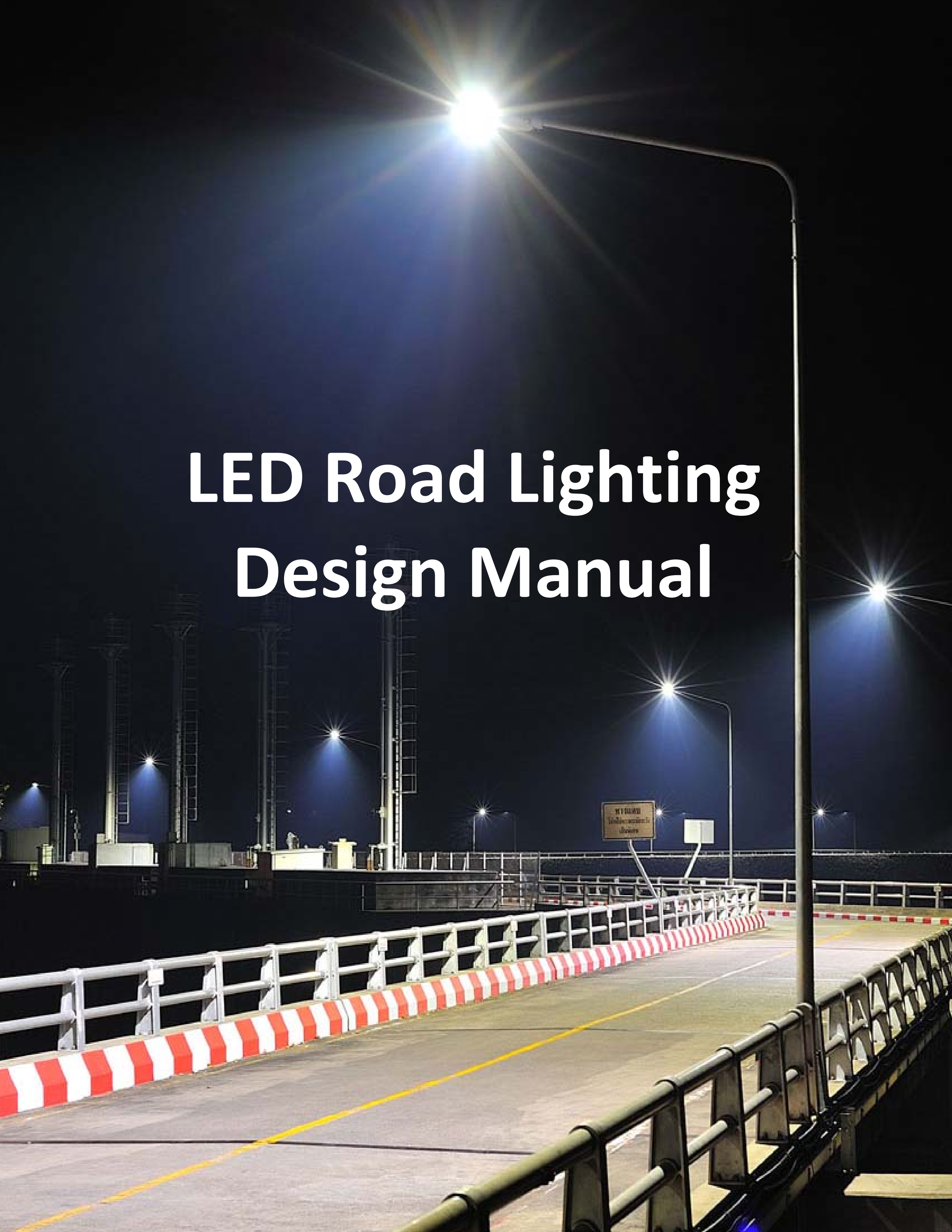
LED Road Lighting Design Manual



LED Road Lighting Design Manual

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<u>About This Report</u>: LED Road Lighting Design Manual

This manual is a vendor-neutral knowledge management tool prepared by Development Finance International, Inc. and commissioned by Philips Lighting for professional reference by transport, urban, and energy sector professionals.

The information presented in this document does not form part of any quotation or contract, is believed to be accurate and reliable, and may be changed without notice.

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Note: In this publication, ‘road lighting’ has been used to represent all lighting for roads, streets, walkways including in parks.

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Abbreviations

AC	Alternating current
BRT	Bus rapid transit
BSL	Los Angeles Bureau of Street Lighting
CIE	*Commission International de L'eclairage* (International Commission on Illumination)
CCT	Correlated color temperature
CRI	Color rendering index
DOD	Depth of discharge
DC	Direct current
EMC	Electromagnetic compatibility
EMF	Electromagnetic fields
EE	Energy efficient
ESCO	Energy service company
GHG	Greenhouse gas
HPSV	High pressure sodium vapor
ICNIRP	International Commission on Non-Ionizing Radiation Protection
IEA	International Energy Agency
IEC	International Electrotechnical Commission
IES	Illuminating Engineering Society
IP	Ingress protection
ISO	International Organization for Standardization
LA	City of Los Angeles
LED	Light emitting diodes
M&E	Monitoring & evaluation
MOW	Malaysia Ministry of Works
OHSAS	Occupational Health & Safety Advisory Services
PPP	Public-private partnerships
PV	Photovoltaic
RP	Revealing power
SDCM	Standard deviations of color matching
SR	Surround ratio
TCO	Total cost of ownership
TI	Threshold increment
UV	Ultraviolet

Weights and Measures

Ah	Ampere-hour
GT	Gigaton
kg	Kilogram
km	Kilometer
kV	Kilovolt
kWh	Kilowatt-hour
Lm	Lumen output
Lm/m^2	Lumens per square meter
Lm/W	Lumen per watt
MT	Metric ton
m/s	Meter per second
Pa	Pascal
TWh	Terawatt-hour
V	Volt
W	Watt
Wp	Watt-peak
W/m^2	Watt per square meter

Executive Summary

Road lighting is an essential service provided by governments to ensure safety and security at night for drivers and pedestrians alike. There is an increasing demand for this service from both rural and urban areas. However, rising energy costs, tight municipal and federal budgets, and rapid growth in overall electricity demand are making it an imperative for authorities to rethink how lighting can be provided in the most cost-effective manner.

Lighting accounts for around 19% of global electricity consumption. Most of it is concentrated in cities and urban areas where road lighting can contribute up to 40% of the city's annual electricity bill. Cities currently comprise of more than two-thirds of the global energy consumption, with energy demand in cities expected to grow by almost 60% by 2030.

The urgency to replace old road lighting with more energy-efficient (EE) technologies can no longer be ignored. This, coupled with the use of renewable energy sources, is essential to meet the expected increase in energy demand in an environmentally-sustainable manner.

Light emitting diodes (LEDs) are proven to be the most efficient option for road lighting today and can help municipalities achieve up to 50 to 70% in energy savings over conventional road lighting technologies such as mercury vapor, metal halide, and high-pressure/low-pressure sodium lamps. There are now more examples of LEDs being successfully adopted in pilot trials and large-scale rollouts, delivering greenhouse gas (GHG) reductions by as much as 50 to 70% and generating significant budgetary savings that can be re-invested in other public services such as education, healthcare, or infrastructure.

The objective of this manual is to provide international funding organizations, client governments, and others stakeholders a useful tool to integrate LED road lighting solutions into relevant Energy, Transport, Urban and Rural Development projects. This manual suggests a practical project design and implementation roadmap that integrates industry best practices, internationally recognized standards, and cost effectiveness.

The LED Road Lighting Design Manual addresses the following topics:

Features of an LED Road Lighting System

This section defines LEDs, LED road lighting systems, and solar LED road lighting systems, as well as the main components which comprise each system. This section also lists the various factors to consider when building an efficient and quality LED road lighting system, as well as the key parameters which differentiate LEDs from conventional lighting technologies.

Benefits of an LED Road Lighting System

This section highlights key technological, economic, and social benefits when implementing LED road lighting. Additional benefits brought about by solar LED road lighting, as compared to grid-connected LED road lighting, are also discussed.

Implementing a Road Lighting Project

This section guides project managers on choosing the most appropriate lighting solution for a road based on type of lighting project to be undertaken, project objectives, and financial/ budgetary requirements. In addition, the section lists the most common questions that need to be addressed when designing the project, covering topics such as: technology to be used; required light levels; pole height, distance, and positioning; and smart controls.

Challenges to LED Road Lighting Adoption

This section enumerates the various challenges which currently hinder the scaling up of LED road lighting. These challenges need to be addressed to enable mainstreaming of LED road lighting into all transport, urban and rural development, and energy sector projects.

Cost Effectiveness and Financing

This section addresses the financial viability of LED road lighting projects. It makes a case for the cost effectiveness of LED road lighting projects as well as available financing options by laying out typical upfront costs of implementing an LED road lighting solution, the lifetime costing when considering the total cost of ownership (TCO), and some successful financing models that have been implemented in LED road lighting projects.

Annexes

The Annexes provide more comprehensive information on the various topics covered in the manual, going into further detail on how to design, specify, and safeguard quality for LED and Solar LED Road Lighting projects, as well as various case studies.

- *Annex 1* lists and dispels common misperceptions about LED lighting.
- *Annex 2* describes various key lighting factors to consider when designing a Road Lighting Project as well as minimum standards that need to be met to ensure safe driving conditions.
- *Annex 3* provides case studies about successful LED lighting projects, covering each case study's background, challenges, solutions, performance and achieved benefits, and financing models applied.
- *Annex 4* goes into further detail, providing (i) industry standards for technical specifications for a tender, (ii) a list of recommended documents for submission with tender bids to ensure quality, and (iii) sample specifications from an actual tender.

Introduction

Future economic growth and energy access need to be planned along a sustainable path that integrates energy conservation and renewable energy use with traditional energy sources. Access to energy is essential for economic growth, especially in urban areas. As Asia, Africa, and Latin America continue to grow, the demand for energy will increase exponentially, placing excessive pressure on finite resources and increasing energy costs. In addition, the use of fossil fuels adds to GHG emissions, which are already at unsustainable levels.

Globally, we can significantly reduce GHG emissions by 670 MT annually and associated energy costs by 50-70% following a switch to LED based efficient lighting.[1] The International Energy Agency (IEA) estimates that lighting accounts for 19% of global electricity consumption and about 1.9 billion tons of CO_2 emissions annually.[2] A switch to LED lighting can help save an average 50% in energy costs, which results in global savings of $160 billion in energy costs, 555 million tons of CO_2, and 1.5 billion barrels of oil every year. This is the equivalent of the annual output of 530 medium sized power stations at 2TWh/year. Road lighting accounts for 4% of global total lighting[3] and up to 40% of a city's annual electricity bill.[4] Thus, it offers an opportunity for quick wins and demonstrability that can lead others, especially private entities, to make the switch to efficient lighting.

LEDs are the most EE option for road lighting today and can help municipalities achieve 50-70% in energy savings over conventional road lighting technologies such as mercury vapor and high-pressure/low-pressure sodium lamps. In addition, the shift to LED based EE road lighting technologies would help reduce GHG emissions and generate significant budgetary savings that could be re-invested in other public services such as education, healthcare, or infrastructure.

EE Road Lighting is particularly relevant for Transport, Urban, and Rural Development sectors:

Transport: The transport sector accounts for roughly 26% of global energy consumption,[5] mainly fossil fuels, making it a priority sector in the sustainability agenda. EE road lighting, non-motorized transport, mass transit systems, and clean fuels are all effective ways of promoting sustainable transport. This manual focuses exclusively on benefits of EE road lighting and ways to incorporate and mainstream EE road lighting in existing and new roads, in cities and rural areas. LED technology, with solar power or otherwise, is strongly recommended for new roads and Bus Rapid Transit (BRT) systems. It is the most cost-efficient technology when product lifetime and energy costs are considered. Besides energy savings and sustainability, EE road lighting also promotes safety and other social benefits.

Urban: Cities house roughly half the world's population today and consume about 67% of the world's energy supply, with energy demand in cities expected to grow by almost 60% by 2030.[6] The lighting sector offers an opportunity to capture quick gains through a switch to LED lighting, starting with road lighting. In addition to the financial and environmental benefits, good quality road lighting promotes security, better aesthetics, efficient use of road network, and reduces road-related accidents. These benefits encourage tourism and extended shopping hours or related outdoor activities at night, resulting in income generation for urban residents. These are substantial benefits and need to be factored in when considering LED road lighting.

Rural Development: For rural communities with limited or no access to electricity, LED / solar LED road lighting can make a significant impact. Using a fraction of the budget needed for grid extension and energy supply expansion, governments can provide LED outdoor lighting and bring light to previously unlit communities. Extended daylight hours in communal areas and properly lit roads enable business, health, education, community and employment-related activities at night, promote social cohesion by bringing members of the community closer together, and make these areas safer at night. Several projects implemented over the last few years in diverse locations across both developed and developing countries demonstrate the longevity, low maintenance, and community benefits of LED outdoor lighting.

As this manual will demonstrate, LED road lighting is a “low-hanging fruit” that can help governments and municipalities significantly reduce their electricity bills, the energy demand-supply gap, and environmental degradation, while promoting economic, social, and sustainable development. This manual will provide a practical guide to LED road lighting project design and implementation, and aims to serve as an impetus for governments and institutions to mainstream LED into their projects.

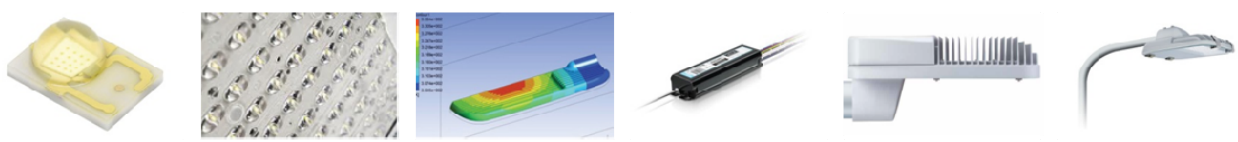
Features of an LED Road Lighting System

This section explains the basics of LEDs, LED road lighting systems, and solar LED road lighting systems, as well as the factors to consider when building an efficient and quality LED road lighting system.

There are several lighting technologies that can be used for road lighting and other outdoor lighting needs, such as for parks, public areas, or parking lots. Conventional lighting technologies include sodium vapor (high/low pressure sodium), mercury vapor, metal halide, fluorescent tube lights, compact fluorescent lamps, and incandescent lights. The latest road lighting systems are based on LED technology.

What are LEDs and LED Road Lighting Systems?

