Energy Efficiency in Bogotá

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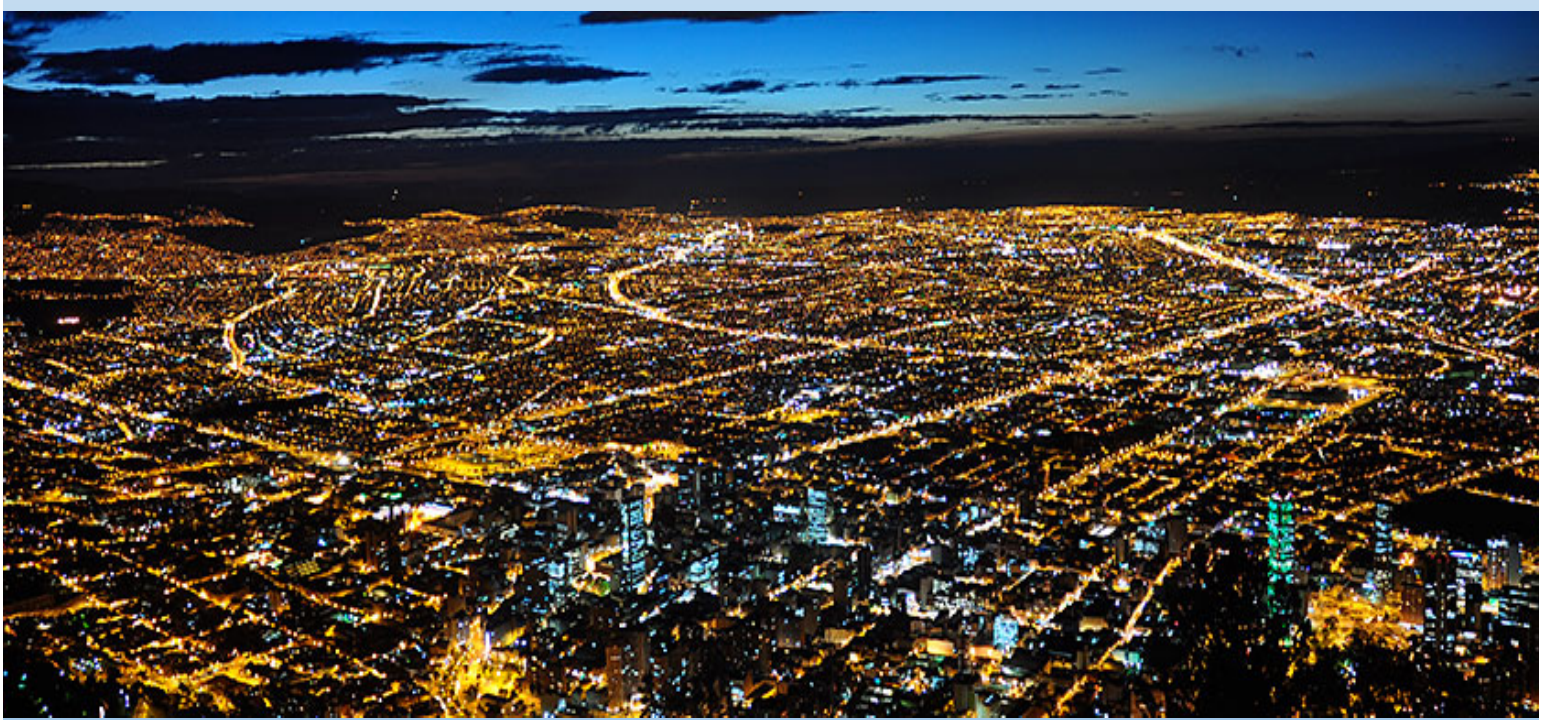

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Definitions

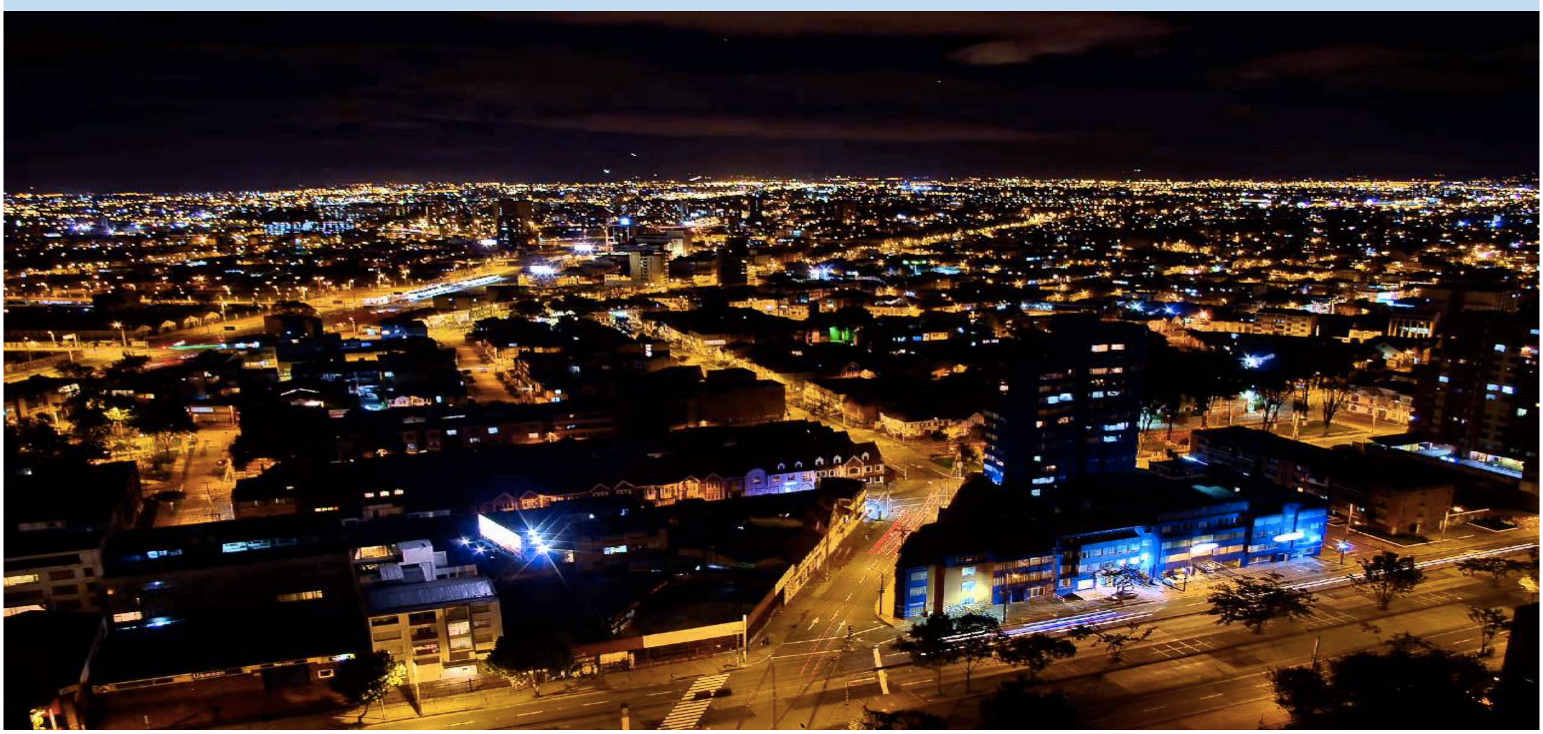
Terms	Description
Watt	Energy needed to power bulb
Brightness (lumens)	Intensity of the light
Efficacy (lumens/watt)	Amount of light emitted at the source for a given power
Color Rendition Index (CRI)	A percentage scale (0-100) used to measure and compare lighting light emissions from bulbs to the sun's natural light (higher CRI = more natural light)
Life Expectancy	Average hours of operation before light source failure
Color Temperature (K)	Color appearance of the light
Warm-up Time	Time taken for bulb to fully turn on
Electrical Ballast	A device that regulates electrical current
Lamp	The fixture that contains the bulb
Luminaries	A light bulb
Illuminance	Lumens per unit area
Failure Rate	% of light failure across the entire light population in a given year
Public-Private Partnership (PPP)	Long-term contract between a private company and a government entity in which risks are shared and remuneration is linked to performance
Private Model	A single or multiple private entities are responsible for the entirety of a project, including, but not limited to, risks and funding
Public Model	A government entity is responsible for the entirety of a project, including, but not limited to, risks and funding
Self-Funding	Municipalities using annual surplus from the municipal budget
Energy Service Companies (ESCOs)	ESCOs can provide a range of energy solutions including installations and financing
Municipal Funding	Issuing municipal bonds or borrowing funds through loans to finance public projects
National Programs	Programs dedicated to specific development initiatives
Transfer of Luminaires	Selling old luminaires to other nations or regions
International Grants	Provided by international organizations that aim to foster development in specific areas
Taxes	Implementing a tax on residents to pay for public lighting
Utility Programs	Utility shares the infrastructure and operation costs

Executive Summary

Mayor Enrique Peñalosa Londoño has proposed a plan to modernize Bogotá's public lighting by replacing 100,000 lights on streets and in parks with more efficient and reliable bulbs. The Mayor's Office is interested in exploring the opportunity to incorporate innovative lighting technologies, such as a central monitoring system or renewable power sources, into this plan.

This report examines four aspects of the public lighting modernization program in Bogotá:

1. **The best lighting technology for a public lighting upgrade and a strategy for determining which lights to start with;**
2. **The implications of incorporating monitoring solutions and renewables into the modernization plan;**
3. **The public lighting ownership and operation models of peer cities;**
4. **Funding options available to fund a public lighting improvement project.**



Mayor Enrique Peñalosa Londoño has proposed a plan to modernize Bogotá's public lighting by replacing 100,000 lights on streets and in parks with more efficient and reliable bulbs. The Mayor's Office is interested in exploring the opportunity to incorporate innovative lighting technologies, such as a central monitoring system or renewable power sources, into this plan.

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The research conducted for this project focused on Ceramic Metal Halide (CMH) lamps and Light Emitting Diodes (LEDs) as the primary options for replacing the High Pressure Sodium (HPS) lamps currently used in the infrastructure. LEDs were chosen as the preferred option because they have lower energy consumption, longer expected life, and a lower failure rate than equivalent CMH lamps. Studies have also shown correlation between replacement of public lighting with LEDs and reduced crime rates, although a causal relationship has not been proven.

The lights in Bogotá's inventory were analyzed to determine which combination of bulb replacement would offer the most impact. The analysis determined that, out of the 40 bulb types in the inventory, the upgrade project should focus on the 70W, 150W, 250W, and 400W bulbs because they represent 91% of the public lighting energy use. The research then analyzed maximum internal rate of return (IRR) for combinations of the 4 chosen lamp types over a 10-year period. *Figure 1* describes the resulting capital costs and corresponding IRRs for the project. The

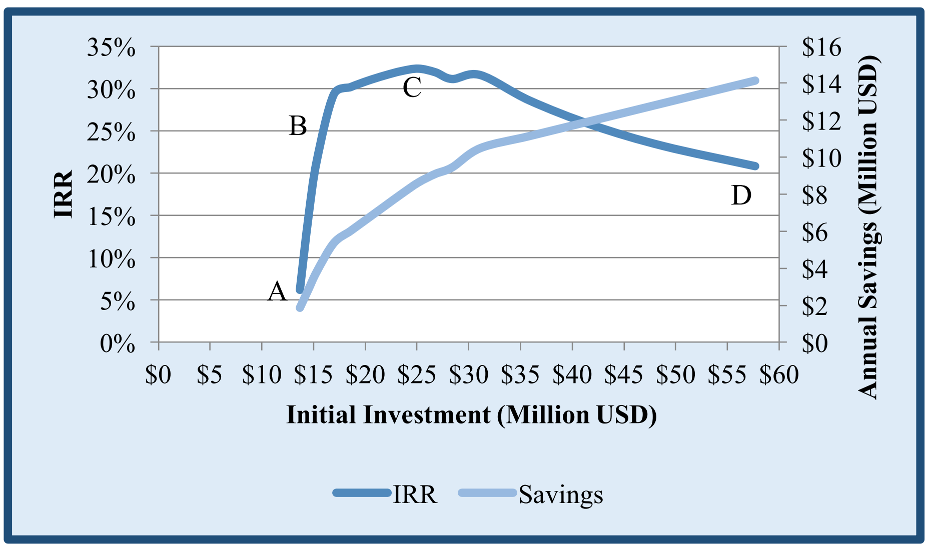

Figure ES1: Financial optimization model for bulb replacement

recommended solution provides a high IRR with a low initial investment by focusing on replacing all of the 67,000 150W HPS lamps and 33,000 of the 70W HPS lamps. Intuitively, the 150W bulbs represent the most cost effective opportunity for savings and the remaining 70W lamps keep the initial investment low. Four different scenarios are presented in this report. The recommended scenario is represented by point B in *Figure ES1* and scenario B in *Table ES1*. Additional expenditures beyond point B provide diminishing returns. Lower expenditures than point B sharply decrease the IRR. This analysis determined that scenario B would require an upfront capital investment of just over USD 16.4 million, while saving the city over USD 5 million per year, with a simple payback of just over 3 years.

Scenario	Lights Replaced				Initial Investment (USD)	Annual Savings (USD)	Simple Payback (years)	IRR
	70W	150W	250W	400W				
A	100,000	0	0	0	$13,646,623	$1,997,539	6.8	8%
B	33,045	66,955	0	0	$16,385,218	$5,289,045	3.1	30%
C	0	66,955	19,437	13,608	$25,756,147	$9,041,969	2.8	33%
D	194,806	66,955	34,767	13,608	$57,676,918	$14,560,818	4	22%

Table ES1: Replacement scenarios

Some cities use LED public lighting projects as an opportunity to incorporate central monitoring systems (CMS) into their public lighting infrastructure. Central monitoring systems provide several benefits to cities:

1. The ability to dim lighting during certain periods of the day in order to reduce energy consumptions and save money;
2. The ability to meter lighting energy use for more accurate billing;
3. Instant remote notification of failed lights for faster replacement.

Installation of a central monitoring system adds to the upfront cost of an LED retrofit project. A monitoring system would add approximately USD 11.5 million to the USD 16.4 million LED replacement investment recommended for Bogotá, resulting in a total project cost of approximately USD 28 million. Estimated energy savings offered by a CMS installation, when compared to the high upfront cost, will not make the project financially attractive on its own. The investment is more attractive when considering together CMS and LEDs as part of a broader lighting modernization program. In this case, the addition of a monitoring system will add less than 2 years to the simple payback of the project and reduce the IRR by between 7% and 14%. Bogotá may wish to consider the installation of the CMS for the quality improvements it provides in the ability to quickly replace failed lights without need for a third party auditing firm to physically identify such lights.

Many cities are also looking at ways to incorporate renewable energy into their public lighting systems as a way to reduce operating costs, provide power for public lighting where grids are not available, and provide back-up power where grids are unreliable. Renewable public lights can be powered by solar power, wind, or a hybrid of the two. Wind speeds in Bogotá are not fast enough to be an effective source of power. Upfront costs for solar are extremely high compared to the energy saved by using renewables. These options are unlikely to be effective in Bogotá, where grid access is largely available.

Cities around the world have a range of ownership and operational models for public lighting, each with its unique parameters. This report compares the ownership and operational model in Bogotá against seven peer cities. The benchmarking exercise considered such questions as: What lighting

technology is currently being used? Who owns and operates the public lighting system? Have any energy efficiency efforts been planned or implemented? How are public lighting services financed?
The emerging observations were organized along three pillars: scale, operations and maintenance (O&M) cost structure, and nature of public-private relationships in the selected cities.

The scale of street lighting upgrades differs across cities, ranging from small pilot projects to large scale modernization programs. Buenos Aires and Bucaramanga have implemented large city-wide lighting upgrade projects, while Santiago has implemented a series of small neighborhood-level pilot efforts to install LED lights, solar LED lights and remote management devices. Both approaches have different benefits. Large projects allow the city to make cost-effective and large scale lighting fixture purchases. Pilots offer a manageable solution to testing the benefits of lighting upgrades, as results can be monitored, quantified and communicated as a viable business case.

Operation and maintenance cost structures vary across the cities. Though most contractual arrangements were not available, it is known that most cities outsource the operation and maintenance to an external service provider. Generally, when municipalities outsource O&M to private companies, the payment structure takes two forms: variable payment or a fixed payment defined in a tender. São Paulo is a city that has used both these payment options. The city's partnership models are explained in detail in the report.

Another key observation of the benchmarking exercise is that public-private partnerships (PPP) have different formats with different outcomes. São Paulo and Mexico City both use PPPs for their public lighting systems. The partnerships differ in scale along with the type of financial guarantor. The partnership can be to manage the lights in the entire city, or phased gradually in neighborhoods of the city, and the financial guarantor can be the federal government or the municipality.

After discussing the technical aspects of Bogotá's public lighting upgrade project and comparing the ownership and operation structure of Bogotá's public lighting with peers, this report provides a scan of the sources of internal and external funding options that are available to Bogotá.

The common thread across all seven benchmark cities was the use of self-financing for at least a portion of their projects. The benchmarking analysis uncovered eight additional funding mechanisms that have been considered. Of the eight mechanisms, International grants, National Programs, and Energy Service Companies (ESCOs) are feasible financing options for the city to look at in order to secure capital investment. International grants from organizations like the Global Environment Facility and the World Bank Group have funded several energy efficiency projects in Latin America, and specifically in Colombia. Additionally, Colombia has several federal programs dedicated to specific development initiatives. In the past, Bogotá has secured national funding from the Clean Investment Fund's Clean Technology Fund for transportation and energy efficiency projects, and can consider this again for the public lighting projects. Energy Service Companies that provide a range of energy solutions, including installations and financing, could be another feasible option for the city to consider. A Shared Savings Partnership Model with an ESCO has worked well in countries like Brazil and India, to help co-finance their lighting upgrades.

Other attractive financing options include a public lighting tax and the use of municipal bonds. At the moment, these are likely to be difficult in Bogotá. Creating a new, dedicated tax would require community support and political backing, and might take significant time to roll out. Municipal bonds are market dependent, and currently the city does not have a booming market for municipal bonds. These two models can be considered in the future should the market or political climate shift.

Moving forward, the city can take a decision regarding the implementation of the public lighting modernization plan, and secure the required funds. In doing so, the city of Bogotá will move towards its vision of creating a safer and more prosperous city for its citizens.

Introduction

The Mayor of Bogotá, Enrique Peñalosa Londoño, has outlined a lighting plan that addresses many of his city's improvement goals: increasing public safety, seeking energy efficiency and fostering economic growth. His plan calls for the installation of 100,000 LED street lights in 100 parks, streets and other public spaces. The Mayor's Office involved Bloomberg Associates and Columbia University in recommending an effective and financially feasible modernization plan for street lights in the City of Bogotá. This report is intended to provide the City of Bogotá with a range of possible plan upgrades, and ways to fund the plan.

Problem Definition

The Mayor of Bogotá, Enrique Peñalosa Londoño, has outlined a lighting plan that addresses many of his city's improvement goals: increasing public safety, seeking energy efficiency and fostering economic growth. His plan calls for the installation of 100,000 LED street lights in 100 parks, streets and other public spaces.

Image I1: A Street in Bogotá which Could Benefit from Lighting Improvement[1]

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Methodology

Initial research was undertaken to understand the public lighting utility structure in Bogotá and the context in which lighting modernization is being proposed. This research included understanding the city demographics, the ownership structure of the public lighting system, the method by which Codensa - the utility which owns the public lighting infrastructure - is compensated by the city, and how the city currently raises funds to pay for its public lighting infrastructure.

Through collaboration with Bloomberg Associates, four key areas of interest were identified:

1. Research of the technologies currently used in public lighting improvement projects. Are there lighting technologies other than LEDs that should be considered, and in what use cases might non-LED technologies provide an advantage over LEDs?
2. Review of the opportunities to incorporate innovative technologies into the lighting improvement initiative: investigation of central monitoring systems and integration of renewable energy.

3. Investigation of the ownership and maintenance structures used by other cities similar to Bogotá. How are compensation agreements structured where other cities do not own the lighting infrastructure or contract with third parties to maintain and operate the system?
4. Research of funding options available to cities interested in undertaking a large scale public lighting improvement project, and examples of successful models.

Research into lighting technologies, monitoring, and renewables was conducted by: i) reviewing available technical documentation, ii) reviewing Bogotá's lighting inventory, iii) corresponding with representatives from companies that provide public lighting technologies or cities that participated in lighting improvement projects, and iv) reviewing publicly available results from cities that are either currently involved in, or have recently completed, significant public lighting improvement projects. Importance was given to cities in Latin America. Due to a lack of detailed publicly available data, some relevant information from non-Latin American cities was used. The information gathered allowed to structure the technical aspects a city should consider when beginning a public lighting improvement project. Technical and financial data about the lighting technologies was used in concert with Bogotá's lighting inventory to make projections of expected capital investment requirements and savings potentials by prioritizing different combinations of lights for replacement. Recommendations were made based on the priorities and limitations of the City of Bogotá.

The recommended scenario for light replacement was used as a baseline to construct a quantitative analysis of the expected capital investment requirements, range of predicted annual savings, and payback periods that could be expected by incorporating a central monitoring system into a lighting improvement project. The analysis conducted tested the sensitivity of savings and payback periods to variation of assumptions made. The sensitivity analysis included the impact on savings and payback when the monitoring project was considered as an independent project, and when considered as part of the larger public lighting improvement project.

In analyzing public lighting utility models most applicable to Bogotá, the city was benchmarked against seven other Latin American cities with similar social, political and economic backgrounds. The cities were short-listed in collaboration with the client. Public lighting ownership, operation, and compensation for the seven benchmark cities were researched through literature reviews and direct correspondence with city officials when possible. Key successes and failures from the cities acted as use cases for the next stage of the research.

The funding options available to Bogotá were investigated by researching methods through which other cities have funded large scale lighting improvement projects. Published reports were reviewed. Direct correspondence and interviews were conducted with city officials and representatives of NGOs that offer potentially relevant funding and partnership opportunities. The information gathered was used to construct a qualitative analysis of which funding options are most applicable to a large scale public lighting improvement project, and would be feasible within the context of Bogotá's public lighting ownership and operation structure.

