPS lamps.

Using electronic ballasts brings in several benefits including:

1. **Immediate lighting:** since there is no starter anymore and no more flickering when first turning the lights on
2. **Improved Efficacy:** at higher frequencies, tubes have better efficacy and this leads to additional electricity saving
3. **Reduced power loss:** Lamps usually consume around 10 to 15 additional watts for standard magnetic ballasts. With electronic ballasts, this additional consumption is reduced by up to 99%. Typical elecromagnetic ballast and electronic ballast consumptions are presented in Table 5.

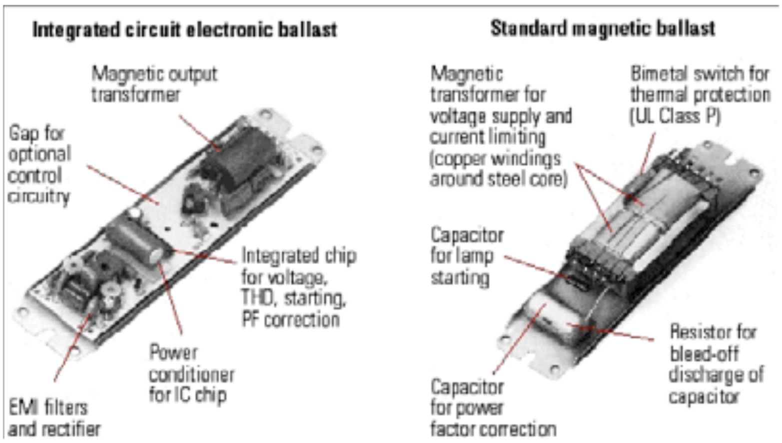


Table 5: Total fixture wattage and savings for magnetic and electronic ballasts

Lamp	Magnetic ballast	Electronic ballast	Power Saving (W)
TFL 40W	51	35	16
LPS 35W	48	32	16
HPS 79W	81	75	6

Occupancy Sensors

In areas of low occupancy, sensors are used to detect the presence of people and decide on turning the lamps on or off. Occupancy sensors are usually passive infrared, ultrasonic, or a combination of both.
Passive infrared sensors are based on heat and are designed to react to heat changes within a certain area. This requires an unobstructed view of the covered region. Passive sensors are best used in open areas where doors, stairways, and partitions are not there to block a sensor's view.
Ultrasonic sensors are active sensors that transmit sound at a certain level above human hearing levels, and it waits to get the waves back. Based on the time and any pattern breaks noticed by the sensor, the control is activated. These sensors are best used in areas requiring 360 degrees coverage.
Several considerations need to be taken when applying occupancy sensors to avoid inconvenience. For example, sometimes the lights might be turned off while people are still in the room. In this case, it is recommended to include manual control switches. It is also recommended to keep ultrasonic sensors away from HVAC ducts to avoid vibration caused by these ducts.

Lighting Controls

Lighting control can be used to automatically switch the lights on and off and apply dimming. These controls include manual timers, automatic timers, and photo-sensors.
Timers act as clocks; they are programmed with the dusk to dawn period duration. We use timers to arrange starting times, turning off times and dimming. The operator, based on the season, day length, and other variations, preset timers manually. Such an activity is usually done every three months and sometimes every six months. Newer technologies use pre-programmed timers that automatically change the time everyday based on the variables fed in regarding dusk and dawn time. These reduce maintenance requirements and lead to better results.
Usually there are three time controls being used. The first and most trivial is a simple time switch that just uses a preset time through which the lighting on and off operation is managed by a turn-on time and turn-off time. The second is a multi-channel time control, which has the ability to control four to sixteen duties allowing for a wider range of control as compared to an on-off operation. The third is a special purpose time control that is used in cycles based on the operational profile of the facility.

The problem with timers is that they only work based on a set time, typically from dusk to dawn; they do not turn on when there are low lighting levels caused by fogs, sand storms, or any other environmental factors. Here is where photo-sensors come in handy.
The role of a photo-sensor is to detect the level of lighting available and decide on whether to turn on the lights, dim them or turn them off based on the availability of light. This solves the problem of lighting demand during the day, but also requires further maintenance especially in areas with high levels of dust. The sensor can be covered with dust or other particles and thus reads low lighting levels, which lead to the lamps turning on during unnecessary times.
In order to apply dimming, additional dimming devices are needed. The role of timers and photo -sensors are to give the order to the lamps but not perform the dimming. When coupled with a supplementary dimmer, lighting levels can be controlled accordingly.

Maintenance

Keeping the lamps in good shape is important to keeping them efficient. Some lamps age and become a waste of electricity; others get dirty and require cleaning. It is important to take care of the fixture, the lamp, the lenses, and the surrounding area to avoid wasted lighting and unnecessary electricity waste.

PUBLIC STREET LIGHTING IN LEBANON

Current Trends

Public street lighting provision in Lebanon encompasses a variety of actors and different authorities. This caused and causes a lack of systematic and structured data and information about this sector on a national level, making it difficult to properly present the current overall situation, the applied technologies, and the distribution of street lighting loads.
Currently, most newly installed public streetlights use HPS lamps. The rating of the lamp varies by application but it is mainly 150 Watts for municipal and inner roads. As for older technologies, such as incandescent and metal halide that are still in operation in certain areas due to insufficient funds to perform retrofits and lighting fixture upgrades, these street lighting facilities are outdated and therefore highly inefficient. This leads to higher energy and maintenance requirements. In areas using these old technologies, street lighting can account for as much as 30-50% of the municipalities' entire power consumption.

Stakeholders: Who Does What?

A variety of stakeholders are involved in this sector. More often than not, coordination between the different parties is lacking, leading to inefficiencies, the lack of standardization, and a lack of follow-up and proper maintenance on the operation of the systems. The major stakeholders are presented in Table 6 with their roles in respect to street lighting discussed briefly hereafter.

Table 6: Major stakeholders involved in the public street lighting sector in Lebanon

Stakeholder	Responsibility	Execution	Ownership	Billing	O&M
Ministry of Public Works	Highways	3	3	3	3
	Primary roads	3	3	3	3
Council for Development and Reconstruction	Highways	3			3[2]
Ministry of Interior and Municipalities	Local Streets	3	3	3	3
Électricité Du Liban	Bills users				
Ministry of Energy & Water	Distribution of lamps				
Lebanese Center for Energy Conservation	RE and EE street lights				
United Nations Development Programme - Lebanon	RE and EE street lights				

CDR

The Council for Development and Reconstruction (CDR) executes highway street lighting projects and delivers to the Ministry of Energy and Water, with a 1-year defect liability period.

[2] For first year

MPW

The Ministry of Public Works (MPW) is responsible for major highways including international roads. They are in charge of the operation, maintenance, and billing of/for public street lights. The MPW pays the bills for the electricity consumption of highways and main roads.

MOIM

All internal roads are governed by municipalities. The execution, retrofit, operation, and maintenance is done by the municipality's team and within their own budgets. Municipalities fall under the authority of the Ministry of Interior and Municipalities (MOIM).

MEW

The Ministry of Energy and Water (MEW) supports municipalities in street lighting through a variety of programs such as distributing lamps on an annual basis. In principle and in lieu of current trends, the ministry distributes 1,500 HPS to municipalities per year. These 150-W lamps are meant to replace damaged and faulty lamps.

Street Lighting Policies

As of 2015, no major policies and/or regulations regarding public street lighting have been set. In 2010, the Ministry of Energy and Water published the Policy Paper for the Electricity Sector (MEW, 2010), outlining the Ministry's strategy to improve the electricity sector and enhance energy efficiency. Initiative 6 of the policy paper presents demand side management and energy efficiency measures and solutions. Action Step "d" in this initiative targets public street lighting by "encouraging the use of energy saving public lighting" (MEW, 2010). The National Energy Efficiency Action Plan (NEEAP) prepared by the LCEC and adopted by the Lebanese government in 2012 discusses public street lighting in Initiative 5: "Design and Implementation of a National Strategy for Efficient and Economic Public Street Lighting in Lebanon". It indicates that "this initiative aims at the design and implementation of a national strategy for public street lighting in Lebanon in order to offer safe and energy efficient street lighting with an intelligent monitoring, control, and maintenance procedure."

Street Lighting Standards & Codes

With no identified and officially adopted standards and codes for public street lighting in Lebanon, it is usually the consultants who decide on the design aspects and international standards to be applied. In general, BS EN standards are adopted in the design, operation, and maintenance of public street lights in Lebanon.
As for the technical specifications of street lighting poles, fixtures, and systems, the LCEC (with its three million lamps project implementation unit), together with the UNDP-CEDRO project, have developed a technical specification document that was shared with involved authorities in case these authorities wish to adopt similar technical specifications.

Support Initiatives

Several support programs and initiatives are in place, mostly in the form of direct central government purchases and grants from international organizations. Some initiatives are supporting municipalities in replacing damaged lamps, while others target a more efficient operation of systems. Recently, a number of support programs are designed to create a shift towards energy efficient street lighting using LED and renewable energy-powered lighting systems using solar and wind.
Some of these programs are listed in Table 7.

Table 7: Main support initiatives taking place in Lebanon (non-exhaustive list)

Initiative	Technology	Poles	Locations	Year
Photosensor supply & retrofit - MEW/LCEC	Photosensor	~15,000	Distributed	2012-2013
800 PVPSL - MEW to Municipalities	PVPSL - LED	800	Distributed	2012-2013
UNDP/CEDRO	PVPSL – LED	~800	Distributed	2010- present
Live Lebanon PSL Support Initiative	PVPSL – LED	89	Sultan Yaacoub (Bekaa)	2012-2014
UNIFIL Support to South Lebanon Municipalities	PVPSL – LED	~100	Marjeyoun (South)	2011- present
MPW Highway Lighting	PVPSL - LED	~1,200	South Lebanon	2010, 2012
			Ras Baalbeck (Bekaa)	
			Hermel (Bekaa)	

STREET LIGHTING OVERVIEW

This chapter gives an overview of street lighting, focusing on both the various components of street lighting, the various options available, the configuration or placement methodology that can be used when designing for optimal lighting for various roads, and general technical specifications for several street lighting options.