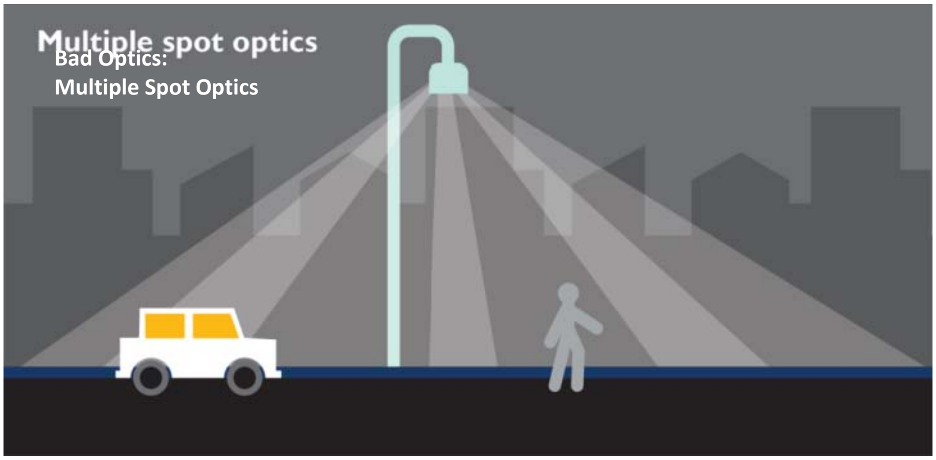
The LED road lighting system is similar to conventional road lighting to the extent that the basic parts are the same – both systems have the pole, cabling, and the luminaire which houses the light source. However, while conventional lighting technologies include a single light source (the bulb), the luminaire of an LED road light unit houses several parts, starting with multiple LED chips arranged in an array, combined with optics, heat management, and a driver – all enclosed in a high pressure die-cast aluminum and glass cover.

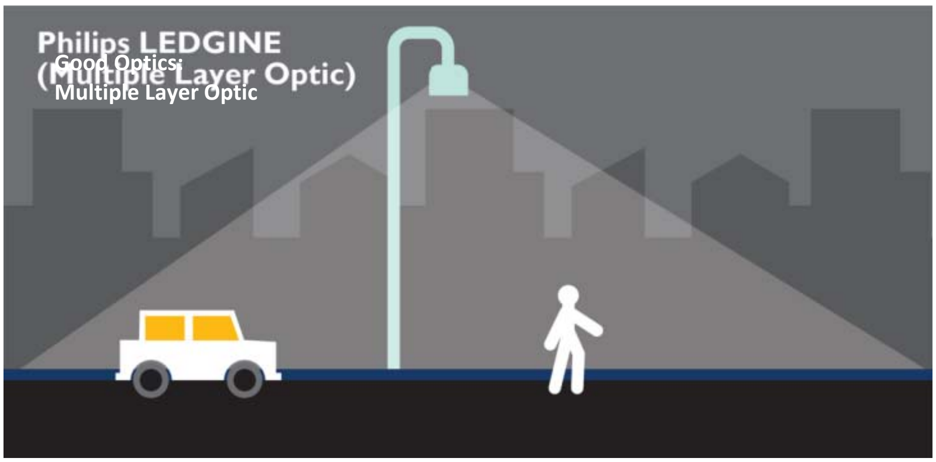


- **LEDs:** LED lights are diodes that emit light, are digital, and are based on the same technology as computer chips. LEDs first appeared in the 1960s, emitting a low-intensity red light and were used as indicator lights. Over the years, LEDs have evolved rapidly and are now available across the visible, ultraviolet, and infrared wavelengths with very high brightness and power. It has thus become possible to use LEDs in various lighting applications, with illumination distances of 400 feet (150 meters) or more.

  Current LEDs are very robust when sourced from quality manufacturers, of which there are a number in business today. High-quality LEDs typically have good color consistency, high lumen efficacy, and can maintain high lumen output over the LED's lifetime. As a digital technology, it is possible to manipulate the light colors and light levels across a continuum.

- **Optics:** Optics manages the distribution of light. Specially designed lens systems should have a unique inner and outer profile to allow maximum spacing between the poles and cover higher road widths. Optics should be arranged in multiple layers to ensure adequate luminance and illuminance uniformity in the unlikely event of individual LED failure.





- **Thermal:** LED sources generate heat via conduction, though not in the light produced. Heat dissipation, (i.e., removing heat from the LED source) is critical to lumen maintenance, light output, light color, light quality, and lifetime since heat negatively affects these factors.

- **Driver:** The driver provides the right amount of current to the LEDs and is an important part of total system reliability. Besides providing a stable flow of current, the driver is responsible for all intelligence, such as dimming and sensor interfacing.

- **Luminaire:** This houses all the components and is responsible for effective protection from dust and water ingression, as well as heat management.

- **Fixture:** Mechanical components such as the pole and internal cables complete the fixture and connect the luminaire to the underground cables supplying electricity.

Features of a Solar LED Road Lighting System

LED road lighting technology has progressed to include solar energy as an energy source. Solar LED road lighting systems have additional components that are not required for grid-connected LED road lighting systems. In addition to the pole, luminaire, and cables that make up a conventional LED road lighting unit, the solar unit comprises a system that collects, stores, and deploys solar energy. A complete solar LED lighting system consists of five main components:

- **Solar Photovoltaic (PV) Panel** is the energy-generating component responsible for harvesting energy from the sun and converting it to a usable form of electricity.

- **Battery** is the energy storage and supply component of the system; it converts stored chemical energy into electrical energy. The battery in a solar lighting system is typically rechargeable and designed to supply energy to the lighting system for up to 3-5 consecutive rainy or non-sunny days. There are called “autonomy days,” defined as the number of days the battery can support the lighting system without recharging.

- **Charge Controller** is considered the “heart of the system.” It harvests the current to charge the battery during the daytime and discharges the battery during the night to power the LED module as efficiently as possible. It also regulates the flow of electric current to and from the battery and prevents over-charging, over-discharging, or over-voltage, all of which may reduce battery performance or lifespan, and may pose a safety risk.

- **Luminaire** here is the same as in the grid-connected LED lighting system. In a solar LED lighting system it is identified as the energy-consuming component responsible for providing an adequate amount of light.

- **Mechanical Components (poles, internal cables)** support the whole system by connecting the PV panel, battery, controller, and luminaire altogether. In a solar LED lighting system, this component plays an even more essential role in the overall reliability of the system.

Having good quality components is not enough to ensure reliability of the system. In fact, precisely because the separate components need to be configured and integrated into a single system, solar LED lighting requires a **system approach** that looks at how the whole unit works optimally and not just the performance of each individual component. A solar LED lighting system is more than just the sum of its parts: it requires seamless system integration and configuration to deliver the required functionality and performance.

The key to a reliable and robust solar LED lighting system is to guarantee the quality of each component and to ensure their proper configuration and integration.

Performance Comparison of LEDs and Conventional Technologies

When comparing the quality of light across technologies as well as across different LED solutions, it is important to understand the key lighting parameters that define quality road lighting. These are:

- **Lumen output (Lm):** Amount of light emitted by the light source.
- **Lamp wattage (W):** Amount of electricity required by the lamp to emit the lumen output.
- **Luminous efficacy (Lm/W):** Luminous or lumen efficacy measures the efficacy of the light source – an LED in the case of LED lighting system, and lamps in case of conventional technologies. It measures how much light is being emitted by the light source per unit of power and is expressed in lumen per watt of electricity used.
- **System wattage (W):** Amount of electricity required by the system to emit the lumen output.
- **System efficacy (Lm/W):** Luminaires include ballasts, drivers, heat management systems, optics, all of which can diminish the original luminous efficacy of the light source. Since the road surface is being lit up by the luminaire as a whole, system efficacy is a better metric to use than luminous efficacy when making comparisons.
- **Watts per square meter (W/m2):** The amount of power required for each lighting appliance to illuminate a road surface to the required light level. For road lighting, this is the most appropriate way to measure the efficiency of a light source, though lumen efficacy or lumen output are often considered easier to measure.
- **Lifetime (hours):** Lifetime of LEDs is measured differently than conventional lighting technologies, which reach end of life at the point when they stop producing light entirely. However, LEDs typically do not stop producing light completely, but depreciate or dim over time to a point where the lumen output is insufficient to meet the required light levels. For LEDs, industry defines lifetime as the point when the LEDs lumen output reaches 70% of the original.
- **Color Rendering Index (CRI):** An index used to measure an artificial light's ability to reproduce the colors of an object, relative to the natural light source (the sun) with CRI of 100. Higher CRI means better visibility.

The table on the next page compares the most popular road lighting technologies in use today across key parameters. For this table, we have assumed a one kilometer stretch of an M2 road[7] that needs to be lit up, with poles in the center median. Based on industry best practices for lighting levels required to light one kilometer of road, we can expect the following:

Table 1: Comparison of Road Lighting Technologies

	LED	High Pressure Sodium Vapor (HPSV)	High Pressure Mercury Vapor
Distance between Poles	30m	30m	30m
Number of Poles	33	33	33
Investment ($)	$$$	$$	$
Lamp Wattage	70W	150W	250W
System Wattage	70W	180W	300W
Luminous Efficacy	90-130 Lm/W (rapidly improving)	100 Lm/W	60 Lm/W
System Efficacy	90-130 Lm/W (rapidly improving)	80 Lm/W	48 Lm/W
Watts per square meter (W/m^2)	0.33	0.86	1.42
Lifetime	50k hours	12k hours	5k hours
Annual Energy consumption (@ $0.15/kWh)	$ 1,532	$ 3,938	$ 6,563
Hazardous Substances	No	Yes	Yes
Color Rendering Index (CRI)	>70	25	<60

The most important differences to note among the three technologies in the table above are the following:

- **W/m^2 and energy consumption costs**: LEDs provide directional light, making them very efficient when lighting up specific surfaces like roads, and thus bringing down the W/m^2 values. In comparison, conventional lamps dissipate light in all directions, including where it is not needed. Hence, LEDs use much less electricity to provide the same lighting level on the road. This is reflected in the annual energy consumption costs, for which LEDs have the lowest.

- **Lifetime**: LEDs also have the longest lifetime, and despite higher initial investment, LEDs tend to be the most cost-effective lighting option in the long run. This is due to other cost savings incurred during its operational lifetime including maintenance, repair, replacement, and disposal costs.

- **Hazardous substances:** LED systems are safer for the environment as they do not contain hazardous substances (e.g., mercury) as defined in international norms and also last longer, thus converting them to trash fewer times.

Not all LEDs are created equal

Low-quality lighting manufacturers often put out misleading claims, especially pairing high light levels with low prices. To guide practitioners, the manual has provided a “Myths and Facts” section in Annex 1 to highlight some of the more prevalent ones. In addition, below are a few key guidelines practitioners should follow:

- Manufacturers claim a certain performance efficacy for their product. Make sure this takes into account the performance of the complete system application (including raw components and the fixture), rather than just that of the LED chips (e.g., for LED chips with a luminous efficacy of 130 lm/W, the whole luminaire may only have an efficacy of 90 lm/W).

- Be sure to choose upgradable, future-proof luminaire designs, which allow new LED modules to replace old ones, without dismantling the luminaire from the pole and with no change to the drivers or other components of the luminaire.

- Manufacturers offer a variety of warranties. Make sure any warranty offered is comprehensive and covers the entire LED application, not just individual components. If the chips are under warranty for ten years, but the optics or heat management is faulty, the product will not function properly. Most high-end manufacturers will offer a comprehensive warranty of around three years.

- A manufacturer with a reliable product will have test reports to back up all reliability and performance claims. Make sure these tests and documents are available. Otherwise, be skeptical of ambitious performance claims.

Benefits of LED Road Lighting

Key Benefits of LED Road Lighting

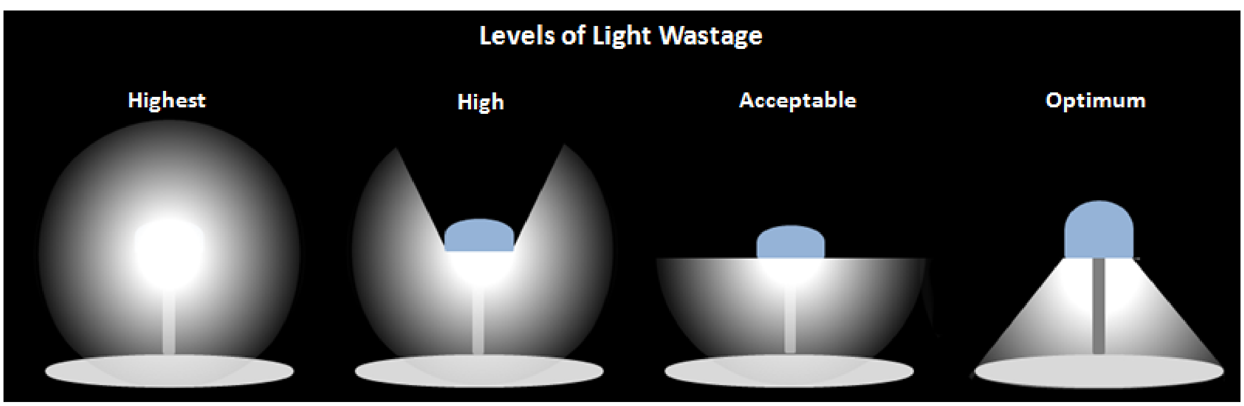
LED road lighting solutions offers significant benefits and options which are not possible with conventional lighting. Some benefits hold true for all LED lighting applications, while others are specific to LED road lighting.

Technological benefits: LEDs represent the next stage in the evolution of lighting technology, moving lighting solutions from analog to digital technology. This is the trend seen across different electrical appliances; radio, telephone, television, and camera have made the switch to digital in the past few decades. The technical benefits offered by LEDs include:

- **High lumen efficacy:** Currently, commercially available luminaires from quality suppliers typically have efficacy levels of 90-100 lm/W. However, with the efficacy levels of LEDs rapidly evolving, it is always recommended to consult with reliable manufacturers or industry representatives for the latest efficacy levels.

- **Directionality and Reduced Light Pollution:** LEDs' directionality contributes significantly to their energy saving potential. LEDs provide directional light, reducing light wastage and directing the light where it is most needed. This can also prevent unwanted dispersion of light to residences, nearby areas, and the night sky, thereby reducing light pollution.[8]

  The high lumen efficacy combined with directionality makes LEDs suitable for many energy-saving lighting applications.



- **Long lifespan**: Laboratory testing and experience indicate that well-produced LED systems last 50,000 hours or more[9], depending on usage. This compares favorably against the 5,000 to 15,000 hour lifetime of most conventional lamps.

- **Superior quality of light:** LED lighting has a high CRI, which together with its white light, offers enhanced night time visibility, making the roads brighter and safer. Some initial research shows that LED road lamps achieve greater light penetration through fog.[10]

Comparison of LED (left) and HPSV (right) under rain and fog conditions: White light from LED produces less glare than the yellow light of HPSV in rain and fog conditions.

- **Extended controllability**: LED lighting is a digital technology making dimming and similar control functions possible and easy. LED users can make precise adjustments to brightness, monitor fixture operation from a centralized location, and optimize energy efficiency by altering light output as needed. In addition, while conventional lighting technologies have shorter useful lives when they are dimmed, the effect on LEDs is the opposite: LED life is extended when dimmed.[11]

- **Durability:** LEDs are highly resistant to vibration and other mechanical stress making them suitable for road lighting, especially on bridges, elevated highways, and where there may be risk of vandalism.[12]

- **Aesthetics:** LED lighting applications can provide colors across the full spectrum[13], and thus help in improving aesthetics of outdoor spaces, bridges, roads and buildings. Some examples include the Empire State Building in New York, USA; the Dragon Bridge in Da Nang, Vietnam; and the Baron Palace in Cairo, Egypt.