Overview of Bogotá

Bogotá is the capital of Colombia and the fourth largest city in South America, with a population of 9,968,000.[2] Bogotá´s current establishment as a city began in 1991 when there was a change in the Colombian Constitution that separated the powers of the government into a "decentralized republic with autonomous territorial institutions". This set the pathway for the political change that the city embarked on, leading to a massive transformation in its social, economic and urban landscape. This was attributable chiefly to the transfer of responsibility of "public services, the administration of resources, and the development of infrastructure" to local municipalities.[3]

The leadership of Mayors Antanas Mockus and Enrique Peñalosa, from 1995 to 2003, took advantage of the new political freedom. This led to two decades of mayoral leadership that created substantial societal change in Bogotá. According to Ricardo Montezuma of the Humane Bogotá Foundation in Bogotá, "the great achievements of both mayors were the result of a new kind of government centred on issues rather than party politics or ideology."[4]

Significant investments were made in city sectors such as infrastructure, mining, education, technology and housing.[5] Transportation infrastructure was first addressed in 1995 by researching a baseline through a census study of transportation use, with the assistance of the Japan International Cooperation Agency. A solution was born in the form of a public-private partnership with bus companies to create the transit authority of Transmilenio, Bogotá's Bus Rapid Transit system in 1999.[6] This was the beginning of Enrique Peñalosa's vision of democratizing Bogotá for every citizen.[7] In addition, the Mayor added about 320 km of bike lanes ("CicloRutas"), and recently secured 70% of funding for a new Metro system from the Colombian government.[8]

Peñalosa initiated the renovation and expansion of many parks throughout Bogotá[9] to make public spaces available for everyone. In the process, over 200 parks throughout the city were either created or revived.[10] Ample sidewalks and bike lanes were also constructed next to each other as independent public spaces to optimize usage and increase safety.[11, 12] The city of Bogotá also embarked on projects to preserve the quality of its water and wastewater infrastructure via partnerships between the national and local governments, and local private utilities.[13]

Bogotá's neighborhoods are found to occupy 4 broad socio-economic regions:[14] the affluent Northern section, the poor Southern section, the Centre (El Centro) or the "downtown", and El Occidente, which features middle-class residential neighborhoods and some sporting venues. Neighborhoods are stratified by six socio-economic stratas or "Estratos".[15] Buildings are designated as being in a zone or stratum with Estrato 1 corresponding to the lowest income bracket and Estrato 6 corresponding to the highest income. The Estratos help verify the rate for taxes and public utilities such as gas, electricity, water and telephone for residents.

From an economic point of view, Bogotá has a large young skilled workforce of 4 million, and a growing service sector focused heavily on business process outsourcing.[16] However, more than half of the population currently works in the informal sector,[17] and the city continues to grapple with vast economic disparities.

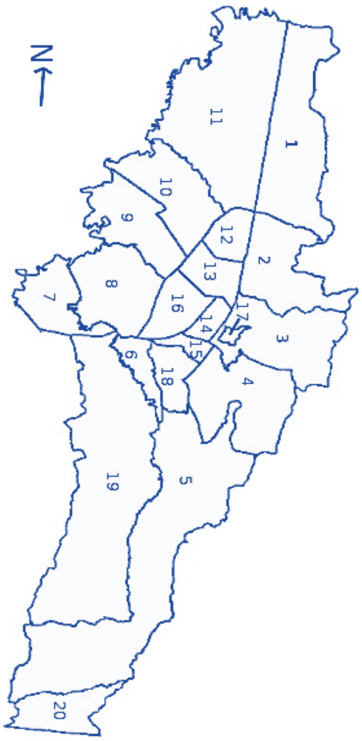

Image I2: Map of Bogotá's districts

Even with a history of government leadership in public infrastructure investments, Bogotá has room to improve in its social, economic and environmental impacts by addressing street lighting for parks and neighborhoods. In doing so, businesses would be able to operate for longer hours, thus increasing the economic productivity of neighborhoods. Citizens would have safer access to public spaces resulting from a consistently lit path for the "first and last-mile".[18]

This is particular relevant in the context of the current state of Bogotá's public lighting. The system faces a number of challenges. There have been concerns regarding public safety in parks, arterial roads and transportation hubs. Such concerns have been exacerbated by the city's rapid expansion. Informal settlements have been growing in the city over the past two decades, adding to the areas lacking access to adequate street lighting. Bogotá is currently spending approximately USD 60 million[19] a year to operate and maintain public lighting.[20] Monitoring of broken or damaged street lighting is manual, and thereby highly inefficient. The current technology comprises the use of inefficient luminaries with a high rate of failure. Improvements to public lighting would involve actions from all concerned stakeholders responsible for the operations, maintenance and financing of lighting infrastructure.

The street lighting system in Bogotá is currently operated by the local electricity provider Codensa, with supervision by the local government through the Special Unit for Public Services (UAESP). Further details on the ownership and operating structure of the city's street lighting services are provided in the subsequent section.

Utility Structure: Codensa

Codensa was created in 1997 and is dedicated to the sale and distribution of electricity. It is the national leader with 24% of the total market. The utility covers 100% of Bogotá and municipalities of Cundinamarca, Boyoca and Tolima. It is a joint venture between the local government and Enel Group - an Italian conglomerate that is engaged in generating and distributing electricity and gas. Codensa owns the public lighting infrastructure and the city pays a monthly fee to the electricity provider based on a formula, which includes electricity, operations and maintenance, and use of light poles. The formula was included in a contract entered into in perpetuity by the local government with Codensa.

Specifically, in 1997, the Convention 766 was signed between UAESP and Codensa. It entails that Codensa will continue providing all public lighting services from 1997 onward. In this Convention, Codensa commits to modernizing the public lighting system and replacing all mercury lights with high-pressure sodium lights in the following three and a half years. Codensa also commits to doing a location-based inventory and keeping it up to date. Codensa discounts electricity and a penalty for each faulty light. The utility also receives complaints on their web page, in written form, by phone and in person in their offices.

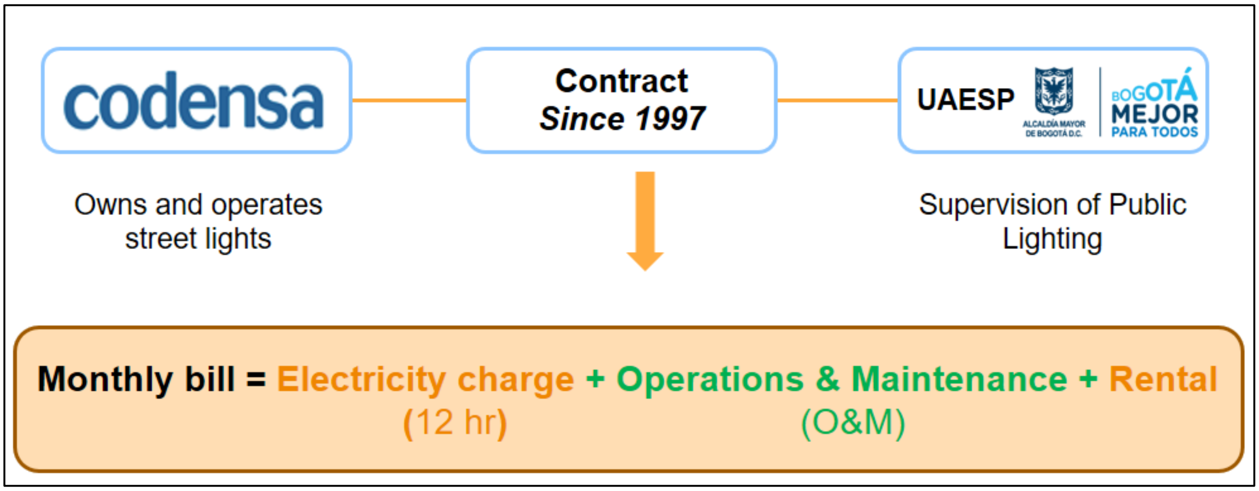

Image I3: Bogotá Public Lighting Cost Structure

Contract 766 of 1997 presents several barriers to the implementation of an energy-efficient public-lighting improvement. Under the current reimbursement structure, total charges for public lighting consist of three items. Bogotá pays to rent the infrastructure from Codensa, it pays an additional operation and maintenance (O&M) charge, and pays for electricity usage. Each component presents a challenge to energy efficiency improvements. Rent and O&M charges are calculated by dividing the annual value of each lamp by its wattage. The O&M charge is multiplied by 2.27% to determine the monthly charge. The current structure of the contract is likely to lead to higher rent and O&M cost despite reducing Codensa's maintenance expenses. Since the annual value of LEDs may be higher than the annual value of the bulbs they are replacing, and wattage of the LED bulb will be lower, the structure of the contact is likely to lead conversion to LEDs to increase both the rent and O&M costs, despite the fact that lower failure rates and longer lifespan of LEDs are likely to reduce Codensa's maintenance expenses. The electricity-use charge provides an additional challenge to the economic feasibility of an energy efficient public lighting improvement project because the charge is based on a calculated value and not actual usage. This calculated charge assumes a fixed 12 hours of operation on street lights instead of a more accurate metered charge. The calculated charge precludes taking advantage of energy saving opportunities offered by the dimming and timing functions of lighting control systems.

Lighting Technology and Innovation

The main objective of Bogotá's sustainability agenda is to modernize the city's street lights with LED bulbs. The city's goal further includes the possibility of implementing innovative lighting management technologies for energy efficiency and public benefit. This section presents a comprehensive, technical review of lighting systems including lighting technologies, remote monitoring, control systems and options for renewable energy sources.

The main objective of Bogotá's sustainability agenda is to modernize the city's street lights with LED bulbs. The city's goal further includes the possibility of implementing innovative lighting management technologies for energy efficiency and public benefit. This section presents a comprehensive, technical review of lighting systems including lighting technologies, remote monitoring, control systems and options for renewable energy sources. Each of these technologies should be considered by policy makers seeking to determine an appropriate and integrated lighting system for Bogotá.

Technical Lighting Systems

The typical street light has three systematic components: the structural system, consisting of the pole and its base; the optical system, containing the luminaries; and the electrical system, consisting of lamps, ballast and service cabinet.[21]

Lighting Types:

Key Takeaways

- Directional LED lighting produces maximum useful light per lumen output.
- The price of LED technologies is in a sustained downward trend, driven by competition among manufacturers.
- LEDs are durable devices with improved lifetime use, and lower operations and maintenance costs.
- CMH lights may be used for aesthetic gains in public parks and monuments.
- LED and CMH lights will elevate the lighting quality in Bogotá.

There are different types of bulbs used to provide public lighting services. Each type has unique properties. Following is a deeper analysis of the three bulb types most commonly used in public lighting: High-Pressure Sodium (HPS), Ceramic Metal Halide (CMH), and Light Emitting Diodes (LED).

Image LT1: Bogotá Street Illuminated by HPS Bulbs[22]

High-Pressure Sodium

High-pressure sodium lights are a type of high intensity discharge (HID) lighting fixture known for their characteristic yellow hue. They are the most common light source present in street lighting, a result of their early and widespread adoption before the development of modern technologies. HPS lighting systems remain commonplace because of a simple operations and maintenance procedure. HPS bulbs are also compatible with a wide range of existing lighting fixtures.

The maintenance of HPS lights is perceived to be a low-cost option for cities providing continued lighting service, when only physical replacement bulb costs are accounted for. This approach demonstrates disregard for additional qualitative factors, such as failure rates and reliability. When these factors are properly accounted for, they provide support for the adoption of new, competing technologies. Increased competition across manufacturers for new technology also continues to disrupt the traditional economic incentive for HPS replacement in perpetuity.[23]

With regards to light generation, HPS light is sourced from an electrical arc caused by a chemical reaction between aluminum oxide and sodium. The light emitted from an HPS bulb is of a broad light spectrum, and produces a poor color rendering when compared to other technologies. While HPS bulbs offer a simple maintenance and replacement procedure, they lose operating efficiency within their required ballast system as power regulation becomes more variable. They also lose operating efficiency within the light bulb itself, when oxide residues permeate the interior surface of the bulb towards the end of their useful life. Overall, an HPS bulb is reliant on many lighting components, which reduces reliability.[24]

HPS light is produced in an omnidirectional lighting tube, and emissions of light are dispersed in all directions. Therefore, HPS technology contributes to an increase in light pollution, and offers limited control over directional lighting application. The broad wavelength spectrum of HPS further pollutes night skies during its use.[25]

Ceramic Metal Halide

Metal halide bulbs present technological benefits beyond HPS bulbs. CMH lighting is characterized by the consistency of color, natural color rendering (CRI 90), and improved efficacy.[26] Inside the lamp tube, a combination of mercury, argon, and halide salts are heated, creating a plasma of vaporized halide salts that boosts light output in the traditional lighting arc. Output in the CMH tube remains multidirectional, and a lighting ballast is required to start and regulate current.

Chicago, Illinois

Public lighting choices made in Chicago shed further light on the trends in retrofits. In April of 2011, the city of Chicago, Illinois installed 11,000 CMH lights on city roadways. The goal of the small street lighting project was to test the improvements in the quality of light, energy efficiency, traffic safety and crime rates attributed to white light from CMH and LED technologies versus the yellow light of HPS bulbs.

Chicago chose CMH lights over LEDs for two reasons. First, LED technology was more expensive than CMH. Second, research into CMH lighting in Europe reassured Chicago that it was an effective and reliable lighting technology.

Five years later, in April of 2016, the city of Chicago announced a plan to replace 270,000 HPS street lights with LEDs over the following four years. The reasons for the lighting upgrade are the same: higher perception of safety in the streets, better quality of light, higher energy efficiency. However, the city will be using LED over CMH. The improvement in LED technology compared to 2011 is a reason for this change in lighting technology. LEDs are now considered sufficiently reliable, affordable and efficient to regain the costs of their installation through energy savings.

Bill Ryan, an HID Product Manager at Philips, refers to CMH as "halogen killers", because their color is so good they can tackle applications like spots and tracks." This description suggests focused indoor use for tight application. Jerry Flauto, a senior product specialist at General Electric, notes that CMH "gives us great color stability, good efficacy, and long life."[27] General Electric markets CMH technology and products as viable and effective replacements for HPS lamps. General Electric also attributes CMH performance benefits to consistent color over life.[28]

CMH may be applied to meet challenging lighting design requirements, from retail to industrial, and from decorative lighting to city beautification. Application of CMH lighting technology is concentrated in retail space and indoor lighting use, where demand for premium color rendition is highest. CMH lighting has become the preferred technology for use in indoor agriculture, where a full color spectrum is provided for plant growth.[29] General Electric also offers an array of CMH lamps for use in retail spaces, including grocery stores and designer flagship locations.[30]

CMH technologies are also used for a similar, white-light aesthetic in outdoor spaces. The City of Bogotá has already piloted a small number of CMH lights,[31] and policy makers should consider using CMH lighting technologies specifically for public lighting in parks and for highlighting city monuments. High color rendering will increase visibility in specific areas where CMH lamps are deployed. In New York City, CMH lamps of varying wattage were used to illuminate the African Burial Ground National Monument, including both the structure and the surrounding trees.[32]

Light Emitting Diodes

LED technologies are one of the most advanced lighting technologies in the market. In comparison to HID lamps, that produce light derived from a chemical reaction housed inside a tube, LEDs use a semi-conductor technology. The diodes of LED are concentrated on one side of the device and, when current flows through, the device emits light in a single direction. In contrast, CMH and HPS technologies emit light in all directions.

LEDs today provide many compelling reasons for cities and municipalities around the world to upgrade their street lighting. LEDs consume less electricity and are environmentally friendly. LED technology has other performance advantages such as better lighting quality, less maintenance needed, lighter weight and a reduced packaging attributed to its compact design. LEDs can have peak emission wavelengths from 250nm (UVC) to 1000nm (infrared) and higher, and cover spectral emissions from the red to yellow region of the visible spectrum, thus emitting more useful light. This makes them more efficient in comparison to HPS bulbs.

LED bulbs last longer and have lower failure rates than other lighting technologies. Most LED bulbs have a useful life of 10 years, but there are models that have a useful life of up to 25 years with no maintenance. As opposed to HPS bulbs that have a useful life of 3 to 5 years, LED bulbs do not fail by burning out. Instead, they gradually become dimmer. Some lamps might still produce up to 80% of their initial light at the end of their specified lifetime. Furthermore, LEDs have been proven to have significantly lower failure rates than traditional lighting technology. According to different case studies, while HID lamps have a failure rate of 6-10%, LED lamps have a failure rate of less than 1%.

The lifetime and performance of the LED depends on the quality of the LED, the system design, the operating environment, and other factors such as the lumen depreciation factor over a period. The lumen depreciation factor is the process which describes how LEDs get progressively dimmer over time. *Figure LT1* below shows that the lumen-per-watt of LEDs declines more slowly in comparison to HPS and CMH over the same period of time. A primary cause of lumen depreciation is heat generated at the LED junction. LEDs do not emit heat as infrared radiation, like other light sources. The heat must therefore be removed from the device by conduction or convection. The more effectively the heat is removed, the longer the LED will last.

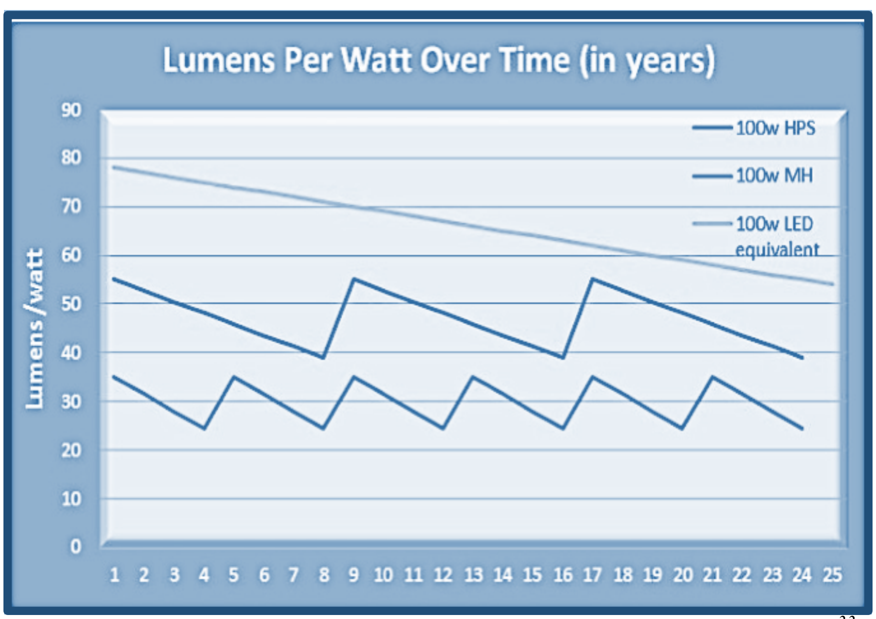

Figure LT1: Expected Performance of 100-watt CMH, HPS and LED[33]

Bogotá Current Inventory Analysis:

Key Takeaways

- The Bogotá lighting inventory is comprised of over 40 different types of bulbs.
- Focusing on 70W, 150W, 250W, and 400W HPS bulbs (instead of all 40+ types) will address 92% of the energy used by public lighting, while simplifying the logistics effort.

In 2012, Codensa compiled an inventory of the roughly 340,000 street lights in Bogotá and organized them by bulb type, ballast type, and wattage. The utility company uses this inventory to calculate the city's monthly public lighting bill.

According to the inventory, 91% of public street lighting uses HPS bulbs, with the remainder composed of CMH and a negligible number of LEDs. A percentage breakdown of each bulb type and their power in Watts (W) is shown in *Figure LT2*. Within the HPS bulb type, the majority of bulbs have the lowest wattage, 70 W (57%).

A breakdown of power use by bulb type, shown in *Figure LT3*, illustrates that nearly half of the energy use is attributed to two bulb types, HPS 150 W and HPS 250 W, even though they account for only 30% of the roughly 340,000 city street lights. The highest wattage bulb, HPS 400 W, consumes 13% of the total power, while accounting for only 4% of the inventory. Although the current inventory holds more than 40 different bulb types, this initial analysis suggests that the modernization efforts should be focused on only four types: 70-, 150-, 250-, and 400-watt HPS bulbs. These four bulb types alone account for over 90% of the total inventory and consume 92% of the power. By focusing on four bulb types, instead of 40, less engineering effort is required when planning the project. Additionally, fewer types of luminaries simplify the job of maintenance crews and reduce the necessary storage space of spare bulbs.

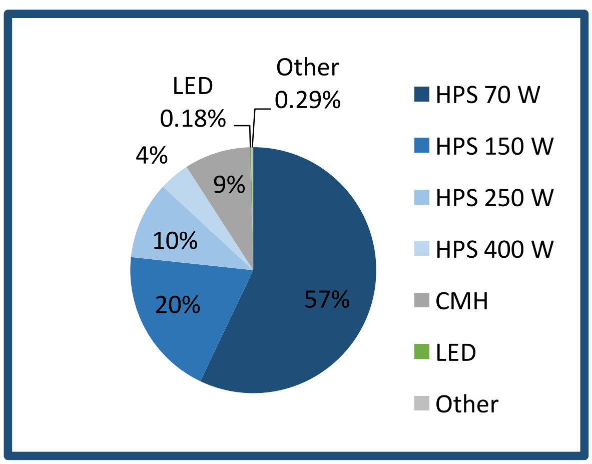

Figure LT2: Quantity of Bulb Types.

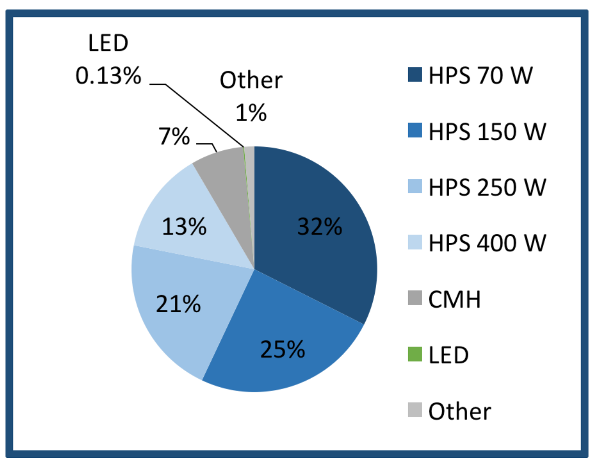

Figure LT3: Relative Energy Consumption of each Bulb Type.

