THE ECONOLER SERIES

SUSTAINABLE STREET LIGHTING

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Brighter cities, brighter future

ECONOLER
www.econoler.com

160, rue St-Paul, Bureau 200
Québec (Québec) G1K 3W1
CANADA

Telephone: 418 692-2592
Fax: 418 692-4899
www.econoler.com

Introduction

Street and public lighting is an essential service provided by national and municipal governments. Good and efficient street lighting services are necessary for road safety, personal safety and urban ambience. In addition, research has demonstrated that well lit streets boost economic opportunities by expanding the hours of commercial activity at night[1].

Providing street and public lighting is also one of the most expensive responsibilities of municipalities and accounts for up to 50 percent or more of energy consumption and greenhouse gas (GHG) emissions in certain cities[2]. Proper general and ambient street and public lighting requires effectively delivering quality illumination to appropriate surfaces with minimal distractions such as dark or bright spots, light that shines directly into the eyes of occupants, also referred to as glare, or excess reflected light, which adds to nighttime light pollution. Ideally, light delivery should utilize the most energy-efficient light sources that are also long lasting, environmentally safer, reliable, as well as smart where appropriate to minimize public resource expenditures.

Econoler has in-depth knowledge related to the design, implementation and financing of sustainable street lighting projects. This booklet introduces the concept and some recommendations to be followed to put this concept into action. It also provides informative and helpful insights gained from previous Econoler sustainable street lighting experience in three different countries.

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1. ADB, 2017. https://www.adb.org/sites/default/files/publication/232351/led-lighting-best-practices.pdf
2. *Good Practices in City Energy Efficiency: Los Angeles, USA - LED Street Lighting Retrofit*. Energy Sector Management Assistance Program Energy Efficient Cities Initiative. Washington, DC. The World Bank. ESMAP. 2011.

Concept

Around the world, many large and small cities and municipalities have made the transition to light-emitting diodes (LEDs - also known as solid-state lighting, or SSL) for their street and public lighting. For many, this process has been mostly smooth technically thanks to both the early adopters who documented and shared their valuable experiences and international organizations working to ease the transition to SSL technology[3]. Some of the key technical takeaways from these experiences are presented here.

More and more cities and municipalities are looking to innovative implementation and financing mechanisms as a means to address their public infrastructure needs – including street lighting – due to either their energy and fiscal situations or the regulatory environment. Among others, the EPC model is used to facilitate public-private partnerships (PPPs), allowing cities and municipalities to effect the transition to energy efficient lighting with solutions that address their particular technical needs and meet their financial circumstances[4].

Thus, a summary of international experiences to date should endeavor to identify a number of key takeaways from both the technical and the financial experiences of cities and municipalities that have converted to LEDs[5]. It may also

3. For example, the International Energy Agency's 4E Solid-State Annex (IEA 4E SSL Annex).
4. Companies assess energy savings potential for projects, propose and implement technical solutions for public energy users (such as government agencies or municipal facilities) and/or invest in such solutions through EPCs. Investors recoup capital and earn profits based on the savings generated by the projects compared to the baseline cases over agreed upon periods, while cities and municipalities can acquire new equipment and/or services without the need to obtain initial capital investments.
5. It should be noted that while documented cases of LED luminaire conversions have been extensive, the adoption of control systems are still early in their cycle, and there are fewer shared experiences available.

be useful to summarize some of the current key challenges common to many cities and municipalities:

1. **Low incentives for EE in the public sector:** The cost of energy constitutes a substantial proportion of public expenditures. However, many cities and regional governments may not be motivated to take action due to a number of reasons, including: (1) low energy costs; (2) budget planning processes that typically do not separate energy costs from other government expenditures (or a lack of control by cities and municipalities over their energy budget); (3) low returns on investments due to the typically high upfront capital costs of EE improvements; (4) public procurement processes favoring lowest first costs rather than lifetime costs.
2. **Insufficient stakeholder capacities:** There are still low levels of awareness about the potential energy savings and benefits of well designed systems in public installations and facilities, and/or recent technological advances in lighting. Smaller or more rural cities and municipalities may be lacking even more capacity, means, or empowerment to take action. Due to a lack of resources/access to international best practices, stakeholders currently obtain information from a range of sources, including suppliers, to develop tenders and other documents related to street lighting equipment applications and procurement specifications. Misconceptions on test requirements, product performance, as well as light outputs and lifetimes result in poor end-user experiences.
3. **High first costs of EE and associated equipment:** Although much progress has been made with respect to LED prices and performance over the past several years, SSL streetlights that equal the performance of traditional technologies are not yet comparable in price, especially for higher output luminaires. Additional functionalities such as self-monitoring, communications, dimming, etc.

can significantly add to per-luminaire replacement costs. Maximizing these added luminaire functionalities also requires investments in new infrastructure[6].