Lighting Fixture

Street lighting usually use discharge lamps. They are normally classified in accordance with the gas they utilize or the pressure level (see Table 8). Lamps are mercury or sodium vapor, and either high-pressure or low-pressure lamps. The properties of each lamp define its applicability and suitability for the situation in hand.

Table 8: Classification of street lighting

		Gas	
		Mercury	**Sodium Vapor**
Pressure	**High**	• Fluorescent	• Low Pressure Sodium
	Low	• Mercury Vapor	• High Pressure Sodium

Fluorescent

Fluorescent lamps are usually used in domestic and industrial applications with clear advantages when compared to incandescent lamps in terms of energy saving and lifespan. Applicability in street lighting is not very common; it is mostly used in domestic lighting.

Mercury Vapor

Mercury vapor discharge is produced at high pressure, producing a wide spectrum including a considerable amount of ultraviolet radiation, which is reported to be highly detrimental to the environment. Overexposure to UV radiation has a negative effect on living organisms including plants, animals, marine, and even humans. In terms of energy performance, it has low efficiency compared to other technologies.

Mercury vapor is not being used that much in street lighting these days, and it could be expected to diminish in the coming few years.

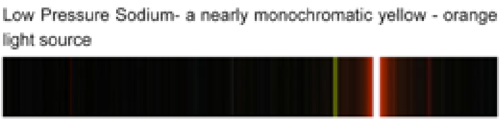
High-Pressure Sodium

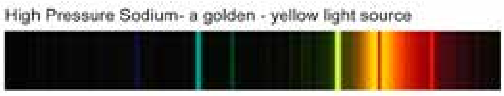
High-pressure sodium lamps are characterized with high efficiency and a long life reaching around 25,000 hours, in addition to high capacity to contrast and easily distinguish objects, making it the most commonly used solar street lamp all over the world, including Lebanon. HPS lamp's ability to refract lighting without spectral color damage or separation (chromatic performance) is not high, but is sufficient for most situations.

Low-Pressure Sodium

LPS is similar to HPS except that it uses low-pressure gas instead of high pressure. It generates higher lumen per watt, probably the highest in the market, but has one main drawback, color rendering. LPS is used on large avenues and boulevards where there is not much need for color reproduction (chromacity). It has an average lifespan of 23,000 hours. From an environmental perspective, it is the best option.

Low Pressure Sodium (LPS) lamps unlike High Pressure Sodium (HPS) lamps emit yellow light (the light spectrum here below shows the difference between both lamps). When designing outdoor lighting for observatories, LPS is preferred as yellow light can be filtered out of the light surrounding the telescope. The human eye is extra sensitive to the blue and green light at the very low brightness which cause sky glow; HPS is 2.5 times brighter than HPS.





Metal Halide

This is a common type of lamp used in street lighting with an average lifespan of 10,000 hours and an average energy performance. Its major advantage is its good capacity for chromatic performance.

Light Emitting Diode (LED)

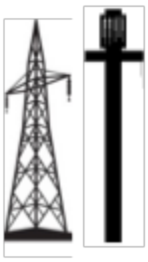
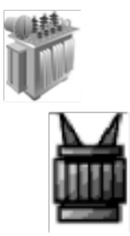
LED is not a discharge type lamp. LED produces no radiant-flux emissions. They have an excellent relative energy performance and offer modularity and flexibility in design.
From an astronomical and environmental perspective, warm color temperature LED with a low blue light content is ideal for ambient use.

Induction

Induction lamps are similar to fluorescent lamps; they create light by using an electromagnetic field to excite mercury particles mixed in an inert gas. They are relatively large providing a broad, diffuse light, from a large-diameter tube, which is not easily controlled.
Compared to LED, induction has limited directionality. Its lifetime is lower and it is negatively affected by heat.

Power Supply

Different schemes and power supply options are available for public street lighting. The basics start with the grid, which is the main power supply option to streetlights. In the absence of grid power, alternative options are available such as private diesel generators, solar PV power, and wind power.
Figure 4, Figure 5, Figure 6, and Figure 7 present the different power supply schemes using the following components:

							
Power plant	**Distribution**	**Transformer**	**Generator**	**Streetlight**	**Solar PV**	**Wind turbine**	**Battery**

The grid commonly powers streetlights, with lines coming from power substations extending from one pole to another and supplying power to the lamp installed on the pole. Power can also be transported underground through special underground cables.
Light availability, in this case, is completely dependent on grid availability.

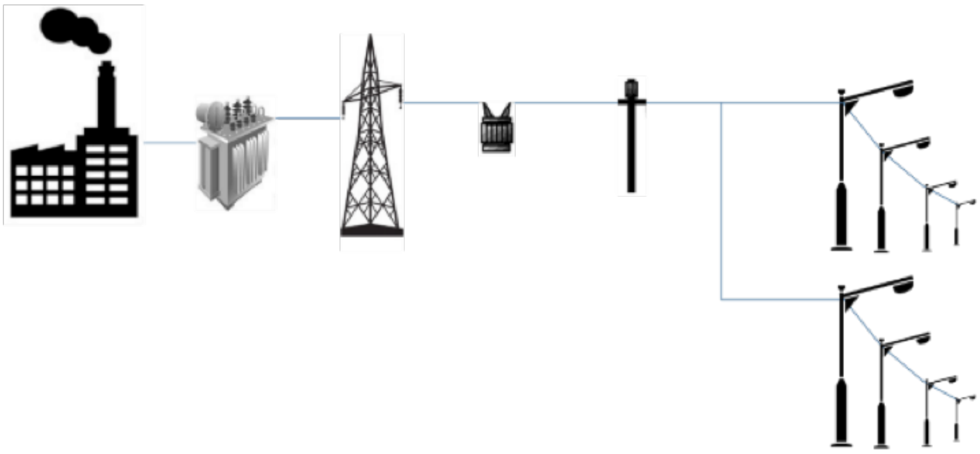


Figure 4: Grid-powered public street lighting

In some cases, especially in remote areas where the grid is not available, a private generator is used to supply power to streetlights. This generator can either be powered by fossil fuels or renewable energy. This is an example of alternative centralized power supply.

This solution is implemented in a few municipalities such as Hazmieh municipality, where a selection of streetlights are powered through a private generator during grid unavailability. The legality of using the grid network for this application during blackouts is, however, not clear.

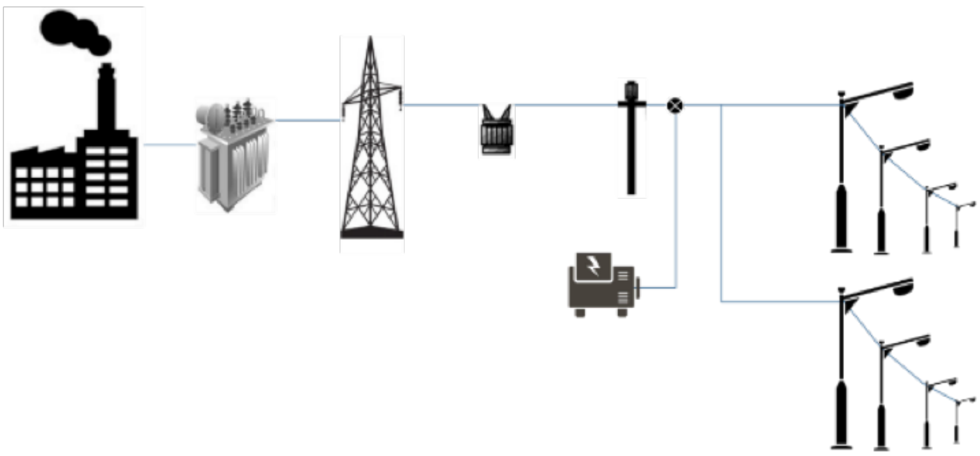


Figure 5: Hybrid grid-private generator street lighting

Hybrid systems are used in centralized systems combining several power sources together based on the grid availability and site available resources such as wind availability and solar radiation sufficiency.

With the need to have streets lit all night, several authorities are connecting their own private generators to the PSL grid, these generators running on fossil fuel will turn on during electricity cut-off and supply power to the street lighting grid.

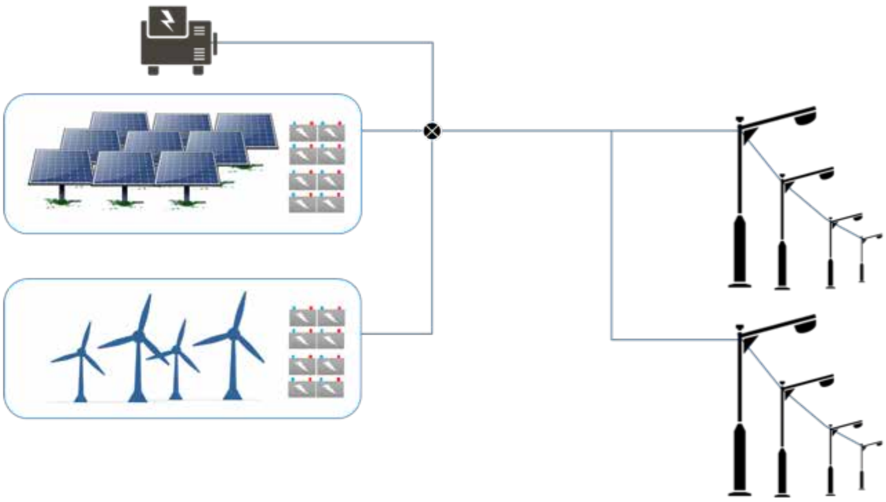


Figure 6: Hybrid PV-wind-private generator street lighting

Decentralized systems offer stand-alone operation of streetlights. They normally utilize renewable energy to power the luminaire. Be it solar, wind, or both together, the panels/turbines are installed together with the luminaire on one pole and a storage capability. Each unit will be independently operating.