LED Improves Aesthetic Appeal of Famous Landmarks: Empire State Building in New York, USA (top-left), Baron Palace in Cairo, Egypt (top-right), and Dragon Bridge in Da Nang, Vietnam (bottom).

Economic Benefits: The strongest argument for a switch to LED road lighting is economic. The direct and indirect economic benefits of LED lighting include:

- **Lower lifetime cost:** During its much longer lifetime of 50,000 hours (compared to 15,000 hours or less for an alternative conventional technology), the total cost of ownership (TCO) of an LED road lighting system is lower by 50% or more. The TCO of a road lighting system includes energy, lamp replacement, and labor and maintenance costs.

- **Income generation:** Effective road lighting helps extend light hours in cities as well as rural areas. This promotes tourism; longer business hours for businesses such as food vendors, shops, entertainment centers; and other evening activities resulting in jobs and income generation.

- **Savings along the energy sector value chain**: By being more efficient, LED road lighting reduces the amount of energy needed from the grid and frees up capacity during peak hours. This allows governments to meet growing energy needs from existing infrastructure and avoid or postpone investments such as for power plants, transmission lines, and distribution networks. Similarly, in off-grid and rural areas, stand-alone solar LED road lighting can help governments meet urgent lighting needs as investments needed to extend the grid are still being made.

Social Benefits:

- **Road safety:** LED road lighting provides better quality light, which increases visibility for both drivers and pedestrians. In off-grid locations, solar LED road lighting can light dangerous intersections or populated unlit spots. Road lighting, and especially LED road lighting, can significantly improve road safety conditions, especially in poorly lit areas and highly populated cities in developing countries.
    - The World Health Organization predicts that road-related accidents will be the world's fifth leading cause of death by 2030.[14]
    - According to Beyer and Ker (2009), road lighting can be an effective measure that reduces the incidence of road traffic crashes, injuries, and fatalities.[15]
    - In Stoke-on-Trent in the UK, crimes decreased by 43% in the areas with improved lighting and by 45% in two adjacent areas, compared with a decrease of only 2% in two control areas.[16]
    - Oya et al. (2003) estimate that installation of lighting on intersections can reduce night accidents by as much as 40%.[17]
    - Clarke (2002) argues that improved lighting can be a good crime deterrent especially in high-crime neighborhoods.[18]
- **Energy savings, environmental benefits:** Road lighting forms a significant part of overall energy consumption by lighting. Besides the energy savings, a shift to LED technology results in an equivalent drop in GHG emissions, about 0.6375 Kg per kWh saved.[19] In addition, LEDs have other "green" benefits: They do not emit infrared radiation or harmful ultraviolet (UV) rays and do not contain mercury, a toxic metal found in several conventional lighting technologies.
- **Better citizen security, livable cities:** LEDs add to a city's aesthetic appeal vibe, helps improve city branding, and cultivates civic pride. In a 2012 survey by The Climate Group, 80% of those surveyed reported that LED street lighting made them feel safer for reasons such as brighter lighting and better facial recognition.[20]

The world has an opportunity to adopt energy efficiency on a large scale, and hence ensure a more sustainable future. These measures are necessary given:

- The IEA estimates that electricity demand will continue to surge and is expected to grow by as much as 67% by 2035; this demand will be primarily met with fossil fuels. Carbon emissions from the power sector will rise from 13.0 GT in 2011 to 15.2 GT in 2035.[21] Despite the growth, the IEA still predicts that nearly one billion people will continue to "live in the dark" by 2035, as they will not have access to modern energy services.[22]

- The United Nations stresses the urgency of action to reverse climate change, as the longer society waits to implement measures against climate change, the more costly and difficult it will be to reverse or limit its effects.[23]

The world needs cost-effective, easy to implement, and high-impact solutions to reduce carbon emissions. EE lighting is a step in the right direction to achieve greener and safer transport, de-carbonize and beautify cities and urban places, and promote sustainable and inclusive growth in rural areas.

The need is high and the urgency is now! To ask if we should switch to LED or not, is the wrong question. Instead the question is how quickly we can make the switch, and where do we start.

Key Benefits of a Solar LED Road Lighting System

Depending on the context, solar LED road lights deliver additional benefits compared to grid-connected LED road lighting systems:

- **Higher energy savings:** Solar LED road lights provide 100% energy savings over conventional road lights, and hence higher savings on the energy bill.

- **Lower initial investment in off-grid areas:** When we factor in the cost of connecting an off-grid area to the electricity grid so it may have road lights, the initial cost of setting up road lights is much lower with solar LED lights.

- **Energy access in off-grid areas:** In many rural areas, solar road lights provide the only source of light. When situated in an off-grid community center, solar LED road lights help lengthen the work day, supporting increased economic activities, community interaction, and education-related activities. Community lighting also becomes the first step to energy access, as households start demanding and paying for energy access in their homes.

- **Climate change mitigation:** As part of their climate change mitigation strategies, many utilities and countries are now setting targets for GHG mitigation and energy generation from renewable sources. Solar LED road lights can be a good way for countries/ utilities to meet both these targets. Installation of solar LED lights can count as solar power generation, and a switch to solar LED lights helps reduce GHG emissions significantly.

When is solar LED the optimum choice?

As solar LED lighting has a higher initial investment cost compared to grid-connected LED lighting, we examine the situations where solar LED road lighting is the best option:

- **Limited, unstable, or no generation capacity:** In most emerging markets, energy demand outstrips supply, and it may be difficult to increase generation capacity in time to meet growing demand for road lighting. This is especially true in many markets in South Asia and Africa.

- **Off-grid locations:** For any area that is currently a mile or more away from an electricity grid, it is more cost-effective to install solar road lighting than to extend the grid. In areas with sparse population it is often faster and more economical to provide solar road lighting and similar off-grid solutions for other energy needs.

- **Opportunity costs:** Often, limited energy supply and competing demands from industry/essential services together impose significant constraints on the electricity grid. In instances such as this, and especially if energy costs are high, adding solar energy supply into the mix through solar LED road lights may be an effective way to provide significant relief during peak demand times.

- **New installation costs:** In some cases, where energy costs are high and when lighting a road for the first time, it may be cost-effective over the product lifetime to opt for a solar solution. One can save on the cabling network between the poles (since no cabling is involved) and even reduce the number of poles needed per kilometer through smart design.

Implementing a Road Lighting Project

This section provides a guide to choosing the best road lighting solution for different situations, tackling topics such as: what technology to use; what light level might be required; pole placement, height, and spacing, and controls.

Project managers first need to consider the type of LED lighting project being undertaken: An “LED retrofit”, where existing, energy-inefficient road lights are switched out for EE LEDs, or an “LED Greenfield” project, where either new or existing roads are being lit up for the first time.

In the case of an **LED retrofit project**, the main purpose of road lighting, i.e., to light up roads, is already being met. The LED retrofit project is being implemented to achieve other goals such as energy savings, better lighting levels or GHG emission reduction. For **LED greenfield projects**, while the need to light up the roads is paramount, the additional features of LEDs offer more options. In addition, the absence of an existing system provides more flexibility in choosing the most cost-effective and future-proof lighting solution possible.

1. ***Define Project Objective:***

As mentioned above, the main purpose of road lighting is to provide appropriate lighting levels for driver and pedestrian safety. However, with LED road lighting, many additional objectives can be met such as reduction in peak energy demand, lower energy bills, improved lighting levels/aesthetics, lower GHG emissions, and lighting for roads in off-grid areas. Project managers need to choose the most important project objective and balance other project goals as the objective will directly influence the choice of a lighting solution.

For example, if the key objective for an LED retrofit project is energy savings, with reduced peak-time energy demand and quick payback as the next two concerns, one might recommend a no frills LED retrofit, with no dimming or controls. However, with the key objective being energy savings, if the next two concerns are lower energy bills and lower GHG emissions, one might want to opt for controls.

2. ***Ensure Financial Viability and Budget Availability:***

For both retrofit and greenfield LED projects, it is essential to consider the financial viability and budget availability of the project. Though the lifecycle costs of LED road lighting projects are typically lower than conventional solutions, the high initial investment continues to be a key barrier for LED road lighting projects. There are financing options available, including ones that avoid the need for upfront investment to help address this common challenge. The lifecycle costing models and financing options are discussed in the financing section.

3. ***Create the Project Design*:**

The project design for LED projects is split into two phases. The first phase is a lighting audit, which is a detailed assessment of the current lighting situation that measures the baseline situation – especially around energy consumption – and identifies critical gaps and areas of improvement.

The factors affecting the lighting audits of LED greenfield projects and LED retrofit projects are usually very different. Accordingly, the first phase for each has been addressed here separately.

Phase I: Lighting Audit

LED retrofit project: Some typical questions addressed during an audit include:

A. Given the road size, the current and projected vehicular and pedestrian traffic, is the current installed system adequate for meeting the lighting needs? What is the correct lighting level?

B. What is the pattern of traffic on this road – is it never busy; busy during certain hours; or busy throughout the night (e.g., airport road)?

C. Do the current installed poles have the right height, strength, and distance to ensure appropriate lighting on the entire road?

D. Can the current infrastructure support the proposed LED luminaire, making a luminaire switch possible, or do the poles need to be re-installed/ modified?

E. What is the condition of the cabling and wiring between and inside the poles?

F. Is the whole lighting system so depreciated that it needs to be re-installed in its entirety?

G. What is the current energy spending for road lighting – in KWh and in dollars?

H. What is the public perception of the current lighting system?

LED greenfield project: LED road lighting solutions offer many additional features, better lighting levels and aesthetics, as compared to conventional lighting. These additional parameters need to be considered in the design of a greenfield road lighting solution. Typical questions addressed during a lighting audit for an LED greenfield project include:

A. What is the optimum lighting level for the road given its size, pedestrian requirements and the current and projected vehicular and pedestrian traffic?

B. What is the pattern of traffic on this road – is it never busy; busy during certain hours; or busy through the night (e.g., airport road)?

C. What is happening around the road? Are there ambient bright lights, trees, open land, pedestrians?

D. Have the project owners expressed a preference regarding the pole spacing and location?

The second phase involves designing an optimal lighting solution that meets the project objectives and budget while incorporating results of the lighting audit as well as the local regulations, lighting/physical factors, and international guidelines around road lighting.

Phase II: Solution Design

A good road lighting system will ensure visual detection of an object at greater distances. The ability of road lighting to illuminate an object – expressed as revealing power (RP) – is affected by lighting factors such as quality of light, glare, uniformity, and physical factors such as traffic level and road surface.

The project team designs an optimal lighting solution that would balance the project objectives and budget, address the gaps highlighted in the lighting audit, and incorporate industry best practices/ standards and regulations to ensure safe driving conditions.

Please refer to Annex 2 for details on the various lighting and physical factors considered while designing an effective lighting system, and the minimum standards that need to be met to ensure safe driving conditions.

Project proponents are encouraged to test project viability by comparing experiences of other successful projects, or testing the solution through a smaller pilot prior to scaling-up. Such benchmarking helps reduce the risk of project failure by providing data around light levels, aesthetic appeal, product stability/suitability, and energy savings.

4. Implement Project:

After determining the viability of the project and the financing mechanism, project implementation is the next step. Implementation involves the procurement, supply and installation, and integration of luminaires to the lighting infrastructure and, if necessary, programming of the smart control systems. Post-implementation services, which include operation, maintenance, and monitoring and evaluation (M&E) are also vital to the success of a road lighting project. These services are essential to ensure the quality of the lighting system throughout its life cycle.

<u>Procurement</u>

The LED lighting market can be profitable and is growing rapidly. With low barriers to entry, the sector has attracted many players offering products with widely varying quality and specifications. The industry is still working towards harmonizing specifications and creating an international standard. This poses a procurement challenge for most municipalities/ governments, as it is difficult to procure LEDs based on specifications alone. Listed below are two key points to consider to help procure quality LED road lighting products:

A. Setting the Right Specs

Following international standards and setting the right specifications are necessary steps to ensure the quality and suitability of the LED road lighting to be procured. The specifications need to be aligned with the project objective(s). For instance, if the objective is to increase light level, then a luminaire with higher lumen package needs to be specified, while in cases where the objective is to save energy, the luminaire should have a higher efficacy.

It is important to note that LED is a rapidly changing technology, with older products being constantly discontinued. At the same time, manufacturers innovate at different rates. To ensure wider competition and also capture the latest technical innovations, specifications should ideally be aspirational but should also allow for some flexibility. To assist project planners, and as a starting point, this manual provides industry-recommended specifications in Annex 4.

B. Choosing the Right Supplier

Equally important is choosing the right supplier. The LED technology has initiated the transition of lighting from a low-value, fast-moving commodity type product to a high-value durable solution. The buying decision should then likewise need to transition from getting the one with 'lowest initial cost' to the one that considers performance level and 'lowest total cost of ownership'. Buyers need to pick a reliable technology partner, with road lighting project experience, innovation history, financial stability, and some assurance of company longevity. The best way to achieve this may be to pre-qualify suppliers based on specific criteria and then tender for price. Some suggested areas include:

- *Technical Capability* – criteria that demonstrate the supplier's capability to supply products to match the required specifications and project design
- *Contractual Experience* – criteria that demonstrate the supplier's previous experience in successfully implementing similar types of projects
- *Financial Capability* – criteria to evaluate the supplier's capability to back the project (including warranties) over the project's lifetime

Monitoring and Evaluation

An important aspect of project implementation, especially for LED retrofits, is a robust M&E mechanism. This provides the project owners and stakeholders a picture of the program and its effectiveness with respect to the project's objectives and helps measure the impact of the program. Typical measures include, among others:

- Improvement in lighting levels
- Savings in energy usage and costs
- Reduction in CO_2 emissions

M&E allows project owners to set benchmarks, identify project learnings and provide recommendations to ensure more successful road lighting projects in the future.

Challenges to LED Road Lighting Adoption

LED road lighting is a technologically superior product and has a significantly lower lifecycle cost compared to conventional technologies. However, several challenges need to be addressed before LED road lighting is mainstreamed into all transport, urban development, rural development, and energy sector projects. These challenges include:

1. **Limited political will, lack of a champion:** Benefits of energy efficiency projects are not visible. There is nothing tangible, such as a power plant, a road, or a school to show for the substantial investment made. What is visible is the substitution of new lights for old ones that are now brighter and more aesthetically appealing, while the environmental benefits, energy, and budgetary savings remain hidden. It thus becomes difficult to justify why scarce resources should be allocated to a service that has already been provided. The challenge is in finding a champion for this project who appreciates the benefits and can market them effectively within the government and to the citizens. The limited political will stems from:

    a. **Lack of awareness:** Most owners of existing or new road lighting are not aware of the facts around LED road lighting technologies, the lower lifetime costing compared to conventional lighting, or how to initiate, design, and implement such a project.

    b. **Distributed customer base:** Typically, road lighting is procured and/or managed by various road authorities, municipalities, urban bodies and counties. The customer base in a country is thus split into several small entities, making it difficult to market, educate, and aggregate to achieve scale and lower costs.

    c. **Ownership mismatch, which limits investment:** The owner of the lighting assets and the one carrying the energy costs are often different entities. This limits motivation for either to invest in high-cost assets to reduce annual maintenance and energy costs.

    d. **Incumbent concessionaires:** Many road lighting contracts have been given out to private sector companies in multi-year contracts. In many cases, the government must wait until the end of that concessionary period before they can switch the lights.

    e. **Failure of early pilots:** Failure of some early pilots which used sub-standard products and often poor project and lighting solution design has scared off early converts. Many governments are now waiting for longer term proof of technical success and a sharp decline in product costs.