4. **Street lighting controls standards:** Currently, there are no internationally accepted standards for lighting controls. The Municipal Solid State Lighting Consortium (MSSLC) has issued recommended procurement guidelines for controls, but it is not yet widely accepted. Streetlight controls tend to be proprietary products specific to the companies that develop them, and may or may not be compatible with other control systems. Many regulations have yet to address the dimming of streetlights, or the use of energy management strategies.
5. **Lack of related standards:** Standardization is a common challenge for many cities and regional governments modernizing their lighting systems. Many countries are just now working to adopt international lighting standards into their national standards (for illumination and/or luminaires). New concepts such as smart lighting and smart cities are also being explored and are not fully defined by international standards as of yet. A lack of reliable information results in uneven or incompatible performance between cities, as well as poor user experience.
6. **Aging infrastructure:** It is not known what percentages of older lighting networks in cities need to be upgraded to meet international standards or to fully take advantage of better lighting and control technologies. Many cities upgrading from conventional lighting technologies to LEDs are doing so using existing infrastructure such as poles, mounting arms, etc., which may limit their ability to maximize the advantages of LEDs compared to areas where new designs are applied.

6. While additional control features may be justified by higher energy savings, the addition of a smart control center, for example, can be difficult to justify based on energy savings alone.

Despite these challenges and others, many cities and municipalities have forged ahead with their transition and have achieved significant successes in terms of energy savings, reduced O&M costs, as well as more satisfied citizens due to better lighting conditions and reduced pollution. While the situation of each city and municipality differ, some of the shared results are summarized below. It should be noted that significant resources for LED street lighting and financial models and templates such as PPPs are now provided by trusted sources such as the US Department of Energy, the Climate Foundation, World Bank, Asian Development Bank, and others (a list of key resources and where they can be found is included at the end of this report).

Since a significant amount of information is now available, it would be difficult to single out one or two cities or municipalities and their experience. Instead, summaries of some key takeaways are provided below:

1. **Governments will realize significant energy savings (and associated O&M costs):** In many cases examined, the realized energy savings that can be generated through the use of LEDs to replace existing technologies are about 50 percent or more. Municipalities can also realize significant O&M savings by this conversion. The exact savings vary significantly between cities, depending on their particular situation, operational and maintenance practices, how much deferred maintenance exists, as well as other factors including local climate and traffic.
2. **LED conversion projects can be justified based on energy savings:** Payback calculations for converting to LEDs in public lighting for many cities and municipalities indicate significant energy savings and relatively short payback periods. Implementing additional controls and smart features helps increase energy savings, but the

additional equipment also carries added costs that cannot be offset by the additional savings[7].

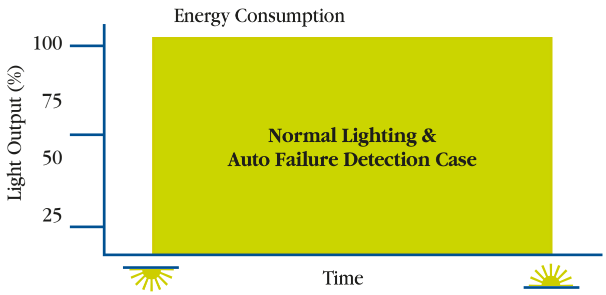
3. **First costs for LEDs remain a challenge for some regions:** Information from cities that have developed their own cost proposals or developed and implemented their own projects indicates that LED product prices remain high relative to conventional products available internationally, even where there is local production.

Control Technologies

The main purpose of lighting controls is to allow operators to easily switch the system on or off, thereby providing lighting service only when needed. Specific to road and public lighting, there are several levels of controls in increasing degrees of sophistication:

- **Regular daily on/off switching of the entire system.** This includes switches or manual timers and photocells. They can be inexpensive but are also the least flexible control methods for public lighting.

Figure 1: Daily on/off system

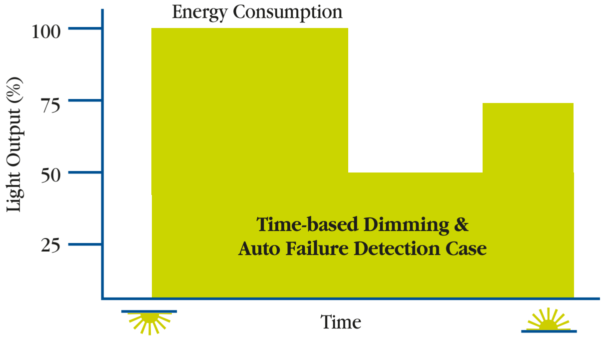


Source: APACK, Inc

7. The additional savings possible from "smart" features depends on the hours of use of the system, and whether or not the city or municipality uses a dimming strategy.