Figure 7: Renewable energy-powered street lighting

Control Systems

Streetlight operation and lighting levels can be controlled for optimized energy use and lighting production. These control components are used to do a variety of tasks such as controlling lighting levels and activating the luminaires based on: (1) Available lighting, (2) Time of day/day of year, and (3) Traffic levels.

Photocell

A photocell is installed on the street lighting pole to measure the lux levels and activate the lamp when levels are low. Photocells play an important role in reducing energy consumption and achieving safety requirements.

The advantage of photocells is their ability to activate the lamps during obscure and darker days, and thus achieving higher safety levels. The drawback of a photocell is its high maintenance requirements. The cell needs to be frequently cleaned or else it will always read low lux levels and the lamp will be activated when it is not needed.

Timer

A timer uses scheduling to activate and deactivate the lamps. Usually, it is based on seasonal sunrise and sunset hours, without any considerations for weather conditions and daylight availability. Scheduling is present by the system operator and applied without frequent interruptions as presented in Figure 8.

Figure8: Typical on-off timer operation profile

Dimming

Dimming is an option that highly contributes to energy saving. It can be applied to luminaries having dimmability features. Dimming is based on three different inputs:

1- Time: when coupled with a timer
2- Lighting level: when coupled with a photocell
3- Voltage: In Solar PV applications

Time-based dimming control uses a similar scheduling process but also accounts for low traffic after midnight. The operator will have the option to decide on dimming times and levels as presented in Figure 9.

Figure8: Typical on-off timer operation profile

Lux-based dimming control provides feedback from the photocell to the lamp and adjusts the lighting output accordingly, leading to huge savings potential compared with other techniques.

Intelligent Control System

The combination of these controllability options for intelligent and efficient operation of street lighting is called an intelligent control system with adaptive lighting options (Figure 10 and 11). This system allows for controlling the lighting levels based on a variety of factors including traffic, available light, date and time, weather conditions, etc.

Through intelligent control, lighting levels and operations can be remotely controlled based on the demand and site needs, through data transfer among different channels and control units. It allows accounting for different factors and manage units collectively or individually to optimize output and energy consumption.

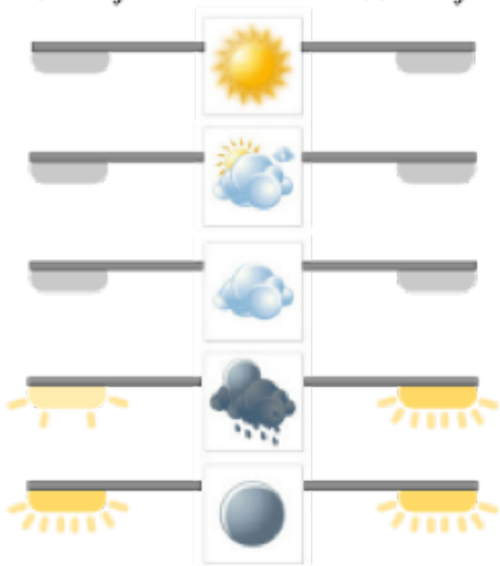


Figure10: Adavtive Liahtina

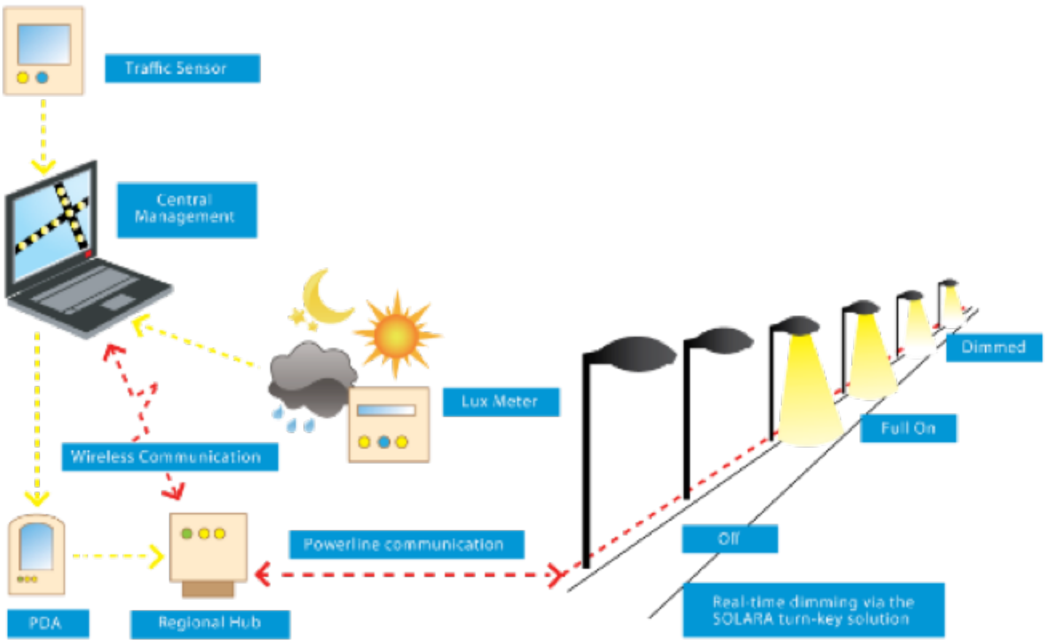


Figure 11: Example of an intelligent control system (by ELSA global energy solutions)

Design Considerations

There are many factors to be considered when designing street lighting to offer proper lighting and reduce environmental impacts. A major issue to be considered is the reduction of glare especially in cities and suburbs. Other major aspects are the energy performance of lamps, scattering effect, ultraviolet and infrared emissions.

With respect to solar street lighting, the following parameters should be considered:

1- Maximize Coefficient of Utilization

In order to maximize the coefficient of utilization, lamps should not be placed far from the target area and light projection beyond the useful zone of the target road should be eliminated.


2- Prevent direct light upward emission

Emission of direct light upwards and at angles near horizon should be avoided. To do so, reflectors should be used when possible. Luminaires should not be tilted from their horizontal position. In addition, asymmetric beam floodlights should be used and adjusted for the target area.

3- Avoid excess lighting levels

With proper codes and regulations in place, the lighting levels should be controlled and should comply with the requirements. The lighting level should be sufficient to provide proper sight at the target area, yet it should not exceed the required level by more than twenty percent. The target area requirements, the traffic volume, and the availability of natural lighting determine the level.

4- Use adaptive lighting

The occupancy profile and traffic volume vary during the day. The levels of natural lighting also vary during the day. Adaptive lighting should be used to reduce unwanted energy consumption and ensure sufficient lighting at all times. Adaptive lighting can be manually or automatically controlled.

5- Avoid wavelengths shorter than 500 nm

It is recommended to avoid lamps with radiant output of wavelengths below 500 nm (no blue light or UV). This is essential to avoid insects and living creatures causing damages and to avoid reducing biodiversity of natural environments.

6- Use proper luminaire distribution design

Selection of the proper luminaire distribution is essential to achieve desired lighting output. Four major luminaire distribution designs are followed in street lighting design.

One-sided Distribution

Luminaires are place on the same side of the road. The spacing is determined based on the luminaires' specifications and road requirements.
This design is only used when the width of the road is less than the mounting height of the luminaire.

Staggered

Luminaires are placed on opposite sides of the road with no opposite facing poles.
This design is mainly used when the width of the road is 1 to 1.5 times the mounting.
This design is very critical to avoid lack of uniformity on the road that could cause alternate bright and dark spots.

Opposite Pairing

Luminaires are placed on opposite sides of the road facing each other.
This design is mainly used when the width of the road is 1.5 times the mounting.

Suspended over Middle of Road

Whenever it is difficult to place poles on the sides of the roads, luminaires can be installed suspended over the middle of the road

7- Follow proper spacing design

In cross intersections, at least one luminaire, oriented at right angles to the road centerline, shall be provided at each intersection at about the point of tangency of the curb as shown in Figure 12.

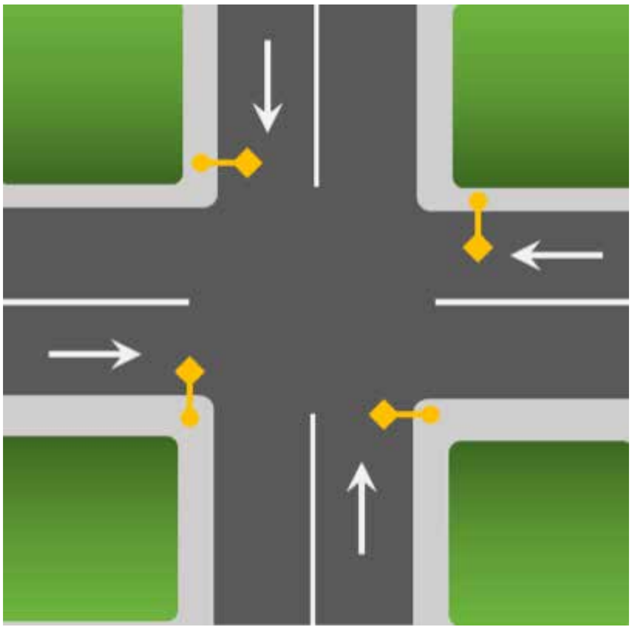


Figure 12: Recommended light location for a cross intersection

In "T" intersections, a luminaire shall be at placed at the center line at the top of the T as shown in 13.