2. **Lack of financing:** Even where energy costs are very high, the lack of access to the upfront cost has limited many projects.

3. **Lack of globally accepted international standards**: There is still no consensus regarding what standards to follow for LED road lighting systems. It is a complex, new product and not many know how to see through tricks played by low-quality suppliers, and set a tender that would keep out poor quality products.

Through this manual, we hope to address some of the concerns above, especially the risk of project failure. The manual will help inform policy makers and project managers in governments/institutions across the globe on how to design an effective LED lighting project, what pitfalls to avoid, and especially how to set a tender that will steer them to quality products and not just ones with a low initial cost.

Cost Effectiveness and Financing

This section addresses the two "elephants in the room" related to LED road lighting:

- Cost Effectiveness: Is LED really more cost-effective than the next best road lighting product? How can one evaluate the different options?
- Financing: How can project proponents source the upfront financing for the high initial cost of either greenfield or retrofit LED road lighting solutions?

This section lays out the typical upfront costs of implementing an LED road lighting solution, the lifetime costing when considering the total cost of ownership, and some successful financing models that have been tested.

Cost Effectiveness of LED Road Lighting

Total Cost of Ownership

LED road lighting has a higher initial cost as compared to conventional road lighting. However, when we consider the TCO of a road lighting solution, which includes the initial product investment, energy costs, lamp replacement, repairs and maintenance costs over the 20 year product lifetime, an LED solution is far less expensive.

Retrofit Projects: For the example below, we have only considered the savings from the first 10 years following the retrofit to LED. As can be seen, a city needs $1.7 million to retrofit a 100km stretch of road with LED. Over the first 10 years following the switch, the city would be able to save $7.7 million in energy costs and $1.3 million in maintenance costs. The city thus achieves a total of 53% savings over conventional technology.

Table 2: TCO Calculation of a Retrofit Road Lighting Project

RETROFIT of 100 KM ROAD, 5,000 LUMINAIRES				
COSTS & SAVINGS OVER FIRST 10 YEARS	Conventional	LED	Savings	Savings
	$'000			%
Fixture + Installation for LED system (est.)	--	$1,675	-$1,675	
Energy Costs	$12,513	$4,784	$7,729	62%
Maintenance, parts replaced, repair, disposal	$1,329	$ -	$1,329	
Total Cost of Ownership	$13,842	$6,459	$7,383	**53%**
CO_2 Emission (Metric tons)	47,468	18,149	29,318	62%
Power Supply (KW) (Energy spent)	1,700	650	1,050	62%

Assumptions:

- The road is Type M3 with 50% Mercury Vapor (system power 400W) & 50% HPSV 250W (System power 280W)
- All are replaced by LED 130W (System power 130W) with no controls
- # of fixtures: 5,000 assuming poles are 40 meters apart; installed in the center median; two Luminaires per pole
- Burning hours of 12 hours per day; Calculation horizon: 10 years
- Energy price: $0.15/kWh; Inflation is estimated at 2.5% per year
- CO_2 conversion factor: 0.6375 kg/kWh
- Luminaire prices are for products only and exclude delivery and fulfillment-related costs. These costs vary from project to project given the chosen project go-to market structure.

A change in assumptions, such as adding controls, increasing/decreasing electricity cost, type of lamp replaced, or type of road would impact the payback period. However, in most cases, over its lifetime, the LED system is 40-70% cheaper than a conventional product over the same time period.

Green Field Projects: When it comes to lighting newly built roads, currently three options are examined:

1. Do not install road lighting
2. Install HPSV road lighting (business-as-usual scenario)
3. Install LED road lighting

Once project owners decide to light up a road or a portion of the road, they compare the lifetime costs of LED to HOSV greenfield projects. For our sample road, the scenario could be as follows:

Table 3: TCO Calculation of a Greenfield Road Lighting Project

GREENFIELD ROAD LIGHTING PROJECT of 100 KM ROAD, 5,000 LUMINAIRES				
COSTS & SAVINGS OVER FIRST 10 YEARS	HPSV	LED	Savings	Savings
	$'000			%
Fixture + Installation Costs	$1,050	$1,675	-$625	
Energy Costs	$12,513	$ 4,784	$ 7,729	62%
Maintenance, Parts replaced, Repair	$1,329	$ -	$1,329	
Total Cost of Ownership	$14,892	$6,459	$8,433	**57%**
CO_2 Emission (Metric tons)	47,468	18,149	29,318	62%
Power Supply (KW) (Energy spent)	1,700	650	1,050	62%

Assumptions: same as above.

Most of the LED performance data available today have been tested in pilots and full-scale projects in several countries across the globe, some of which are presented in this report. A number of these projects were presented as case studies in The Climate Group's report, "Lighting the Clean Revolution," published in June 2012. The case studies share proof points, benefits of LED road lighting, and the different reasons cities have adopted LED.

Business Case

For greenfield projects, the business case is established by doing a lifecycle, total cost of ownership comparison between the various options as demonstrated in Table 3 above.

For retrofit projects, the **Payback Method** is the most straightforward and often-used method to build a business case. The payback method simply measures the number of years it takes to recover the initial investment and highlights the continuing savings following loan payback.

To accurately compute the payback period of LED road lighting projects, one must consider the real costs of electricity (not the subsidized tariff rates) and financing costs as these factors strongly affects a project's business case.

For list of financing options, please refer to "Financing Options" towards the end of this section.

The payback for the retrofit example in Table 2 above is as follows:

Table 4: Payback Calculations

FINANCING	RETROFIT PROJECT
Simple Payback	2.1 years
Payback with financing	2.4 years

Assumptions:
- Annual financing rate 8%
- Tenor: 4 years, 4 payments per year
- Warranty 3 years

CASE STUDY: Business Case for the City of Los Angeles

The City of Los Angeles (LA) owns the second largest road lighting system in the United States, after New York City. There are an estimated 210,000 street lights on 4,500 miles of lighted streets, of which 140,000, mostly HPSV lights, were converted to LEDs between 2009 and 2013.

The project, implemented in collaboration with the LA Mayor's office, LA Department of Water & Power, Bureau of Street Lighting (BSL), the Clinton Climate Initiative, and the City, was delivered on time and with higher than projected energy savings.

The project cost of $56.7 million was funded through $13.2 million in energy efficiency rebate ($0.24 per kWh reduced), a $3.5 million fund from the Bureau's Street Lighting Assessment Fund and a loan of $40 million at an interest rate of 5.25%. The payback for the project was calculated at seven years based on expected annual energy and maintenance savings of around $8.2 million.[24] Once the loans are paid off, the City will save $10 million annually on road lights operation and maintenance compared to current costs.

Below are the project's statistics, as shown in a recent report of BSL (June 2014),[25] showing how the project exceeded its expected annual energy savings of 68 GWh.

Table 5: Los Angeles Street Lighting Project Statistics

Total Number of Units	152,986
% Energy Savings	62.9%
Annual CO_2 Reduction (in metric tons)	53,724 MT
Annual Energy Savings (GWh)	90.84 GWh
Annual Energy Savings ($)	$8,082,842

Financing Options

There are many ways of financing LED projects, depending on the availability of funds and the City/Municipality/ Road Authority's ability to internally market and sell the project and financing model. In most emerging markets, implementing demand-side energy efficiency initiatives has become an imperative as energy demand far outstrips supply. The TCO analysis above and the list of financing options provided below should help project proponents design and market these projects. Some popular financing mechanisms are listed below.

Self-Financing: This is the traditional and straightforward strategy for funding road lighting projects. This allocates funding directly from the local government's annual capital budget, or loans/grants from bilateral or multilateral development agencies focused on climate change and energy and efficiency initiatives. Self-financing can lower the total costs of projects as commercial bank financing is generally more expensive. However, the availability of funds and the internal approvals needed to allocate, approve, and disburse the funding may delay a project.

Leasing: A customer could choose to rent the lighting system rather than purchase it from the supplier/project developers. A variety of financing structures are available, including the operating lease, capital/finance lease, and hire-purchase agreements. The product is handed over to the city once the payback on the project has been achieved, usually a pre-designated time period.

Public-Private Partnerships (PPPs): This is a contract between the government and the private sector. In PPPs, the private sector brings in capital funding and expertise, and takes in all the financial and performance risks of the project while the government retains the management control and key decision powers.

Performance Contracting: Energy Performance Contracts are comprehensive bundles of services – technical evaluations, equipment installations, energy monitoring, and evaluation – and are usually implemented by Energy Service Companies (ESCOs). In the *shared-saving performance contracting model*, the bulk of the capital is provided by the ESCO, and it is structured in a way that energy savings are shared between the ESCO and the client over a defined period of time. In the *guaranteed savings performance contracting model*, the customer raises project capital based on the saving performance guarantee issued by the ESCO. Both contracting models work on the assumption that the lighting system will incur enough energy savings to compensate for the capital outflow. However, performance contracting may not work in emerging countries, where the right enabling environment is lacking, and therefore the ESCO sector in these markets is virtually non-existent.

Carbon Financing: EE road lighting projects can be registered to earn Certified Emission Credits, which are then traded in the carbon market. The carbon funds from the trading of these Certified Emission Credits are then used to make the project economically viable. However, this mechanism has not been active in the past few years as the market value of these credits has declined to very low levels. Alternative carbon financing sources are available through multilateral development banks and select commercial banks.

To determine which of these strategies is most suitable for a project, it is important to carefully assess the customer's available capital resources, appetite for risk, need for external expertise, desire for asset control, and impact of the project on the customer's balance sheet.

Annex 1: LED Myths and Facts

The Myths and Facts presented in this section are largely based on the information collated by Philips Lighting in their tool, *The Road Planner's Guide.* [26]

No.	Myth	Fact
1	LEDs are not reliable	• **A well-designed luminaire delivers at least 70% of initial lumen output (L70) over 50,000 hours of use.** This translates to nearly twelve years of reliable use, based on a daily 12-hour duty cycle. • High ambient temperatures and electrical grid instability can influence lumen depreciation. • Not all LED chips are of equal quality. To ensure quality, refer to independent test reports like the LM 80 for the true indication of the projected lifetime of the LEDs used at different operating temperatures.
2	LED systems are too expensive	• **TCO analyses demonstrate that LED systems cost less than conventional systems over lifetime**, as ○ LED systems typically offer 50 - 70% of energy savings compared to conventional technologies. ○ LED systems do not require frequent lamp changes, reducing expensive labor costs and replacement of lamps. • The breakeven point on the initial investment varies between 2 to 3 years based on the cost of energy.
3	Higher lumen per watt performing LEDs are better	• Claims from vendors that show impressive **lumen output of 160 lumens/watt or higher do not reflect real-world use**. These vendors use, for example, isolated pulse tests (that switch on the LED for periods shorter than a second) which do not reflect the real use of the LED chip. Although percentages vary, it is not uncommon to see losses of 30 to 40% in lumen/watt power when the chips are placed in the luminaire. • Check if the tests are conducted by independent testing laboratories and not based solely on the manufacturer's own claims.
4	LED chips do not generate heat	• Conventional lighting sources only convert a fraction of electrical power into visible light, the rest is wasted as heat (infrared radiation). As this excessive heat travels within the light beam, it reduces the light's effectiveness. Prolonged exposure to heat (infrared radiation) can be hazardous to eyes, skin, and fabrics. • LED chips on the other hand, are able to convert most of electrical power as light and the **emitted light does not carry heat**. However, an amount of heat is generated at the LED driver and PCB (printed circuit board) section. • A carefully engineered heat sink helps to dissipate heat efficiently. Choose an LED road

No.	Myth	Fact
		lighting system vendor that designs, simulates, and tests their products for high thermal efficiency to ensure optimal performance and maximize the lifetime of the LEDs.
5	LED technology is still in its infancy	• Since its invention in 1963, LED technology has become a highly evolved lighting solution that offers excellent efficacy, usability, and reliability. Today, LEDs are used in a wide range of demanding outdoor lighting applications and are here to stay.
6	LED lights are not resistant to vibration	• With no moving parts, filaments or fragile glass enclosures, LED chips are perfect for use in road & bridge lighting applications where there are high risks of vibration and vandalism.
7	LED chips cannot switch on and off rapidly	• LEDs are capable of reaching their full output almost instantly after switching on and can remain on for long periods without shortening the useful life.
8	LED lights cannot operate in extremely cold environments	• LED light fixtures operating in extreme cold tend to be more efficient and enjoy a longer lifetime.
9	LED lights cannot be dimmed and controlled	• LED lighting systems are highly customizable. Systems can be upgraded with light, traffic, and visibility sensors. • A control system can easily manipulate light intensity to suit the prevailing weather or traffic conditions.
10	LED chips have consistent color	• Lighting vendors who are not critical in their quality control and LED chip selection process can end up with LED lighting solutions with inconsistent color temperature. • High quality vendors subject their LED chips to 100% testing, and employ sophisticated binning technology to ensure similar light characteristics for every fixture. Leading LED chip manufacturers in the industry today include Philips Lumileds, Cree, Nichia, and Osram.
11	The Correlated Color Temperature (CCT) of LEDs are always very cold, almost bluish	• LEDs are available in many different color temperatures. LEDs with color temperatures from 3000 Kelvin to 6500 Kelvin are considered as white and are suited for road use. • In many countries warmer variants are used for urban and pedestrian walkways, while the cooler temperatures are used for roads and expressways, depending on local preference.
12	LED light quality is poor for roads	• In a study commissioned by the Mayor of London's office on the effects of LED road lighting, an overwhelming majority of those surveyed said that, with the same amount of lumen output, the white light of LED road lighting "allowed them to see better."[27] • The CRI for white LED light is around 70 as compared to a CRI of 25 for conventional HPSV light. A higher CRI indicates better recognition of objects.
13	LED road lighting requires power grid connection	• Given the low power consumption of LEDs, they are perfectly suitable for use with solar power technologies in areas where grid power is limited or not available.

<table>
<tr><th>No.</th><th>Myth</th><th>Fact</th></tr>
<tr><td>14</td><td>LED road lighting fixtures are expensive yet provide minimal energy savings over conventional fixtures.</td><td>

• The following table compares the power consumption of LED and conventional lighting solutions, both offer comparable lighting performance on the road.

Table 6. LED Equivalents of Typical HPSV Wattages

<table>
<tr><th>Conventional Wattage (HPSV)</th><th>LED Wattage*</th></tr>
<tr><td>70 W</td><td>35 W</td></tr>
<tr><td>150 W</td><td>70 W</td></tr>
<tr><td>250 W</td><td>130 W</td></tr>
<tr><td>400 W</td><td>280 W</td></tr>
</table>

*Actual comparison may be favorable when compared to poorly designed or low quality conventional fixture.

• LED systems give a superior TCO over the total project lifetime compared to conventional lighting.

• Depending on the cost of energy, the payback period typically varies between 2 to 3 years.
</td></tr>
<tr><td>15</td><td>The required lumen output of LED fixtures should match those of conventional fixtures</td><td>

• Conventional light sources emit light over their entire surface. A complex system of reflectors and diffusers are needed to direct the light to the road, which results in significant loss of light on the surface.