- **Regular daily on/off switching and the ability to vary light output at preset levels and/or for predetermined periods.** This is a relatively new development in LED luminaire drivers. Simply put, a luminaire driver can be preprogrammed at the factory to reduce the power output after a set period at full-power consumption[8]. These non-networked solutions (in combination with simple switching or photocells) provide simple and inexpensive dimming solutions for many locations where sophisticated controls are not required or affordable. These tend to be more expensive than switches, but they also provide a degree of flexibility and increase energy savings[9].

Figure 2: Daily on/off system with preset levels and/ or for predetermined periods

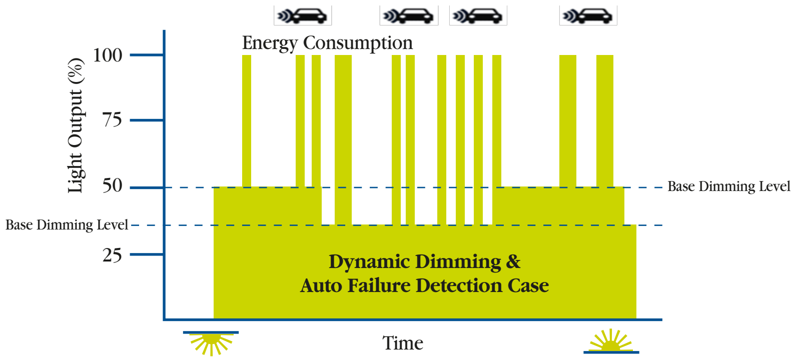


Source: APACK, Inc

8. For example, a luminaire can be programmed to reduce power consumption to 50% after five hours of operation at full-power, thus automatically dimming the light output during low-traffic periods, resulting in additional energy savings.
9. It should be noted that dimming strategies are much more compatible with LEDs than conventional lighting technologies, due to the fact that HID lamps are not compatible with frequent dimming, yielding poor lighting performance, and fail much earlier.

- **Real-time regular daily on/off switching and the ability to vary light output levels according to conditions or needs, based on inputs across the entire lighting network or for specific areas (such as traffic, emergency, weather, energy supply levels, time-based or demand-based electricity tariffs, etc.), with or without integration of other city or municipality systems.** To operate these advanced control systems, luminaires or luminaire groups must be controllable or addressable using one-way or two-way communication mechanisms installed between the luminaires and the control center (wired or wireless). These smart systems take advantage of miniaturization and the prevalence of communication technologies. The management system can be installed at municipal premises or reside in the cloud; they can be available at the control center or on a tablet or smart device. These systems provide the most service flexibility but also require the most components, thereby increasing costs. Generally, they are proprietary systems available only through the integrator or developer as a package, or as software that works with proprietary hardware add-ons to generic luminaires that meet certain requirements.

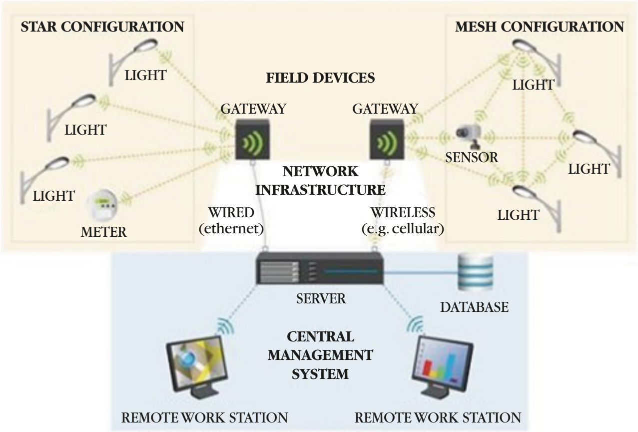
Figure 3: Daily on/off switching with variable light output levels



Source: APACK, Inc

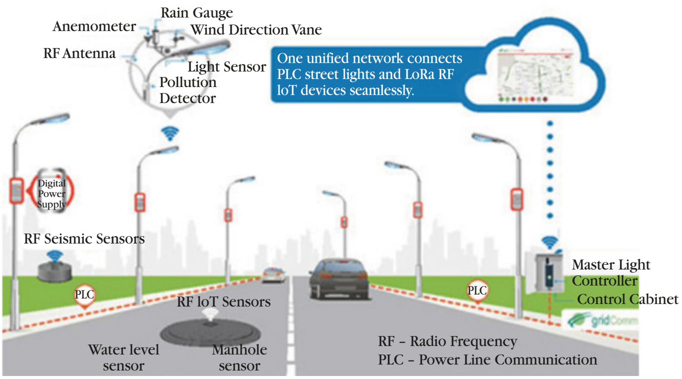
These more advanced controls rely on controllable, flexible light sources such as LED technology and leverage the Internet of things (IoT). These increasingly smart systems will continue to be improved by integrating artificial intelligence, controls, wireless connectivity, and sensors into street and roadway lighting infrastructure (Appendix IV)[10].