Remote Monitoring:

Key Takeaways

- Monitoring can reduce maintenance costs and improve lighting service.
- Most cities implementing monitoring have done so in conjunction with major LED retrofit projects.

An increasing number of cities are using LED upgrades as an opportunity to incorporate central monitoring systems (CMS) into their public lighting. Monitoring systems offer an opportunity for cities to meter actual lighting energy consumption and be billed accordingly. Monitoring systems also improve lighting maintenance and avoid energy wastages by providing real-time information on malfunctioning lights, so that they can be quickly repaired. Finally, CMS systems can give cities the ability to adjust lighting levels as needed and achieve additional cost savings.

Metering and Fault Detection

The use of smart monitoring technologies would enable measuring actual electrical usage. Today, Bogotá is charged for its lighting based on a formula that assumes all public lighting is on for 12 hours a day. Real time metering would allow the city to monitor how much electricity is used, instead of relying on the formula.

Moreover, these monitoring tools provide real time detection and reporting of lighting failures. At the moment, in Bogotá, these failures must be reported by the auditory firm or by a citizen, which can require a long period of time. Real time detection would allow the city to avoid paying for broken lights that have not yet been reported, and eliminate the need to hire auditors to detect faults and failures. Glendale, Arizona has installed monitoring devices on its public lighting, leading to a 90% reduction in malfunctioning street lights and a reduction in system wide outages from 20% to 3%.

Dimming Options: Timers vs. Sensors

The dimming control offered by a central monitoring system can be performed by using either sensors to detect external conditions or by using timers to control lighting based on time of day. Sensors allow more precise adaptation to external changes, but add complexity to the system. Timers have been employed successfully with central monitoring systems to dim lights during twilight and late at night. While LEDs work well when dimmed to partial light, ballasts that allow the LEDs to be dimmed have a higher cost than standard ballasts.

Currently, the street lights in Bogotá are operated at full output for 12 hours/day and use photocells to determine when the lights need to be turned on or off. Connecting street lights with a network monitoring and control system can offer more precise control of on/off schedules and detection of street lights that are operating at unnecessary times.

Street lights can be dimmed using timers to preset and sensors to adjust luminosity levels according to changes in the environment, and both can potentially lead to significant energy savings. With street lights connected to the control system, timers can be used to schedule the fixtures to dim or switch on/off at an exact time. This avoids energy to be wasted when street lights are not needed. A number of cities are piloting systems using motion sensors to allow street lights to be triggered to full luminosity when vehicle or pedestrian traffic is detected. Motion sensors offer energy savings by dimming lights, while automatically providing full lighting when needed. *Figure LT4* below describes this system.

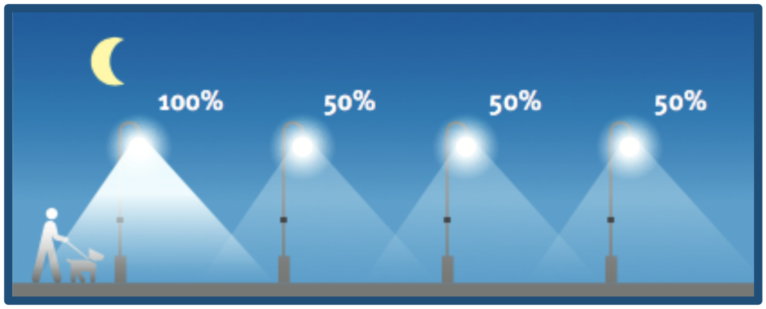

Figure LT4: Brightness Level Adjusted According to Motions Detected[34]

With these two features, two dimming strategies would be possible. With dusk/dawn dimming, brightness level could be raised when natural lights become insufficient, dimming lights in areas that are over lighted. With this strategy, the system can help save energy by taking advantage of the natural light levels during twilight, so that street lights only supplement what is needed for people to see clearly during partial light periods. Another dimming strategy is late night dimming when vehicular and pedestrian traffic is very low. Determining where late night dimming is appropriate requires some significant analysis of traffic and use patterns by a city, and developing criteria to determine areas that can be dimmed.

Some cities are concerned that dimming lights will negatively impact safety or the perception of safety. However, a study conducted by the San Francisco Public Utilities Commission found that the perception of safety in an area does not change when the street lights are dimmed. A similar study conducted in England and Wales found that the impact of street light reductions at night were minimal, as many respondents did not even notice street lights had been. Another study found that there is no strong relationship between the dimming of street lights and crime rates. A final study also shows similar findings and found weak evidence of harmful effects of street light reduction at night.[35]

Despite studies showing that there was weak evidence for the association between crime and reduced street lighting, the relationship between perceived safety and better lighting is strong.[36] Two separate experiments found that the perception of safety increases when there is light in the surrounding area. Therefore, when it comes to installing intelligent street light control systems, it is important to ensure that the system can adapt to pedestrians by lighting up the part of the street that is sufficient for road users to feel safe.

One way to address this concern is to utilize motion sensors on street lights. However, this technology is relatively slow to develop. Small scale trials in San Francisco indicated that the solutions provided by the three companies participating were not ready for full scale deployment. The city of Oslo, Norway also attempted to include motion sensors into their control system in 2011, but removed them due to difficulties in making the sensors function correctly.[37]

Component Considerations

There are some technical considerations regarding the choice of components for the system. In order for the central monitoring system to match specific nodes on each individual light upon activation, the control system needs to be 'pre-commissioned' or have the location and ID code of each fixture recorded during installation. Using nodes with GPS chips embedded saves a significant amount of time and effort during set up and commissioning, while preventing the mismatch of fixtures as a result of installer errors.[38]

Control products that offer the standard National Electrical Manufacturers Association (NEMA) twist-lock receptacle allow for a simpler installation process, as no additional wiring is necessary. However, it is important to note that a standard NEMA twist-lock installation is not sufficient to allow dimming. A better option might be the new 7-pin twist-lock receptacle standardized as of February 2014, which allows the control nodes to be directly connected to the dimming devices. This new standard has been adopted by manufacturers in countries around the world, including those in South America. In the case of gateway failure and communication loss, each node controller should have enough memory to store program and energy data.

Network monitoring and control system for street lighting typically consists of three major components: node controller, gateway and central management server (CMSe). Each node monitors and controls an individual light and is typically connected directly to that light. Gateways facilitate the wireless communications between the nodes and the CMSe. The CMSe stores data for analysis and allows the manager to operate the system. Transmission range between different nodes, and nodes-and-gateways, varies from 60 cm to three km depending on the surrounding environment and products used.

As show in *Figure LT5*, network of nodes and gateways can be configured in three different ways: point-to-point, star and mesh network.

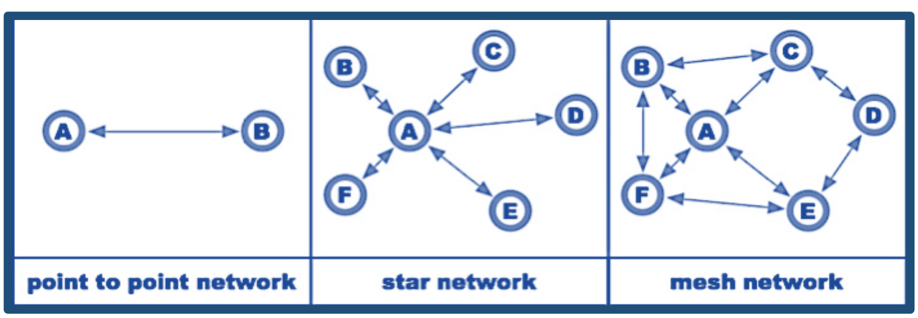

Figure LT5: Typical Network Configuration[39]

For the standard point-to-point network, each node communicates with one another. This type of configuration is often used for simple remote monitoring application and might not be suitable for large scale implementation.

In a star network, a single node serves as the central communication hub for all nodes. This type of configuration allows centralized management and is easy to set up. However, this system is highly dependent on the functioning of the central hub, and total network size is limited by the number of connections that can be made to the central hub.

In the mesh network, each node is connected with one or more nearby nodes and does not require a central point of control. Advantages include scalability and self-healing, as when one node goes down, it does not bring the entire network down. However, these systems can be complex to set up and require more power to operate, as each node has to act as both an endpoint and router. This is the most common configuration for large scale lighting projects, as design is typically more robust and less susceptible to communications breakdowns.

Renewable Energy Systems for Public Lighting

Renewable energy sources were investigated as they have low environmental impact and low operating expenses. The city of Bogotá has shown interest in using renewables as a backup electricity source for street lights. Solar and wind energy were the focus of the research.

It has been determined that the upfront costs for implementing individual solar modules on public lighting fixtures tend to be high. However, solar power is a technically feasible option for Bogotá. Moreover, when equipped with a battery system, solar energy can power public lights at night and during periods when the grid is vulnerable to outages. Wind technology is unfeasible, as the climate in Bogotá does not provide enough wind speed to produce power.

Solar:

Key Takeaway

- Bogotá's geographical position and climate make the city a good candidate for solar power. However, upfront costs may be prohibitive.

Research was conducted to determine the viability of solar energy as a renewable power source for the city of Bogotá to use in the retrofitting of public lighting. Solar resource availability in Bogotá was then compared to Rio de Janeiro, Brazil and Santiago, Chile for benchmarking purposes, as these cities have implemented solar public lighting and have relatively similar Hours of Standard Sunlight (HSS) - the amount of solar energy that strikes a square meter of land in a single day.

The photovoltaic potential throughout Colombia averages 4-5 kW per square meter. The northern area has the highest potential in the country with 5.5 to 6 kW per square meter. In Bogotá, the average HSS per annum is 4.31, and the photovoltaic potential average per annum is 4-4.5 kW/m^2.[40]

LED and solar technology share many technical characteristics. This makes the two technologies an ideal combination. LED bulbs operate under low voltage, low heat and low power requirement.[41] A solar panel also utilizes low voltage, between 12 or 24 volts direct current, which will produce around 200 watts of peak power in controlled conditions.[42] Solar power can be integrated with LEDs in public lightning in either grid connected or grid independent manner .

Grid Connected

Grid connected systems have a meter to measure the generated electricity. Without a meter, power generated cannot be fiscally accounted for. Jurisdiction needs to be configured with the utility, as literature reviews indicate stakeholders tend to be skeptical about the absence of control on electricity that is being put into the grid. Electricity generated by the solar panel during the day will be stored in a battery, providing back-up power when the primary source of power is not available.[43] Once the battery is fully charged, the excess energy is transferred to the grid.

There are three types of batteries: Lead Acid, Nickel-Cadmium and Lithium-Ion. If Bogotá opts for battery, it may choose Lead acid as it is the cheaper option, less hazardous and has the most mature technology.

When solar powered public lights are used in a grid connected configuration, they can provide a backup source of power when the grid is vulnerable. For instance, during events of El Nino, when hydropower is not available, as hydropower is the main power source for electricity in Bogotá, the solar and battery combination can maintain functional public lighting. The autonomy, or the time the battery system can supply power without being recharged, is typically approximately three days. The duration that the batteries can provide backup power depends on the amount of time the grid is unavailable, and the amount of sunlight available during that time to recharge them.

Rio de Janeiro, Brazil

4,360 grid-independent solar street lights were installed on the 73 km stretch of the Arco Metropolitano, a highway designed to connect the five main highways across the municipality of Rio de Janeiro. With a 150 Watt LED bulb and a 3-day autonomy attribute to the battery storage, it is expected to produce 2.8 GWh of PV annually. The objective of this infrastructure project was accelerating conventional cargo and passenger traffic. To increase the level of safety while driving at night, the regional government of Rio de Janeiro decided to fund the freestanding solar street lights. A benefit of the off-grid solar lights identified by the local government was to avoid overburdening the local electric grid.

The solar resource condition in Rio De Janeiro is better than Bogotá. Rio De Janeiro has a 6.09 average hours of standard sunlight and 5.18 kWh/m^2 of solar potential, while Bogotá only has 4.31 hours of standard sunlight and 4-4.5 kWh/m^2 of solar potential.

The project was funded by local authorities and managed by Kyocera Solar in partnerships with Philips Lighting, using the Philips GreenVision Xceed Solar light. fixture.

Grid Independent

Under this system, the street lights are completely isolated from the grid and are self-sustaining, as the generated photovoltaic power is stored in a battery. A majority of cases show that grid independent solar street lights tend to be installed where there is no grid connection.[44] In areas where there is not an established grid or connectivity to a grid, standalone solar public lighting fixtures may be a good option. Standalone solar lights avoid costs associated with connecting to the grid, such as trenching and cabling. Therefore, grid independent solar light might be an attractive option in areas that are far from the grid and would require significant expenditure to extend the grid, or areas where the ground conditions would make trenching costly.

Santiago, Chile

Thirty grid independent solar public lights were installed in Juan Pablo Park, Chile. The solar resource condition in Santiago is better than Bogotá. Santiago has 6.44 hours of standard sunlight and 6.31 kWh/m^2 of solar potential in comparison to Bogotá. The project was commissioned by the Municipality of Las Condes - Santiago, with Emelta S.A. as the managing company. Installation in a public park at a similar scale can be a suitable piloting project for solar street lights in Bogotá.

Solar Costs

The upfront cost estimates of pole mounted solar panels and batteries range from $2,000 to $6,000 per pole.[45][46][47] The payback is between 56 and 166 years. Due to the high upfront costs and the extended payback period, solar public lighting is not recommended in areas where there are existing poles and ready access to the grid. The financial feasibility of solar powered public lights may be worth investigating in areas far from the existing grid, or where the local conditions would make the cost of trenching particularly high.

Scenario	Upfront Costs per Light (USD)	Avoided Energy Costs per Light (USD)	Simple Payback (years)
Low Estimate	$2,000.00	$36.00	56
High Estimate	$6,000.00	$36.00	166

Table LT1: Solar Street Light Payback Periods

Wind:

Key Takeaways

- Wind powered public lighting is not a feasible option as Bogotá wind levels rarely reach minimum speeds necessary to power turbines.

There are two types of turbines that can be used in public lighting – horizontal and vertical. These turbines have different cut in speeds. The horizontal turbine works with high wind speeds with a cut in speed of 3.0 (to produce electricity) and cut out speed of 20 m/s. The horizontal type turbine can automatically be excluded as an option. The vertical turbine would also not be an effective technology to invest in, as Bogotá's wind speed is insufficient. A vertical wind turbine needs a cut in speed of 2.0-2.5 m/s on average to produce electricity. In Bogotá, the high average wind speed is 2.68 m/s, while the low average is 1.79 m/s.[48] As it is, Bogotá's wind resources do not match the necessary wind requirements to propel a wind turbine.

Hybrid Power:

> Key Takeaways
>
> - Hybrid systems take advantage of both wind and solar resources to provide power to public lighting. Bogotá does not have sufficient wind resources to make hybrid a viable option.

A hybrid power fixture is a combination of wind and solar technology. Hybrid street lights tend to have a higher upfront cost than their single source counterpart and they tend to be grid independent. The primary benefit of having two power sources instead of one is the higher degree of autonomy, i.e. the time in which the technology can provide electricity independent from the power source. Hybrid technology has been implemented in Malta, in Brazil in the mountainous area, but is not feasible in Bogotá because of the low wind speeds.[49]

Investment and Savings Analysis

LED Retrofitting:

> Key Takeaways
>
> - Although the specific characteristics of LEDs vary by manufacturer, they offer advantages in energy use, color rendering, and life span over HPS lights.
> - LEDs with lower brightness can replace HPS bulbs with higher brightness, because the light is directed specifically where it is needed.

The three common lighting technologies – high pressure sodium vapor (HPS), ceramic metal halide (CMH), and light emitting diodes (LED) – were compared against each other on aspects such as cost, energy efficiency, life expectancy and light quality.

The research indicated that LEDs would be the best choice in technology to replace the HPS bulbs that are currently in use. This is true for all replacements, with the exception of lights located in parks and monuments, which may benefit from the higher light quality of CMH bulbs despite their inferiority in long term cost and efficiency. In order to estimate the potential savings and costs of an LED retrofit, it was necessary to compare the characteristics of Bogotá's current streetlights against the equivalent LED technology. *Table LT2* includes a comparative analysis of the costs and main characteristics of each of the bulbs recommended for replacement.

Since specific brand and models of the current bulbs were not included in the lighting inventory, proxy values of the comparable characteristics for HPS lights were gathered through research on industry standards averaged from commercial distribution websites.[50] The comparable characteristics for LEDs were acquired through case study reviews and expert consultation.[51, 52, 53, 54, 55, 56] A list of prices and potential LED brands and models can be found in Appendix A.

	70 W HPS		150 W HPS		250 W HPS		400 W HPS	
	HPS	LED	HPS	LED	HPS	LED	HPS	LED
Power Usage (watts)	70	45	150	60	250	100	400	150
Ballast efficiency* (%)	86%	100%	79%	100%	83%	100%	84%	100%
Brightness (lumens)	6,300	4,500	16,000	6,000	29,000	9,000	50,000	13,500
Color Temperature (K)	2,000	5,700	2,000	5,700	2,000	5,700	2,000	5700
Color Rendition	22	80	22	80	22	80	22	80
Lamp Life (hrs)	24,000	50,000	24,000	50,000	24,000	50,000	24,000	50,000
Failure Rate	10%	0.12%	10%	0.12%	10%	0.12%	10%	0.12%
Lamp and Fixture Cost** (USD)	$5	$136	$6	$177	$7	$348	$8	$523
10 Year Life Cycle Costs (USD)	$431	$370	$1,000	$489	$1,580	$868	$2,506	$1,303
Total Lights in Inventory	194,806		66,955		34,767		13,608	

* Calculated from the Codensa monthly bill (Billed energy consumption/bulb wattage).
** HPS prices and specifications from Inter Eléctricas Bogotá, personal communication, December 2016..
LED prices and specifications from Urban Light Bogotá, personal communication, September 2016.

Table LT2: HPS to Equivalent LED Comparison Chart

When replacing a light, the intuitive approach would be to install an LED of equal brightness to the current HPS bulb. As brightness is measured in lumens, *Table LT2* shows the lumen value of an HPS light is higher than its LED equivalent. This is due to the fundamental difference in the fixtures that allow LED light to be better directed onto the desired surface and less light to be lost in unproductive directions Additionally, the white light that LEDs emit, with a higher color rendition index, allows for better night vision than the traditionally yellow light of HPS bulbs.[57] Consequently, an LED lamp is able to deliver the same amount of useful light despite having a lower total brightness.

The costs related to HPS lights considered in this analysis are based on industry research. However, the actual costs that the city incurs on the lighting infrastructure already in place might differ from these average costs. If the bulb replacement costs incurred by the city are higher than those considered here, the general recommendation remains valid, but the rate of return of the upgrade is greater. This is due to the higher operation costs avoided. When accounting for HPS prices that are one third of the LEDs, a rate of return of 39% and a simple payback of 2.5 years is obtained. If HPS costs were to be half of the LEDs, the retrofitting project would be paid back in 2.2 years with a rate of return of 44%. These alternative HPS cost scenarios can be found with greater detail in Appendix D.

Financial Optimization Model for Bulb Replacement:

Key Takeaways

- A financial model was developed to determine the ideal combination of bulbs of each wattage that should be replaced in order to obtain the greatest return for the least initial investment.
- Our recommended scenario requires an initial investment of USD 16.3 million that would be paid back over 3 years with annual savings of more than USD 5 million.

The Mayor of Bogotá stated the goal of modernizing the public lighting system by replacing 100,000 street lights with LEDs in parks, major street intersections and the historic district. The purpose of the financial optimization model is to provide the best combination of bulb types to upgrade 100,000 street lights to LEDs that could be legitimately argued as financially feasible. This section presents the replacement strategy that has the best return for the lowest possible initial investment. Using the characteristics and costs outlined in *Table LT2*, financial metrics were calculated for a single light of each bulb type. These metrics can be found in *Table LT3*.

	70 W HPS	150 W HPS	250 W HPS	400 W HPS
Simple Payback (years)	6.8	2.6	3.3	3.0
Annual Savings (USD)	20	69	106	172
Reduction in Energy Use	44%	68%	67%	69%
Internal Rate of Return (IRR)	8%	37%	28%	31%
Annual GHG Saved*** (tCO2e)	0.06	0.21	0.33	0.54

*** Calculated with emission factor from SIAME Colombia.[58]

Table LT3: HPS to LED financial comparison chart

As seen in *Table LT3*, the 70 W HPS bulb replacement has a significantly lower internal rate of return (IRR) than the other three bulb types. The highest return can be obtained when replacing HPS bulbs of 150 W. When replacing higher wattage bulbs, it is possible to obtain higher savings, but such bulbs also require higher initial investment.

The comparative costs and savings between HPS bulbs and their LED equivalent were fed into an Excel solver, with constraints on the level of initial investment and staying within the boundaries of the current inventory. Several iterations were run with progressively higher limits on initial investment while maximizing internal rate of return (IRR). The results are shown in *Figure LT6* and further detailed in *Table LT3*. Even though greater up front investments continue to produce additional financial savings, our analysis suggests that there is an opportunity for high return rate and low initial investment - this opportunity is labeled as Scenario B in *Figure LT6*.