• LED light sources project their light in a directional manner, hence require fewer lumen-sapping reflectors and diffusers to direct the light onto the road.

• That is the reason why a conventional 3800 lumen light source can be replaced by a 2800 lumen LED fixture approximately.
</td></tr>
<tr><td>16</td><td>LEDs contain hazardous substances</td><td>

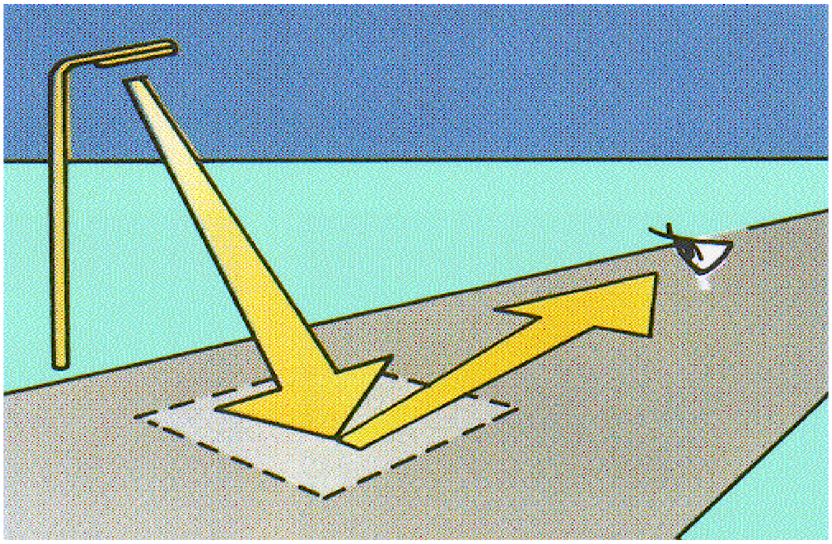
• Unlike HPSV, Fluorescent or Induction-.based technologies, LEDs do not contain mercury, lead or other toxic materials.
</td></tr>
</table>

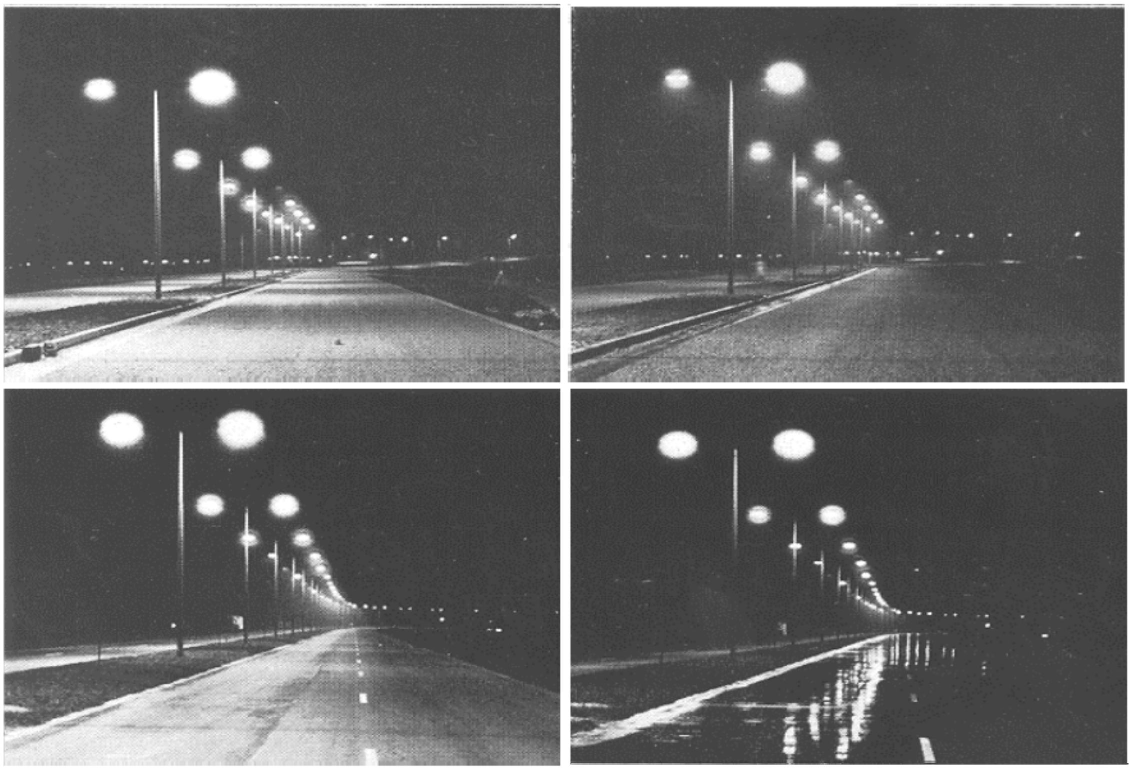
Annex 2: Key Factors to Consider When Designing a Road Lighting Project

The main purpose of road lighting is to provide an appropriate level of visibility to motorists to ensure safety in driving. In cities, road lighting plays an additional role of creating a more inviting and safe environment. The ability of road lighting to illuminate an object – expressed as RP – is affected by the quality of light and other physical factors such as traffic level and road surface. A good road lighting system will ensure visual detection of an object at greater distances. This section describes the various lighting factors the industry considers while designing an effective lighting system, and the minimum standards that need to be met to ensure safe driving conditions.

Comparison between HPSV (left) and LED (right): While conventional technologies can meet the key lighting factors (luminance, uniformity, glare, surround ratio, color rendering index), LEDs meet these at more desirable levels, making it more pleasing to the eye, as evident in the pictures above.

1. **Road Luminance** is a measure of how visible the road is to a motorist. Luminance is dependent on the light distribution of the luminaires, the lumen output of the lamps, the installation design of the road lighting, and the reflection properties of the road surface. The higher the luminance level, the better the lighting. Based on industry standards, a 75% RP is considered sufficient in most road conditions.





Luminance on Different Road Surfaces: (Upper left) Smooth and dry road surface, (Upper right) Smooth and wet surface, (Lower left) Rough and dry surface, (Lower right) rough and wet surface.

2. **Uniformity** is a measure of how evenly distributed the light on the road is, which can be expressed as Overall Uniformity (U_O) and Longitudinal Uniformity (U_L). A good overall uniformity ensures that all spots and objects on the road are sufficiently lit and visible to the motorist. The industry accepted value for U_O is 0.40.

Overall Uniformity. The picture on the left shows a road with good U_O while the picture on the right has low level of U_O. The box is more visible in the road with higher U_O. Having higher U_O allows the motorist to see the road clearly and anticipate potential road hazards (e.g. open manholes, road excavations, sharp objects on the road, people crossing the street).

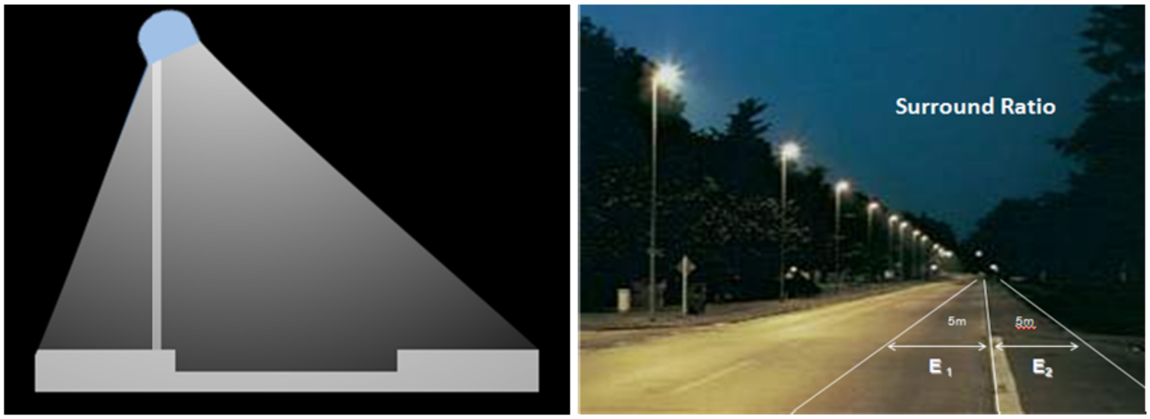
On the other hand, a good level of longitudinal uniformity ensures comfortable driving conditions by reducing the pattern of high and low luminance levels on a road (i.e. zebra effect). It is applicable to long continuous roads.

Longitudinal Uniformity. The picture on the right shows a road with low level of U_L demonstrating the 'zebra effect' while the picture on the left has high level of U_L. The 'zebra effect' can cause discomfort to motorists, posing a risk to road safety. Ensuring good level of uniformity can reduce the luminance level needed.

3. **Glare** is the blinding sensation when the brightness of the light exceeds the adaptation level of the human eye to light. It produces discomfort and reduces road visibility. It is measured in Threshold Increment (TI), which is the percentage increase in required luminance to compensate the effect of glare (i.e., make the road equally visible as in the absence of glare). The industry standard for glare is 10% TI.

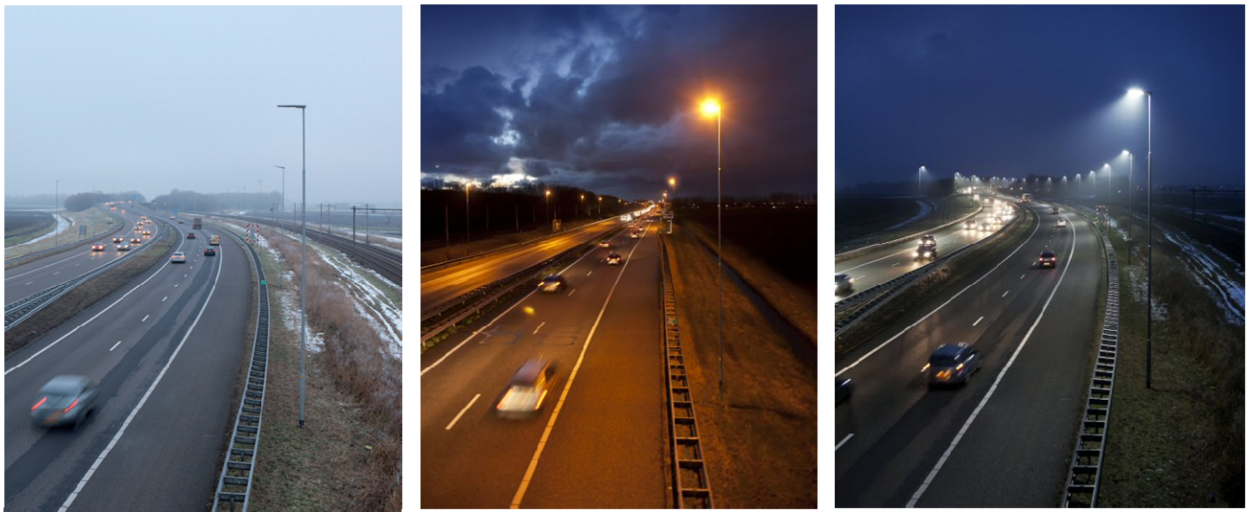
Glare. The pictures above demonstrate the effect of glare. High levels of glare can make the road appear hazy (less visible) which poses a safety risk to motorists and pedestrian alike.

4. **Surround Ratio (SR):** Road lighting should light up not only the road, but also the adjacent areas so motorists can see objects in the periphery and anticipate potential road obstructions (e.g., a pedestrian about to step onto the road). The SR is the visibility of the road's periphery relative to that of the main road itself. As per industry standards, SR should be at least 0.50, as this is ideal and sufficient to create a proper adaptation to the eyes.



Surround Ratio: (Left) A schematic diagram of how road lighting should illuminate both the main road and its periphery. (Right) A real-life example of a road with good SR.

5. **Color Rendering Index** measures the ability of the artificial light to show or reproduce the colors of the road or objects on the road, relative to a natural light source. The natural light source (the sun) has CRI of 100. The higher this index the better the visibility will be. For all types of road CRI ≥ 70 is recommended.



Color Rendering Index: Road under natural light (left), HPSV (middle), and LED (right).

Industry Standards for Road Lighting Levels

The right levels of these factors are determined by the internationally-accepted standard *Commission Internationale de l'éclairage* (CIE, International Commission on Illumination).[28] This standard defines the required lighting for every type of motorized road, with roads classified according to a set of defining characteristics such as traffic volume and composition, number of lanes, usage, weather conditions (fog, rain), and type of road surface (paved, unpaved, cemented, asphalt, cemented), among others.[29]

The roads are classified from M1 to M6 with M1 being the largest (e.g., highways, expressways). Table 1 below displays the lighting performance expected for each of these factors, based on the type of road.

Table 7. Lighting Classes for Motorized Traffic[30]

Road category	Road Luminance	Uniformity	Glare	Surround Ratio
	Lav (cd/m^2)	U	TI (%)	Rs
M1	≥2.0	≥0.4	≤10	0.5
M2	≥1.5	≥0.4	≤10	0.5
M3	≥1.0	≥0.4	≤15	0.5
M4	≥0.75	≥0.4	≤15	0.5
M5	≥0.50	≥0.35	≤15	0.5
M6	≥0.30	≥0.35	≤20	0.5

Additionally, the CIE standard has recommended lighting levels for pedestrian roads or areas. These roads are classified from P1 to P6, according to traffic volume and composition, ambient luminance, and the requirement for facial recognition, among others.[31] An important lighting parameter to consider for this type of road is illuminance.

- **Road Illuminance** is the amount of light (lumens) incident on per unit area of the road surface, and is expressed as *lm/m^2* (lumens per square meter) or lux.

Table 8. Lighting Classes for Pedestrian and Low-Speed Traffic Areas[32]

Road category	Average Horizontal Illuminance	Minimum Horizontal Illuminance	Additional Requirement if facial recognition is necessary	
			Minimum Vertical Illuminance	Minimum semi-cylindrical Illuminance
	$E_{h,av}$ (lx)	$E_{h,min}$ (lx)	$E_{V,min}$ (lx)	$E_{sc,min}$ (lx)
P1	15	3.0	5.0	3.0
P2	10	2.0	3.0	2.0
P3	7.5	1.5	2.5	1.5
P4	5.0	1.0	1.5	1.0
P5	3.0	0.6	1.0	0.6
P6	2.0	0.4	0.6	0.4

Physical Factors

Physical factors can either enhance or detract from the performance of the road light, so it is imperative to give these factors ample consideration when creating a lighting system.

Poles should be strong enough to carry and support the luminaire, should have the appropriate height, and should be properly spaced to achieve optimal lighting. Obstructive structures like trees should also be taken into consideration in planning for the layout of road lighting.

Smart Control Systems are infrastructure communication systems that allow instantaneous control of the lighting system. These can automatically adjust the level of lighting depending on the condition of the surroundings. Studies show that LED-based road lighting coupled with smart control systems can maximize the lifespan of the luminaires, minimize maintenance costs, and increase energy savings up to 80%.[33]

Cables connect the luminaire to the energy source and to the smart control systems. It should match and be responsive to the energy demands of the lighting system.