Figure 4: Major Components of a Centralized Outdoor Lighting Control System



10. Examples of commercially available smart streetlight energy management solutions include CityTouch (Philips), T Light (Telematic Wireless), InteliLIGHT (Flashnet SA), LightingGale (Cimcon), and many others. These systems communicate using wireless means such as the General Packet Radio Service (GPRS), radio frequencies (RF), Wi-Fi, or wired means such as power-line communications (PLC).

Figure 5: Smart Street Lighting Features



Source: Instruments Universal Report, 2018.

Since more and more functions are being added to control systems, they can now provide operators with more information about the lighting network; many now offer details about associated lighting panels and other system components with complete information, electrical diagnostics, and GPS locations. These smart systems track a vast array of electrical parameters to help operators monitor operations, minimize energy losses, and continuously improve lighting services. When integrated with other systems, such as CCTV cameras, pollution sensors, noise detectors, traffic density sensors, local area wireless networks (Wi-Fi) or even EV (electrical vehicle) charging infrastructure, these control systems add to the safety and functionality of the urban environment, further discussed below.

In the appendix II we have a comparative Overview of the Light Sources

Non Energy Benefits

One key advantage of the smart public-lighting system is its ability to create new experiences for citizens, businesses, communities and leaders around the world. By using the communications network connected to smart lighting, cities and public-service organizations can add various types of sensors and devices and implement new Internet of Things (IoT) applications and projects to meet the evolving needs related to public safety, environmental protection, transportation and many other infrastructure sectors.

Public Safety

Public safety is a priority for all governments and the implementation of smart public lighting is in line with this priority. Indeed, public safety technologies such as video surveillance cameras have long been commonplace in urban environments. Many of these devices will require upgrades in the coming years, and many cities are deciding to leverage their smart lighting infrastructure to provide public safety and new security solutions to reduce deployment costs.

Table 1: Technologies in the Public Safety Sector

Technologies	Description
Gunshot detection	With specialized acoustic sensors and software for users, it is possible to detect and locate the location of gunshots in real time.
Road accident detection	Acoustic sensors are used to monitor, group, and visualize ambient sound in different areas of the city, thus to detect road collisions. Cameras can also be used to detect changes in traffic patterns.
License plate recognition	This cost-effective technology captures all license plate models of all formats and countries, day and night. Cameras integrate both visual and in-camera analysis, storing records even when no operator is connected.
Emergency buttons	Smart public lighting infrastructure is used to integrate emergency response buttons. The system includes a physical button and the corresponding software. When used, emergency responders are warned.

Environment

The integration of different sensors is an interesting starting point for the development of new services in smart lighting infrastructure. Using existing infrastructure significantly reduces the cost of deploying sensor networks. In addition, it powers the sensors, thus eliminating the need for expensive battery replacement programs. Sensors, combined with a high-bandwidth network, enable researchers to collect, monitor, analyze, and make decisions based on granular information in real time. This information is used not only to improve lighting, but also to monitor the quality of the environment. A range of sensors can be integrated into public lighting infrastructure to monitor and assist in this important area.

Table 2: Technologies in the Environmental Sector

Technologies	Description
Waste management	The system informs the garbage collection service whenever the neighborhood garbage cans need to be emptied. With the help of these, it is possible to review the waste collection network and the number of garbage cans needed in public places.
Management of wastewater and water resources	It is possible to monitor water sources and record several water-related data such as water levels and quality by connecting sensors to smart lighting instruments.
Air quality	Enables the deployment of dense networks of low-cost sensors that provide real-time data on air quality levels. This data may allow cities to reroute traffic as a means to reduce local air pollution.
Charging stations for electric vehicles	Allows charging stations to be built for electric vehicles in public lighting installations.

Transport

Smart street lighting infrastructure is increasingly being used to facilitate several intelligent transportation optimization solutions that are aimed at reducing congestion and increasing the efficiency of urban transit systems.

Table 3: Technologies in the Transport Sector

Technologies	Description
Parking management	With a smart public lighting system, solutions for parking guidance, paid parking system management, and long-term occupancy data analysis can be implemented.
Digital signalization	Systems are in place to display information on digital screens or projectors instead of conventional printed signs. The connectivity of smart streetlights allows to update the information displayed in real time.
Detection and management of traffic jams	By attaching data transfer modules to traffic lights, a traffic jam road checks can be made in real time.

Other Advantages

In addition to all the benefits of transportation, safety and the environment, other applications can be linked to a smart lighting system.

Table 4: Technologies in other sectors

Technologies	Description
A sky full of stars	With the help of an adjusted smart public lighting system, it is possible to make the sky visible to the population again by eliminating light pollution.
Dynamic and easy-to-use interface	The interface that controls all technologies is easy to use and very dynamic.
Wi-Fi network deployment	It is possible to use smart streetlights throughout the city to host wireless networks.
Reading meters	IoT devices are attached to the smart lighting system and the various meters (electric, water and gas). Using these devices, it is possible to read the meters and collect the associated data and transfer them to authorized persons or entities by radio signal.