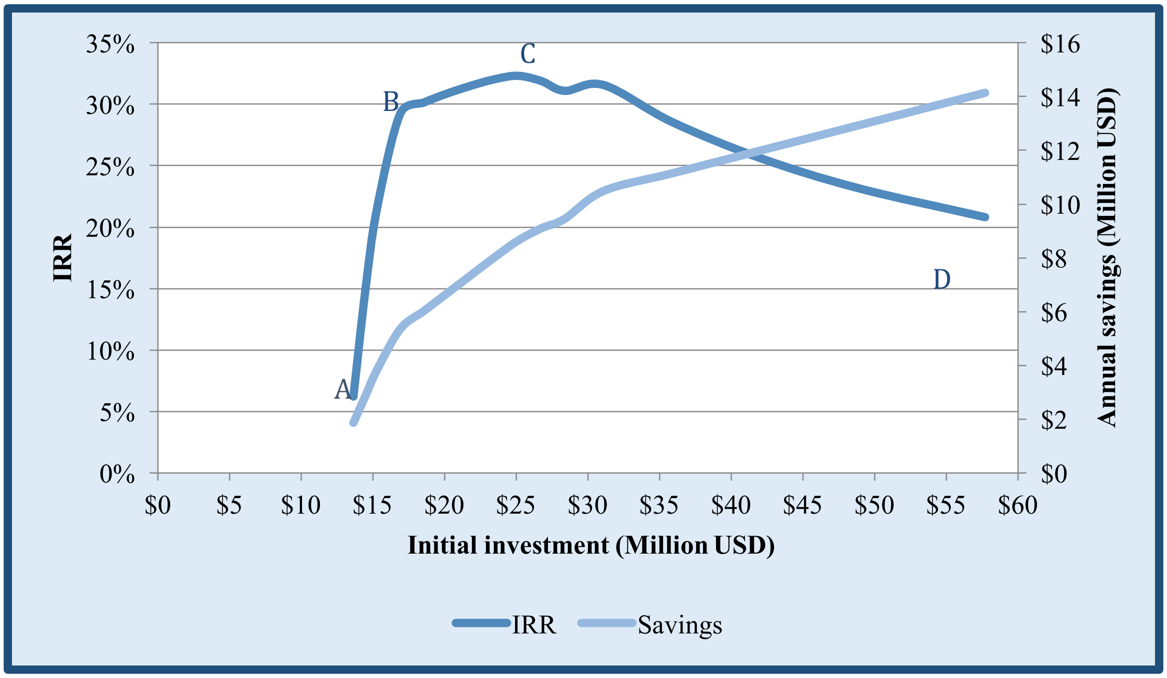

Figure LT6: Financial Optimization Model for Bulb Replacement

Scenario	Lights Replaced				Initial Investment (USD)	Annual Savings (USD)	Simple Payback (years)	IRR
	70W	150W	250W	400W				
A	100,000	0	0	0	$13,646,623	$1,997,539	6.8	8%
B	33,045	66,955	0	0	$16,385,218	$5,289,045	3.1	30%
C	0	66,955	19,437	13,608	$25,756,147	$9,041,969	2.8	33%
D	194,806	66,955	34,767	13,608	$57,676,918	$14,560,818	4	22%

Table LT4: Replacement Scenarios

In *Figure LT6* and *Table LT4*, Scenario A depicts the lowest possible initial investment when replacing 100,000 HPS lights, achieved by replacing only the lowest wattage lamps. Scenario D shows the initial investment required to replace all 340,000 lights with LED along with the annual savings and rate of return. Two additional points are of significant interest. Scenario C is where the IRR is at its system maximum. In order to achieve the greatest return on investment, the model suggest an investment of USD 25.7 million to replace all the HPS 150 W and 400 W bulbs and a little over half of the 250 W, but none of the 70 W HPS bulbs. To achieve the overall highest return, the model prioritizes the lights with the individual highest return.

Scenario B is notable because it corresponds to the highest ratio of IRR to initial investment. If low initial investment and high return are priorities, then point B is the optimal investment strategy for bulb replacement. Scenario B requires less than USD 4 million in additional upfront investment than the lowest possible initial investment, but provides a 23% higher IRR due to greater energy savings. In order to gain the additional 3% and achieve the highest possible IRR, it would cost an extra USD 9 million in initial investment. This scenario calls to replace all of the 150 W bulbs, which have the highest individual IRR, and the rest of the 70 W bulbs, which require the lowest initial investment. Based on our understanding of the City's needs, we recommend that they follow this strategy to obtain a high return with a low upfront investment.

Savings Opportunities through Remote Monitoring:

Key Takeaways

- Remote monitoring systems include metering for each light, and presents an opportunity to reduce public lighting costs through billing for energy actually consumed, rather than using an equation that may not reflect the actual energy use.
- Remote monitoring systems combined with LEDs can be used to dim lights during certain portions of the normal operating time to provide energy savings beyond those achieved with LEDs alone.

In order to understand the potential savings that could be achieved by a monitoring system, an additional model was built. The purpose of this model was to determine a reasonable expectation for what Bogotá could potentially save by using a central monitoring system (CMS). The base case for the model was a replacement of 100,000 HPS bulbs with LEDs. The bulbs that were assumed to be replaced in all of the monitoring system savings and payback models were the same combination recommended and described as Scenario B in *Table LT4*, which clarifies the specific bulb size and number and reiterated in *Table LT5* for clarity.

Two distinct opportunities for savings provided by installation of a remote monitoring system were analyzed. The first savings opportunity is based on the more accurate billing that is made possible by the metering capability of a CMS. The second opportunity comes from the energy savings that can be achieved by dimming lights during certain portions of the normal operating hours. Monitoring systems add additional cost to a public lighting upgrade project from the monitoring system itself, as well as from the added cost of purchasing luminaires with ballasts that allow diming of the LEDs. The additional cost of the dimming and monitoring components were compared to the expected savings in order to determine the payback period for a CMS on its own, and when considered as an integrated part of a public lighting LED replacement.

Baseline					
LED Lamp Size (watts)	45	60	100	150	Total
Number of Lamps Replaced	33,045	66,955	0	0	100,000
kW of Lights Replaced	1,487	4,017	0	0	5,504
Time in Operation (hrs/ day)	-	-	-	-	12
Annual kWh Used	-	-	-	-	24,108,944
Annual Energy Costs (USD)	-	-	-	-	$2,893,073

Table LT5: Baseline of the Savings Model

Billing Accuracy

Savings were modelled first for the improved billing accuracy that could be achieved by monitoring of the lights, because this would be possible without the increased cost of dimmable LEDs.

Billing accuracy includes two categories of savings. Because the current billing agreement charges for 12 hours of energy use per day, regardless of whether the light is functional or not, the first opportunity concerns savings from being charged only for lights that are functioning. The second is savings for charges only when lights are actually on, rather than the 12 hours currently charged as a result of the lack of metering. To determine the hours that lights are actually on, it was assumed that lights come on immediately following civil twilight. The average lighting period for the year was determined to be 11.16 hours.[59, 60]

The results of savings from billing accuracy are shown in *Table LT6*. If billed only for hours that the lights are actually in use, Bogotá would save an estimated 7% as compared to the 12 hours per day that is currently charged.

At present, Bogotá pays for electricity consumed by broken and non-functional street lights. If the lights were metered, the city could pay for lights that were in actual operation.[61] Due to their low failure rate, the number of LEDs expected to be out of operation at any time is not likely to result in significant savings. LEDs used in municipal public lighting have been observed to have annual failure rates between 1% and .2%.[62,63] For this analysis an annual failure rate of .2% was assumed. Even if failed lights remained out for a month before being repaired, only .02% of lights would be expected to be out at any time, leading to energy savings of only USD 596 per year.

Billing Accuracy Assumptions and Inputs			
Actual Hours of Light Operation			11.16
Hours of Operation Reduced			0.84
Percent of Lights Not in Operation Due to Failure			.02%
Savings From Billing Accuracy			
	Annual Savings (kwh)	Annual Savings (USD)	% Cost Reduction
Time of Lighting	1,652,025	$198,243	7%
Lights Out of Service	N/A	$579	.02%
Accuracy Total	1,692,110	$203,053	7.02%

Table LT6: Savings from billing accuracy

Twilight and Late Night Dimming

For dawn/dusk dimming, in this savings model it was assumed that all 100,000 lights were equipped with dimming capability and that each light was dimmed to 50% of its full light during nautical twilight.[6465] Dawn/dusk dimming could be expected to reduce the amount of time public lights are in operation by approximately 4% per year.

In many cities, a portion of the public lights are dimmed significantly during the late hours of the night where pedestrian and vehicular traffic are significantly below normal levels. In one example, followed in this analysis, public lights are dimmed by 60% between the hours of 11pm and 5am.[66] Dimming lights is not appropriate for all public lighting areas. A city intending to employ a late night dimming strategy should make an investigation into which areas of the city are appropriate for late night dimming of public lighting, and may need to adjust the selected areas based on public feedback or changes in the ways in which inhabitants utilize areas of the city.[67]

Because of the potential variability in the number of areas that would be considered appropriate for a late night dimming strategy, two different tests were performed to determine the sensitivity to the percentage of lights that could be dimmed. Scenario A assumed that 20% of the public lighting could be dimmed, and scenario B assumed that 50% of lights could be dimmed. With only 20% of the lights dimmed between the hours of 11pm and 5am, energy consumption and the associated cost is estimated to be reduced by 6%. With 50% of the lights dimmed during the same time period, the annual savings increases to 16%. The total savings from dimming varies from 10% to 20% depending on the number of lights dimmed. The results of savings from dimming are shown in *Table LT7* below.

Assumptions and Inputs for Dimming		
	Dimming Scenario A	Dimming Scenario B
% Lights Dimmed at Twilight	100%	100%
% Lumen Reduction for Twilight Dimming	50%	50%
% Lights Dimmed Late Night	20%	50%
Lumens Reduced by (%)	60%	60%
Dimming Starts	11pm	11pm
Dimming Ends	5am	5am

Savings From Dimming				
	Dimming Scenario A		Dimming Scenario B	
	Annual Savings (USD)	% Cost Reduction	Annual Savings (USD)	% Cost Reduction
Twilight	111,378	4%	$114,767	4%
Late Night	185,149	6%	$476,955	16%
Dimming Total	296,527	10%	591,722	20%

Table LT7: Savings for Dimming

Payback Scenarios:

Key Takeaways

- Monitoring and control systems add 20% to 50% to the cost of a public lighting upgrade.
- A ballast that allows dimming adds an additional 20% to the cost of a luminaire.
- The energy savings offered by monitoring systems are not significant enough to make them an attractive investment, based on financial considerations alone.

Additional Costs

The monitoring system includes two additional costs over the base price of LED street lights. One is the cost of the monitoring system, the other is the cost of dimmable LED ballasts.[68] The research conducted found different estimates of costs for monitoring systems. General Electric estimated a monitoring system would add 50% to the cost of an LED street light replacement.[69] A Silver Spring white paper estimated the additional cost at 20%.[70] The estimate for the additional cost of a dimmable ballast is 20% of the LED cost.[71] To determine simple payback period, a 20% premium was added to the cost of the LEDs for dimmable ballasts, using both 20% and 50% for the added cost of the monitoring system.

Payback Scenario 1: Only Monitoring, No Dimming

In a scenario with only monitoring, the only savings for the system are from the accuracy of billing based on metering. The upfront cost includes only the monitoring system, not the higher cost for dimmable ballasts.

Payback for Monitoring Only			
Cost of LED Replacement Only (USD)			$16.4M
Additional Cost of Monitoring System (%)			50%
Additional Cost of Monitoring (USD)			$8.2M
Total Project Cost			$24.6
Savings for Monitoring Only			
	Annual Savings (USD)	% Cost Reduction	Simple Payback (years)
Time of Lighting	$202,475	7%	40.5
Lights Out of Service	$579	0%	14,159.0
Accuracy Total	$203,053	7%	40.4

Table LT8: Payback for Monitoring Only and 50% Monitoring Premium

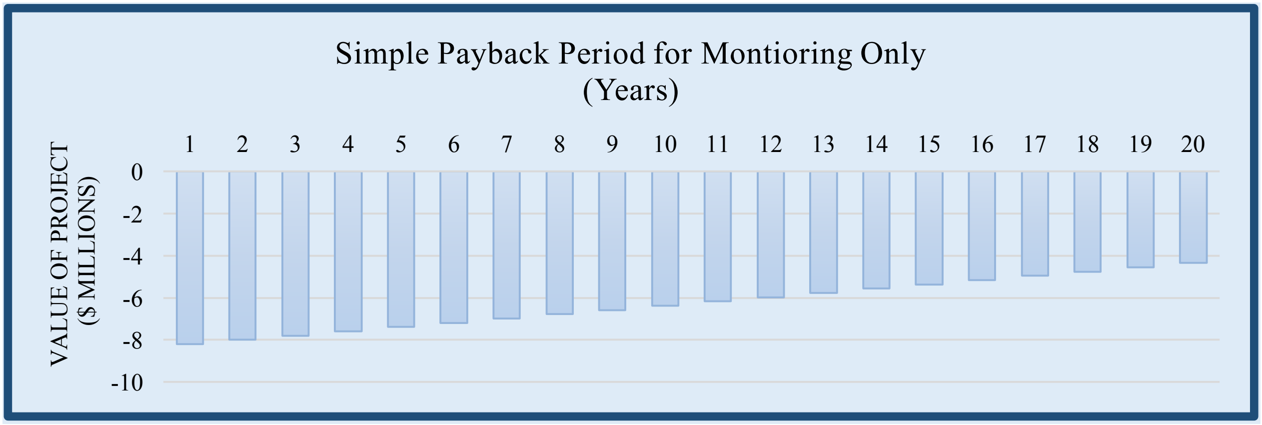

Figure LT7: Simple Payback Period for Monitoring Only

Monitoring alone, with the intent of reducing costs through more accurate billing, does not present an attractive payback period. The low failure rate of LEDs makes any avoided charges from lights that are out of service negligible. The only notable savings are achieved by operating lights for only 11.16 hours per day, instead of the 12 hours per day currently being billed for.

The total payback offered by monitoring only, without the dimming component, is 40 years. A 40-year payback is longer than what should be considered viable for a project. One source did provide a more favorable estimate of a 20% additional cost to the LED project for monitoring. Under these more favorable conditions, the payback would be unviable at over 16 years.

Payback Scenario 2: Monitoring and Dimming

Dimming along with monitoring will add more cost to the system, but will also allow the city to have control over the brightness of lights and will give the opportunity to achieve more savings.

Two scenarios were run to estimate the range of paybacks that could be expected for the monitoring and dimming. One "best case scenario" with a 20% premium on the cost of the monitoring system and the ability to dim 50% of the lights during the late night hours. In this scenario, the addition of the monitoring and dimming system has a simple payback of about 8.5 years. A "worst case scenario" was also tested to determine the payback where it was assumed that the additional cost of including monitoring added 50% to the cost of the LED retrofit and only 20% of the public lighting could be dimmed between 11pm and 5am. In this scenario, the simple payback period of the monitoring system becomes 23 years.

There is significant variation in the possible payback periods of a CMS. Even if using the most favorable of the inputs for cost and energy saving opportunity that were identified during research, a payback of nearly 8.5 years is longer than what should be considered a viable project. Monitoring system payback is significantly longer than that of the LED replacement alone and does not improve the economics of the project. Other factors, such as remote notification and the ability to quickly address failed lights, may make the remote monitoring system attractive for non-financial reasons.

Assumptions and Inputs for "Best Case Scenario"			
Cost of LED Replacement Only (USD)			$16.4M
Additional Cost of Monitoring System (%)			20%
Additional Cost of Dimmable Ballasts (%)			20%
Additional Project Cost for Dimming and Monitoring (USD)			$6.6M
Total Project Cost (USD)			$22.9M
% Lights Dimmed Late Night			50%
Payback for "Best Case Scenario"			
	Annual Savings (USD)	% Cost Reduction	Simple Payback (years)
Billing Accuracy Total	$203,053	7%	32.28
Dimming Total	$574,250	20%	11.41
Energy Total	$777,303	27%	8.43

Table LT9: Payback for Best Case Scenario

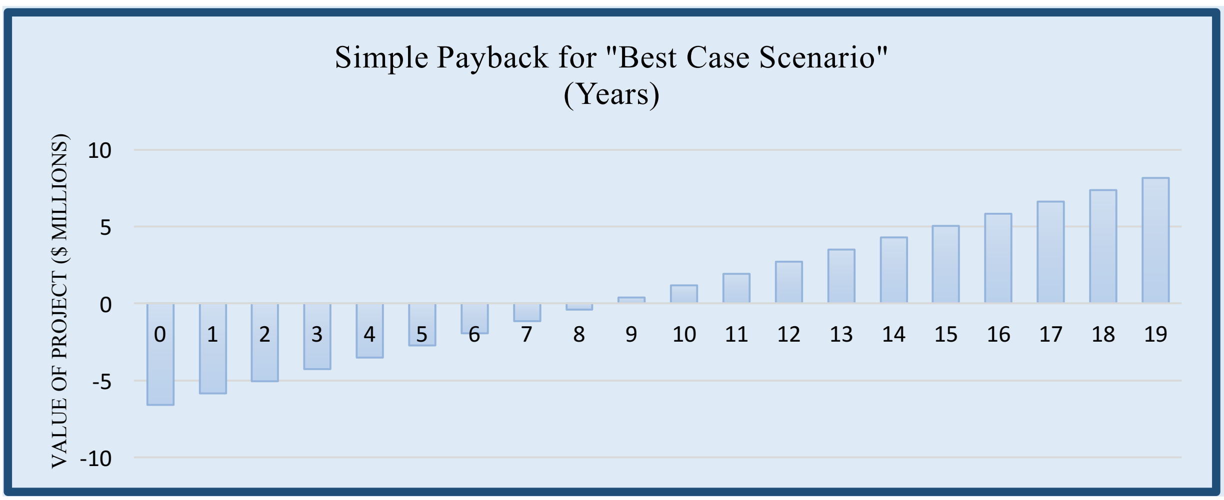

Figure LT8: Simple Payback for "Best Case Scenario"

Assumptions and Inputs for "Worst Case Scenario"			
Cost of LED Replacement Only (USD)			$16.4M
Additional Cost of Monitoring System (%)			50%
Additional Cost of Dimmable Ballasts (%)			20%
Additional Project Cost for Dimming and Monitoring (USD)			$6.6M
Total Project Cost (USD)			$22.9M
% Lights Dimmed Late Night			20%
Payback for Worst Case Scenario			
	Annual Savings (USD)	% Cost Reduction	Simple Payback (years)
Billing Accuracy Total	$203,053	7%	32.28
Dimming Total	$296,527	10%	38.68
Energy Total	$499,580	17%	22.96

Table LT10: Payback for Worst Case Scenario

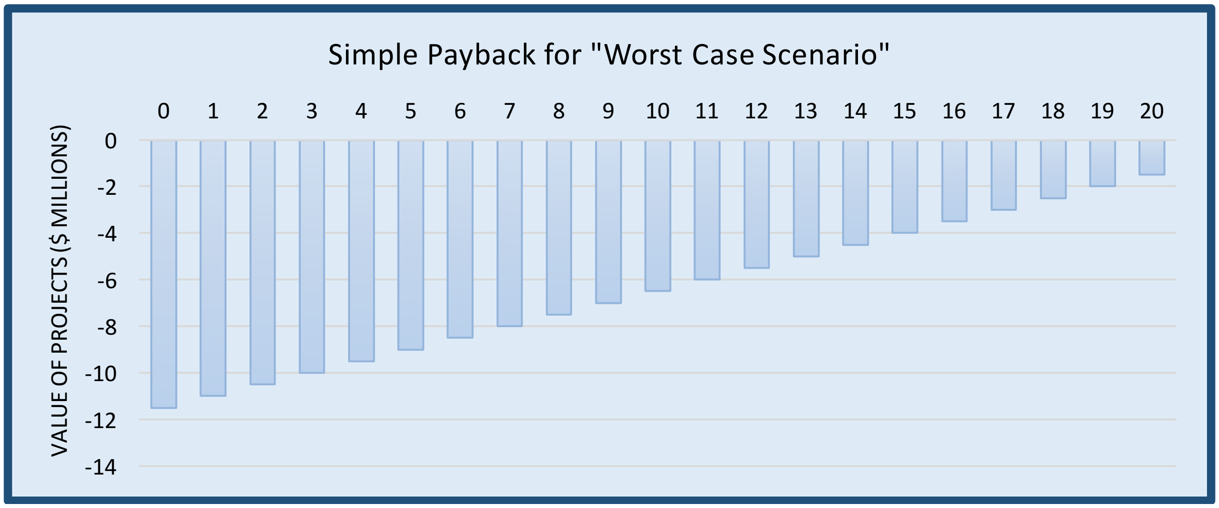

Figure LT9: Simple Payback for "Worst Case Scenario"

Integrated Payback Scenario:

Key Takeaways

- A CMS can add an additional 8% to 12% in energy savings to the recommended LED replacement project.
- The monitoring system will not improve the payback period of an LED replacement that does not include a monitoring system.
- When included as part of the large scale LED replacement project, the CMS adds between 8 to 20 months to the LED project.

The best case and worst case scenarios were also tested within the context of the full LED replacement to determine the overall impact on the payback of the combined LED and monitoring system replacement project. Within the context of the entire LED replacement project, monitoring and control adds between 8% and 12% energy savings to the replacement of LEDs alone. The variation between the best case and worst case monitoring scenarios is only 4% of the total energy savings of a combined LED and CMS project. The initial capital investment required by the addition of a CMS adds between .68 and 1.71 years to the payback period of an LED project. The variation between the best and worst case scenarios is approximately one year. The payback under the least favorable conditions is still less than 5 years and may be considered a viable project, but the IRR could be reduced by as much as 16%.

The total cost of replacing 100,000 lights with LEDs using the high IRR and low initial investment scenario is estimated to be USD 16.4 million. Adding a remote monitoring system would increase the cost of the combined project to between USD 23 million and 27 million. The additional energy savings possible by including the monitoring system will not offset the additional cost enough to make the monitoring system financially attractive. However, the impact is low enough that if there are non-financial factors that make the replacement attractive to the city, the combined LED and centralized monitoring project could still be justified.