When auditing a road lighting design, the important factors to check are[34]:

- Is the road lighting luminance appropriate to traffic safety needs of road users, keeping in mind physical factors, uniformity and glare effects?
- Is the light on the road uniform? Are there unlit short lengths of roadway mixed with lit sections?
- Are there lighting transitions provided where road lighting ends?
- Do the lighting poles and cables constitute a roadside hazard or significantly obstruct drivers' sight?

Annex 3: Success Stories

LED Road Lighting: Malaysia

Client: Malaysia Ministry of Works (MOW), Maintenance Department

Location: Kuala Lumpur, Malaysia

Background

As part of Malaysia's commitment to green solutions, the prime minister of Malaysia called for a reduction in CO_2 emissions by 40% by 2020, based on 2005 levels. Existing lighting systems in the country were all based on HPSV technology, leading to growing concerns about lighting performance, reliability, and energy and maintenance costs. To help the country reach both its emissions reductions target and to address these concerns, the government of Malaysia developed a lighting retrofit project for the expressways of Kuala Lumpur. The contract replaced 3,145 HPSV lamps (400W) with LED road lighting luminaires (186W), replaced 2,010 poles from 12m high to 10m high, installed more than 100km of new power cables, and replaced existing feeder pillars with new feeder pillars and relevant accessories.

The project was implemented across three of the city's major arterial roads totaling 63.1 km: Middle Ring Road (45.3 km), Federal Highway (10.1 km), and Subang Airport Road (7.7km).

Challenges

The inefficiency and unreliability of the road lighting on Kuala Lumpur's expressways were imposing budgetary constraints for Malaysia's MOW (the authority responsible for public road lighting). The HPSV road lights were resulting in increased spending on both energy costs as well as maintenance costs. The MOW sought a solution that could improve efficiency – and thereby reduce costs – as well as help the country reach its CO_2 emissions targets while simultaneously creating clear night vision and a safe environment for motorists.

Solution

The lighting retrofit solution was customized to comply with current road safety regulations and local lighting standards, and the contractor was able to offer a bundled solution that also included project financing support and long-term maintenance services.

Benefits

- Achieved an average energy savings of 62%
- Improved the distribution of light to guarantee excellent light uniformity
- A range of color temperatures from white to cool light ensure motorists are comfortable and safe to travel at night, without any distracting glare
- Allowed for aesthetically pleasing and enjoyable experience on the road due to the light's high color rendering
- Ensured long-term reliability, as the solution has a good heat system management and has longer lifetime than HPSV
- Solution's modular concept provides flexibility for LED upgrades, future-proofing the lighting system
- Has successfully pioneered LED road lighting in Malaysia, demonstrating tangible results, and opening the door for possible future LED road lighting projects

Financing

The project was financed through two independent contracts.

1. A commercial bank was brought in by the contractor to serve as intermediary with the government. The government provided a sovereign guarantee (fixed, monthly rate to the bank throughout the 7 years of the contract). In turn, the bank paid the contractor in 9 tranches based on pre-agreed milestones of installed products and services delivered.
2. A separate independent servicing contract between the contractor and the government is in place. The government will pay the contractor every quarter throughout the 7 years of the contract for the ongoing maintenance of the LED system.

Solar LED Road Lighting: China

Client: Nanyang Road Bureau

Location: Nanyang, Henan Province, China

Background

The Nanyang city government constructed the city circular highway to facilitate the logistics for the upcoming National Peasant Games. In the long-term, the highway will serve as a key transportation channel that connects the villages to the city center.

Under a business-as-usual scenario, the city would have installed grid-connected HPSV (400W) luminaires on the road, which would have led to high energy costs and poor quality of light. However, because of the city's drive to improve their green image, the Nanyang city government decided to install solar LED road lighting along the 14.4 km stretch of road to help reduce the city's CO_2 emissions. The contract was a comprehensive solution – from technical studies and lighting design up to the supply, installation, and commissioning of 915 sets of off-grid solar LED systems. The project is one of the largest solar road lighting projects in China by volume.

Challenges

The city government wanted to be "green" and therefore considered installing solar lighting along the new road. To better understand how they could be green and meet the lighting performance requirements, during the planning process, the Nanyang city government consulted with other Chinese cities with regards to prior solar lighting installations. Through these consultations, they found that some prior solar lighting installations have had lower life spans resulting in higher maintenance costs and poor lighting performance (i.e. poor visibility) at night, all due to poor system configuration and battery performance. The Nanyang city government was not convinced of the reliability and capability of solar lighting technologies to deliver required lighting performance yet still wanted to install an environmentally-friendly lighting solution.

Solution

Addressing the government's reservations, the contractor offered a comprehensive approach to the project. In addition to project implementation, project preparation was a crucial part of the contract. The project conducted **technical studies** to determine key system parameters (e.g. autonomy days), created an optimal **lighting design** following local Chinese road lighting standards, and ensured **proper system configuration**.

The project also included an initial pilot installation of 40 sets to demonstrate the reliability of the technology to the government and to verify that the actual lighting performance met both the expected and the required lighting performance. To further assuage any lingering doubts, the contractor also provided a full 2-year system warranty to protect the customer from any premature failures.

The proposed solution addressed the city government's reservations and re-instilled their confidence in solar lighting technology's ability to deliver required lighting performance.

Performance

Field test results show that the solar LED lighting solution meet the required lighting levels as set out in the local Chinese road lighting standard. A summary of the lighting performance (planned versus actual levels) is found in the table below. As of May 2014, nearly two years after installation, no failures have been reported – a testament to the technology's high quality, robustness, and reliability.

Table 9: Lighting Performance Test Results for Nanyang Solar Road Lighting Project

Lighting Performance	Planned	Actual
Central illuminance	18.9lux	22lux
Average illuminance	12.5lux	14lux
Illuminance uniformity	0.6	0.67
Average luminance	0.86cd/m²	0.86cd/m²
luminance uniformity	0.59	0.66
Uniform glare	7.5	7.5
Surround ratio	0.5	0.5
Autonomy days	3	3

Benefits

- Achieved the following annual savings and reductions when compared to conventional HPSV:
  - 1.3 GWh of electricity saved (equivalent to $208,000)
  - 530 tons of CO_2 emissions reduced
- Improved the distribution of light to guarantee excellent light uniformity
- Allowed for aesthetically pleasing and enjoyable experience on the road due to the light's high color rendering
- Ensured long-term reliability because of proper configuration of the charge controller with the rest of the lighting system
- Solution's modular concept provides flexibility for LED upgrades, future-proofing the lighting system
- Resulted in excellent illumination with no grid energy input, which makes it possible to save 100% on energy costs

TCO Report

Satisfying the local climatic and environmental needs, the solar lighting solution offered triple benefits to the customer: improved lighting performance; minimized environmental impact; and quick economic returns considering the TCO.

While the initial investment for off-grid solar LED road lighting solution in a new road is more expensive than the on-grid HPSV lighting system, the difference can easily be recovered through energy and maintenance cost savings.

In fact, considering the average annual energy and maintenance cost savings for this project, savings on the first year already accounted for the difference in initial investment. To illustrate the cost advantage of solar LED lighting solution, the table below shows the TCO calculation.

Table 10: TCO Calculation for Nanyang Solar Road Lighting Project

GREENFIELD SOLAR LED ROAD LIGHTING PROJECT of 14.4 KM ROAD, 915 LUMINAIRES			
COSTS OVER 3 YEARS	**HPSV**	**Solar LED**	**Savings**
Luminaire + Installation Costs	$ 688,635	$ 2,469,048	$ (1,780,413)
Energy Infrastructure Costs (cables, transformer substations)	$ 1,564,444	-	$ 1,564,444
Total Initial Investment	**$ 2,253,079**	**$ 2,469,048**	**$ (215,969)**
Energy Costs	$ 624,046	-	$ 624,046
Maintenance, Parts replaced, Repair	$ 35,619	-	$ 35,619
Total Operational Costs over 3 years	**$ 659,665**	**-**	**$ 659,665**
Total Cost of Ownership over 3 years	**$ 2,912,744**	**$ 2,469,048**	**$ 443,696**

Annex 4: Technical Specifications

This section provides (i) industry standards for technical specifications for a tender, (ii) a list of recommended documents for submission with tender bids, and (iii) sample specifications from an actual tender.

Appropriate technical specifications (Tech Specs) ensure procurement of quality products and hence the operational effectiveness and efficiency of a road lighting project. This section lists key technical parameters that should be considered to ensure quality products, as per industry best practices, and explains importance of each key parameter.

It is important to note that technical parameters change with technological developments. In addition, the parameters are interdependent, which means a change in one may require or result in a change in another parameter. Hence, tech specs should always be considered as a set or a whole. While this list serves as a guide to ensure the project proponents are aware of the key specifications and their relevance, it is important to continuously engage in a dialogue with the industry (especially since LED technology is rapidly evolving); have a technical expert design the actual tender specs based on the project goals, latest products available, and budget; and consider testing shortlisted products.

The list of recommended documents, test reports, and certifications on the next pages helps ensure that manufacturers provide proof regarding the quality of the product being supplied.

Technical Specifications and Documents for LED Road Lighting Solutions

This section lists the typical technical specifications and recommended documentation requirement for grid-connected LED road lighting solutions.

Recommended Technical Specifications

	Parameters	Ideal Specifications	Reason/Justification for Recommendation	Proof of Technical Compliance
1	Light Quality and Overall Uniformity Ratio	As per CIE standard for road type	These parameters will ensure sufficient levels of light on the road for safety purposes, per end-user road specification	– 9-point light level measurement based on mockup submitted, measured using calibrated lux meter
2	System Efficacy	≥90 lm/W	All quality suppliers today offer ≥90 lm/W system efficacy, at which level one can ensure more than 50% energy savings at the system level compared to existing HPSV solutions of even 85 lm/W efficacy. (LEDs provide directional light resulting in higher light levels on targeted surface for the same lumen output.) There is a difference in efficacy values between Alternating Current (AC) and Direct Current (DC) luminaires, with the former having lower efficiency to optimize cost. Meanwhile, DC-based luminaires have higher efficacy to optimize the system (i.e. more efficient luminaires need less energy and hence, will require smaller solar panel and battery) *NB.* Efficacy values of LEDs are rapidly evolving. It is always recommended to consult with a reliable manufacturer for the latest efficacy levels.	– LM 79 test report
3	Rated Lifetime and Lumen Maintenance	L70 at 50,000 hours or better	LED luminaires typically do not go to zero output as conventional lights do. They just dim over time, until the light output is not sufficient for required function. The lighting industry has determined that LED ceases to be a useful light source when its lumen or light output reduces to 70% of its original level. The lifetime of an LED is thus determined to be the point in time (in hours) when its lumen output depreciates to 70% of the initial lumens. The industry has set up a standard way to test their LED applications for lifetime, and this is presented in the 'LM80' LED Lumen maintenance report. Currently, the industry standard for lifetime for LED road lights is at 50,000 hours.	– LM 80 LED Lumen Maintenance report
4	Operating Temperature	-30°C to 45°C	This specification asks for the temperature range within which a road lighting fixture needs to be able to operate. Road lights operate during night time (i.e., from 6:00 PM to 6:00 AM). Evening operating temperatures usually do not exceed 40 degrees; hence a range from -30 to 45 degrees is sufficient.	– IEC 60598 Test report
5	CCT and Color Consistency	4000 ± 500 K (Neutral White) <7 SDCM	A crisp neutral white color creates a more inviting environment. In a survey conducted by The Climate Group, the public showed preference for the white light	– LM79 Test Report – LED Manufacturer Declaration

	Parameters	Ideal Specifications	Reason/Justification for Recommendation	Proof of Technical Compliance
			provided by LEDs over the color of conventional road lighting, as it allowed them to feel safer.[35] Better color consistency prevents visual color differences between light points.	
6	Color Rendering Index	≥70	A CRI of ≥70 is specified to ensure enhanced ability over HPSV (with CRI of 25 to 30) to show true colors of objects.	– LM79 Test Report – LED Manufacturer Declaration
7	Ingress Protection (IP) Rating	• ≥ IP66 without glue (for luminaires with lumen package of >7000 lumens) • ≥ IP65 without glue (for luminaires with lumen package of <7000 lumens)	IP ensures lifetime protection of LEDs & other electronic components inside the luminaire. The use of glue is not suitable since its bonding properties weaken over time because of the heat and external weather conditions. An IP66 rating is recommended for luminaires with higher lumen packages because its seals are under heavier stress due to the following: 1. Higher lumen package luminaires tend to be placed at a higher mounting height and therefore more exposed to weather influences 2. Because they are mounted higher, higher lumen package luminaires are typically less accessible. IP66 would require less frequent maintenance. 3. The higher the lumen package, the more heat is generated within the luminaire.	– IEC60598-2-3 Test Report
8	IK Rating	≥ IK08	IK rating specifies for protection against vandalism & breakage. For road lighting luminaires, IK08 is sufficient.	– IK test report
9	Cover	Tempered glass cover	Glass has better light transmittance over its lifetime. Tempered glass is safer to use; when broken, it disintegrates into small pieces. It also protects against entry of dust, water & UV rays from the sun	– Luminaire Manufacturer's declaration – Visual inspection of sample
10	Housing	High pressure die-cast aluminum w/ heat management system in light gray color	The specified housing should be long-lasting, robust, and with good heat management.	– Luminaire Manufacturer's Declaration – Visual inspection of sample
11	Weight	10,000 lumens < 7 kg 15,000 lumens < 9 kg 30,000 lumens < 15 kg	Fixture should not be too heavy to be suitable for existing pole installation.	– Visual inspection of sample
12	Maintenance	Tool-less opening Replaceable gear tray	For maintenance cost-saving, specify for a fixture that is easy to open and replace components.	– Visual inspection of sample
13	Warranty	5 years full warranty for the LED system (chip/ driver and other accessories)	A full warranty provides peace of mind and real warranty in case of failure. This will guard the client against premature failures below 50% of rated life.	– Luminaire Manufacturer's Declaration
14	System Voltage	220V-240V, 50Hz/60Hz	System voltage should be suitable to operate as per the power grid.	– 3rd party report / certification
15	Voltage Fluctuation Tolerance	+/- 10%	This is the usual range of voltage fluctuation of electricity.	– 3rd party report / certification
16	Power Factor	≥ 0.90	Grid-connected LED luminaires should be High Power Factor to be more compatible with the power grid (less reactive power).	– 3rd party report / certification

	Parameters	Ideal Specifications	Reason/Justification for Recommendation	Proof of Technical Compliance
17	Electrical Insulation	Class I	Class I will make replacement / routine maintenance safe for maintenance staff.	– IEC 60598-2-3 Test Report
18	Electrical Protection	Double stage surge protection for both LEDs and driver 10KV	This will ensure there is protection for the system against power surge of up to 10KV.	– 3rd party report / certification
19	Termination Type	Plug & play terminal blocks	Plug & play terminal blocks enable ease of maintenance.	– IEC 60598-2-3 Test Report

Recommended Documents for Submission with Bid

The following "**Reliability Checklist**" lists documents that demonstrate the quality, durability, and safety of an LED road lighting luminaire and should be required in all road lighting tenders. Additionally, these test reports should be accompanied by the issuing testing laboratory's **ISO 17025 accreditation certificate** to prove reliability of the results, i.e. lab is properly calibrated and tests are executed according to international protocols.