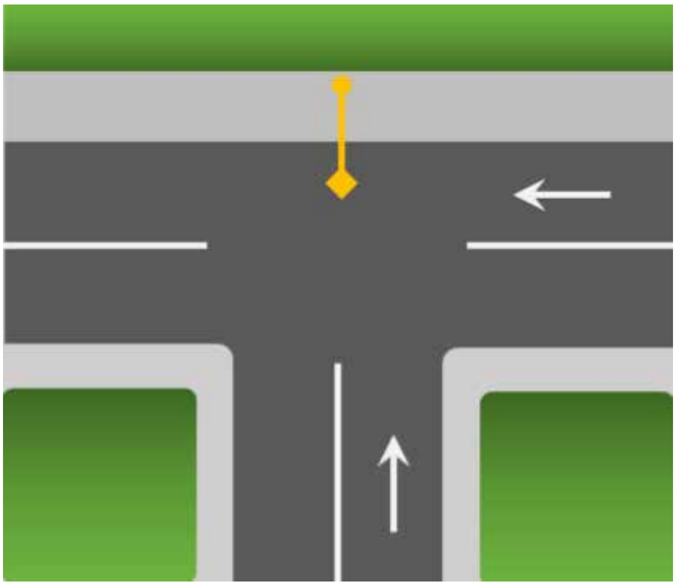


Figure 13: Recommended light location for "T" intersection

The proper spacing between the poles shall be determined using the following formula:

$$S = \frac{(L \times U \times 0.8)}{(I \times W)}$$

Where:

S: Spacing measured along center line of road (m)
L: Lamp lumens (lm)
U: Coefficient of utilization
I: Minimum required average illumination (lm/m2)
W: Road width (m)

Recommended Technical Specifications

Pole

In order to ensure reliability and strength of the pole, the pole must be water and corrosion resistant and have a conical shape with a sufficient base size. The pole thickness should be no less than four millimeters, with a solid concrete base.

LED Lamp

The lamp and its performance is an important factor to account for when selecting the solar lighting system. Selection of inadequate LED lamps results in reduced performance, a high maintenance cost, and a shorter lifespan.
In order to ensure proper operation of the LED lamp, the following specifications are recommended (as of October 2015 – as the technology is ever evolving):

- **Lifespan:** ≥ 50,000 hours
- **Color Temp.:** 2300K - 4000K
- **CRI:** ≥ 75
- **Working Temp.:** -10 °C to 45 °C
- **Rel. humidity:** 50% to 95%
- **Warranty:** 3 years
- **Certification:** CE, ISO9000
- **Protection:** IP65

When selecting the LED lamp, it is essential to pay attention to the following:

- The lamp should have a high-efficiency LED driver
- Power rating should be selected making sure required luminous flux is achieved
- The lamp should maintain 80% of initial lumen output after 50,000 operating hours
- Materials and Finishing: Fixture; die cast aluminum corrosion resistant parts, grey powder coat finish.
- LED light to be protected by clear acrylic lens, or approved equivalent

Solar Panels

The solar panels should be selected properly in terms of wattage and voltage to match the application requirements. Sizing depends on the system demand and the power requirement.
In order to ensure proper operation of the modules, the following specifications are recommended:

- **Module type:** Crystalline (Mono or Poly)
- **Efficiency:** ≥ 13%
- **Wind resistance:** 120 km/h
- **Cell Coating:** Tempered glass
- **Voc:** ≥ 21V (under STC)
- **Warranty:** 5 years on material
20 years 80% power output warranty
- **Certification:** CE, ISO9000
- **Protection:** IP65

When installing the PV modules, it is essential to make sure the following information is provided:

- Name of the manufacturer
- Model number
- Serial number
- Month and year of the manufacture
- I-V curve for the module
- Peak wattage
- Im, Vm and FF for the module

Battery

The batteries make up a major component of the solar lighting system, with a big share of the investment cost and a bigger share of the lifecycle maintenance (replacement) expenses.

Batteries' size and specifications depend on the site and the power demand, with main reliance on the desired autonomy period.

In order to ensure reliable batteries, maintenance-free batteries should be selected with the following specifications recommended:

- **Type:** Gel or AGM batteries
- **Discharge:** Deep Cycle Discharge
- **Lifespan:** 5 years
- **Deep discharge capacity:** 75%
- **Warranty:** 2 years
- **Certification:** CE, ISO9000
- **Protection:** IP65

Flooded batteries require regular maintenance, which is not suitable with street lighting applications; while Gel Batteries perform perfectly by maintaining a constant temperature, thus better performance.

Absorbed Glass Mat (AGM) batteries feature excellent performance, with their woven glass mat installed between plates to hold electrolytes. AGM batteries are maintenance-free, leakage-proof, and emit no gas, with slower self-discharge and longer-lasting lifespan.

In low temperature applications, the use of nickel-cadmium cells is recommended despite the high investment cost.

STREET LIGHTING TECHNOLOGIES - COMPARE

Ten street lighting options are studied employing HPS, LED, and induction luminaires. With different control methods and various power supply options. These options are selected to provide a comparison between the most commonly used street lighting options worldwide with focus on HPS (the widely used luminaire in Lebanon) and LED (the growing luminaire type in Lebanon), offering a different power supply option including Lebanon's most popular grid power, and the immerging solar PV street lighting.

Each of the options is studied technically, financially, and environmentally compared for five different cases based on a variety of factors such as pole spacing, road width, and mounting height. These classifications are referred to as L1 to L5.

Table 9: Lamping types L1 to L5 specifications

Classification	Ref. HPS	Lumens	Lux/m2
L1	50W	5,000	3.5
L2	70W	7,000	3.5
L3	100W	10,000	3.5
L4	150W	16,000	3.5
L5	250W	33,000	4.5

In order to clearly demonstrate the different options, and compare apples with apples when analyzing the different technologies and lamping options, L1 to L5 are designed as presented in Table 9.

The variations between the different options are related to the pole details and the road specifications.

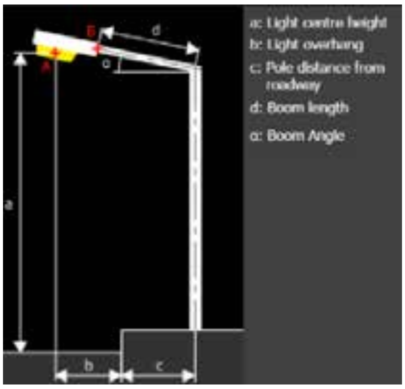
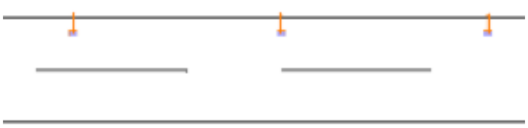
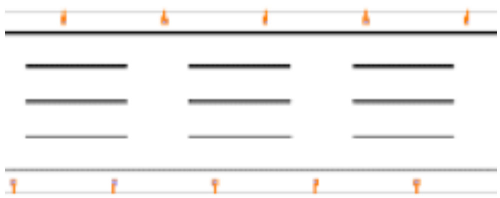
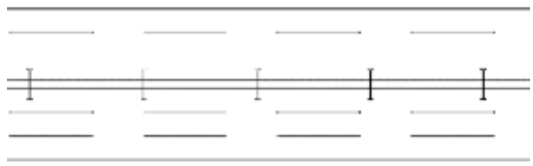


Table 10: Classification design aspects

	Type of Road	Road details	Pole Details
L1		• Ways: 1 • Lanes/Way: 1 • Total Width: 3.5m • Poles type: one-side • Lamps/pole: 1	• a: 4m • b: 1m • c: 0.65m • d: 1.65m • α: 0°
L2		• Ways: 2 • Lanes/Way: 1 • Total Width: 6m • Poles type: one-side • Lamps/pole: 1	• a: 6m • b: 1m • c: 0m • d: 1m • α: 0°
L3		• Ways: 2 • Lanes/Way: 2 • Total Width: 14+4m • Poles type: Staggered • Lamps/pole: 1	• a: 7m • b: 0m • c: 2m • d: 2m • α: 0°

L4		• Ways: 2 • Lanes/Way: 3 • Total Width: 25m • Poles type: Middle • Lamps/pole: 2	• a: 12m • b: 2m • c: 0.5m • d: 2.5m • α: 15°
L5		• Ways: 2 • Lanes/Way: 5 • Total Width: 37m • Poles type: Middle • Lamps/pole: 2	• a: 10m • b: 2m • c: 0.65m • d: 2.65m • α: 15°

Business as usual scenarios are presented in Table 12 for HPS, the choice of LED and Induction lamps alternative was done based on Dialux analysis. Dialux is an internationally used software for lighting design and planning. The easy-to-apply software is available free of charge on Dial's official website www.dial.de, with available learning material and training manuals accessible and downloadable free of charge from www.dial.de/DIAL/en/dialux/manuals.html.
Using Dialux, lamp specifications are fed into the system and analysis is performed with the restrictions mentioned in Table 10 to obtain the pole spacing requirement for each lamp type and size applying the EN13201 standard.
The factor making the difference between different options used is lamp spacing. Taking lighting levels and requirements, together with the pole height, as fixed based on the selected lamps sample for each option, with the only variable being lamp spacing. This indicative result leads to the number of lamps that can be saved when switching from a technology to another.
For reference the lamps specifications applied are shown in Table 11.

Table 11: Lamps specifications applied in Dialux

Classification	Wattage range
HPS	50-250 W
LED	19-91 W
Induction	55-150

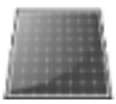
In calculating the energy consumption, sunrise and sunset values for Lebanon are calculated using present weather data, summing to a total of 4,447 hours per year; adding half an hour before sunset and another half after sunrise, the total becomes 4,812. During winter there is a potential of dark days and fog requiring street lighting, which is estimated to lead to an additional 180 hours to reach a total of 4,992 hours per year.
Table 12 presents the ten options analyzed categorized by the control method and the lamp type.

Table 12: Analyzed street lighting options

	Control Method					
	On/Off	**Timer & Photocell**		**Intelligent Control**		
Induction						
LED						
HPS						

The different characteristics of the considered lamp types (HPS, LED and Induction) are detailed in Table 13, emphasizing the possible applicable technologies (energy source, dimming, control, etc…).