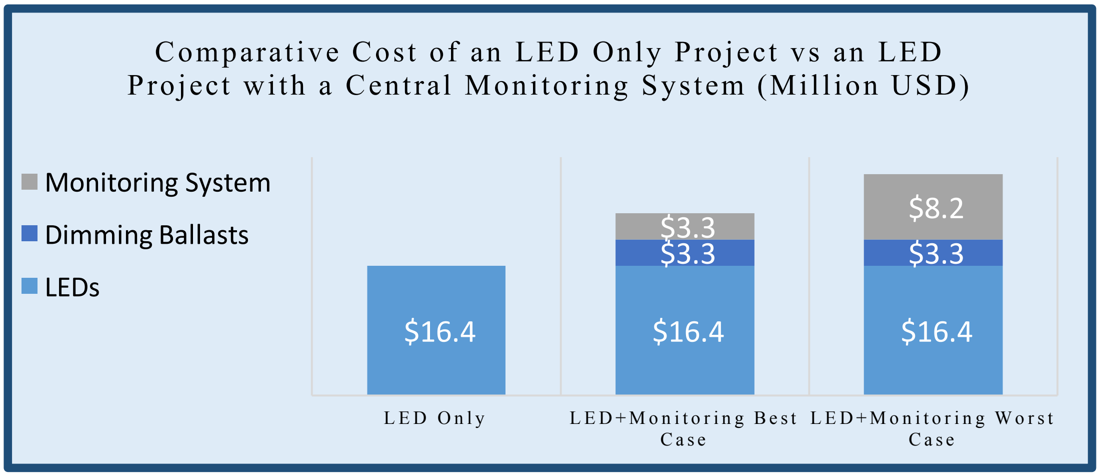

Figure LT10: Comparative Cost of an LED Only Project with a Central Monitoring System

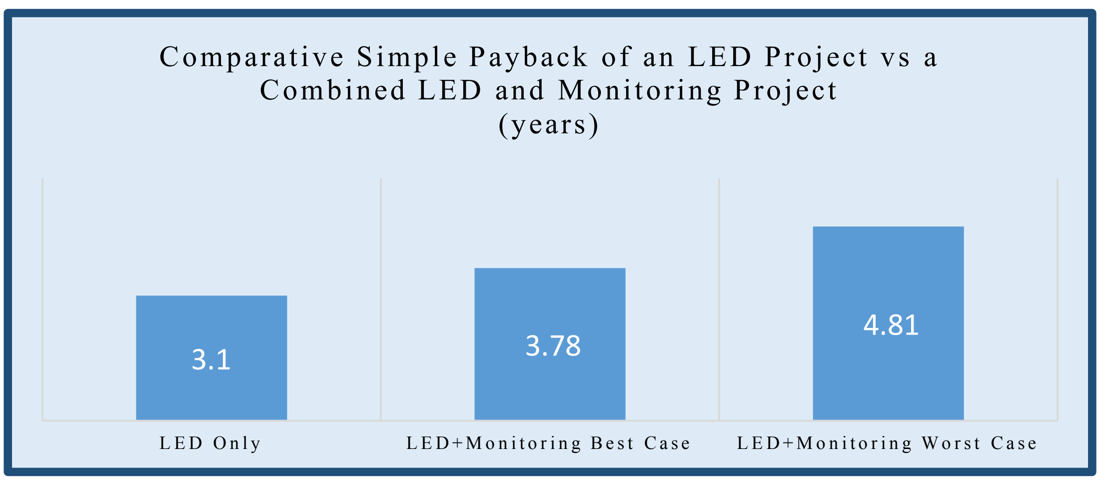

Figure LT11: Payback for Worst Case Scenario

Social and Environmental Considerations:

Key Takeaways

- Energy efficient public lighting will help reduce the city's carbon footprint.
- LEDs have been shown to correlate with lower crime rates. Although causation has not been proven, it may be related to increased civic pride and not specific deterrent effects caused by improved lighting.
- White light, such as light provided by LEDs, has been found to have a positive effect on perception of safety.
- Adequate street lighting has been shown to reduce traffic accidents.
- Some studies have shown that blue light may have negative impacts on health. LEDs can be designed to produce light colors across the spectrum, and consideration should be given to utilizing LEDs with warmer light.

In addition to the financial benefits already mentioned, improved lighting technologies have various non-financial benefits. Namely, environmental benefits and social benefits, such as reduced GHG emissions, reduced crime rates, improved perception of safety, and reduced traffic accidents.

Environmental Benefits

By changing their current HPS bulbs to more energy efficient LED bulbs, the city can reduce its carbon footprint. LED lights consume less energy than traditional HPS lights and thus lower the emissions associated with energy generation. As shown in *Figure LT12*, changing 100,000 lights can reduce the greenhouse gas (GHG) emissions between 5,800 to almost 30,000 tons of CO_2 equivalent. Scenarios A, B, C, and D are outlined in the following graph. Scenario B, as per our recommendation, will decrease the city's carbon footprint by 16,207 tons of CO_2 equivalent each year. As evident in the *Figure LT12*, there is a positive correlation between initial investment and GHG emissions reduction. Replacing higher wattage bulbs is more expensive, but has greater energy savings, and this translates into less GHG emitted.

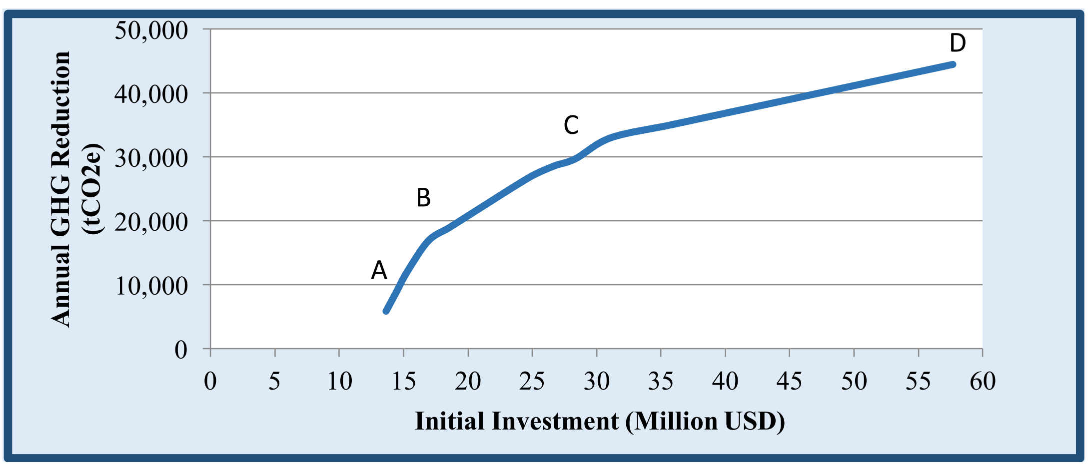

Figure LT12: Annual Greenhouse Gas Reductions at Different Levels of Investment

The addition of a monitoring system will reduce the GHG emissions related to Bogotá's street lighting by an additional 1,050 tons to 2,030 tons of CO_2 equivalent per year.

Crime

Many studies have attempted to draw a relationship between improved lighting and crime reduction. While they have seen mixed results, the studies reviewed and discussed below conclude that improved lighting does help reduce crime rates.

In a study conducted by the Campbell Collaboration where 13 street lighting evaluations were analyzed, the authors conclude that improved lighting does lower crime rates. However, crime rates decreased by an equal level during both nighttime and daytime.[72] This led them to believe that the reduction is due to the increased community pride and confidence caused by the visible investment in the community, rather than the deterrent effects or the increased surveillance. In the City of Los Angeles, the Bureau of Street Lighting reports that following an LED retrofit project of 140,000 street lights, they saw a 13% reduction in vehicle theft, an 8% reduction in burglary, robbery, and theft, and an 11% reduction in vandalism.[73] In the City of Chicago, a study linked street light outages in whole blocks with a 7% increase in crime compared to the periods immediately prior and after the outages.[74]

Perceived Safety

The implementation of LED and CMH technologies in Bogotá will generate improvements in the perception of public safety in Bogotá, thereby creating opportunities for increased economic activity and use of public space.

These tangible benefits may be categorized in two segments: LEDs may be used to increase average illuminance on the ground, and the quality of light emissions at the street level may also increase. The resulting gains in public well-being derived from these two factors do not require an increase in energy consumption. Results from a related study show positive correlation between public perception of safety and the average illuminance on the ground. White light was determined to have more impact on safety perception relative to yellow sodium.[75] White light, consistent with LED and CMH technologies, also contributes to the perception of public safety because it provides relative ease of facial recognition at a distance. This factor is determined to mitigate or avoid accidents.[76]

Road and Traffic

Street lights are traditionally installed as a form of traffic infrastructure. Many studies have investigated the connection between roadway safety and street lighting.[77] General consensus concludes that an increase in lighting leads to a safety increase on the road. Research has suggested that, although the overall risk is higher during inclement weather, the risk of an accident on an unlit road is nearly four times greater than a lit road. The greatest risk on roadways is directed towards pedestrians. However, street lighting reduces the chances of a pedestrian accident by approximately two and a half times.[78]

Although the scientific consensus is that street lighting increases traffic safety, some studies also argue that increased lighting increases drivers' average speed and decreases concentration. This is due to an increase in perceived safety. Despite this, the risk aversion when comparing lit streets versus unlit streets outweighs the negative effects of a driver's increase in perceived safety.[79] A study from the International Association of Traffic and Safety Sciences found that there was a 19% drop in night crashes for each 0.5 footcandle/m^2 (which measures brightness at ground level) increase in average luminance.[80]

Potential Health Effects

Despite the energy efficiency benefits, there are studies and publications suggesting that some LED lights have adverse health effects when used as street lighting, particularly at night.[81] There have been concerns about the impact of LEDs on the sleep rhythm, due to its blue light nature[82]. LEDs are more "blue" than HPS, though LEDs can be configured to produce a warmer light.

This has led to concerns from the American Medical Association (AMA), which suggests a few considerations to mitigate this impact.[83] It also encourages proper attention to optimal design and engineering features when converting to LED lighting in order to minimize detrimental health and environmental effects.[84] The guidelines recommend proper shielded outdoor lighting, adaptive controls that can dim and turn lights off at night, and limit the Correlated Color Temperature (CCT) to less than 3000K. Correlated color temperature predicts the spectral content of light,[85] and LEDs with higher CCT will produce more blue light. The AMA findings also underscore the fact that harmful effects of blue-rich LED lighting affect not only humans but other species.

The AMA findings and recommendations have been met with some disagreement. The Illuminating Engineering Society and the National Electrical Manufacturers Association stated that the guidelines misinformed the public. They indicate that the use of CCT of below 3000K will compromise the lighting industry ability to meet critical design for each application.[86]

Case Studies of Successful Implementation

Key Takeaways

- Sonsonate, El Salvador is an example of an LED and monitoring public lighting project completed through partnership with a local utility.
- Los Angeles, California's project magnitude is a demonstration of economies of scale and investment savings.

The collection of case studies in this section focuses on public lighting projects that involve installation of LED lights with monitoring and control system in four cities: Sonsonate, El Salvador; Buenos Aires, Argentina; Los Angeles, CA and Oslo, Norway. These studies describe how these cities have adopted monitoring and control systems, and the outcome of such adoption. The case studies have provided insights to the strategies Bogotá can follow in its LED project.

In general, the scale of the projects is similar to that of Bogotá, with tens of thousands of street lights being replaced with LED lighting and connected to the remote monitoring system. Los Angeles, California and Oslo, Norway were chosen as case studies because they have both successfully integrated a remote monitoring system and achieved significant savings.

Other Latin American cities that have launched similar projects include Bucaramanga, Colombia and Rio de Janeiro, Brazil. Bucaramanga launched a renovation plan and set the goal of converting at least 40% of the lighting into LED with a remote management system by the end of 2016. More than 900 Teceo lights were fitted with the Owlet Nightshift system installed on the most important avenues linking the North and South of the city.[87] The luminaires are dimmed to 50% for 7 hours of an average 12-hour night, when less light is needed. Rio de Janeiro is considering a public-private partnership with Rioluz, a city-owned company in charge of street lighting. Rioluz is developing a plan for installation and maintenance of 60,000 fixtures out of the 420,000 total points in the city.[88]

Sonsonate, El Salvador:

The city of Sonsonate in El Salvador is the first Latin American city to adopt a remote management public lighting system. It is a conjoint project by AES El Salvador, UNITAPE LATINOAMERICA and General Electric to install 4,000 LED lights with a GE LightTouch remote monitoring system.[89]

AES is an international energy company and distributes nearly 80% of electricity to citizens in Colombia. They have four distribution companies and one of the subsidiaries AES CLESA was awarded the USD 4,403,785 contract by the municipality of Sonsonate for the supply and installation of LED lights to be used in park lighting and at the Ana Mercedes Campos Municipal Stadium.

The contract work includes the lighting design, electrical design, fixtures and accessories, indoor and outdoor lighting, emergency lighting, signage and lighting of hazardous areas, and mobile projectors.[90] Research uncovered some of the more detailed information of the work involving UNITAPE. UNITAPE suggested, when replacing a bulb for an LED, to replace the entire fixture and not just the bulb. UNITAPE also estimates that a remote management system can generate between 10% to 50% more savings, depending on local laws and how the energy consumption is charged to the municipality.[91] An important piece of information to consider from this case study is the funding method of such projects, which relies on the electric savings receipt of the city.

Buenos Aires, Argentina:

Buenos Aires partnered with Philips and converted more than 70% of the city's street lights to LED lighting and adopted the CityTouch lighting management system.[92] The renewed street lighting system provides the possibility to switch off or dim lighting levels, depending on specific requirements, thus reducing energy consumption. The installation process was completed in three phases over the course of three years. A total of more than 90,000 new light points were installed, which is 75% of the lightings in the city. The city is expected to save over 50% of its energy consumption and operational costs after the renewal process.

Los Angeles, CA:

Los Angeles has launched a major public project to retrofit the city's street lighting with LED fixtures and implement a remote monitoring system. It's a collaboration between the LA Bureau of Street Lighting, the LA Mayor's Office, the Department of Water and Power, and the Clinton Climate Initiative Cities Program.[93]

Image LT2: Los Angeles Street Lights Before and After LED Replacement[229]

It is the largest LED street lighting retrofit ever undertaken and the energy cost savings are surpassing original projections. The installation of 51,035 LEDs in the first two years of the project has produced energy savings of 59 percent in the retrofitted fixtures, yielding annual energy savings of 21,241 MWh and annual cost savings of USD 1.8 million. Feedback from the community, including residents, politicians, and law enforcement officials, have also been positive.[94]

Oslo, Norway:

Oslo connected the city's street lighting into a single, remotely accessible network that allows monitoring and control of street lighting levels through an internet-based application. Like Bogotá, Oslo's street lights were controlled by the local utility and Oslo did not pay for usage.

The smart street light system began operation in 2011. It involves more than 65,000 street lights connected to 650 processing stations. The processing stations connects to the central management system via General Packet Radio Service (GPRS) modems. Each processing station controls five to thirty street lights via hard-wire connections and collects data from each individual fixture. With this system, the city is able to control the lights either manually or remotely using internet-based interfaces.

The biggest benefits from the new system have been adding lighting control and system feedback capability, both of which have contributed to cost reductions. The city is now saving approximately USD 1.3 million annually on electricity costs.[95] This is reported by the city, but it is important to note that lights were not previously metered. Other benefits include reduced maintenance costs and improved lighting service.

Public Lighting Models

This section describes street light services in seven Latin American cities (provided by the representatives of Bogotá administration) that are comparable as benchmarks for Bogotá. Looking at other cities that have implemented public lighting upgrades to improve safety for citizens, and energy efficiency, provides learning experience for Bogotá's future endeavors. City case studies may identify feasible public lighting options for Bogotá. Cities of particular interest for learning potential display similar characteristics to Bogotá, such as location, size, population, economic factors, and government structure.

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City	City Size (km squared)	Population (million)	GDP per Capita (USD)	Human Development Index	Gini Coefficient (Inequality)
Bogotá	1590	8	$15,891	0.965	0.53
Bucaramanga	165	0.57	$14,292	0.711	0.44
Buenos Aires	203	2.89	$20,036	0.879	0.49
Lima	2,672	8.89	$11,376	0.734	0.44
Mexico City	1,485	8.9	$20,960	0.83	0.48
Quito	372	2.6	$6,345	0.732	0.45
Santiago	641	5.1	$24,224	0.812	0.49
São Paulo	1520	11.9	$12,340	0.805	0.56

Table PL1: Economic and Social Measures for Benchmark Cities

The benchmarking exercise answers questions such as:

- What lighting technology is currently being used?
- Who owns and operates the street lights?
- Have any energy efficiency efforts been planned?
- How are street lighting services financed?
- What are the contractual arrangements to supply public services or manage public assets? (can typically be done publicly, privately, or through public-private partnerships)

Key Observations from Case Studies

Key Takeaways

- The scale of street lighting upgrades differs across cities, ranging from small to large scale projects and pilot projects.
- Operations and maintenance cost structure can relate to the success of lighting modernization plans.
- Public private relationships can have different natures that might relate to different outcomes

Scale of Lighting Upgrades:

The scale of street lighting upgrades differed across cities. For cities like Buenos Aires and Bucaramanga, a single large city-wide project was initiated with one private firm for technology upgrades. As mentioned in the previous section, Buenos Aires implemented a large project with Phillips in 2013, in order to upgrade 75% of street lighting to LED lights and introduce remote management. This had projected energy savings of 70,000,000 kWh per year, and 50% projected cost savings.[96] In 2014, Bucaramanga launched a renovation plan to upgrade 40% of public lights to LED luminaires through a partnership with Schreder Lighting.[97]

In contrast to large scale projects, some cities have implemented smaller pilot projects in different neighborhoods. Santiago has implemented a series of small neighborhood-level pilot efforts to install LED lights, solar LED lights and remote management devices to optimize usage. Two of these were implemented in parks via public bids. A city-wide effort, Smart City Santiago, was launched by the Ministry of Energy and Enersis (a private utility) and is aimed at reducing overall energy consumption by 20% by 2025 using LED street lighting and remote management.

There have also been two national level efforts in Chile to upgrade to energy efficient street lights. Enlighten 2020 - launched as a partnership this January between the Chilean government, the UNEP, Osram, Phillips and the National Lighting Test Center of China – is aimed at upgrading all street lights to LED and expects to save 4.8% of the country's electricity consumption per year. The second effort ("Programa de Recambio Masivo de Luminarias de Alumbrado Público") is led by the Chilean Energy Efficiency Agency, and aims to replace 200,000 lights across the country over a period of 4 years. The first call for proposals of this project was made in August 2014. There is currently limited information on the success of these large country-wide projects, despite the wide variety of technologies and goals planned.

These differences in scale represent integrated and phased lighting modernization efforts - two approaches that offer differing benefits. Large projects allow the purchase of lighting fixtures at wholesale rates, proving cost-effective to the city. Their impact can be monitored and controlled centrally. Pilots offer a manageable solution to testing the benefits of lighting upgrades, as benefits can be monitored, quantified and communicated as a viable business case to citizens. The scale of pilots is easier from a management point of view.

Operations and Maintenance Cost Structures:

The second aspect that can be observed in the benchmarked cities is public lighting operation and maintenance (O&M) cost structures. Some municipalities consider this information confidential, making it difficult to find. This section identifies information that was publicly available or obtained through interviews with city representatives.

When municipalities outsource O&M to private companies, the payment structure can be done in two main ways: i) through variable payment or ii) through a fixed payment defined in a tender.

São Paulo is the city with most information available and is a good example to clarify the difference between the two structures. Currently, São Paulo outsources the O&M to two private companies and the monthly payment is variable, related to the amount of services that were provided by each company in that specific month, including labor and materials.[98] There is a pre-defined cost list that is frequently updated to include new services and price variability, such as LEDs prices dropping. However, this payment does not include performance and quality indicators, and does not incentivizes enough the companies to provide a high-level service.

The city has launched a PPP tender that will select one company to upgrade all the public lighting to LED in five years, install remote monitoring, and be responsible for the O&M. In this PPP, São Paulo will switch to a monthly fixed payment for the chosen company, which will be defined in the tender process. Quality and performance factors will be applied to this fixed monthly amount, so the company is accountable for the service it is providing.[99]

Public-Private Partnerships:

The third key observation is related to different formats of public-private partnerships (PPPs). Two case studies that exemplify PPPs are São Paulo and Mexico City.

The main differences between those PPPs are the final financial guarantor and scale of the projects. São Paulo has the municipality as the guarantor and Mexico City has the federal government. São Paulo's proposed PPP is to manage the whole public lighting system (over 620,000 lamps) in one phase,[100] while Mexico City is working in phases. It launched the first PPP in 2010 for the city center and some of the main roads (49,000 lamps),[101] followed by a second PPP tender expanding to a new region (43,000 lamps).[102] There are different outcomes that might be related to the different approaches. São Paulo's PPP tender had a lack of interest of companies in submitting proposals. In turn, Mexico City had a successful PPP in 2010, followed by a second one in 2016, both done by the same company, Citelum. When talking to representatives from São Paulo's municipality,[103] it was clear that some companies did not submit proposals due to a high risk perceived related to financial guarantees, and others did not have the infrastructure needed for a project of this size. *Table PL2* summarizes the main findings from the benchmarked cities. Details on the energy sector, technology and upgrades, and funding can be found in Appendix B.

City	Total Number of Lights	Percentage of Lighting Upgraded	Remote Management	Energy Savings (forecast vs actual)		Forecast Cost Savings
Bogotá	340,000	NA	Planned	TBD	-	TBD
Bucaramanga	50,000	40%	Schreder Owlet Nightshift	61% (CO_2e)	-	61%
Buenos Aires	126,000	75%	Philips CityTouch System	70 GWh	-	50%
Lima	370,000	-	-	-	-	-
Mexico City	480,000	57% (3%to LED)	Muse CMMS tool on Main Streets	25%	44%	USD 15MM (23%)
Quito	250,000	2%	Smart Management System	65%	63%	USD 128,512 USD 200,000
Santiago	-	-	Planned	50%	-	30% in O&M
São Paulo	620,000	36% to Sodium Vapor 14% to LED	Planned via PPP	52%	-	-

Table PL2: Public Lighting Technology in Benchmarked Cities

Financing Strategies

This section summarizes the public lighting financial models used in the seven Latin American benchmark cities, and discusses the potential financing mechanisms available for Bogotá to finance the public street lighting modernization plan.

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The financial models used by the seven Latin American cities are presented in *Table F1* below. All seven cities use the city budget to finance their street lights. However, they have adopted different financing mechanisms to fund their energy efficiency upgrades. Based on the funding options used by the seven cities, a comprehensive list was analyzed further. These different financing options are explained in the next section.