As demonstrated by the applications described above, the potential of smart lighting infrastructure is much greater than just street lighting. Using smart modules, streetlights can not only enable the cost-effective deployment of discrete applications such as sensor networks and transport optimization applications, but also serve as a smart city platform allowing interactions between applications in response to real-time events.

Recommendations

Clearly, many technical and resource challenges preventing cities and municipalities from widely and consistently adopting sustainable street and public lighting. There are also financial and policy/regulatory challenges cities and municipalities choose to implement these lighting projects as PPPs. Nevertheless and given the high level of interest and needs among cities and municipalities, if local governments choose to adopt public-sector energy conservation, use the PPP model for projects, as well as take advantage of the opportunities and energy savings potential that currently exist, it is possible for cities and municipalities to upgrade their public lighting systems while generating substantial savings. Moreover, innovative arrangements have proven to be useful financing models where appropriate.

However, for projects to go forward, some of the key technical and financial hurdles to be addressed are:

- **Access to project financing:** Cities and regional governments with limited investment funding will benefit from access to capital and competitive international product pricing.
- **Government budgeting process:** When cities or local governments apply PPP models, their budgeting processes sometimes have to be adapted to suit the required financial arrangements. In general, the budget for street lights and related infrastructure is part of the city or regional governments roads and/or public service budgets. A specific budget for public street lighting is needed and should consist of two main elements: the utility (electricity) budget and O&M budget. It is recommended that cities and regional governments develop a clear budget plan with a business case to justify maintaining the same utility/O&M budget for the duration of the PPP contract. In other

words, the significant energy (and maintenance) reduction expected as a project outcome do not entail utility budget reductions. The same applies to the O&M budget if the scope is shifted to a PPP service provider.

- **Some key regulatory areas may need to be strengthened:** In addition to adapting municipal budgeting processes, governments may need to take additional steps to: (1) Provide clearer guidance for public implementation of the ESCO/PPP model in relation to ESCO business operations, EPC, asset management, and long-term service contracts with the government if they are not already available; and (2) Empower the public sector to set its own EE targets and develop its own strategy and tactics to meet said targets with clear ramifications.
- **Maximize PPP flexibility:** Generally, two conditions need to be satisfied for a project to be considered a PPP:
  - The private sector wholly or partially finances public projects;
  - The private sector implements at least one of the following processes: construction, development, restoration, outfit, maintenance, rehabilitation, and operation.

  These conditions allow for a wide range of commercial options that can eventually be assessed and adopted to suit each city or province, including:

  a) Build, Finance, Lease, and Transfer;

  b) Build, Operate, and Transfer;

  c) Build, Rehabilitate, Operate, and Transfer;

  d) Design, Build, Finance, and Operate;

  e) Design, Construct, Manage, and Finance;

  f) Concession, Build, Operate, and Renew Concession.

These options should be analyzed considering technical and financial risks, operational responsibilities, state of infrastructure and correction of defects, as well as investment arrangements and sources of project finance.

- **Coordinated development of technical standards and MRV framework:** The use of international best practices for illumination, luminaire performance, and controls goes a long way toward facilitating the development of a common set of procurement requirements for projects nationwide if they currently do not exist. This helps guide the development of national standards. At a minimum, cities and regional governments need to consider (and agree upon) a common set of procurement objectives and specifications for luminaires and other components to encourage as many product suppliers as possible to participate in the procurement process and minimize costs. They also need to agree on a measurement and verification framework (what needs to be measured), in order to facilitate the evaluation and reporting process.
- **Externalize the costs of smart city infrastructure:** It is challenging to justify the costs of a smart system on energy savings alone due to the additional investment costs compared to the incremental energy savings generated. It is conceivable that the O&M burden can be further reduced with smart infrastructure. This would reduce the higher costs associated with scheduled normal inspections and light maintenance for example. However, it should be noted that in addition to potential benefits associated with O&M and energy savings, a smart system has other wider economic benefits that include:
  - Enhanced roadway safety;
  - Integration with security and monitoring systems;
  - Social, environmental, and community benefits.

These added economic benefits are dependent upon many external factors. Economic modeling is needed and should be integrated with other smart infrastructure components to fully realize the added benefits.

- **Pilot/demonstration projects can be useful first steps in determining the appropriate implementation strategy and equipment:** Since the situation of every city or municipality is unique, certain specific technical or operational requirements sometimes require in-situ validation, such as the appropriate level for commercially mixed districts or the most optimal dimming periods. A pilot/demonstration project with specific objectives helps to address stakeholder concerns, including realistic returns on savings and documented illumination performance, obtaining feedback for specific strategies from law and emergency service personnel on the appropriate levels of dimming, as well as residents' concerns about light pollution.

Case Studies

Summaries of case studies on successful sustainable street lighting improvement projects in which Econoler has been involved are presented below.