Table 13. The different characteristics of the considered lamp types (HPS, LED and Induction)

	Lamp type		
	HPS	**LED**	**Induction**
Description	High-pressure sodium is the most widely used lamp type in Public Street lighting worldwide and in Lebanon as well. It offers the highest photopic illumination per watt, but when considering scotopic and photopic light, HPS which produces yellow light apears to fall behind white light sources. Studies have shown that white light doubles driver peripheral vision and increases driver brake reaction time by twenty-five percent (GRAH Lighting, 2015).Comparing HPS to conventional Metal Halide at the same photopic light levels, a street scene illuminated at night by a metal halide lighting system is brighter than a street scene illuminated by a high-pressure sodium system (Bullough, 2009).	LEDs are the next big thing. They are becoming a more and more widely-used alternative for HPS in outdoor lighting applications with a developing technology and a promising future. LED offers great scotopic and photopic illumination per watt	Induction lamps have been around for more than a century now. The technology is mature with not much potential for development. It offers good lighting levels with good savings potential, yet, when compared to LED, induction lamps have limited directionality. One major concern for induction lamps that remains unresolved is the radio interference they cause.
	High lumen output per watt, offering energy saving potential when compared to other technologies such as metal halide and mercury vapor. It is among the best luminaire types when considering the lumen per watt ratio.	High lumen output per watt, offering energy saving potential when compared to other technologies. It is among the best luminaire types if considering the lumen per watt ratio.	High lumen output per watt, offering energy saving potential when compared to other technologies such as metal halide and mercury vapor. It is among the best luminaire types if considering the lumen per watt ratio.
	Although it is always possible to power HPS with solar PV, it is impractical to do so due to the high rating of HPS lamps, requiring larger PV units.	LED is the best option to be powered by solar PV or other renewable energy sources. Its low watt rating and dimming capabilities make it very convenient with renewable energy applications.	Induction lamps are compatible with renewable energy applications such as wind and solar PV.
	Dimming HPS lamps result in flickering; HPS are affected by a reduction of 50°K to 200°K in color temperature when dimmed.	LED lamps are perfectly dimmable offering a dimmability range of 1% to 100%. The dimmability options creates additional room for saving	Dimmability is possible with a range from 50% to 100%.
	An HPS lamp would need ten to fifteen minutes to turn on to its full capacity, making it a less attractive solution for on-off operations.	No start-up delay exists with LED lamps. The lamp can turn on immediately to its full power.	Induction lamps might witness delay in turn-on in cold weather. Reaching full capacity might take a few minutes.
	Timer control is possible for HPS. The timer works based on preset schedules varying by season to save on energy consumption of the lamps.	Timer control is possible for LED. The timer works based on preset schedules varying by season to save on energy consumption of the lamps.	Timer control is possible. The timer works based on preset schedules varying by season to save on energy consumption of the lamps.
	There are some HPS lamps with improved CRI levels, yet they are still low compared to other technologies.	LED offers great CRI levels, making it a suitable option for different applications especially ones requiring face recognition.	Induction lamps offer great CRI levels, making it a suitable option for different applications especially ones requiring face recognition.
	With a lifespan of 12,000 to 16,000 hours, HPS is considered to have an average lifespan of around 3.5 years for an estimated twelve hours of operation per day.	With a lifespan of 50,000 to 100,000 hours, LED is considered to have a lifespan of around 11 to 22 years for an estimated 12 hours of operation per day.	With a lifespan of 50,000 to 100,000 hours, induction lamps are considered to have a great lifespan of around 11 to 22 years for an estimated 12 hours of operation per day.
	Although mercury is found in limited and nontoxic volumes, it remains an issue to consider when disposing of HPS lamps. This is a major issue for the environment that is considered when performing lifecycle environmental analysis.	No toxic material or components is used in LED lamps. Recycling is not a major issue.	Induction lamps use a power couple to energize solid mercury inside the lamp bulb. Mercury is a toxic material that needs to be well-handled.

A cost analyses have been developed for the various scenarios considering the 3 potential lamp types applicable for road lighting; cases considered (as listed in Table 9 to 13)

HPS-G-CO: Grid Powered with on/off operation
LED-G-CO: Grid Powered with on/off operations
LED-G-C1: Grid Powered with timer and photosensor
LED-G-C2: Grid Powered with Intelligent Control
LED-P-C2: PV – powered with intelligent control
LED-H-C1: Hybrid Powered with timer and photosensor
LED-H-C2: Hybrid powered with intelligent control
IND-G-C1: Grid powered with timer and photosensor
IND-P-C2: PV powered with control

Table 14 summarizes the life cycle cost and CO2 emissions per detailed scenario; the detailed cost tables can be found in Annex V.

Table 14. Summary of life-cycle costs and CO2 emissions per scenario

		Life cycle Cost				
		L1	**L2**	**L3**	**L4**	**L5**
HPS	HPS-G-CO	336,469	317,202	267,846	300,446	346,989
LED	HPS-G-CO	158,261	135,424	161,167	192,408	194,308
	LED-G-C1	155,884	121,186	151,714	179,785	179,499
	LED-G-C2	121,601	102,186	119,345	141,428	141,801
	LED-P-C2	162,972	135,648	163,259	185,817	178,182
	LED-H-C1	208,206	169,933	204,179	236,294	226,427
	LED-H-C2	180,496	150,858	185,137	211,006	203,039
Induction	IND-G-C1	196,638	211,189	274,930	320,521	493,424
	IND-P-C2	264,886	164,750	196,736	197,798	277,954
		CO2 emissions				
		L1	**L2**	**L3**	**L4**	**L5**
HPS	HPS-G-CO	589995	600,722	555,290	674,280	842,850
LED	HPS-G-CO	155361	147,184	245,307	308,905	338,226
	LED-G-C1	129468	104,255	204,422	257,421	281,855
	LED-G-C2	110047	104,255	173,759	218,808	239,577
	LED-P-C2	0	0	0	0	0
	LED-H-C1	0	0	0	0	0
	LED-H-C2	0	0	0	0	0
Induction	IND-G-C1	349666	377,355	499,505	634,211	104,644,8
	IND-P-C2	0	0	0	0	0

RESULTS & CONCLUSION

Life Cycle Cost Analysis

Lifecycle cost (LCC) analysis is performed to assess the cost of each of the analyzed solutions, considering investment cost, operation cost, replacement cost, and other costs such as maintenance, etc. This assessment is done for a distance of one kilometer over a period of twenty years.

The results of the LCC are shown in 6. The applications that are being compared:
- **HPS-G-C0:** High Pressure Sodium, Grid Power, No Control
- **HPS-G-C1:** High Pressure Sodium, Grid Power, Basic Control
- **LED-G-C0:** Light Emitting Diode, Grid Power, No Control
- **LED-G-C1:** Light Emitting Diode, Grid Power, Basic Control
- **LED-G-C2:** Light Emitting Diode, Grid Power, Advanced Control
- **LED-P-C2:** Light Emitting Diode, PV Power, Advanced Control
- **LED-H-C1:** Light Emitting Diode, Hybrid Power, Basic Control
- **LED-H-C2:** Light Emitting Diode, Hybrid Power, Advanced Control
- **IND-G-C1:** Induction Lamp, Grid Power, Basic Control
- **IND-P-C2:** Induction Lamp, PV-Powered, Advanced Control

Applications with no control (C0) have no timer or photocell applied and demonstrate the least controllable option. Basic control (C1) utilizes a combination of photocells and timers to control lighting on-off operations. Advanced control adds the dimmability option to basic controls and is considered the highest practical controllability option. The option of having intelligent systems is not considered to be a practical option in the case of Lebanon with its current street lighting setup, and thus is not included in the analysis.

The results show LED to be the highest cost-effective lamp to be utilized in street lighting applications. LED-G-C1, LED-G-C2, and LED-P-C2 had the lowest lifecycle cost over a period of twenty years for all applications from L1 to L5 as the results in Table 14 show.
The lifecycle cost accounts for investment, operation, maintenance, replacement, and power supply expenses.

Table 15: LCA results for the different options in USD

	L1	L2	L3	L4	L5
HPS-G-C0	336,469	317,202	267,846	300,446	346,989
HPS-G-C1	294,642	276,041	231,411	257,794	295,567
LED-G-C0	158,261	135,424	161,167	192,408	194,308
LED-G-C1	155,884	121,186	151,714	179,785	179,499
LED-G-C2	121,601	102,186	119,345	141,428	141,801
LED-P-C2	159,972	133,215	161,037	183,317	175,909
LED-H-C1	211,909	173,397	211,028	244,266	234,578
LED-H-C2	184,199	154,322	191,987	218,978	211,190
IND-G-C1	196,638	211,189	274,930	320,521	493,424
IND-P-C2	262,886	162,523	193,936	195,071	274,354

Table 15 shows that the grid powered LED lamps have the lowest lifecycle cost whereas the HPS and Inductive lamps have the highest costs. The lowest lifecycle cost is for Grid connect LED lamps on a 2-way street (L2 design). Savings when switching to advanced control LED lamp street lighting could total up to 351,623$ in the case of L5 street type.

Environmental Analysis

An environmental analysis of the before listed scenarios was performed over a 20 year span. The results are shown in table 16. Renewable energy powered systems have the lowest emissions due to the absence of fossil fuel-generated power and the use of emission-free resources.