City	Public Lighting Funding	Energy Efficiency Funding
Bucaramanga	City Budget	City Budget
Buenos Aires	City Budget	International Grant & City Budget
Quito	City Budget	National Budget – Tax Funds
Mexico City	City Budget	National Loans & Grants
Santiago	City & National Budget	City & National Budget (future ESCO)
Sao Paulo	City Tax & Private Investment	Tax Fund, International Grants, & National Development Bank
Lima	Private Funding	International Grant

Table F1: Summary of Financial Models used by Benchmark Cities

Preliminary Financing Options

The range of financing options available to Bogotá depends on factors such as initial investment, regulatory framework, financial strength, creditworthiness, certainty of revenues, commercial financing environment, nature of project, etc.[104] Currently, Bogotá spends from its city budget around USD 60 million[105] annually on public street lighting. The modernization plan proposed would ideally require a USD 30 million upfront cost.

Based on the above parameters, various funding options were studied to determine feasible options for Bogotá. The eight funding options obtained and analyzed are:

1. Self-Funding
2. Energy Service Companies (ESCOs)
3. Municipal Funding
4. National Programs
5. Transfer of Luminaires
6. International Grants
7. Taxes
8. Utility Programs

Self-Funding:

Key Takeaways

- If surplus revenue is accessible, this is the easiest option for a municipality to fund the lighting upgrades.
- Municipalities assume majority of the performance risk.

If feasible, self-funding is probably the simplest way to pay for an LED retrofit project. With this method, municipalities make modernization investments using the annual surplus from the public lighting revenues or the municipal budget.[106] The seven Latin American cities researched use self-funding as a mechanism to fund their public lighting projects. In Bucaramanga, for instance, the Ministry of Infrastructure has been financing all lighting infrastructure upgrades since 2013.[107]

When municipalities lack other financing options to raise resources for their projects, self-funding the project for a longer period of time is an option. However, this creates a high-cost and high-risk scenario. The city is the primary investor, and is responsible for the implementation of the project. The municipalities assume majority of the performance risk, and may lack other primary stakeholder to share the costs or risks with. Additionally, if the surplus revenues are not easily accessible, this funding option may require complex approvals for the allocation or reallocation of funds from the city or national budgets.

Energy Service Companies (ESCOs):

Key Takeaways

- Energy Service Companies can provide a range of project development, financing and execution services, to ensure cost and energy savings for the municipalities.
- ESCOs can simply help mobilize finances, but cannot help access funds that the municipality don't have access to.
- Guaranteed Savings, Shared Savings, and Annuity Based models are most commonly used around the world. These models differ in the expected project deliverables, and the way the projects are finances.

ESCOs are private companies that provide assessments and installations for energy-efficiency retrofits. The services can also include financing assistance, which allows the host facility to put up little or no upfront investment. Typically, the municipality pays for the project with the expected savings from reduced energy usage.[108]

When looking at a PPP model, ESCO contracts play an important role. In developing countries, these contracts range from full-service and high-risk contracts to low-service and low-risk ones. A full-service or "shared savings" contract is a partnership where the ESCO designs, finances and implements the project, measures the energy savings and shares a fixed savings percentage with the municipality. A low-service, low risk contract example could be a partnership with a technical consultant, who can audit and/or assist with a portion of the implementation of the project. ESCO services generally consist of three components: integration of a wide range of project services, facilitation of financing, and guarantee of project performance.[109] The exact package of services covered by an ESCO needs to be customized to cater to the public agency's needs. These models have been successfully implemented in several cities and regions in India and Brazil. Furthermore, as mentioned previously, Chile has used the ESCO model to fund three energy efficiency projects.[110]

In general, the main limitations of ESCO models are the high barriers to develop an energy efficiency market in Latin America, as well as the lack of appropriate financing for ESCOs to develop such projects. While ESCOs may help mobilize finances from the financial institutions, they cannot help access funds that were otherwise unavailable to the municipalities. An ESCO's ability to raise finances is dependent on the creditworthiness of its clients. It is noted that local financial institutions are conservative in lending funds to private sector companies due to lack of knowledge of energy efficiency projects and risk appetite. ESCOs are good complimentary funding mechanisms, but not the primary financing option.

There are three common models for ESCOs that have proven to be successful in the developing world: Guaranteed Savings Model, Shared Savings Model, and Annuity Based Model. The difference in the first two options lies in the way projects are financed and the way energy and cost savings are allocated between service provider and host.

Guaranteed Saving Model

In this model, the municipality takes on the loan to pay for the upfront costs of the program. It uses those funds to pay a vendor/partner to complete the improvement project. In return, that partner guarantees a reduction in energy bills. These savings are then used to repay the original loan. In short, the city takes the loans and the risks, provided the utility partner guarantees energy savings and a consequently reduced bill. For Bogotá, this model can act as an option to ensure a reduced energy bill.

Figure F1 below describes the relationship between the three stakeholders in this model.

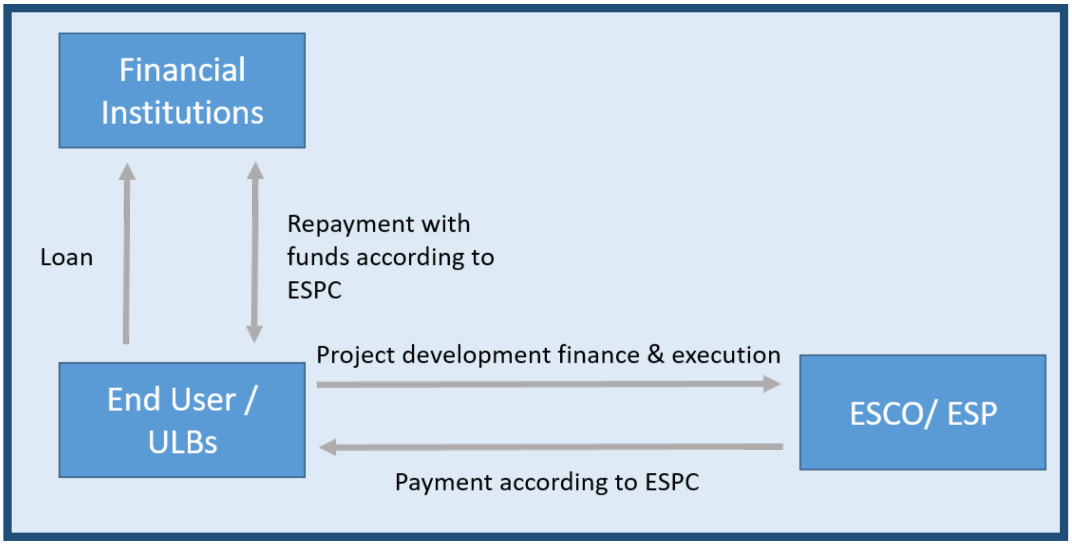


Figure F1: Summary of Financial Guaranteed Saving ESCO Model[111]

Shared Saving Model

In this second model, the upfront costs are partially covered by the ESCO. In return for completing the project without receiving full payment, the municipality agrees to share any savings that are realized. The specific savings figures are not guaranteed. The savings are shared for an agreed upon length of time to allow the ESCO to recover its costs and receive a desired return on investment. This is a feasible option for Bogotá, as it ensures the sharing of costs and performance risks with the ESCO.

Figure F2 below represents the relationship between the three stakeholders of this model.

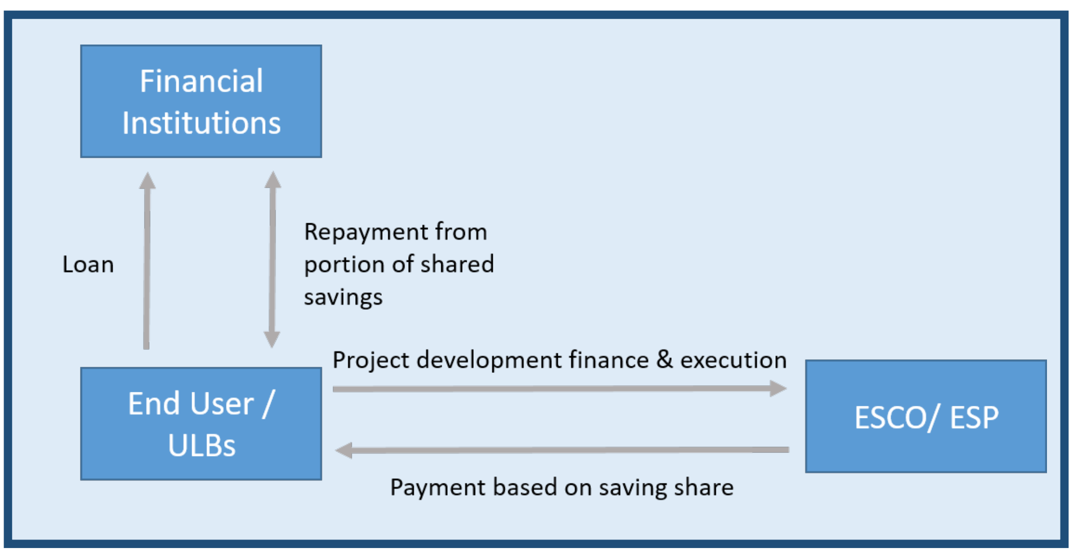


Figure F2: Summary Shared Saving Model[112]

Annuity-Based Deemed Savings Model

This method involves multiplying the number of installed energy efficiency measures by an estimated (deemed) saving per measure, derived from historical evaluations. This method ensures that the best available technology is retrofitted, such that there is an overall cost saving to the municipality. The ESCO covers the upfront cost, and charges a service charge after successful demonstration of the technologies. This service charge is based on demonstrated savings, capital costs (invested by the ESCO), operation and maintenance, and possibly a reasonable return on the ESCO's investment. The municipality pays annuity based on the cost savings incurred because of the energy efficiency measures. The model divorces the requirement of periodically demonstrating energy and cost savings to obtain the returns on investments.

This method only ensures successful implementation of the energy efficiency projects, at a reduced price. It does not guarantee energy savings over time. This option simply encourages more investment in the energy efficiency sector. For Bogotá, this may not be as useful as the other ESCO models described earlier.

Municipal Funding:

Key Takeaways

- Bogotá's credit rating as per FitchRatings is BBB and stable; thus, the city can access commercial financing, or access loans from Findeter, the Colombian development bank.
- Green Bonds market is an attractive option. Latin American green bonds market is catching up with Nafin, Mexican development bank issuing $500 million green bonds for environmental projects and the Inter-American Development Bank will underwrite up to $450 million for energy efficiency projects.

A municipality can issue municipal bonds or borrow money to finance public projects. In such a case, the municipality is responsible for raising funds. The two forms of municipal financing are as follows:

Municipal Loans

A municipality can borrow from the commercial market, and repay its debt from the cost savings of the project. Municipal loans can provide scalable and sustainable financing solutions, where the full project cycle is financed[113]. However, access to external financing by a municipality is influenced by national legislation and the level of fiscal decentralization. There may be restrictions on the borrowing capacity and availability of collateral for a municipality. A poor credit rating of a municipality also leads to high-rate loans. In this context, Bogotá's credit rating as per FitchRatings is BBB and is stated stable[114]. Thus, Bogotá can access commercial financing from banks to raise funds for this project.

Latin American countries often have public or municipal development banks that can help finance municipal projects, including energy efficiency. Mexico's national government has facilitated such loans for the municipalities, provided by the Bank of Public Works and Services, a development bank. Additionally, municipalities can access funds from the Ministry of Energy through the Energy Transition and Sustainable Energy Use Fund.[115]

In Colombia, the development bank – Findeter - offers comprehensive solutions for structuring, financing and technical consulting on sustainable infrastructure projects that improve the quality of life of the regions.[116] Bogotá can borrow from Findeter considering it has a stable rating.

Municipal Bonds

Municipal bonds are issued by a local government to private parties in order to finance public projects. The municipality can issue tax-exempt bonds and obtain funds at a lower interest rate than normal. Repayment of bonds can be done by revenue bonds, which are municipal bonds supported by the revenue from a specific project[117]. With Bogotá's stable credit rating of BBB, it can issue tax exempt bonds because the modernization plan offers benefits to the public in terms of well-lit public lighting infrastructure, perception of safety and growth in economic operations.

In addition, specialized bonds, such as green bonds, are an attractive option and are an emerging source of funding for green projects around the world. The green bond market has picked up pace in recent years with USD 42 billion issued in 2015, almost four times the 2013 issuance of USD 11 billion.[118] Green bonds are instruments where proceeds are exclusively applied towards new and existing green projects. These projects promote climate or other environmental sustainability purposes. Proceeds from these bonds are earmarked for green projects but are backed by the issuer's balance sheet.

In Latin America, this market is slowly gaining traction. The USD 500 million issuance of green bonds by Nafin, the Mexican development bank, demonstrated that green bonds is an effective way to channel money for environmental projects in the region.[119] The deal was five times over-subscribed, showing significant interest from investors.

To further develop this market, the Inter-American Development Bank (IDB) has approved financing of a regional Energy Efficiency Green Bond Facility. IDB provides up to USD 450 million to underwrite energy efficiency projects. In addition, the Green Climate Fund will also provide up to USD 217 million in funding. It was noted that Colombia is one of the first few countries to gain access to this funding mechanism.[120] In view of the growth of this market, Bogotá can explore this emerging mechanism.

National Programs:

Key Takeaways

- There are various channels of for Colombia to partner with organizations for National Funding. The three main ones are the International Development Bank (IDB), the World Bank, and Columbia's Clean Technology Fund (CTF).
- Colombia's CTF currently has a pool of $39 million USD for energy-efficiency projects throughout the country.

The use of national programs in this context means partnering with organizations who help fund projects and initiatives that are aligned with certain outlined goals and agendas.
Colombia developed an investment plan in 2010 in coordination with the International Development Bank (IDB) and the World Bank that aimed to tap USD 150 million in financing from Colombia Investment Fund's Clean Technology Fund (CTF) for a range of urban transport and energy efficiency projects. CTF financed projects are expected to raise additional USD 1.1 billion in public and private co-financing.[121] Colombia has access to these programs to finance its public transport infrastructure and energy efficiency in Bogotá, along with seven other cities.

The limitations of this methodology include: the difficulty to create partnerships and qualify for this money, due to the high demand and strong competitiveness of other neighboring countries, and the lack of long-term planning capabilities with this source of funding. This can contribute to the initial capital investment required for a project, but is not a sustainable source of funding in the long-term.

Transfer of Luminaires:

Key Takeaways

- The Transfer of Luminaries financing method requires little initial capital investment with a short timeframe needed for proper and successful execution.
- This methodology was ruled out due to the difficulty of coordinating with neighboring countries and the unique ownership structure where a third party organization owns all the light bulbs.

This methodology consists of using the sodium or metal vapor equipment left over after a city converts to a LED lighting infrastructure. After a city has switched to LEDs, it can sell the old HPS lamps to other cities that still use them. Generally, facilitating this transfer requires little initial capital investment with a short timeframe needed for proper and successful execution, in comparison to buying brand new light bulbs, because the light bulbs are second-hand and have been depreciated in value.[122] Some Latin American cities have already started or plan to start a LED retrofit. This means that a lot of used sodium or metal vapor light bulbs are or will be ready to be purchased at low price, or procured for free. Overall, this methodology may not be the most attractive option due to varying reasons, like the implementation of used light bulbs, but some cities that are unable to gather the required initial costs for improved lighting utilize this option.

When looking into Colombia, and more specifically Bogotá, this option poses another unforeseen obstacle that the benchmark cities have not faced. The nature and structure of a third part owning the lighting in Bogotá makes this model a lot more challenging.

International Grants:

Key Takeaways

- Some international organizations/funds that Bogotá can approach are: Copenhagen Centre on Energy Efficiency, Global Environment Facility, World Bank, Clean Technology Fund, etc. to seek funding
- Other Latin American cities such as Buenos Aires secured $15.5 million from Global Environment Facility to implement its energy efficiency project.

This method of financing relies on applying grants provided by international organizations to implement new initiatives in alignment with the organizations' vision and mission.[123]

Over the last few decades, many nations and cities have opened channels to this international pool of financial resources to achieve sustainability goals. There are many South American countries and cities that have implemented energy-efficiency projects through the application of international grants. For example, Sao Paulo and Buenos Aires have capitalized on this opportunity. Sao Paulo's ambitious public lighting project will be funded by Brazil's national development bank (BNDES) and the International Finance Corporation, an affiliate of the World Bank Group.[124] Although no official transfer of money has happened yet due to the pause in the tender process for Sao Paulo, BNDES and IFC are predicted to finance $670 million USD over the span of 20 years via low-cost loans. At the current time, there is no public information regarding what the interest rate will be set at or how the loan structure is organized. [125, 126] Argentina secured 15.155 million USD from Global Environment Facility (GEF) in 2004 to implement energy efficiency projects within the country. With the support of this grant and the organization, Buenos Aires implemented lighting upgrades in residential, commercial, streets and public buildings. One hundred-thousand lamps for street lights and buildings were upgraded as a part of this project.[127] Several other Latin American countries have secured substantial funding for their energy efficiency projects using international grants.

Bogotá can approach various international organizations that especially provide grants for energy efficiency projects, such as:

i) The Copenhagen Centre on Energy Efficiency, a joint effort by the Danish Government, the United Nations Environment Program (UNEP) and the Technical University of Denmark funds several energy efficiency initiatives and opportunities in Latin America and the Caribbean.

ii) Global Environment Facility[128], established in 1991, has the longest record of financing climate change mitigation and adaptation programs and projects. In its Fifth Cycle (2010-2014), $1.14 billion was dedicated towards climate change. There are a few criteria that need to be met to secure GEF Funding. These are:
   a. Undertaken in an eligible country consistent with national priorities and programs.
   b. Addresses one or more of the GEF Focal Areas, improving the global environment, or advances the prospect of reducing risks to it.
   c. Consistent with the GEF operational strategy.
   d. Seeks GEF financing only for the agreed-on incremental costs on measures to achieve global environmental benefits.
   e. Involves the public in project design and implementation.
   f. Is endorsed by the government(s) of the country/ies in which it will be implemented.

iii) The World Bank[129] is one of the most important organizations in this context. It provides grants along with low-interest rates and interest-free credits to developing countries. The Bank also acts as an implementing agent with GEF where it combines GEF grants with sovereign loans to scale up funding support.

iv) Clean Technology Fund[130] seeks to support programs that achieve GHG emissions savings objectives by providing broader development and environmental benefits. The total CTF funding is $4.6 billion which is committed to 15 investment programs in large developing countries.

Taxes:

Key Takeaways

- Can be delivered in multiple ways, in a group tax with other municipal services or by itself
- Tax rate can be based on consumption of electricity or strata level.
- There is also an option of how to collect taxes, either through the municipal government or an energy company

Buenos Aires has a tax called Alumbrado, Barrido, Limpieza (ABL)[131] which is a charged based on the resident's neighborhood, similar to the way utility service rates in Bogotá vary by "stratas".[132] ABL tax groups three different services: street lighting, street cleaning, and trash collection. Sao Paulo is another city that uses tariffs to generate funds for public lighting. In 2015, USD 89.49 million was generated through a charge on consumers' electricity bill, the Contribuição para o Custeio dos Serviços de Iluminação Pública- COSIP ("contribution for payment of public lighting services").[133] For Bogotá, this first became an option after the federal government approved that municipalities in Colombia have the authority to implement a tax to pay for public lighting. Despite this federal law the city of Bogotá has not introduced the tax because of lack of citizen support and political buy in. This rejection comes even after the current mayor, Enrique Peñelosa, has expressed interest in implementing a tax.[134] With better citizen engagement an opportunity can arise where this may become a viable option for funding for public lighting.

Utility Programs:

Key Takeaways

- Model dependent on the municipality's relationship with the utility and how much funds the utility has access to.
- Considering current arrangement with Codensa, this is not a feasible option for Bogotá.

Utilities can provide loans to municipalities, which can then be repaid by the municipality and the consumers through a small electricity tariff increase. This program is advantageous to municipalities that have few options to raise funds and are seeking a low risk payback due to cost being below capital market levels. Additionally, this model requires regulatory changes and provides small financial return.[135] This model is dependent on the municipality's relationship with the utility and how much funds the utility has access funds to.

Potential Funding Models for Bogotá

Key Takeaways

- Self-funding, international grants, national programs, Energy Service Companies, and municipal funding could be feasible funding mechanisms for Bogotá.
- All the benchmarked cities have used self-funding to fund a portion of their energy efficiency upgrades.
- Global Environment Facility, the World Bank Group and the United Nations are organizations worth considering for international grants.
- Shared Savings Partnership with Energy Service Companies can help the city share both costs and risks of the energy efficiency project in Bogotá.
- The national Clean Technology Fund can be considered for public lighting upgrades in the city.
- Municipal bonds and taxes are other options worth exploring in the future.

Benchmarking and feasibility analysis were applied to the eight financial options. Of the options considered, utility programs, transfer of luminaires and taxes do not seem feasible for Bogotá. Transfer of luminaires was eliminated because it is not available for LED lights, only for older technologies. Taxes are not an immediate solution due to current political opposition, but can be considered in the future. Utility programs are currently complex, since it requires regulatory changes and a different partnership structure with the utility provider.

As seen in *Figure F3* below, all the seven cities analyzed use self-funding for a significant portion of their energy efficiency projects. The city of Bogotá should consider self-funding as an option, in addition to raising funds through other sources.

The remaining four financing sources, namely municipal funds, ESCOs, national programs, and international grants, were further analyzed based on their benefits and challenges.

Table F2 below highlights the cities that have used the funding strategies as described in the Public Lighting section.

	Bucaramanga	Buenos Aires	Quito	Mexico City	Santiago	Sao Paulo	Lima
Self-Funding	X	X	X	X	X	X	X
International Grants		X				X	X
National Programs			X	X			
Energy Services Company					In the Future		
Municipal Funding				X			

Table F2: Potential Funding Options

The next step was to analyze based on a risk versus complexity matrix to assess sources that are most readily available with the least possible risk.

The horizontal axis in the following chart represents complexity in accessing funds. For example, it is relatively simpler to obtain funds through an international grant or a national program wherein project specific conditions must be satisfied. On the other hand, funding sources such as municipal loans are more complex to procure because of limits on borrowing capacity, availability of collateral, credit rating etc.

The vertical axis represents risk in terms of payback. For example, funds provided through an international grant or a national program would require minimal or no payback of funds.[136] On the other hand, municipal loans or an ESCO model would require taking risk through higher repayment of borrowed funds (risk under ESCO would differ depending on the type of model).