Brazil

Scope: The Belo Horizonte project covers the replacement of all the city's 182,000 existing light points by LED luminaires. The project included the implementation of a remote management system for the main roads. This smart system provided computerized and remote control of lighting points from a control center and enabled the monitoring of all electrical information online. It also provided real-time information on possible failures and opportunities for maintenance interventions (preventive or corrective).

Implementing arrangement: The project was implemented through a PPP agreement with a private-sector service provider and included the operation and maintenance of the system for the city.

Financing: The selected PPP concessionaire is exclusively responsible for obtaining the necessary financing (underwritten by the IDB).

Key contract details: The duration of the Belo Horizonte PPP contract between the city and the PPP concessionaire was 20 years, with the estimated value of the contract (foreseen in the bidding) being estimated at USD 375.6 million. The business model foresaw the provision of USD 26.8 million in funds per year. The concessionaire was selected by the city using a public procurement process. Payment to the concessionaire was structured around an index of performance composed of five main indicators:

1. Modernization Index (MI): Maintenance of the modernization levels achieved by the PPP concessionaire in accordance

with the framework of the modernization and efficiency schedule.

2. Efficiency Index (EI): Maintenance of the efficiency levels achieved by the PPP concessionaire in accordance with the framework of the modernization and efficiency schedule.
3. Quality Index (QI): Quality of services provided.
4. Operation Index (OI):Availability of the infrastructure and services as well as the respect of the established deadlines thereof.
5. Conformity Index (CI): Compliance with the deadlines and requirements set for the presentation of certificates, reports and for the calculation of the theoretical account.

Key technical requirements: The procurement process consisted of both administrative and technical requirements. The key technical performance requirements for the lighting system modernization include:

- Visual quality: Minimum average CRI of 65 (CRI = Color Reproduction Index);
- Efficiency of system: reduction of at least 45% of the Installed Average Load;
- Prioritization of lighting:
  - Priority was given to the densest populated areas of the city with lower levels of education and income, as well as higher rates of crime and vehicular accidents;
  - Installing public lighting in squares and parks with a high pedestrian traffic at night;
  - Installing public lighting in places where public services are provided at night, such as hospitals and schools.

Payments are based on monthly installments that are adjusted according to the levels of energy expenses invoiced by the electricity distribution company. Additional payments (energy bonus payments) are included after a set of milestones have been achieved, adjusted using key performance indicators and only if energy savings are above 49 percent of the baseline amount. This bonus is to be paid annually.

India[11]

Scope: The project covered seven cities encompassing nine urban local bodies: Latur, Akola, Pune, Ajmer and Alwar Municipal Corporations, Ajmer and Alwar Urban Improvement Trusts, Bikaner, and Indore. The urban local bodies were responsible for infrastructure improvements in the cities. The cities were spread across three states in central and northwestern India, namely Rajasthan, Madhya Pradesh, and Maharashtra. They range in size from 260,000 (Alwar) to 2.6 million (Pune), with most in the range of 300,000 to 500,000 inhabitants.

The project was built around three innovations in India at the time:

- The advent of EPCs that allow cash-strapped municipalities lacking access to debt capital to fund street lighting retrofits through savings shared with private contractors;
- Significant improvement in lighting technology from incandescent to more efficient LEDs;
- The possibility of partnering with Econoler to tap into carbon offset markets for emission reduction credits.

Significant energy savings were achieved in all nine locations. The ESCO provided reliable maintenance for many years, often significantly upgrading degraded street lighting infrastructure and ensuring that upwards of 90 percent of luminaires were in operation at all times. The installed CFLs achieved reductions in monthly bills of up to 40 percent. Electricity savings across the nine urban local bodies were estimated at 47,000 MW.

11. https://www.esmap.org/sites/esmap.org/files/DocumentLibrary/EESL%20-%20Proven%20LED%20Delivery%20Models8_Optimized_Final.pdf

Implementing agreement: The nine different projects were implemented on a build-own-operate-transfer (BOOT) basis through an ESCO shared savings model. Shared savings means that the ESCO and the municipality shared performance risk; each would receive a fraction of the savings resulting from the investment.

Financing: The projects collectively had a combined capital cost of USD 5.83 million. As it signed on municipalities to street lighting energy performance contracts, the ESCO negotiated ancillary CDM revenue-sharing clauses as part of the shared savings agreements, promising to pass along 50 to 97.4 percent of carbon credit proceeds (each city negotiated a different rate, which the ESCO attributed to the wide range of monitoring and compliance costs in each municipality).

Key contract details: The cities involved in these nine projects procured ESCO services independently and one at a time over four years. However, in the absence of national guidance, each urban local body developed its own procurement process.

Key requirements: The energy savings accrued from these investments were quantified and shared between the ESCO and each city according to pre-agreed ratios for a period of five to seven years. Generally, the ESCO negotiated payment of 80 percent of electricity savings to cover its capital, operating, and upfront financing expenditures.