Table 16: Environmental impact results in kg CO2

	L1	L2	L3	L4	L5
HPS-G-C0	589,995	600,722	555,290	674,280	842,850
HPS-G-C1	492,651	501,609	463,672	563,030	703,788
LED-G-C0	155,361	147,184	245,307	308,905	338,226
LED-G-C1	129,468	104,255	204,422	257,421	281,855
LED-G-C2	110,047	104,255	173,759	218,808	239,577
LED-P-C2	0	0	0	0	0
LED-H-C1	0	0	0	0	0
LED-H-C2	0	0	0	0	0
IND-G-C1	349,666	377,355	499,505	634,211	1,046,448
IND-P-C2	0	0	0	0	0

Retrofit Financial Analysis

The results of the financial retrofit analysis show that the following 3 options have a positive impact on the National Energy consumption:

- **LED-G-C1:** Light Emitting Diode, Grid Power, Basic Control
- **LED-G-C2:** Light Emitting Diode, Grid Power, Advanced Control
- **LED-P-C2:** Light Emitting Diode, PV Power, Advanced Control

A comparative study for the investment cost and impact analysis is done using the business as usual scenario
(HPS-G-C0: High-Pressure Sodium, Grid Power, No Control), with a power rating of 150 Watts on a one kilometer length roadway. Two scenarios are considered, the first being a complete retrofit of existing streetlights and the second being the adoption of these technologies for a new street lighting installation. Cash flow, ROI (Return On Investment) , IRR (Internal Rate of Return) , and NPV (Net Present Value) analysis are performed.
Detailed cash flows for the different options are presented in Annex VI: Detailed cash flow for different solutions.
A comparative financial analysis is performed for the three selected options (listed above) compared with the business as usual scenario, taking into account factors like investment per pole, the required number of lamps per kilometer, operation and maintenance expenses and recurring expenses such as replacement.

Street Type L1

The results showed a higher IRR for new installation when compared to the retrofit of the existing installations; When considering basic control implementations, grid powered LED lamps had an IRR of 32% for new installation and 16% for retrofit of the existing one. Whereas advanced control LED implementation had 29% for new and 17% for retrofit of the existing installation. And finally PV powered LED registered 14% for new and 6% for the retrofit of an existing installation, which had a negative NPV.
The highest NPV value was for grid-powered LED with advanced control amounting to $27,068 for retrofitting of the existing installations and $42,068 for new installations. The results of the financial analysis are presented in table 17.

Table 9: Lamping types L1 to L5 specifications

		HPS-G-C1	LED-G-C1	LED-G-C2	LED-P-C2
Investment per Pole		$120	$320	$360	$639
Poles per km		125.0	100.0	100.0	100.0
Total Investment		$15,000	$32,000	$36,000	$63,930
Investment Difference		$0	$17,000	$21,000	$48,930
O&M Expenses		$9,837	$3,691	$2,162	$600
O&M Saving		$0	$6,146	$7,675	$9,237
Replacement Cost		$15,000	$32,000	$36,000	$36,000
Replacement Period		3.2	16.0	18.9	18.9
Retrofit	NPV	-	$21,675	$27,068	**$2,321**
	IRR	-	16%	17%	6%
New Installation	NPV	-	$36,675	$42,068	$19,961
	IRR	-	32%	29%	14%

Street Type L2

The results also showed a higher IRR for new installation when compared to the retrofit of the existing installations; when considering basic control implementations, grid powered LED lamps had an IRR of 47% for new installations and 24% percent for the retrofit of the existing ones. Whereas advanced control LED implementations had a 40% IRR for new and 32% for the retrofit of the existing ones. And finally, PV powered LED registered an IRR of 10% for new installations and 12% for the existing ones.

The highest NPV value was for grid-powered LED with advanced control amounting to $39,801 for retrofitting the existing installations and $52,075 for new installations. The results of the financial analysis are presented in Table 18.

Table 18: Financial analysis input data for L2 solutions

		HPS-G-C1	LED-G-C1	LED-G-C2	LED-P-C2
Investment per Pole		$135	$385	$465	$834
Poles per km		90.9	66.7	66.7	66.7
Total Investment		$12,273	$25,667	$31,000	$55,570
Investment Difference		$0	$13,394	$18,727	$43,297
O&M Expenses		$9,743	$3,468	$2,251	$608
O&M Saving		$0	$6,276	$7,492	$9,135
Replacement Cost		$12,273	$25,667	$31,000	$31,000
Replacement Period		3.2	18.9	18.9	18.9
Retrofit	NPV	-	$37,424	$39,801	**$19,567**
	IRR	-	24%	23%	12%
New Installation	NPV	-	$49,697	$52,075	$12,944
	IRR	-	47%	40%	10%

Street Type L3

The results also showed a higher IRR for new installation compared with the retrofit of the existing installations; grid-powered LED lamp featuring advanced control implementations have the highest IRR at 27% percent for new installations and 18% for existing lamps; whereas for basic controlled LED lamps, the IRR is 24% for new installations and 14% for the retrofit of the existing ones PV powered LED had an IRR of 25% for new installation and 8% for the retrofit of the existing ones.

The highest NPV value was for grid-powered LED with advanced control amounting to $21,157 for retrofitting of the existing installations and $29,687 for new installations. The results of the financial analysis are presented in Table 19.

Table 19: Financial analysis input data for L3 solutions

		HPS-G-C1	LED-G-C1	LED-G-C2	LED-P-C2
Investment per Pole		$145	$420	$500	$1,180
Poles per km		58.8	55.6	55.6	55.6
Total Investment		$8,529	$23,333	$27,778	$65,578
Investment Difference		$0	$14,804	$19,248	$57,048
O&M Expenses		$8,729	$5,015	$3,385	$556
O&M Saving		$0	$3,714	$5,344	$8,174
Replacement Cost		$8,529	$23,333	$27,778	$27,778
Replacement Period		3.2	16.0	18.9	18.9
Retrofit	**NPV**	-	$13,125	$21,157	**$2,443**
	IRR	-	14%	18%	8%
New Installation	**NPV**	-	$21,654	$29,687	$39,356
	IRR	-	24%	27%	25%

Street Type L4

The results also showed a higher IRR for new installation when compared to retrofit of the existing installations; When considering grid powered LED lamps featuring advanced control, new installations had an IRR of 26% and 19% for the retrofit of the existing ones. Whereas basic control LED lamps had an IRR of 22% for the new installations and 15% for the retrofit of the existing installations. PV powered LED had an IRR of 27% for new installation and 9% for the retrofit of the existing ones.

The highest NPV value for new installations was for PV-powered LED with advanced control amounting to $50,463, while grid-powered LED with advanced control had the highest NPV for retrofitting existing installations at $25,887. The results of the financial analysis are presented in Table 20.

Table 20: Financial analysis input data for L4 solutions

		HPS-G-C1	LED-G-C1	LED-G-C2	LED-P-C2
Investment per Pole		$160	$470	$550	$1,335
Poles per km		47.6	55.6	55.6	55.6
Total Investment		$7,619	$26,111	$30,556	$74,189
Investment Difference		$0	$18,492	$22,937	$66,570
O&M Expenses		$10,328	$6,106	$4,203	$625
O&M Saving		$0	$4,222	$6,125	$9,703
Replacement Cost		$7,619	$26,111	$30,556	$30,556
Replacement Period		3.2	16.0	18.9	18.9
Retrofit	**NPV**	-	$16,034	$25,887	**$9,269**
	IRR	-	15%	19%	9%
New Installation	**NPV**	-	$23,653	$33,506	$50,463
	IRR	-	22%	26%	27%

Street Type L5

The results also showed a higher IRR for new installation when compared to the retrofit of the existing installations; when considering advanced control with grid-powered LED lamps had an IRR 39% for new installations and 29% for the retrofit of the existing lamps. Whereas basic control LED installations had an IRR of 36% and 26% for new and the retrofit of the existing installations respectively. PV powered LED had an IRR of 17% for new installations and 14% for the retrofit of the existing ones.

The highest NPV value was for grid-powered LED with advanced control amounting to $57,289 for the retrofit of the existing installations and $50,860 for new installations. The results of the financial analysis are presented in Table 21.

Table 21: Financial analysis input data for L5 solutions

		HPS-G-C1	LED-G-C1	LED-G-C2	LED-P-C2
Investment per Pole		$180	$520	$600	$1,556
Poles per km		35.7	45.5	45.5	45.5
Total Investment		$6,429	$23,636	$27,273	$70,705
Investment Difference		$0	$17,208	$20,844	$64,276
O&M Expenses		$12,596	$6,361	$4,509	$568
O&M Saving		$0	$6,235	$8,087	$12,028
Replacement Cost		$6,429	$23,636	$27,273	$27,273
Replacement Period		3.2	16.0	18.9	18.9
Retrofit	**NPV**	-	$40,242	$50,860	**$40,267**
	IRR	-	26%	29%	14%
New Installation	**NPV**	-	$46,670	$57,289	$47,315
	IRR	-	36%	39%	17%

REFERENCES

Fleiter, T., Hirzel, S., Jakob, M., Barth, J., Quandt, L., Reitze, F., Toro, F., Wietschel, M. (2010). Electricity demand in the European service sector: A detailed bottom-up estimate by sector and by end-use. Improving Energy Efficiency in Commercial Buildings (IEECB). Retrieved May 13, 2015, from http://www.isi.fraunhofer.de/isi-wAssets/docs/e/de/publikationen/IEECB__10_No50_Final_2.pdf

Box, P.C. (1970) Relationship Between Illumination and Freeway Accidents. IERI Project 85-67 Illuminating Research Institute, New York April, pp. 1-83.

Commission Internationale de l'Éclairage. (1992) Road Lighting as an Accident Countermeasure. CIE No. 93. Vienna, Austria: Commission Internationale de l'Éclairage

Scienceline. Stray Voltage Still on the Loose. 2006-08-04. Retrieved 2014, December 12.

Krames M. 2007. Progress in high-power light-emitting diodes for solid-state lighting. Proceedings of the 11th International Symposium of the Science and Technology of Light Sources, May 20th-24th, Shanghai, China. pp. 571-573.

Bureau of Energy Efficiency. (2005). Best Practice Manual – Lighting. Ministry of Power

Steinle, H. (2010, May 18). What is High Energy? www2011.mpe.mpg.de/heg/www/he.html

European PPP Expertise Center (EPEC), 2015. Energy Efficient Street Lighting. European Investment Bank, Luxembourg

Maurath, J. (2012). Streetlighting Evolution. Retrieved July 18, 2015.