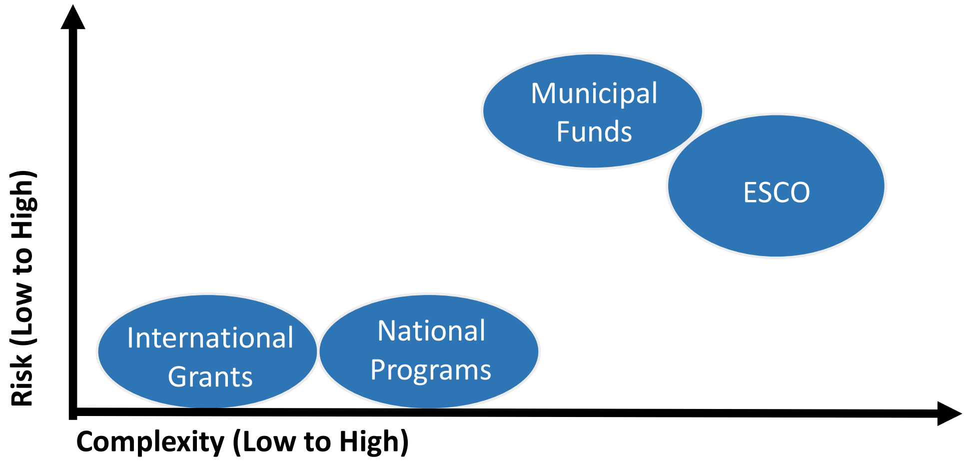


Figure F3: Feasibility Framework of Funding Sources

Table F3 below provides a summary of the benefits and challenges for the four potential models that were arrived at:

Financing Model		Pros	Cons	Case Study
International Grants		- Easy external support - Less risk	- Not consistent - Additional effort to meet criteria	Brazil, Argentina
National Programs		- Easy access - No repayment required	- Not consistent	Ecuador
ESCO		- Guarantee energy savings - Shared costs & risks	- Expensive - Complex	Brazil, India
Municipal Funds	Bonds	- Easy to implement	- Repayment may be expensive - Need a reliable market	Colombia (water)
	Loans	- No spending restrictions	- Repayment may be expensive & risky	Mexico

Table F3: Analysis of Potential Financing Options

To apply for international grants, Bogotá could connect with the United Nations, national banks, and the World Bank. There are many grants available that the city is eligible to apply for. Many of Bogotá's neighboring cities and countries have already capitalized on this opportunity. Overall, this financing option has the least complexity to adopt given the current financial situation at Bogotá. Furthermore, there is very little financial risk associated with this option because it is a pool of resources specifically allowed for energy efficiency and sustainability projects worldwide. Grants could be a feasible option for the city, as it has helped fund several energy efficiency projects in the country in the past. Since 1999, Global Environment Facility (GEF) has awarded 16 climate change project grants to Colombia, with an average award of $2.83 million.[137] This international pool of funds can help support the city's public lighting energy efficiency projects.

With respect to national programs, Bogotá has access to money from an investment plan created in 2010 amongst Colombia, the IDB, and the World Bank. As explained in the previous section, this plan allows access to USD 150 million in financing from Colombia Investment Fund's CTF for a range of urban transport and energy efficiency projects[138]. Of this amount, USD 50 million was allocated to energy efficiency projects. On June 1, 2016, USD 10 million from this fund, was approved for a single significant project.[139] Presumably, the remainder of the USD 50 million is available for Bogotá to consider for future energy efficiency projects. Overall, national programs are very similar to international grants. They both have a straightforward implementation process, for it requires applying for funds and incorporating them into modernization plans. Also, they both have very low financial risk because no money is required to be paid back to the source of funding. This program has worked for Bogotá in the past, and could be a feasible option to consider for relevant energy efficiency projects in the future.

For municipal financing, although green bonds and the use of Findeter are great options, public taxes would be the most sustainable and effective way to approach this category. It has been noted that a public lighting tax in Bogotá is difficult to pass. As of May 2016, there has been vocal opposition for the tax from citizens and political leaders. It is then difficult for the common citizen to understand where the funds being collected are going. Therefore, proposing another tax for public lighting retrofit could be challenging.[140] The tax can also face opposition from private property owners such as residents of gated communities, who already pay for public lighting as part of their membership fee.[141]

A suggestion for Unidad Administrativa Especial de Servicios Publicos (UAESP), and the office of Ministry of the Environment and Sustainable Development, would be to combine tax lines into groups, as Buenos Aires has done with ABL. In addition, Bogotá should plan the public lighting project in advance with the associated costs, so that an estimated end date can be announced with the tax, thus increasing the opportunity to have a tax passed. Finally, this can help focus how the tax will be spent, and increase the confidence of the stakeholders when proposal is shared with council members and residents affected.

When analyzing municipal financing, municipal bonds and loans both are difficult to adopt given the current financial situation of Bogotá. They both require to be addressed legislatively. The municipal loans are more complex, for they need more intense screening and checking of creditworthiness. In terms of financial risk, they are both relatively risky options due to their interest rates which vary with credit risk. The municipal loans are riskier because they tend to have a greater interest rate in comparison to municipal bonds.

Lastly, ESCO models are the most complex feasible financing option. The shared savings ESCO model provides full-service to the municipality and helps share both cost and risk of the project. This is a partnerships structure that Bogotá could prioritize. The difficulty in identifying an energy service provider, however, is a huge obstacle to the integrating process. However, with respect to financial risk, this option fairs in the middle, because the burden of finances is shared between both the energy service provider and the state. This is a feasible model for Bogotá to consider. It helps share performance risk, and will help with the implementation of the projects. Based on the above analysis, the potential financial models recommended are: Self-funding, International Grants, National Programs, ESCOs and Municipal Funds. These funding models would help the city of Bogotá secure funds to implement the public street lighting modernization plan.

Conclusion

Bogotá's sustainability goals call for the installation of 100,000 LED street lights in parks, major street intersections and the historic district, controlled by a central remote management system. The report findings can guide Bogotá to move towards its vision of being a safer and economically prosperous city, retaining its thriving street life and strengthening the relationship of its citizens with public spaces.

Bogotá's sustainability goals call for the installation of 100,000 LED street lights in parks, major street intersections and the historic district, controlled by a central remote management system. The report findings can guide Bogotá to move towards its vision of being a safer and economically prosperous city, retaining its thriving street life and strengthening the relationship of its citizens with public spaces.

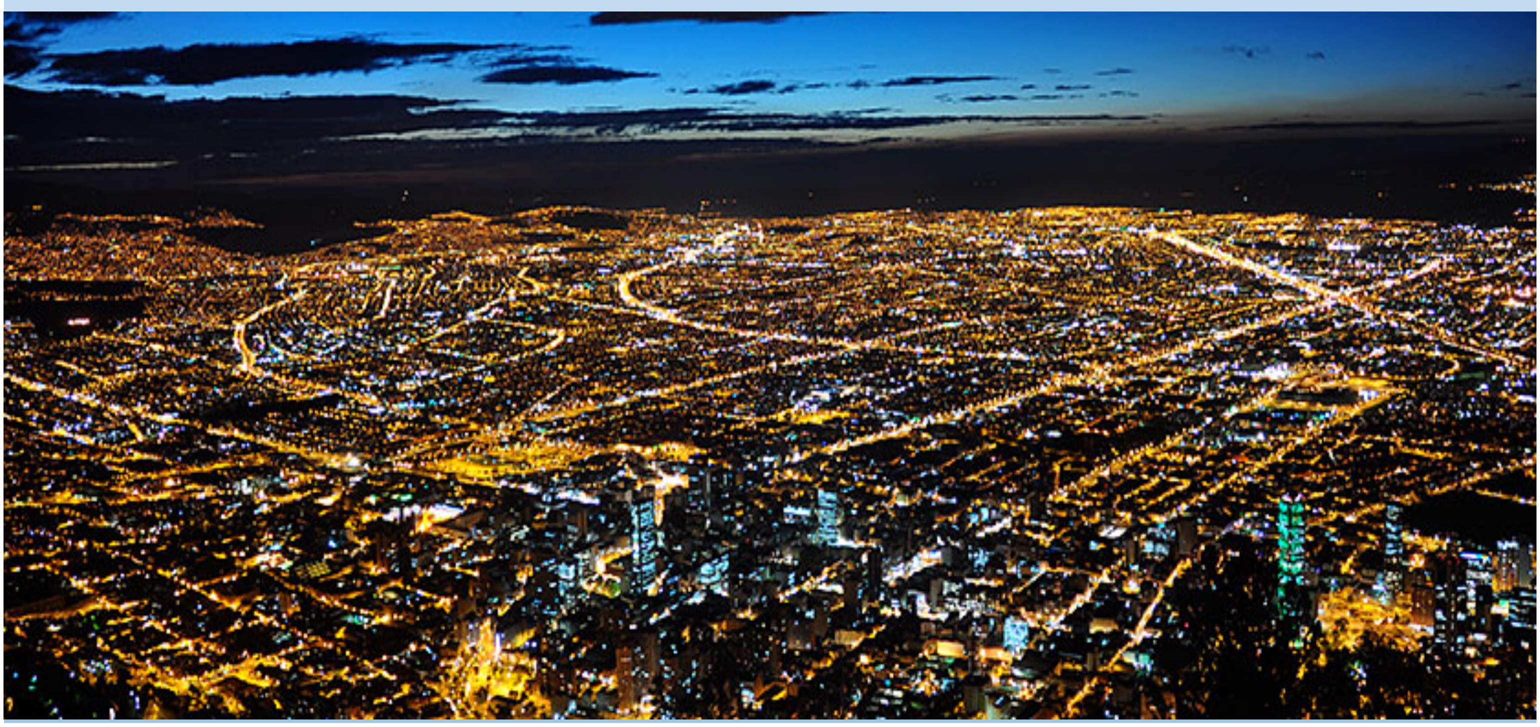
This report finds that the city can replace 100,000 street lights with LEDs in a financially feasible manner. There are four possible bulb replacement scenarios, of which the one with a high IRR and low initial investment is estimated to cost USD 16.4 million. This LED replacement project can act as a good opportunity to incorporate a central monitoring system into the city's public lighting model. This may be an additional cost, but has several societal benefits. Solar and wind powered streetlights were also considered, but they increase the upfront cost substantially and have a long payback period. The city can raise funds for their public lighting modernization plan using one or more suggested funding mechanisms: international grants, national programs, partnerships with energy service companies, or consider using the city budget.

For the next stage of the public lighting modernization plan, the city of Bogotá will require technical specifications regarding the existing technologies, and acquire pricing and service quotes regarding the public lighting retrofitting and the proposed technologies. Consequently, the city will also need to take a decision regarding the inclusion of central monitoring systems within the modernization plan. Additionally, acquiring geographic data regarding lights may help roll out the implementation of the modernization plan, and can help track the success of the project better.

Once the modernization plan has been finalized, the city should apply for the relevant international grants and national programs to secure funding for the technology upgrades. The city could also consider partnering with an energy service company to share costs, performance risk and energy savings, and help roll out the modernization plan. In order to do so, the city will need to create opportunities for the companies to share their proposals. Ideally, the city can then start designing the sequence of proceedings to implement the public lighting modernization plan. Setting clear tangible deliverables can help track the progress of the project.

With the successful implementation of the public lighting modernization plan, the city of Bogotá can set an example for the other Latin American cities, and lead the way forward.

Appendix



Appendix A: Consultation and LED Pricing Quote

LED de Colombia
Iluminación & Automatización

NIT. 900.643.874-4
Tels.8615834 - 313 2174525
Carrera 1 # 5- 30 Tercer Piso
CHÍA - CUNDINAMARCA

COTIZACIÓN No. 1022

Cotizado a:	Alejandra Reyes	Fecha:	**09-nov-16**
Atención :		Dirección:	
Número de Contacto :		Vigencia :	**15 dias**
E-mail:	alejandrareyesretana@gmail.com	Vendedor :	Mauricio Villegas N.
Forma de pago :	30 60 **Otro**		mvillegas@ledecolombia.com

ARTICULO	REFERENCIA	DESCRIPCIÓN	CANTIDAD	V. UNITARIO	V. TOTAL
	LCAP45	LUMINARIA ALUMBRADO PUBLICO 45 W, 4.950 lm, 120°, temperatura de color: 5000/6500K 100-240V, IRC >80, Garantia 5 Años IP65 IK08	1	489.600	$489.600
	LCAP60	LUMINARIA ALUMBRADO PUBLICO 60 W, 6.600 lm, 120°, temperatura de color: 5000/6500K 100-240V, IRC >80, Garantia 5 Años IP65 IK08	1	504.000	$504.000
	LCAP100	LUMINARIA ALUMBRADO PUBLICO 100 W, 11.000 lm, 120°, temperatura de color: 5000/6500K 100-240V, IRC >80, Garantia 5 Años IP65 IK08	1	768.000	$768.000
	LCAP150	LUMINARIA ALUMBRADO PUBLICO 150 W, 16.500lm, 120°, temperatura de color: 5000/6500K 100-240V, IRC >80, Garantia 5 Años IP65 IK08	1	1.138.000	$1.138.000

Observaciones

No incluye instalación
Términos de pago: 50% anticipo y 50% restante a la entrega.
Términos de entrega: A acordar
Vida estimada de 50000 horas de uso

SUBTOTAL	$2.899.600
IVA	$463.936
TOTAL	$3.363.536

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Appendix B: City Case Studies

Bucaramanga, Colombia:

Bucaramanga is the capital city of the department of Santander, Colombia. It is the seventh largest city by population in Colombia with 571,820 inhabitants, it covers 165 km2, and has a GDP per capita of USD 14,292.00.[142] With 160 parks throughout the city, Bucaramanga has been given the nicknames "La Ciudad de Los Parques" ("The City of Parks") and "La Ciudad Bonita de Colombia" ("Colombia's Beautiful City").

Key Takeaways

- Public-private partnership with Schréder Lighting.
- 40% LED lighting upgrades.
- Owlet Nightshift, an integrated telemanagement system, improves management of outdoor lights and allows remote dimming of lights to increase energy and cost savings.
- Publicly funded under the Ministry of Infrastructure.

Energy Sector

Bucaramanga's energy sector is highly dependent on hydroelectric power and thermal power.[143] The integral management of public lighting is made directly by the city of Bucaramanga. Electricity is purchased through reverse auctions for the best price available on the energy market. Billing and collection is done by the various energy companies such as ESSA, Ruitoque SA ESP, VATIA SA, ISAGEN SA, and EPM. Integrated Service Management System of street lighting is certified by the Colombian Institute of Technical Standards and Certification (ICONTEC), a non-profit private Colombian organization, under standards ISO 9001: 2008, ISO 14001: 2004 and OHSAS 18001: 2007 issued by Commission of Regulation of Energy and Gas (CREG).[144]

Technology/ Upgrades

In 2014 Bucaramanga entered a public-private partnership with Schréder, an international lighting group that specializes in outdoor lighting and is represented in 33 countries, to expand and optimize lighting service in vulnerable areas of the city. The goal of the partnership was to improve energy efficiency, reduce greenhouse gas emissions, and in effect improve infrastructure, social behaviors and communities.[145] To address these goals, 40% of all 50,000 city lights on streets and in parks were replaced with LED lighting technology and integrated with the Owlet Nightshift telemanagement system for monitoring, controlling, metering and managing outdoor lighting.[146] More than 900 Teceo LED luminaires were installed, which are dimmable and set to 50% power for 7 hours of an average 12 hour night, when less light is required. Bucaramanga also installed Akila luminaires on 21m high masts and the Nano LED luminaires for the Villa Olimpica area. Schréder forecasts that the upgrades will cut energy costs and CO2 emissions by 61%.[147]

Funding

Since 2013, the Ministry of Infrastructure of the city of Bucaramanga has financed the lighting infrastructure in Bucaramanga. Prior to this set-up, the city was funded through a private investment company. The financing includes the maintenance and operation as well as the expansion of its public lighting, including energy efficient projects, which comes from the local city budget. These funds are raised through a tax, which is billed with the assistance of Eletrificadora de Santander S.A. (ESSA), an energy company based out of Medellin, Colombia.[148] The tax rate is based on who consumes the electricity which is tiered in the following scale: 10% for residential, 15% for commercial, and 5% for the industrial sector, of which strata levels are not considered in the final billing process.[149]

Buenos Aires, Argentina:

Argentina's capital, Buenos Aires, is the country's largest city and the fourth most populous metropolitan area in the Americas. The 203 km^2 city is home to 3,059,122 people and has a GDP per capita of USD 20,036.[150] For administrative purposes, the city is divided into 48 official neighborhoods.[151]

Key Takeaways

- In 2013, public-private partnership with Philips to upgrade 75% of public lighting to LED technologies and install a remote management system.
- Project completed in 2016: replaced 91,000 street lights with LED and installed CityTouch telemanagement system.
- Funded by national and local governments through a partnership with Global Environment Facility (GEF).

Energy Sector

The Greater Buenos Aires region has by far the largest energy demand compared to other Argentinian regions.[152] CAMMESA S.A. (Compañia Administradora del Mercado Mayorista Electrico SA), is Argentina's wholesale electricity market administrator. CAMMESA S.A. offers operation and dispatch of generation, price calculation in the spot market, and the administration of the commercial transactions in the electricity market.[153] The electricity generation market is highly competitive with generators that are mostly private (75%) and some public (25%). Transmission and distribution are less competitive than generation and are highly regulated. Transmission and O&M is performed by Transener under a long-term agreement with the Argentinian government. Distribution in Greater Buenos Aires is primarily run by the Argentinian government under two main electric power distributors, Edenor and Edesur.

Technology/Upgrades

In 2013, Buenos Aires entered a public-private partnership with Philips to upgrade 75% of public lighting to LED technologies and install a remote management system. By 2016 the project had replaced 91,000 street lights with LED and installed a remote management system, CityTouch, to improve installed operation and maintenance costs. The CityTouch system allows for monitoring, switching, and dimming of each lighting point on the network. Philips forecasted the upgrades to achieve energy savings of 70000000 kWh per year and 50% cost savings.[154]

Funding

The operations and maintenance of public lighting are funded by a municipal Lighting, Sweeping, and Cleaning Tax.[155] This results in $12.4 million USD available for electricity of public lighting and $8.7 million USD for maintenance of public lighting infrastructure.[156] The public lighting upgrades installed by Philips Lighting between 2013 and 2016 cost $57 million USD and was funded jointly by the municipal government and international grants from the Global Environmental Facility (GEF).[157]
Historically, electricity consumption has been partially subsidized by the federal government. However, there is an effort underway to increase the rate users pay and reduce that subsidy.[158]

Lima, Peru:

Peru's capital, Lima, is the largest city in the country, with almost 10 million people.[159] Lima is also the country's industrial and financial center and it is the second largest city in South America after São Paulo.[160]

Key Takeaways

- Focusing on expanding public lighting to the suburbs and developing metering (only 77% of the city is metered).
- LED street lights and remote management are not a priority due to budget limits

Energy Sector

In 1992, the Electric Concessions Law was passed in order to promote private investment and modernize the regulation of the electric sector in Peru. The government separated power generation from transmission and electricity distribution, unbundling the different components of the electricity supply chain.[161] The government also created the Supervisory Agency for Private Investment in Energy (OSINERG)[162] to regulate tariffs and control the quality and quantity of combustibles and service provision. However, the national privatization process in the electric sector has not yet been completed. So far, only the distribution companies Edelnor[163] and Luz del Sur[164] in the department of Lima, have been fully privatized without public control.

In particular, Lima's distribution grid was divided in two concessions of similar sizes in the South and North of Lima. Edelnor, which is majority owned by Enel, is in charge of distribution in the North of the city, while Luz del Sur - owned by Ontario Quinta srl – is in charge of the South.[165] Electricity rates are regulated by law, through an autonomous technical agency: the Commission for Energy Rates (GART), its supervision being under the responsibility of OSINERG.

Public Lighting & Upgrades

In terms of technology used, 87% of public lights installed in the city of Lima are high pressure sodium while the rest are mercury vapor. No LEDs are used.[166] Moreover, only 77% of the city is metered and, in these areas which are metered, there is no remote management. Given this background, the current priority of the city of Lima is to expand public lighting to the suburbs and increase the share which is metered, rather than working on lighting retrofits and modernization projects.[167] Citizens can report lighting failures or other topics related to public lighting through a phone number listed on the utilities' website.[168] The residential and commercial customers are billed for public lighting depending on their monthly electricity (kWh) consumed.

Funding

Lima's current funding of lighting infrastructure is completely private under control by Edelnor and Luz del Sur. In July 2016, Peru established a national program called the "National Efficient Lighting Strategy" in collaboration with the UNEP-GEF's "en.lighten" initiative. This project is funded by the Global Environmental Facility (GEF), a branch of the World Bank that has a mission to start an investigation process understanding the new lighting technologies, learn how to make best use of the technology and explore funding mechanisms. The project aims to strengthen the national regulatory framework, which promotes a sustainable efficient lighting market, establishes a framework for the environmentally sound management of used lighting products, and enhances stakeholders' awareness on the benefits of advanced lighting.[169]

Mexico City, Mexico:

Mexico's capital, Mexico City is the most populous city in the country, with 8.9 million[170] people and a GDP per capita of USD 20,960.[171] It comprises 16 different municipalities, each with its own municipal chief, under a Head of Government, who is responsible for the executive power.

Key Takeaways:

- Mexico City has a successful PPP with Citelum, with a first tender launched in 2010 and won by the company, and a second tender won by the company in 2016, for a different region of the city.
- The energy savings are higher than predicted (44%) and failure rates dropped to 0.9%.
- Both PPPs together cover approximately 21% of the city lamps.

Energy Sector

The electricity sector in Mexico is regulated by the Secretaría de Energía- SENER (Energy Secretariat). The Electricity Federal Commission (CFE) is responsible for generating two-thirds of the country's energy.[172] In 1992, the sector was open to private participation, which generates the remaining one-third of energy. Private players are not allowed to sell directly to consumers, instead private generators sell the output to CFE. Transmission and distribution of electricity is a monopoly by CFE. In 2008, two laws were created to regulate and upscale renewable energy and energy efficiency. In the context of those laws, the federal government acts as the main source of funding for projects and oversees energy efficiency programs for municipalities.