In later years, the ESCO began to separate capital improvements (luminaire replacements and infrastructure upgrades) from service contracts to secure guaranteed paybacks for capital improvements independent of shared savings stemming from operations and maintenance. Ostensibly, this separation did not change the terms or structure of the energy performance contracts (and thus was not challenged by municipalities), yet this practice helped to ensure the ESCO could collect payments. Separate installation and maintenance contracts also allowed for flexibility in negotiating the extent and terms of maintenance.

Payments: Payments were made mainly through a portion of the savings generated by projects. Following the experience of the pilot project in Indore where it took an extra year for the city to provide payment for services after the end of the three-year project, the ESCO, working with the World Bank, designed a mechanism to receive expedited payment for the installation and maintenance of LED lighting systems out of the savings. Measures to expedite payments – such as pre-calculated payments, automatic payments, and expedited government approvals – helped to shorten and limit arrears, although they did not eliminate them entirely.

Jamaica

Scope: The project was initiated by the Government of Jamaica that was responsible for covering the cost of the entire public lighting system of the country. The public lighting system was under the management of the Jamaica Public Service Company (JPSCo) that was paid through an imposed electricity tariff. The objective of the initiative was to identify appropriate commercial structures for retrofitting 125,000 light points with LEDs.

Implementing agreement: The project was implemented through a partnership with JPSCo, and the latter agreed to a 10-year plan to gradually replace and finance all 125,000 light points of the country.

Financing: Financing was provided directly by the utility after an agreement with the Government of Jamaica to resolve certain payment arrears issues that occurred over the previous years.

Key contract details: The agreement was negotiated as a side contract between the Government of Jamaica and JPSCo without having to interfere with the electricity distribution agreement already in place. No tariff structure modification was involved and JPSCo agreed to continue providing the same operation and maintenance services as before and be paid through the cost of electricity sold to the government for the street lighting systems.

Key technical requirements: The agreement involved a complete retrofit of all existing lamps of the street lighting systems with LED lamps, which would offer the same level of lighting as the previous technology. No improved lighting levels were included in the agreement; nonetheless nothing prevented the utility from identifying and implementing improvements.

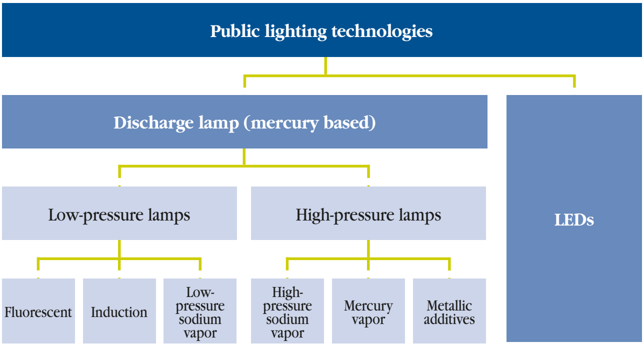
Payments: The entire initiative was paid for directly by JPSCo even though it was going to see its global revenues decrease due to reduced electricity sales. What made the agreement attractive was the approval by the Government of Jamaica to settle certain significant arrears amounts over the last few years since these were leading to important consequences for JPSCo.

Appendix I
Light source types and technologies

Light Source Types and Technologies

Energy efficient solid-state lighting technologies (or LEDs) applied to street lighting designs dramatically decrease costs compared to less efficient technologies, along with corresponding reductions in GHG emissions. These savings reduce the need for new generating plants and serve to redeploy scarce capital to deliver energy access to other areas in need. A list of available light-source technologies currently used in street lighting networks is presented below.

Figure 1: Technologies Currently Used in Street Lighting



Source: Econoler

Prior to the emergence of LED lighting, technology options for intensive, frequent cycling, and long-burning applications such as road and area lighting included gas-discharge sources, notably metal halide (MH), high-pressure sodium (HPS), mercury vapor (MV), low-pressure sodium (LPS), fluorescent (FL) and induction (all referred to as conventional sources). Each technology is capable of generating a significant amount of light fairly efficiently and over a reasonably long lifetime, compared to incandescent filament sources[12]. However, as the summary table further below clearly indicates, solid-state lighting is the preferred choice for use in street and public lighting due to its combination of efficiency, directionality, color-rendering abilities, and compatibility with controls, as further elaborated below.

12. Since many of the conventional light sources have been for in use for 50 years or more, the principles behind their operation are well-known and covered extensively and comprehensively in many scientific, technical, and engineering publications. They are therefore not covered here. Similarly, the working principles of LEDs and induction lighting (two relative newcomers to street and public lighting) are extensively covered elsewhere and are not included here.