Lighting Component	Document required	Reason/Justification for Recommendation
Luminaire	**IEC 60598-2-3 Test Report** Particular Requirements - Luminaires for Road and Road Lighting	General requirements for road lighting luminaires including classification, marking, and mechanical and electrical construction.
Luminaire	**LM 79 Test Report** Performance Test Report for Luminaires	Measures the luminaire's performance including lumen output, light distribution, luminous efficacy, color characteristics (CCT, CRI), among others.
Luminaire	**Electromagnetic Compatibility (EMC) Test Reports**	Indicates: • (**EN 55015 - Emissions**) if the luminaire's EM emissions are within limits and does not affect radio, telecommunications, and other equipment • (**EN 61547 – Immunity**) the luminaire's immunity to interference/emissions (i.e. there is no loss in performance) • (**IEC 6100-3-2 – Harmonics**) if the luminaire meets the limits on harmonic current emission and voltage fluctuation (flicker)
Luminaire	**IEC 62493 Electromagnetic Fields (EMF) Test Report**	Checks if the luminaire complies with the EMF restrictions given in the ICNIRP (International Commission on Non-Ionizing Radiation Protection) publication "Guidelines for Limiting Exposure to Time-varying Electric, Magnetic and Electromagnetic Fields."
Luminaire	**IEC 62471 Photo-biological Safety Test Report**	Covers the optical radiation safety of luminaires to the human skin and eye. Indicates if the luminaire is within the prescribed radiation emission limits.
Luminaire	**Salt Spray Test (ISO 9227)**	Checks the corrosion resistance of the fixture
Luminaire	**IEC 60598 Vibration Test Report**	Indicates the luminaire's robustness to vibration and other mechanical stress (i.e. resistance to breakage). The test must be executed in accordance with IEC 60598 and takes into account vibration over all three axes.
LED Chip	**LM 80 LED Test Report**	Indicates the lumen maintenance and lifetime (based on extrapolated data) of the luminaire. Available from the LED chip manufacturers.
Driver	**IEC 61347-1 and IEC 61347-2-13** Safety Test Report for LED Driver	Measures the safety parameters of the driver
Driver	**IEC 62384** Performance Test Report for LED Driver	Indicates the performance of the driver
All Components	**ISO 9001 or ISO 14001 or OHSAS 18001**	Ensures that quality standards in the factory where the components are manufactured. These standards are audited on a regular basis.

Technical Specifications and Documents for Solar LED Road Lighting Solutions

This section lists the typical technical specifications and recommended documentation requirements for solar-powered LED road lighting solutions. Requirements for the different key parts are listed separately. For solar, the key concerns include ensuring the highest efficiency of each part, and how the parts are connected to each other in the most efficient manner, thereby losing the least amount of energy.

Recommended Technical Specifications

I. Luminaire and LED Driver (Luminaire Test Standards: IEC/EN 60598-1, IEC/EN 60598-2-3, IEC/EN 62471, IEC 62471-2, IEC 62778, EN 62493, EN 55015, EN 61547, EN 61000| LED Driver Test Standards : IEC 61347-1, EN 61347-2-13, EN 62384, EN 55015, EN 61547, EN 61000)

	Parameters	Ideal Specifications	Reason/Justification for Recommendation	Proof of Technical Compliance
1	Light Quality and Overall Uniformity Ratio	As per CIE standard for road type	These parameters will ensure sufficient levels of light on the road for safety purposes, per end-user road specification	– LM79 Test Report – Data Sheet – Luminaire Supplier Declaration
2	System Efficacy	≥100 lm/W	All quality suppliers today offer ≥100 lm/W system efficacy for DC-based luminaires, at which level one can ensure more than 50% energy savings at the system level compared to existing HPSV solutions of even 85 lm/W efficacy. (LEDs provide directional light resulting in higher light levels on targeted surface for the same lumen output). There is a difference in efficacy values between AC and DC luminaires, with the former having lower efficiency to optimize cost. Meanwhile, DC luminaires have higher efficacy to optimize the system (i.e. more efficient luminaires need less energy and hence, will require smaller solar panel and battery) *NB.* Efficacy values of LEDs are rapidly evolving. It is always recommended to consult with a reliable manufacturer for the latest efficacy levels.	– LM79 Test Report
3	CCT and Color Consistency	4000 ± 500 K (Neutral White) <7SDCM	A crisp neutral white color creates a more inviting environment In a survey conducted by The Climate Group, the public showed preference for the white light provided by LEDs over the color of conventional road lighting, as it allowed them to feel safer.[36] Better color consistency prevents visual color differences between light points	– LM79 Test Report – LED Manufacturer Declaration
4	Color Rendering Index	≥70	A CRI of ≥70 is specified to ensure enhanced ability over HPSV (with CRI of 25 to 30) to show true colors of objects.	– LM79 Test Report – LED Manufacturer Declaration
5	Housing	High pressure die-cast aluminum w/ heat management system in light gray color	The specified housing should be long lasting, robust, and with good heat management.	– Luminaire Manufacturer's Declaration – Visual inspection of sample
6	Cover	Tempered glass cover	Glass has better light transmittance over its lifetime. Tempered glass is safer to use; when broken, it disintegrates into small pieces. It also protects against entry of dust/water & UV rays from the sun	– Luminaire Manufacturer's declaration – Visual inspection of sample
7	Maintenance	Tool-less opening Replaceable gear tray	For maintenance cost-saving, specify for a fixture that is easy to open and replace components.	– Visual inspection of sample

	Parameters	Ideal Specifications	Reason/Justification for Recommendation	Proof of Technical Compliance
8	Weight	9,000 lumens < 7 kg 12,000 lumens < 9 kg 19,000 lumens < 15 kg	Fixture should not be too heavy to be suitable for existing pole installation	– Visual inspection of sample
9	IP Rating	• ≥ IP66 without glue (for luminaires with lumen package of >7000 lumens) • ≥ IP65 without glue (for luminaires with lumen package of <7000 lumens)	IP is to ensure lifetime protection of LEDs & other electronic components inside the luminaire. The use of glue is not suitable since its bonding properties weaken over time because of the heat and external weather conditions. An IP66 rating is recommended for luminaires with higher lumen packages because its seals are under heavier stress due to the following: 1. Higher lumen package luminaires tend to be placed at a higher mounting height and therefore more exposed to weather influences 2. Altitude of higher lumen package luminaires is typically less accessible. IP66 would require less frequent maintenance. 3. The higher the lumens, the more heat is generated within the luminaire	– IEC 60598-2-3 Test Report
10	IK Rating	≥IK08	IK rating specifies for protection against vandalism & breakage. For road lighting luminaires, IK08 is sufficient.	– IK Test Report – IEC 60598 Vibration Test Report
11	Electrical Protection for Luminaire	Surge Protection of 2KV Device	This specification will protect the luminaire against power surge from lightning strike of up to 2kV.	– 3rd party lab report / datasheet
12	Rated lifetime and Lumen Maintenance	L70 at 50,000 hours or better	LED Luminaires typically do not go to zero output as conventional lights do. They just dim over time, until the light output is not sufficient for required function. The lighting industry has determined that LED ceases to be a useful light source when its lumen or light output reduces to 70% of its original level. The lifetime of an LED is thus determined to be the point in time (in hours) when its lumen output depreciates to 70% of the initial lumens. The industry has set up a standard way to testing their LED applications for lifetime, and this is presented in the 'LM80' LED Lumen maintenance report. Currently, the Industry standard for lifetime for LED road lights is at 50,000 hours.	– LM80 LED Lumen maintenance report
13	Input Voltage of LED Driver	12V (<6000lm) or 24V (≥6000 lm)	The higher the voltage, the higher capability to support higher lumen packages. Specifying for input voltage of the LED driver will reduce cable loss and power consumption.	– Datasheet – Luminaire Supplier Declaration
14	Operating Temperature	-40°C to 45°C	This specification asks for the temperature range within which a road lighting fixture needs to be able to operate. A wide range of operating temperature provides stable performance for aggressive outdoor applications in different locations.	– IEC 60598 Test Report
15	Electrical Insulation	Class I	Class I will make replacement / routine maintenance safe for maintenance staff.	– IEC 60598-2-3 Test Report
16	Termination Type	Plug & play terminal blocks	Plug & play terminal blocks enable ease of maintenance.	– IEC 60598-2-3 Test Report
17	Electrical Protection for LED Driver	Output Short Circuit Output Overload Input reverse protection	Specifying for this will protect LED driver and avoid premature failures due to electrical malfunctions	– IEC 61347-2-13 Test Report

II. Solar Photovoltaic Module (Test Standards: IEC 61215, IEC 61730)

	Parameters	Ideal Specifications	Reason/Justification for Recommendation	Proof of Technical Compliance
1	General Requirements	Solar PV Modules made of poly or mono-crystalline silicon solar cells, equipped with weather proof connectors	Crystalline silicon has a higher charging efficiency than other current solar cell technologies, thus requiring smaller solar panels. The weatherproof connectors provide safe and long lasting connection between the module and other components.	– Data sheet – Panel supplier declaration – Certificate of testing showing product conforming to relevant IEC standards.
2	Rated Output Power	250Wp with tolerance of ±5W	It is important to have a panel large enough to generate electricity that will ensure the actual power needed for the luminaire to be operational at night.	– Data sheet – PV panel supplier Declaration – IEC61215 Test Report
3	Voltage at Rated Output Power	17.5V for each module	Voltage at Rated Output Power is a necessary technical parameter to identify the panel feature. This specification is important to ensure that the battery will be charged. Typical Voltage at Rated Output Power is 17.5V for solar panels.	– Test report – Data sheet
4	Open Circuit Voltage	22.0V for each module	Open Circuit Voltage is a necessary technical data to identify the panel feature. If the open circuit voltage of the solar panel exceeds the maximum amount of voltage that can be applied to an electrical equipment (e.g. luminaire), the equipment will be damaged or destroyed. Typical value for open circuit voltage is 22.0V per module.	– Test report – Data sheet
5	IP Rating	IP 65 for junction box IP67 for cable connector	Water-proof and dust-proof specifications make the panel and connectors more reliable and last longer.	– Test report

III. Charge Controller (Test Standards: EN 62109-1, EN 55015, EN 61547, EN 61000)

The Charge Controller is considered the “heart of the system” that regulates the flow of current in the system and starts the light when it detects darkness. It controls power harvested from the PV panel to charge the battery, with the intent of safely and reliably maintaining battery life and a high state of charge. Multiple stages of battery charging protect the battery from over-discharging, thereby extending battery life. The charge controller also controls the power available from the battery, with the intent of limiting the depth of battery discharge to prolong battery life.

	Parameters	Ideal Specifications	Reason/Justification for Recommendation	Proof of Technical Compliance
1	General Requirements	Designed to match the proposed solar PV module, battery, and LED drivers. To have a clear and reliable LED or Liquid Crystal Display that indicates operating status.	Charge controllers affect the energy efficiency of the system as well as the life of the battery, a key and expensive component. It is important to ensure that the controller is compatible with the system (panel, battery, luminaire) to achieve optimal performance. Controllers are not typically bought off the shelf. Low-quality charge controllers that are not properly configured with other components could result in early failures of the solar lighting installation. The operating status indication is important and convenient for field installation, monitoring, and debugging.	– Test certificates from international accredited testing and certification organization providing multiple stages of battery charging.
2	Nominal Charge Voltage	12/24V DC Auto	Auto voltage detection offers the customer the flexibility to put it into 12V or 24V system without pre-configuration.	– Datasheet
3	Operating Temperature	-40°C to 60°C	A wide range of operating temperature provides stable performance for aggressive outdoor applications in different locations.	– Datasheet

	Parameters	Ideal Specifications	Reason/Justification for Recommendation	Proof of Technical Compliance
4	IP Rating	IP 66	High Protection Class provides the capability to sustain operation under aggressive application environments.	– Datasheet
5	Protection Class	Load disconnect/reconnect voltage Battery overvoltage protection Short circuit Reverse polarity Over Charge, Over Discharge, Over load, Short circuit, Reverse current, polarity reverse connection, Surge	Full electrical protection safeguards battery and load operations. It also prevents the components from damage due to installation mishandling (i.e. human error) or external environment/electrical interference.	– Datasheet

IV. **Batteries** (Test Standard: IEC 61427)

	Parameters	Ideal Specifications	Reason/Justification for Recommendation	Proof of Technical Compliance
1	General Requirements	Shall be sealed maintenance-free lead-acid or gel type battery. Fully-sealed Maintenance-free gel battery	Lead-acid and gel batteries are commonly used types of batteries for solar road lighting installations. However, Gel batteries have longer cycle lifetime, longer storage time, and better deep discharge recovery ability. Maintenance-free batteries allow for savings in maintenance costs. The make, type, nominal voltage, and nominal capacity must be available from battery manufacturer/ recognized test lab.	– Test certificates from international accredited testing and certification organization – Datasheet
2	Rating Capacity	Maximum capacity 12V/250Ah or 24V/250Ah	Specifying for maximum capacity ensures that the battery can store enough power to support the operation of the lighting system. In addition, when evaluating bidders with similar capacity (i.e. 250Ah), consider the rate of discharge (CX, where x is the number of hours before the battery gets discharged). Usually, discharge rates are C10 or C20. Thus, a 250Ah C10 battery discharges 25A every hour for 10 hours. To illustrate, suppose a load profile of a road lighting tender is 10A for 10 hours and the tender only indicate the rating capacity (e.g. 100Ah). Then, Manufacturer A offered a 105Ah C10 battery (10.5A/hour discharge rate) and Manufacturer B offered a 109Ah C20 battery (5.45A/hour discharge rate). Evidently, while both meet the required rating capacity, only manufacturer A is capable of supporting the load profile of the tender.	– Datasheet
3	Average Self-Discharge Rate	≤3% per month at 25°C	Average self-discharge rate should be as specified to minimize the impact on the remaining capacity of the battery	– Data sheet/ test report
4 A	Protection Class (Under or above ground)	Batteries to be supplied in a box with protection Class of at least IP68, which ensures batteries not damaged if 1.3m underwater for 30 days.	Dust and water ingress will impact the battery capacity and lifetime. Sufficient IP protection will prolong battery capacity and lifetime.	– 3rd party test report / certification

	Parameters	Ideal Specifications	Reason/Justification for Recommendation	Proof of Technical Compliance
4B	Protection Class (on the pole)	Batteries to be supplied in a box or a suitable enclosure with protection Class of at least IP21	Dust and water ingress will impact the battery capacity and lifetime. Sufficient IP protection will prolong battery capacity and lifetime.	– 3rd party test report / certification
5	Operating Temperature	Charge (-22°C to 55°C) Discharge (-10°C to 55°C) Storage (-22°C to 55°C)	Higher temperatures impact the battery's service lifetime while lower temperatures impact the battery's actual capacity. A wider range of operating temperature can prolong battery lifetime and guarantee battery performance.	– Datasheet
6	Cycle Life	Cycle life of the battery must exceed 700 cycles when discharged down to an average depth of discharge (DOD) of 50%	As batteries charge and discharge, a small amount of damage is done to them. The amount of damage depends on the type of battery and how deep the discharge is. Batteries are lab-tested to determine how many cycles the battery can experience before it reaches its residual life. These cycle test results are an excellent way of comparing batteries.	– Graphical information on cycle life versus depth of discharge (at specified temperatures) – Datasheet

V. Other Specifications

	Parameters	Ideal Specifications	Reason/Justification for Recommendation	Proof of Technical Compliance
1	Accessory	Shall be provided with complete set of wiring and terminals with a minimum of IP67 protection class, mast-arms, and brackets.	Waterproof accessories especially for outdoor applications will ensure longer lifetime and enhance system mechanical and electrical performance.	– 3rd party lab report/certification
2	Wind Load Rating	Any system equipment/component in the pole shall withstand a max wind load of 2.0Pa (57 m/s).	The system should be able to endure the critical conditions in outdoor environment.	– 3rd party lab report/certification
3	Warranty	Min. of 2 years from date of delivery. Warranty should be for the full system (luminaire, charge controller, PV panel, battery, and other accessories.	Warranty gives customers good service within a guaranteed period of time.	– Warranty paper

Recommended Documents for Submission with Bid

The following "**Reliability Checklist**" lists documents that demonstrate the quality, durability, and safety of a solar LED road lighting luminaire and should be required in all road lighting tenders. Additionally, these test reports should be accompanied by the issuing testing laboratory's **ISO 17025 accreditation certificate** to prove reliability of the results, i.e. lab is properly calibrated and tests are executed according to international protocols.