GRAH Lighting. (2015). Street lighting technology comparison. Retrieved March 4, 2015, from http://www.grahlighting.eu/learning-centre/street-lighting-technology-comparison

Bullough, John, MS Rea, and Y Akashi. "Several views of metal halide and high pressure sodium lighting for outdoor applications." 2009. Lighting Res. Technology. 31: 297-320.

Medve, D., Kolcun, M., Stolárik, R., & Vaško, Š. (2011). Importance of Batteries for Photovoltaic Systems.Inteligentné Riadenie Výroby a Spotreby Elektriny Z Obnovitených Energetických Zdrojov 2011, 22. September 2011, Stará Lesná, Vysoké Tatry.

Annex I: Selection Parameters and Design Factors for Lighting Classes in CIE 115:2010

Class M

CIE 115: 2010 is a revision of the 1995 report "recommendations for the lighting of roads for motor and pedestrian traffic". Class M specifies the appropriate lighting quality criteria / requirement for motorized traffic.

The selection of the class for a certain application is described in Table I-1 and detailed after. Upon selection of the desired class, the requirements in Table I-2 should be fulfilled to ensure safe roads and proper illumination levels.

The recommended average illuminance over the total used surface (Lav) in candela per square meter, and the threshold increment (TI), as well as the surround ration (SR), uniformity of illuminance (UO) and longitudinal uniformity of illuminance are listed and should be abided by to conform to the standard.

Table I-1: Motorized traffic lighting classification system (CIE)

Class	Dry			Wet[3]	TI	SR
	Lav (cd/m2)	UO	UL	UO		
M1	2.00	0.40	0.70	0.15	10%	2.00
M2	1.50	0.40	0.70	0.15	10%	1.50
M3	1.00	0.40	0.60	0.15	10%	1.00
M4	0.75	0.40	0.60	0.15	15%	0.75
M5	0.50	0.35	40	0.15	15%	0.50
M6	0.30	0.35	0.40	0.15	20%	0.30

The identification process of the M-type for motorized lighting is done following Table I-2, where numbers are added up to reach a total value that will be used to find the exact road type. The factors are given weighted values, and upon selection of each option its weighted value is added up to the overall total.
For example, a road with high speed is given a value of 1 as compared to 0 for low speed roads. The traffic volume is classified in very low, low, moderate, high, and very high with weighting values from -1 to 1.

As for traffic composition it is 0 for motorized only, 0.5 for mixed, and 1 for mostly non-motorized. The list continues as shown in the table to include way separation, intersection density, parked vehicles, ambient luminance, visual guidance, and traffic control.

Criteria are given weighted values which are summed up to give an overall total. IIn order to identify the road type, the weighted values per criteria are summed up and subtracted from 6. For the example demonstrated in the Table 22 here after, the overall total is 4, thus leading to a road type M2.

[3] Applicable in addition where road surfaces are wet for a substantial part of the hours of darkness and appropriate road surface reflectance data are available

Table I-2 Selection of category M lighting class with example illustrated

Parameter	Options	Weighting Value	Check	Value
Speed	High	1	✔	1
	Moderate	0		
Traffic Volume	Very High	1		0
	High	0.5		
	Moderate	0	✔	
	Low	-0.5		
	Very Low	-1		
Traffic composition	Mostly non-motorized	1		0
	Mixed	0.5		
	Motorized only	0	✔	
Separation of ways	No	1		0
	Yes	0	✔	
Intersection density	High	1	✔	1
	Moderate	0		
Parked vehicles	Present	1	✔	1
	Not present	0		
Ambient luminance	Very high	1	✔	1
	High	0.5		
	Moderate	0		
	Low	-0.5		
	Very low	-1		
Visual guidance, traffic control	Poor	0.5		0
	Good	0	✔	
	Very good	-0.5		
			Total	**4**
			Class	**M2**[4]

Class C

Class C is dedicated for conflict areas, where vehicle streams intersect each other or run into areas frequented by pedestrians, cyclists, or other road users, or when the existing road is connected to a stretch with substandard geometry, such as a reduced number of lanes or a reduced lane or road width. Class C is divided into five categories from C1 to C5. The selection of the class for a certain application is described in Table I-4, detailed here after. Upon selection of the desired class, the requirements in Table I-3 should be met to ensure safe roads and proper illumination levels.
The recommended average illuminance over of the total used surface (L_{av}) in lux, and the threshold increment (TI) for both high and low speed conditions, as well as the uniformity of illuminance (U_o).

[4] Class = 6 - Total

Table I-2 Selection of category M lighting class with example illustrated

Class	Lav (lx)	Uo	TI[5]	
			High & moderate speed	Low & very low speed
C1	50	0.40	10%	15%
C2	30	0.40	10%	15%
C3	20	0.40	10%	20%
C4	15	0.40	10%	20%
C5	10	0.40	15%	25%

The identification process of C-type roads is very similar to M-type for motorized lighting. An example illustrating the process is presented in the Table I-4 here after.
For this working example, the overall total is 3, leading to a selected road type C3.

Table I-4: Selection of category C lighting class with example illustrated

Parameter	Options	Weighting Value	Check	Value
Speed	High	2	✔	**2**
	Moderate	1		
	Low	0		
Traffic Volume	Very High	1		**0.5**
	High	0.5	✔	
	Moderate	0		
	Low	-0.5		
	Very Low	-1		
Traffic composition	Mostly non-motorized	1	✔	**1**
	Mixed	0.5		
	Motorized only	0		
Separation of ways	No	1		**0**
	Yes	0	✔	
Ambient luminance	Very high	1		**0.5**
	High	0.5		
	Moderate	0		
	Low	-0.5	✔	
	Very low	-1		
Visual guidance, traffic control	Poor	0.5		**0**
	Good	0	✔	
	Very good	-0.5		
			Total	**3**
			Class	**C3**[5]

Class P

Class P is dedicated to pedestrian and low speed traffic areas, divided into six categories from P1 to P6. The selection of the class for a certain application is described in Table I-4, and detailed here after. Upon selection of the desired class, the requirements in Table I-5 should be fulfilled to ensure safe roads and proper illumination levels.

[5] Applicable where visual tasks usually considered for the lighting of roads for motorized traffic (M classes) are of importance
[6] Class = 6 - Total

The recommended average illuminance over of the total used surface (L_{av}) and the minimum (L_{min}) in lux, and the threshold increment (TI), as well as minimum semi-cylindrical illuminance ($E_{sc,min}$) and minimum vertical illuminance ($E_{v,min}$).

Table I-5: Pedestrian and low speed traffic areas lighting classification system (CIE)

Class	Lav (lx)	Lmin (lx)	TI[7]	Additional Requirements for facial recognition	
				$E_{v,min}$	$E_{sc,min}$
P1	15	3.0	20%	5.0	3.0
P2	10	2.0	25%	3.0	2.0
P3	7.5	1.5	25%	2.5	1.5
P4	5.0	1.0	30%	1.5	1.0
P5	3.0	0.6	30%	1.0	0.6
P6	2.0	0.4	35%	0.6	0.4

The identification process of P-type roads is very similar to C-type and M-type. An example illustrating this process is presented in Table I-6 here after.
For this working example, the overall total is 2, leading to a selected road type P4

Table I-6: Selection of category M lighting class with example illustrated

Parameter	Options	Weighting Value	Check	Value
Speed	Low	2	✔	**0**
	Very low	1		
Traffic Volume	Very High	1		**0**
	High	0.5	✔	
	Moderate	0		
	Low	-0.5		
	Very Low	-1		
Traffic composition	Pedestrians, cyclists & motorized	1	✔	**0**
	Pedestrians & motorized	0.5		
	Pedestrians & cyclists	0		
	Cyclists	1		
	Pedestrians	0	✔	
Parked vehicles	Present	1		**1**
	Not present	0.5		
Ambient luminance	Very high	0		**1**
	High	-0.5	✔	
	Moderate	-1		
	Low	0.5		
	Very low	0	✔	
Facial recognition	Necessary	-0.5		**1**
	Not necessary			
			Total	**2**
			Class	**P4**[8]

[7] Applicable where visual tasks usually considered for the lighting of roads for motorized traffic (M classes) and conflict areas (C classes) are of importance

[8] Class = 6 - Total

Annex II: Road Transport Lighting in Developing Countries Requirements in CIE 118:2007

CIE 118:2007 has a set of requirements for road transport lighting in developing countries, offering recommended uniformity of illuminance and average illuminance values for residential areas with pedestrians and many non-motorized vehicles, largely residential with only some motorized vehicles, major access roads with distributors and minor main roads, important rural and urban traffic routes, and high-speed roads with dual carriageways.
The required levels are presented in II-1

Table II-1: Road Transport Lighting requirements in developing countries (CIE)

Class	L_{avg}	U_o
Residential areas, pedestrians & many non-motorized vehicles	1-2 lux	0.2
Largely residential, but some motorized vehicles	4-5 lux	0.2
Major access roads, distributors and minor main roads	8 lux	0.4
Important rural and urban traffic routes	15 lux	0.4
High-speed roads, dual carriageways	25 lux	0.4

Annex III: Technical Requirements in EN 31201 Standards

According to British Standards, roads are classified in ME categories from ME1 to ME6, with ME3 having three subcategories and ME4 having two subcategories. The identification of the road type is presented in Table III-1.