Appendix II
Cost trends

Lighting Equipment Costs

According to the US DOE's latest forecasts, the price-performance ratio for LEDs will continue to improve in the near future[13]. The DOE expects the general price trends for street and roadway luminaires to become more competitive with traditional HID-based luminaires. This is because LED package (chip) costs have benefited greatly from high volume manufacturing and advances in the laboratories. Some key factors that can influence product prices are as follows:

- As LED prices continue to fall and their performance continues to improve, LED packages will have less of an impact on overall street lamp and luminaire costs;
- The prices of other components such as housing, lenses, electronics, etc., may remain comparable to conventional streetlight component prices and are subject to the same market conditions;
- Significant future cost reductions will depend not so much on any one component such as LEDs, but rather on improvements in multiple component categories;
- LED luminaire manufacturers will tend to set their products at comparable price targets.

In general, the average price for LED luminaires will become more comparable to prices of other traditional technologies such as HPS, MH, or CMH.

Control System Costs

The costs of control management systems (CMS) are generally in line with the size of the network and added functions

13. *Energy Savings Forecast of Solid-State Lighting in General Illumination Applications*, US Department of Energy, 2014.

beyond the basic capabilities of remotely scheduling streetlights to turn them on or off. For example, reporting information on individual luminaire energy consumption, alerts for outages or abnormal operation, generation maintenance and repair orders, among many others require more sophistication in the luminaire, control system, and communication methods. In general, costs of control systems depend on the complexity of the system and the architecture proposed, including:

- Whether it is wireless, wired, or a hybrid;
- The chosen data sensing, reporting, storage (centralized, distributed, or hybrid), and analysis strategy;
- The software, storage, and online security/reliability measures.

In addition, these systems often require installing new equipment and often have specific installation requirements that may allow or prevent their deployment at existing facilities[14].

Operation and Maintenance

The LED combination of efficiency and directionality has resulted in significant reductions in operating costs for those municipalities that have transitioned to this technology.

- Energy savings reported by cities range from 40 to 60 percent due to LED replacements alone[15];

14. The overcrowding of electric cabinets and/or loss of tension on power lines can cause interference to PLC-based systems that prevent their proper operation. The installation of wireless communication systems also needs to consider the particularities of where each system segment is used in order to address any physical barriers and other issues that hinder radio communication.
15. For example, *LED Street Lighting Best Practices*, Asian Development Bank, 2016 (https://www.adb.org/publications/led-lighting-best-practices-indonesia); or *Restoring Detroit's Street Lighting System*, US DOE 2015. https://www.energy.gov/sites/prod/files/2015/09/f27/2015_restoring-detroit.pdf.

- The addition of CMS, dimming, and other measures to reduce unnecessary lighting use further increase energy savings;
- Since the use of CMS and other means of reducing energy consumption are more recent, the range of possible energy savings has not yet been firmly established.

Cities and municipalities adopting LEDs have also reported reductions in maintenance costs due, in part, to the longer lifetime of LEDs and better specifications for luminaires used in procurement.

Appendix III
Comparative overview of light sources

Table 1: Comparative Overview of Light Sources

Lamp Type	Light Efficiency (lm/W)	Color Temperature (K)	CRI	Useful Life (h)	Maintenance of Luminous Flux (%)	Effects of External Temperature	Auxiliary Equipment	Ignition Time (min)	Immediate Reignition	Adjustable (Dimming)
Mercury	20 - 40	4,000 - 6,000	15 - 50	16,000 - 24,000	60 - 70	No effect	Ballast	3 - 5	No	No
High-pressure sodium-vapor	80 - 120	1,900 - 2,200	22 - 70	15,000 - 40,000	75 - 90	No effect	Ballast + starter or electronic ballast	2 - 4	Yes, or with a special device	Yes, not practical
Low-pressure sodium-vapor	130 - 170	1,700 - 1,800	0	16,000 - 18,000	70 - 85	No effect	Ballast + starter or hybrid system	15	Yes, with a special device with two-cap lamp	No
Metal Halides	40 - 110	3,000 - 4,200	60 - 94	10,000 - 20,000	55 - 80	No effect	Ballast + starter or electronic ballast	5 - 7	No, except with special device	No, not practical
Fluorescent	80 - 85	2,700 - 5,000	80 - 85	6,000 - 20,000	95	Low temperatures increase ignition time	Ballast + starter or electronic ballast	Almost instantaneous (warm-up time)	Yes	Yes
Induction	50 - 85	3,500 - 5,000	80 - 85	100,000	65 - 70	Low temperatures reduce luminous flux	High-frequency generator (electronic ballast)	Instant (warm-up time)	Yes	Yes, in some cases
LED	Up to 160 or more	2,700 - 7,000	Up to 97	70,000 +	70 - 95	High and low temperatures can reduce lifetime and increase the depreciation of luminous flux	Electronic driver (other electronics needed for smart features)	Instant	Yes	Yes

Table source: Own elaboration based on

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About Econoler

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www.econoler.com

160, rue St-Paul, Bureau 200
Québec (Québec) G1K 3W1
CANADA

Telephone: 1 (418) 692-2592
Fax: 1 (418) 692-4899
www.econoler.com