Lighting Component	Document required	Reason/Justification for Recommendation
Luminaire	**IEC 60598-2-3 Test Report** Particular Requirements - Luminaires for Road and Road Lighting	General requirements for road lighting luminaires including classification, marking, and mechanical and electrical construction.
Luminaire	**LM 79 Test Report** Performance Test Report for Luminaires	Measures the luminaire's performance including lumen output, light distribution, luminous efficacy, color characteristics (CCT, CRI), among others.
Luminaire and Charge Controller	**EMC Test Reports**	Indicates: • (**EN 55015 - Emissions**) if the luminaire's and charge controller's EM emissions are within limits and does not affect radio, telecommunications, and other equipment • (**EN 61547 – Immunity**) the luminaire's and charge controller's immunity to interference/emissions (i.e. there is no loss in performance) • (**IEC 6100-3-2 – Harmonics**) if the luminaire and charge controller meets the limits on harmonic current emission and voltage fluctuation (flicker)
Luminaire	**IEC 62493 EMF Test Report**	Checks if the luminaire complies with the EMF restrictions given in the ICNIRP publication "Guidelines for Limiting Exposure to Time-varying Electric, Magnetic and Electromagnetic Fields."
Luminaire	**IEC 62471 Photo-biological Safety Test Report**	Covers the optical radiation safety of luminaires to the human skin and eye. Indicates if the luminaire is within the prescribed radiation emission limits.
Luminaire	**Salt Spray Test (ISO 9227)**	Checks the corrosion resistance of the fixture
Luminaire	**IEC 60598 Vibration Test Report**	Indicates the luminaire's robustness to vibration and other mechanical stress (i.e. resistance to breakage). The test must be executed in accordance with IEC 60598 and takes into account vibration over all three axes.
LED Chip	**LM 80 LED Test Report**	Indicates the lumen maintenance and lifetime (based on extrapolated data) of the luminaire. Available from the LED chip manufacturers.
Driver	**IEC 61347-1 and IEC 61347-2-13** Safety Test Report for LED Driver	Measures the safety parameters of the driver
Driver	**IEC 62384** Performance Test Report for LED Driver	Indicates the performance of the driver
Driver	**CISPR 15 Test Report**	Indicates if the emission (radiated and conducted) of radio disturbances of the driver is well within tolerable limits
Solar Panel	**IEC 61215 Test Report**	Indicates the performance of the solar panel
Solar Panel	**IEC 61730 Test Report**	Measures the safety parameters (electrical, thermal, mechanical, fire hazards) of the solar panel
Charge Controller	**EN 62109 Test Report**	Measures the safety parameters (electrical, thermal, mechanical, fire hazards) of the charge controller
Battery	**IEC 61427**	Measures the performance of batteries used in photovoltaic energy systems
All Components	**ISO 9001 or ISO 14001 or OHSAS 18001**	Ensures that quality standards in the factory where the components are manufactured. These standards are audited on a regular basis.

Sample Specifications

Captured in the table below are the specifications from a successful LED road lighting tender under the Turnkey, Pakistan BRT System project. The success from this experience was attributed to the following two factors:

- **A well-defined set of specifications and standards** that left no room for ambiguity and ensured the quality of the lighting systems to be procured.

- **Comprehensive Scope** (including *design, maintenance and local support*) helps deter the participation of substandard, inexperienced companies in the tender. In addition, having the winning bidder responsible for full project lifecycle (i.e., design, maintenance and local support) ensures the seamless integration, efficient operation, and required performance of the system through its expected lifetime.

<table>
<tr><th colspan="4">Sample Specifications of a Turnkey Tender</th></tr>
<tr><td>Client</td><td colspan="3">Pakistan – Traffic Engineering and Transport Planning Authority, Lahore Development Authority</td></tr>
<tr><td>Project</td><td colspan="3">Metro Bus Transit System/ BRT System for Lahore, Pakistan</td></tr>
<tr><td>Contract Title</td><td>Supply, Installation/ Supervision during Installation, Testing, and Commissioning of LED Road Lighting Fixtures (National Competitive Bidding)</td><td>Date of Tender</td><td>July 2012</td></tr>
<tr><th colspan="4">Scope of Contract</th></tr>
<tr><td colspan="4">Design, manufacturing, supply, installation, testing, and commissioning of LED Road Lighting Fixtures of make Philips, Indal, Thorn, conforming to the international standards and suitable for ME1, ME2, and ME3 roads.

<u>Major Contract Components:</u>
1. Lighting Design Calculations for project specific requirements
2. Design and manufacturing
3. Type Testing (or test reports from independent laboratories on similar fixtures)
4. Factory Acceptance Testing
5. Supply and Transportation to Site and Installation at Site
6. Site Acceptance Testing and Commissioning
7. Maintenance and local support during 3-year warranty period after defect liability of one year and the associated equipment or hardware thereof.</td></tr>
<tr><th colspan="4">Technical Specifications</th></tr>
<tr><td rowspan="2">Wattage Ranges</td><td rowspan="2">• 90-95 W
• 120-135 W
• 180-200 W
• 220-240W
• Flood Lights 90-120W</td><td>Surge Protection</td><td>Minimum surge protection of 2kV</td></tr>
<tr><td>IP Protection/ Impact Resistance</td><td>• IP66 for reliable performance and minimal maintenance
• Impact Resistance of IK08 or better
• No chemical glue should be used</td></tr>
<tr><td>Housing and Glass Cover</td><td colspan="3">• Full die cast aluminum housing providing adequate rigidity, strength, and heat dissipation
• The housing shall have integrated driver and LED lamp components for better heat dissipation and convenience in maintenance, and shall feature highly reflective components to increase light output.
• The LED compartment shall have extra-white thermally hardened glass cover and high quality silicon gaskets. The glass cover must be tightly secured with the housing.</td></tr>
<tr><td>Optics</td><td colspan="3">• Light Output Ratio of ≥85% and Efficiency of ≥65 lumen per watt
• The multilayer optics design shall ensure adequate luminance and illuminance uniformity in the unlikely event of an individual LED failure.
• The fixture shall offer choice of narrow, medium, wide beamlight distribution
• The optical lens system shall feature long life with no discoloration (UV protection), highest possible light transmission and white painted circuit board for high reflectivity for maximum light output</td></tr>
</table>

LED Driver/ Electronic Control Gear	• *Preferred Manufacturers*: Harvard, TCI, Philips, Lumotech, VOSSLOH Schwabe, Ligtech • Should operate at 230V +10%, -15%, 50Hz, single phase mains AC supply • *Efficiency*: ≥85%	**LEDs**	• *Preferred Manufacturers:* Philips Lumiled, Cree, Nichia, Osram • *Lumen Maintenance:* L70 at ambient temperature of 35°C • *Burning hours:* 50,000 hours • *Color Rendering Index*: 70±10 • *Color Temperature*: >5000K (preferably 6500K) • *Color Consistency*: within 7 SDCM	
Photometrics	• IES Type I and II distribution pattern, with short or medium longitudinal distribution • LM 80 LED and photometric test reports and IES files from a third party laboratory is required	**Applicable Standards and Codes**	For Fixtures • IEC 60598-1 • IEC 60598-2-2 • IEC 60598-2-3 • IEC 62471	For LED Drivers • EN 61347-1 and EN 61347-2-13 • EN 62384 • EN 55015 • EN61547 • EN61000-3-2:2006 • EN61000-3-3: 2008

NOTE: One may notice the differences in the specifications listed in this case study and the specifications recommended in Annex 3, specifically on efficiency of the luminaire and color consistency of LEDs. These are a result of continuous technological improvements in LED. So it is always important, in setting specifications for a project or tender, to have consultations with reputable representatives from the lighting industry on the latest standards and level of specifications.

Glossary

Autonomy days	The number of days the battery can support the road light without charging in the day due to weather conditions. For example, a fully-charged battery with 3 autonomy days can provide electricity to a road light for 3 consecutive days, without charging on days 2 and 3.
Average illuminance	Average amount of light (illuminance) over a specified surface. In practice, this parameter can be approximated by an average of the illuminance at a representative number of points on a given surface.
Average luminance	Average luminous intensity (luminance) over a specified surface. In practice, this parameter can be approximated by an average of the luminance at a representative number of points on a given surface.
Central illuminance	The amount of light (illuminance) in the brightest-lit spots over a specified surface.
Cycle Life of Battery	The number of charge-and-discharge cycles before the battery's residual life drops below 80% of the rated Ah capacity. It also indicates the useful life of a battery and varies from technology to technology.
Depth of discharge	The measure of the battery capacity that has been discharged, expressed as a percentage of maximum capacity (e.g., a DOD of 100% means the battery is fully discharged while a DOD of 80% means that the battery still has 20% capacity).
Glare	A condition of vision where there is discomfort or a reduction in the ability to clearly see an object or the road. This is caused by unsuitable distribution of luminance or when the brightness of the light exceeds the adaptation level of the human eye.
Illuminance	The amount of light that falls on a surface, measured in lumens per square meter or lux. Illuminance can be expressed as horizontal (illuminance on horizontal planes like roads) or vertical (illuminance on vertical planes like walls).
Illuminance uniformity	Measure of how equally distributed the illuminance is on a surface. It is expressed as the ratio of the minimum illuminance and average illuminance of a given surface. The closer the two values (i.e. the ratio is close or equal to one), the more uniform the illuminance of the space is.
Light Emitting Diode	A solid-state semiconductor device that converts electrical energy directly into light. On its most basic level, it is comprised of two parts: (i) p-region which contains positive electrical charges; and (ii) n-region which contains negative electrical charges. When voltage is applied and current begins to flow from n-region to p-region. The movement of electrons releases energy which produces photons with visible wavelengths (light).
LED lifetime	LEDs typically do not stop producing light completely, but only depreciate over time. As per industry definition, LED lifetime is defined as the point when the LEDs reach 70% of their original lumen output.
Longitudinal Uniformity	The ratio of the minimum to the maximum luminance in the longitudinal direction along the center line of each lane
Lumen maintenance	Lumen maintenance is a measure that compares the initial amount of light produced from a light source to the amount of light output at a specific time in the future (i.e., how much has the light depreciated over a specified time).

Lumens/ Lumen output	The amount of light being emitted by a light source
Luminance	The luminous intensity or brightness of a surface in a given direction per unit area.
Luminance uniformity (Overall Uniformity)	Measure of how equally distributed the luminance is on a surface. It is expressed as the ratio of the minimum luminance to average luminance of a given surface. A good overall uniformity ensures that all spots and objects on the road are sufficiently visible to the motorist and pedestrian.
Luminous efficacy	Measures the efficacy of the light source, i.e. how much light is being emitted by the light source for every unit of electricity consumed.
Lux	The SI Unit for illuminance, or luminous flux incident on a unit area.
Minimum Horizontal Illuminance	Minimum illuminance landing on a horizontal surface such as a road.
Minimum semi-cylindrical Illuminance	Minimum illuminance landing on a vertical semi-cylindrical surface. This is an important measure especially for pedestrian areas where facial recognition is necessary.
Minimum Vertical Illuminance	Minimum illuminance landing on a vertical surface such as a wall. This is an important measure especially for pedestrian areas where facial recognition is necessary.
Surround Ratio	The ratio of the average illuminance on the 5m width strip zones adjacent to the edges of both sides of the carriageway to the average illuminance on the adjacent strips in the carriage way.
System efficacy	The percentage of total lamp lumens that a lighting system emits, net of any optical losses and driver inefficiencies, for every unit of electricity used. System efficacy is always lower and more relevant in comparing across technologies than the efficacy of the LED chip.
System wattage:	Amount of electricity required by a lighting system to emit the lumen output
Threshold Increment	Threshold Increment is the percentage increase in required luminance to compensate the effect of glare (i.e., make the road equally visible as in the absence of glare).
Zebra effect	The pattern of high and low luminance levels on a surface such as a road, resulting from poor distribution of light.

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[7] Under CIE 115:2010, roads are classified from M1 to M6 with M1 being the largest (e.g., highways, expressways). Road classification is based on a number of factors including speed, traffic volume, traffic composition, separation of carriageways, intersection density, presence of parked vehicles, ambient luminance, and visual guidance or traffic control.

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[28] The International Commission on Illumination (CIE, Commission International de L'eclairage) is an international organization devoted to exchange of information with matters relating to lighting, including road lighting. One of its objectives is to develop, prepare, and publish standards, reports, and other publications on lighting. CIE's publications are widely accepted around the world, as CIE is recognized as the authority on all aspects of light and lighting. In 2010, it published CIE115:2010 (2nd Edition), an updated technical report on road lighting which could serve as a framework for countries in developing their own national codes of practice and standards.

[29] Commission International de l'Eclairage (CIE). *Lighting of Roads for Motor and Pedestrian Traffic*.Technical Report*. Vienna:CIE, 2010.*

> A comprehensive list of parameters and the methodology to categorize the roads are found on Table 1 (Parameters for the selection of M lighting class) on page 10 of the technical report.

[30] Commission International de l'Eclairage (CIE). *Lighting of Roads for Motor and Pedestrian Traffic*.Technical Report*. Vienna: CIE, 2010.*

> Based on Table 2. Lighting Classes for Motorized traffic, based on road surface luminance on page 11. Please note that the table in this manual is a simplified version of the table from the technical report.

[31]Commission International de l'Eclairage (CIE). *Lighting of Roads for Motor and Pedestrian Traffic*.Technical Report*. Vienna:CIE, 2010.*

> A comprehensive list of parameters and the methodology to categorize the roads are found on Table 6 (Parameters for the selection of P lighting class) on page 18 of the technical report.

[32] Commission International de l'Eclairage (CIE). *Lighting of Roads for Motor and Pedestrian Traffic*.Technical Report*. Vienna:CIE, 2010.*

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