Table III-1: Selection of ME lighting classes for traffic routes

Type	Description	Detailed description	ADT	Class
Motorway	**Limited Access**	Routes for fast long distance traffic. Fully grade-separated and restrictions on use		
		• Main carriageway in complex interchange areas	≤ 40,000	ME1
			> 40,000	ME1
		• Main carriageway with interchanges <3km	≤ 40,000	ME2
			> 40,000	ME1
		• Main carriageway with interchanges ≥3km	≤ 40,000	ME2
			> 40,000	ME2
		• Emergency lanes	-	M4a
Strategic Route	**Trunk and some principal "A" roads between primary destinations**	Routes for fast long-distance with minimal pedestrian traffic. Speed limits in excess of 65 km/h with few junctions. Pedestrian crossings segregated or controlled, parked vehicles prohibited		
		• Single carriageways	≤ 15,000	ME3a
			> 15,000	ME2
		• Dual carriageways	≤ 15,000	ME3a
			> 15,000	ME2
Main Distributor	**Major urban network and inter-primary links Short- to medium- distance traffic**	Routes between strategic routes & linking urban centers to strategic network with limited frontage access. In urban areas speed limits usually 65 km/h or less, parking restricted at peak times with positive measures for pedestrian safety reasons.		
		• Single carriageways	≤ 15,000	ME3a
			> 15,000	ME2
		• Dual carriageways	≤ 15,000	ME3a
			> 15,000	ME2
Secondary distributor	**Classified Road (B and C class) and unclassified urban bus route, carrying local traffic with frontage access and frequent junctions**	Rural areas (Zone E1/2d) These roads link larger villages to strategic and Main Distributor Network.	≤ 7,000	ME4a
			> 7,000 ≤15,000	ME3b
			>15,000	ME3a
			> 15,000	ME2
		Urban areas (Zone E3d) Speed limits 48 km/h, high pedestrian activity, crossing facilities, unrestricted parking except for safety reasons	≤ 7,000	ME3c
			> 7,000 ≤15,000	ME3b
			>15,000	ME2

Link road	**Road linking between Main and Secondary Distribution Network with frontage access and frequent junctions local traffic with frontage access and frequent junctions**	Rural areas (Zone E1/2d) Linking smaller villages to distributor network. Vary in width, not always capable of carrying two-way traffic.	Any	ME5
		Urban areas (Zone E3d) Residential or industrial interconnecting roads, 48 km/h speed limits, random pedestrian movements, uncontrolled parking	Any	ME4b or S2
			Pedestrian traffic	S1

The identification of road type starts by selecting the type of the road from motorway to strategic route, main distributor, secondary distributor and linking road. Based on the average daily traffic (ADT), and the detailed description of the road, the road classification is then made.

Once the road type is selected, the specifications presented in III-2 as per the EN 31291 standard, set average illuminance levels, uniformity ratios and threshold increment.

Table III-2: Recommended specifications for ME classes in BS EN

Class	**Luminance of road surface in dry condition**			
	L_{av} (cd/m2)	**U_O**	**U_L**	**TI**
ME1	2.0	40%	70%	10%
ME2	1.5	40%	70%	10%
ME3a	1.0	40%	70%	15%
ME3b	1.0	40%	60%	15%
ME3c	1.0	40%	50%	15%
ME4a	0.75	40%	60%	15%
ME4b	0.75	40%	50%	15%
ME5	0.5	35%	40%	15%
ME6	0.3	35%	40%	15%

Annex IV: Lamination Requirements in ANSI/IESNA RP-8

According to ANSi.IESNA standards, roads are classified into freeway (2 classifications), expressway, major road, collector road, and local road. The pavement classification is material dependent (asphalt, concrete, etc...), as they determine the reflective properties of the pavement. Most commonly, pavements are of R-3 type: asphalt with a rough dark surface. The pavement classification types are:

R1: Portland cement concrete road surface
R2: Asphalt road surface with an aggregate composed of minimum 60% gravel or 10-20% artificial brighter in aggregate
R3: Asphalt road surface (regular and carpet seal) with dark aggregate; rough texture few months of usage
R4: Asphalt road surface with very smooth texture

Knowing the pedestrian conflict whether high medium or low, the illumination levels and uniformity factors are established as presented in Table IV-1.

Table IV-1: Lamination requirements in different roads (ANSI/IESNA)

Road & Pedestrian Conflict Area		Pavement Classification (lx)			Uo	$L_{v,max}/L_{avg}$
Road	**Pedestrian conflict**	**R1**	**R2 & R3**	**R4**		
Freeway Class A	N/A	6	9	8	3.0	0.3
Freeway Class B	N/A	4	6	5	3.0	0.3
Expressway	High	10	14	13	3.0	0.3
	Medium	8	12	10	3.0	0.3
	Low	6	9	8	3.0	0.3
Major	High	12	17	15	3.0	0.3
	Medium	9	13	11	3.0	0.3
	Low	6	9	8	3.0	0.3
Collector	High	8	12	10	4.0	0.4
	Medium	6	9	8	4.0	0.4
	Low	4	6	5	4.0	0.4
Local	High	6	9	8	6.0	0.4
	Medium	5	7	6	6.0	0.4
	Low	3	4	4	6.0	0.4

Annex V: Detailed Financial Analysis

The tables here after (table V-1 to V-8) detail the cost entailed for all scenarios investigated. Investment cost refers to the upfront cost that the municipalities will have to pay for to purchase the system (depending on the scenario; for example: pole with grid powered HPS lamp with simple on/off operation).

Replacement cost refers to the cost plus labor fees of replacing the lamp and / or the system (control, sensors, energy source ...), and the frequency of the replacement cost is lamp life dependent.

Maintenance cost refers to the cost and labor fees of maintaining the poles and the parts constituting the systems.

Electricity cost refers to the National Electricity bills paid by the municipalities
Life cycle cost is the sum of all above costs;

Table III-2: Recommended specifications for ME classes in BS EN

HPS-G-CO	Unit	L1	L2	L3	L4	L5
Investment Cost:	USD	12,500	10,455	7,353	6,667	5,714
Replacement Cost:	USD	99,278	82,517	57,843	52,228	44,574
Maintenance Cost:	USD	25,000	20,909	14,706	13,333	11,429
Electricity Cost:	USD	199,691	203,321	187,944	228,218	285,272
Life Cycle Cost:	USD	336,469	317,202	267,846	300,446	346,989
CO2 Emissions:	kg	589,995	600,722	555,290	674,280	842,850

Table V-2: LED Grid - Powered with on/off operation

HPS-G-CO	Unit	L1	L2	L3	L4	L5
Investment Cost:	USD	30,000	24,333	22,222	25,000	22,727
Replacement Cost:	USD	45,677	36,941	33,696	37,856	34,377
Maintenance Cost:	USD	30,000	24,333	22,222	25,000	22,727
Electricity Cost:	USD	52,584	49,816	83,027	104,552	114,477
Life Cycle Cost:	USD	158,261	135,424	161,167	192,408	194,308
CO2 Emissions:	kg	155,361	147,184	245,307	308,905	338,226

Table V-3: LED Grid - Powered with timer and photosensor

HPS-G-CO	Unit	L1	L2	L3	L4	L5
Investment Cost:	USD	32,000	25,667	23,333	26,111	23,636
Replacement Cost:	USD	38,064	26,166	28,080	31,547	28,647
Maintenance Cost:	USD	42,000	34,067	31,111	35,000	31,818
Electricity Cost:	USD	43,820	35,286	69,189	87,127	95,397
Life Cycle Cost:	USD	155,884	121,186	151,714	179,785	179,499
CO2 Emissions:	kg	129,468	104,255	204,422	257,421	281,855

Table V-4: LED Grid - Powered with intelligent control

HPS-G-CO	Unit	L1	L2	L3	L4	L5
Investment Cost:	USD	40,000	31,000	27,778	30,556	27,273
Replacement Cost:	USD	32,354	26,166	23,868	26,815	24,350
Maintenance Cost:	USD	12,000	9,733	8,889	10,000	9,091
Electricity Cost:	USD	37,247	35,286	58,811	74,058	81,088
Life Cycle Cost:	USD	121,601	102,186	119,345	141,428	141,801
CO2 Emissions:	kg	110,047	104,255	173,759	218,808	239,577

Table V-5: LED PV - powered with intelligent control

HPS-G-CO	Unit	L1	L2	L3	L4	L5
Investment Cost:	USD	67,930	55,570	65,578	74,189	70,705
Replacement Cost:	USD	32,354	26,166	23,868	26,815	24,350
Maintenance Cost:	USD	62,688	53,912	73,813	84,813	83,127
Electricity Cost:	USD	0	0	0	0	0
Life Cycle Cost:	USD	162,972	135,648	163,259	185,817	178,182
CO2 Emissions:	kg	0	0	0	0	0

Table V-6: LED Hybrid - powered with timer and photosensor

HPS-G-CO	Unit	L1	L2	L3	L4	L5
Investment Cost:	USD	65,516	55,151	68,693	78,471	75,755
Replacement Cost:	USD	38,064	26,241	25,132	31,547	28,647
Maintenance Cost:	USD	104,626	88,541	110,354	126,276	122,025
Electricity Cost:	USD	0	0	0	0	0
Life Cycle Cost:	USD	208,206	169,933	204,179	236,294	226,427
CO2 Emissions:	kg	0	0	0	0	0

Table V-7: LED Hybrid - powered with intelligent control

HPS-G-CO	Unit	L1	L2	L3	L4	L5
Investment Cost:	USD	73,516	60,484	73,138	82,916	79,391
Replacement Cost:	USD	32,354	26,166	23,868	26,815	24,350
Maintenance Cost:	USD	74,626	64,208	88,132	101,276	99,298
Electricity Cost:	USD	0	0	0	0	0
Life Cycle Cost:	USD	180,496	150,858	185,137	211,006	203,039
CO2 Emissions:	kg	0	0	0	0	0

Table V-8: IND Grid - powered with timer and photosensor

HPS-G-CO	Unit	L1	L2	L3	L4	L5
Investment Cost:	USD	21,818	24,091	30,000	29,091	38,000
Replacement Cost:	USD	20,472	19,287	25,467	27,683	36,442
Maintenance Cost:	USD	36,000	40,091	50,400	49,091	64,800
Electricity Cost:	USD	118,349	127,720	169,063	214,656	354,182
Life Cycle Cost:	USD	196,638	211,189	274,930	320,521	493,424
CO2 Emissions:	kg	349,666	377,355	499,505	634,211	1,046,448