Public Lighting & Upgrades

The city public lighting system has approximately 480,000 lamps, covering 99.5% of the city.[173] The infrastructure is owned by the municipalities that are also responsible for operating and managing the largest part of it (around 79% of the lamps). In 2007, Mexico launched a public-private partnership tender for operation and maintenance of the remaining 21% of the lighting in the city center and main streets.[174] In 2010, the public-private partnership was won by EDF Citelum, a local subsidiary of the French company EDF, costing the city 2,600 million Mexican

Pesos (USD 139 million) to be paid in 10 years (USD 13.9 million per year).[175] EDF Citelum was chosen based in technical and economic performance. This was the first public-private partnership for public lighting in Latin America and the results have been better than forecasted: energy savings are approximately 44% (25% was forecasted initially) and the failure rate has dropped from 59% to 0.9%.[176]

In 2016, Mexico City entered another six-year contract with EDF Citelum for public lighting. The cost was approximately USD 145 million for the upgrade and management of 43,000 new lighting bulbs (12,500 of those to LED, the remaining is unclear which technology will be used) and a remote monitoring system through the proprietary system Muse® CMMS.[177] The Federal government is the financial guarantor for both projects. It is worth noting that Citelum is a global company, focused in public lighting, present in over 1,000 cities, including Cali, Colombia.[178]

In order to upgrade and modernize the remaining 340,000 lighting bulbs in secondary streets, the municipalities are working together in a project called "Iluminamos tu ciudad" (“We enlighten your city”). The most recent public update for this project was in 2014, which stated that 158,000 bulbs had been upgraded from 250W to more efficient ceramic metal halide lamps of 140W. The total cost of the project (for the 340,000 lights) was estimated to be around USD 140 million.[179]

There are currently other pilot projects in place, such as the FreeLED solar roadway system, a partnership between Lighting Science Group and BHP Energy México. The initial pilot was the installation of 500 units of solar powered LED on remote streets.[180] No information on the project cost was discovered.

Funding

Mexico City uses the city budget to fund public lighting projects.[181] For energy-efficiency projects, the city also accesses international and national loans. Loans from the Ministry of Energy and the Bank of Public Works & Services (BANOBRAS) are available through a special fund, “Energy Transition and Sustainable Energy Use Fund. [182,183]” This fund could cover as much as 15% of the needed investment, or 10 million Mexican Pesos (USD 487,100), whichever is lower. [184]

Quito, Ecuador:

Quito is an important center of commerce and industrial activity in the Ecuadorian economy. With a population of 1.6 million people, it is the second most populous city in Ecuador.[185] Quito also makes the largest contribution to national GDP.[186] Regarding the administrative framework, the Municipality of Quito is an autonomous local government according to the Ecuadorian Constitution. It owes this special status to its condition of capital of the country.

Key Takeaways:

Quito’s LED upgrade project in the historical city center was successful for two reasons:

- The project was split into two phases in order to better manage progress and address problems
- The project focused on the benefits of well-lit streets in terms of night time tourism and economic activity

Energy Sector

The Empresa Electrica Quito (EEQ), an autonomous and publicly owned corporation that supplies Quito with electricity, is in charge of transmission, distribution and maintenance of Quito's public lighting system. It is owned by public administration entities: the Government Department of Electricity (68%), the Quito Municipality (24%), and the City of Pichincha (8%). Quality of service is ensured by the Department of Public Lighting. Agencia de Regulación y Control de Electricidad (ARCONEL) is the public agency responsible for regulating electricity rates. Residential and commercial customers pay for street lighting through a fee in their monthly bill.[187]

Public Lighting & Upgrades

The city of Quito has approximately 250,000 public lights, covering 99.9% of the city. The infrastructure is owned by EEQ, which is responsible for operating and managing the lamps. Since 2009, Quito has started to replace mercury vapor lamps with sodium vapor. In February 2014, Quito realized a LED upgrade project for its historical city center in a two phase project. Overall, a total of 2,940 114-Watt LED lights were installed every 20 meters,[188] accounting for the energy savings equivalent to 715,254 tons of CO_2.[189] This project has also included installation of a remote management system using GPRS and 3G networks to communicate lighting status to the managing utility company.[190] The total cost of the modernization project was estimated to be around USD 3 million, which is expected to be offset by the savings produced. Overall, this project was conducted to evaluate whether transitioning to a lighting network with LEDs and a remote management system is financially and environmentally opportunistic. The utility has recently created expansion plans and is ready to install LED lights in the tourist sites of El Panecillo, the Top of La Libertad and Itchimbía Park.

Funding

Local, state and federal government administrations work in collaboration to finance the public lighting network and energy efficiency projects. When broken down, it can be observed that the city budget is used for public lighting projects while the national budget, which is formed through tax funds, is used for energy efficiency projects. Quito also has an additional source of funding for its energy efficiency projects that is provided by the government. Currently, 80% of total energy efficiency funds come from this source, which correlates to around USD 20 million per year.[191]

Santiago, Chile:

Chile's capital, Santiago has a population of 6.5 million[192] people and a GDP per capita of USD 24,224. The city is approximately 641 km^2 in size.

Key Takeaways:

- Range of pilot efforts to promote energy efficiency via street lighting upgrades.
- Focus on public parks where pilot projects have involved solar LED and regular LED lights.

Energy Sector

Street lighting infrastructure in Santiago is owned by the municipality, but services such as operations and maintenance (O&M) are outsourced via service contracts to private operators. The municipality is broken up into various zones and it releases tenders for infrastructure projects. Private operators selected via tender for each zone are responsible for completion and maintenance of projects under the supervision of the city. The private operators involved in providing electricity and maintaining street lights in Santiago are subsidiaries of Enersis - a global energy player, which has a 60.63% ownership by Grupo Enel. In 1988, Enersis was divided into 5 businesses, two of which are Endesa and Chilectra. Endesa is the energy company that acts as the primary utility for Santiago. Its ownership structure is: 59.98% Enersis, 15% AFP, 4% ADR, and 4% minor shareholders. The Chilean Energy Efficiency Agency, AChEE (Agencia Chilena de Eficiencia Energética) acts as the regulator. Transmission, distribution and O&M for street lights is managed by Chilectra.[193, 194, 195]

Lighting Technology & Upgrades

Street lights are primarily sodium vapor, metal halide and fluorescent lamps. However, Santiago has witnessed a series of neighborhood-level pilot efforts to install LED lights, solar LED lights and remote management devices to increase the energy efficiency of street lights. Two notable efforts have been in public parks. Solar LED lights were installed in 2010 in Juan Pablo II Park[196] by Carmanah technologies, and a public bid to replace High Pressure Sodium lights with 90 Watt LED street lights in Parque Metropolitano (Santiago's National Park), was given to Enlogik.[197] Details on the number of lights replaced are not publicly available for these projects. The neighborhood of Nunoa[198] ran a pilot to replace 10,740 lights with more energy-efficient lamps to increase energy savings by 25%. A pilot by Kraftwerk[199] saw the installation of the "Power Controller" optimization device for street lights, and was implemented along the Tunel San Cristobal, one of Santiago's main thoroughfares. The effort was supported by Chile's Association of Public Infrastructure Works, and is projected to save 20-40% of energy costs. Kraftwerk has partnered with three of Santiago's largest municipalities - Puente Alto, Santiago, and Las Condes – to expand the effort. Smart City Santiago[200] is another effort launched by the Ministry of Energy and Enersis, and includes many interventions aimed at reducing overall energy consumption by 20% by 2025, including LED street lighting and remote management.

Santiago is also influenced by a number of national-level efforts by the Chilean government to implement energy efficiency upgrades for public lighting. The Energy Efficiency Act[201] proposed in Congress in March 2016, features an efficiency planning program for the replacement of street lighting. Enlighten 2020[202] is a nation-wide effort launched as a partnership in January 2016 between the Chilean government, Fundación Chile, the UNEP, Osram, Phillips and the National Lighting Test Center of China. The project is aimed at upgrading all street lights from incandescent lamps to LED and expects to save 4.8% of the country's electricity consumption per year. This implies a projected reduction of 1.2 million tons of carbon emissions and projected savings of USD 596 million by 2020. The project also seeks to set guidelines to create a business model for the recycling of mercury waste present in traditional lamps. Lastly, the Programa de Recambio Masivo de Luminarias de Alumbrado Público[203] is an effort led by the Ministry of Energy and is being implemented by the Chilean Energy Efficiency Agency. It aims to replace 200,000 street lights across the country with more energy efficient lamps over a period of 4 years. The first call for proposals was made in August 2014, and was closed in December 2014 for the replacement of

130,000 luminaires with a remote management system. The implementation phase began in 2015 in the town of San Clemente. There is currently limited information on the success of these large country-wide projects, despite the wide variety of technologies and goals planned.

Funding

Chilectra, the energy distribution company, is also responsible for the billing of electricity in Santiago. The tariff structure is defined and calculated by the regulator, considers both energy and capacity costs, and is different for high and low voltage networks. The tariff typically has the following components:[204]

- Fixed distribution costs
- Capacity payment at peak hours
- Capacity payment outside peak hours
- Cost of energy bought at power substations plus distribution losses

Street lighting is categorized as a low voltage network and has no direct metering for billing, but uses a monthly contracted energy measurement and capacity tariff called BT2[205] that has a fixed charge, a demand charge (max kW per month), an energy charge (per kWh) and a winter surcharge (per kWh).[206]

Street lighting is partially funded via a tariff to Chilectra, while a part of the funding is organized as a public-private partnership with Citelum.

As of April 2015, it was noted that Citelum continued their expansion and presence in Chile by also developing its public lighting activities with the contracts of Puento Alto, Rancagua, and Lo Barnechea.[207] Overall, Santiago and Citelum work together to deliver public lighting services to the citizens of the local community.

The city of Santiago currently uses both city and national budgets to finance their public lighting and energy efficiency projects. However, there have been talks and considerations to transition to an Energy Services Company (ESCO) model soon. Nonetheless, the process for this transition is yet to be enforced and is still at its early stages of conversations.[208]

A deeper dive into Santiago's sources of funding shows that The Division of Energy Efficiency (EE) funds Santiago's public lighting while the Chilean Energy Efficiency Agency (AChEE) funds the city's energy efficiency initiatives in collaboration with the EE.[209] AChEE is the organization that coordinates the public-private agenda and channels funding while, EE is the organization that provides technical assistance, such as for operations and maintenance of the bulbs.

São Paulo, Brazil:

São Paulo is the most populous city in the Southern Hemisphere, with a population of 11.9 million people.[210] It is also the most important city of Brazil's economy, representing 10.7% of its GDP.[211] As the largest city in the country, São Paulo has an average monthly electricity consumption of 50000000 kWh.212

Key Takeaways:

- The city is changing the way it manages its public lighting: it currently outsources O&M to two private companies and it will change to a PPP (process currently suspended), aiming to modernize all the lighting to LED in five years.
- High LED upfront costs were a barrier for the city to modernize the public lighting by itself.

Energy Sector

The energy sector in Brazil is regulated by a national public agency of electricity, Agência Nacional de Energia Elétrica- ANEEL. In 2010, ANEEL determined through national law 414/2010[213] that, starting in 2014, all municipalities would be responsible for its public lighting management. ANEEL's resolution remarks that cities can outsource the service to private providers through contracts per service delivered or through PPPs. São Paulo currently outsources the O&M of the network to two private companies: FM Rodrigues and Alusa. The electricity that is provided to the city is generated by Companhia Energética de São Paulo- CESP,[214] a joint stock company, mostly publicly owned. The transmission and distribution (T&D) of the electricity is done by AES Eletropaulo, owned 78% by AES Corporation, 20% by the national government, and the remaining 2% by investors.[215]

Public Lighting & Upgrades

Public lighting in São Paulo comprises 620,000 lamps, of which 50% are mercury vapor, 36% are sodium vapor, and slightly more than 14% are LED.[216] The lighting infrastructure is partially owned by the city and partially by AES Eletropaulo. AES does not charge the city for the infrastructure, only for electricity.[217]

The public agency responsible for managing the public lighting in São Paulo is ILUME. Currently, the agency outsources O&M to two private companies, as previously mentioned. The agency has a list negotiated with the companies that includes all services and related costs (considering material and labor), which is frequently reviewed and updated to incorporate price variability, such as falling costs for LED. All the material that is used is previously tested and approved by the city to ensure quality and performance.

In 2014, the agency launched a PPP tender to modernize all public lighting system to LED in five years (estimated energy savings are 52% for the PPP) and also include a remote management system in main streets (50,000 lamps). The main reason for this decision is the high upfront cost needed for the modernization plan. The company that wins the PPP will upgrade all the lighting to LED in five years, while the city will spread the payment in 24 years. The first stage of the process was a demonstration of interest, when eleven companies submitted studies and comments about the proposal. The process is currently suspended due to a legal procedure, started by one of the companies that was not allowed to participate in the tender. The tender had a lower adherence than expected, with three companies submitting final proposals. When talking to representatives from São Paulo's municipality,[218] it was clear that some companies did not submit proposals due to a high risk perceived related to financial guarantees and others did not have the infrastructure needed for a project of this size. When the PPP gets signed, it will be the largest in the world for public lighting. Costs and payment structures related to the current situation and the PPP can be found in Appendix C.

In 2016, IlLUME started the program “LED nos bairros” ("LED in Neighborhoods"), which is already in place in 14 areas of the city that were prioritized considering the Human Development Index and a vulnerability index. So far, 86,000 LED lamps have been installed in the regions with the lowest index values.[219] There is no research yet on the improvement of safety, however, the local population affirms that they feel safer and are now able to use the public space at night.[220] The agency is responsible to define where the modernization will take place, and the service is done by the two private companies. The project started because of the delay in the PPP process.

In October 2016, São Paulo elected a new mayor from the opposition party, to start in the office in January 2017. City’s representatives that were interviewed believe that changing parties will not affect the continuity of the process that is already in place.[221]

Funding

Funding for public lighting is provided through a charge on consumers’ electricity bill, the Contribuição para o Custeio dos Serviços de Iluminação Pública- COSIP (“contribution for payment of public lighting services”). This tariff is regulated and defined by ANEEL, and it is updated every January according to national electricity prices. In January 2016, COSIP increased 72%[222] in comparison to the previous year, due to a drought that affected the electricity price, as Brazilian's energy sector is mostly based on hydropower[223]. The budget for public lighting provided by the COSIP, amounted to R$289.6M (USD 89.49M) in 2015 and is expected to be around R$530.7M (USD 164M) in 2016. The yearly management planning is based on the expected budget, and according to Mrs. Fernandes, an ILUME representative, 2016 saw an above the average increase on the COSIP amount, which enabled the city to start installing LEDs before the PPP process was concluded, through the “LED Nos Bairros” (“LED in Neighborhoods”) program.

The Mayor's office tried to create a special account with revenue from COSIP to be managed by an independent third party. This account would be used to directly pay the PPP winner. However, the creation of this account was not approved by the local congress. Many companies saw this non-approval as a high risk on the financial guarantee of the project and therefore did not submit proposals.

Appendix C: São Paulo Public Lighting Cost Structure

All the conversion from Reais to US Dollars were done using a conversion rate of 3.236
The funding for public lighting comes from COSIP, a flat monthly tariff for consumers, in the electricity bill.

Consumer	COSIP in Reais (flat rate)	COSIP in USD
Residential	R$ 9,32	$2.88
Non-Residential	R$ 29,30	$9.05

Consumers with electricity bills lower than 80kWh and consumers that live in streets that do not have public lighting are exempt.

Currently, the O&M for public lighting is outsourced to two companies (Alusa and FM Rodrigues). The monthly payment is based on a fixed value of USD 6 M per month (USD 134M for 22 months of contract)[224] and a variable amount that depends on quantity and kind of services that were provided on that month. There is a list with all services and related costs (material and labor). This list is frequently reviewed and updated to incorporate price variability (for example, LED lowering prices). The average monthly variable amount was not disclosed by the Municipality.

Monthly payment = Fixed amount + Monthly variable according to services provided

As the public lighting system currently does not have a monitoring system, the electricity payment to AES Eletropaulo (T&D) is done monthly through a pre-determined formula.[225] The installation of LED lamps automatically reduces the cost, as the voltage factor gets reduced.

Payment structure in the proposed PPP tender:
In the proposed PPP, the monthly payment will be a fixed maximum amount (defined through the tender) with performance and quantity factors applied to it. The formula is shown below, with each factor described sub sequentially.

Monthly payment = 0.9*FDI*Max Payment + 0.1*FDE*Max payment[226, 227]

FDI: Availability factor (related to quantity of lamps)

FDI= (FDIa x Ia) + (FDIb x Ib)

Ia= percentage of the public lighting that was not modernized yet (starts at 100% and in 5 years gradually goes to 0%).
Ib= percentage of the public lighting that was modernized.

FDIa:

x= (1- di/Di)
di= number of non-modernized bulbs operating well
Di= total number of non-modernized bulbs

If x<= 4%, then FDIa= 100%

If x> 4%, then

FDIa= y(x)= ((e^(-x-0.4586)- 0.5820)
e = 2,718281828;

This will be verified based on a monthly check of a sample of at least 3,000 lamps.

FDIb:

x= (1-ti/TI)
ti= amount of time that bulbs were on
TI= amount of time that lamps should have been on

If x<= 1%, then FDIb= 100%

If x> 1%, then

FDIb= y(x)= ((e^(-x-0.4586)- 0.5820)

This should be measured by remote metering

FDE: Performance factor (related to quality)
FDE=NI*(P1*A1+P2*A2+P3*A3+P4*B1+P5*B2+P6*B3+P7*B4+P8*C1+P9*D1+P10*E1+P11*E2+P12*F1+P13*F2+P14*F3)

Variables	Initial 5 years	Following years
A1= % of non-modernized bulbs off during the day	P1=0.06	-
A2= % of modernized bulbs off during the day	P2=0.06	0.07
A3= minimum level of uniformity	P3=0.09	0.1
B1= % of urgent calls attended on time	P4=0.09	0.1
B2=% of non-urgent calls attended on time	P5=0.06	0.07
B3= % of non-modernized bulbs in tunnels on during the day	P6=0.06	-
B4= performance of sub-districts	P7=0.03	0.03
C1= Reliability index	P8=0.16	0.2
D1= Expansion rate	P9=0.06	0.07
E1= Data convergence rate	P10=0.03	0.03
E2= Time to update	P11=0.03	0.03
F1= Availability rate of the remote management system	P12=0.09	0.1

F2= Compliance rate in the information transmission	P13=0.09	0.1
F3= Compliance rate in the scan of information	P14=0.09	0.1

NI= minimum level of lighting
NI= pi/PI *100%
pi= luminance factor of bulbs
PI= total of bulbs
Max payment= defined through the tender

Cost estimation for the PPP:[228]

To calculate the cap value of the tender, the city considered fixed investments and variable costs that the winning company will have to bear. Fixed investments include mainly vehicles to monitor the public lighting and a call center. Variable costs include the remote metering system and the LED lamps.

Itens	Includes	Reais	Dollars
Total		2 Billions	620.8 M
Fixed investments:		115.3 M	35.6 M
Vehicles	88 Vehicles	54 M	16.7 M
Call center	Building infrastructure, operational infrastructure, system integration, equipment, software, furniture	61 M	18.85 M
Variable		1.9 billions	585.2 M
Remote metering	for 50,000 lamps	351 M	108.5 M
Public lighting	modernization of 580,604 lamps to LED and 76,000 new LED lamps	1,542 M	476.51

The price of LED used for calculation if the following, with an expected reduction of 2% per year and an expected lifetime of 12 years.

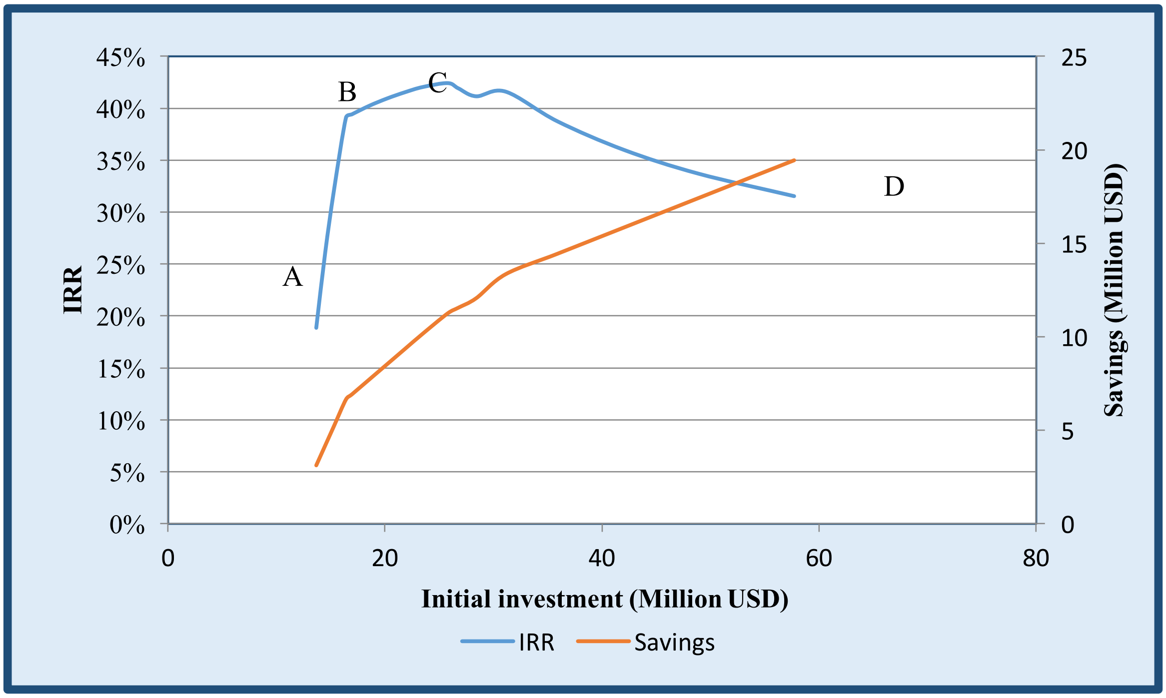
Estimated cost of LED	R$1241.78	USD 383.74	for modernizing lamps
	R$2500	USD 772.56	for new lamps

The O&M estimated cost per month is the following

O&M- current	R$10 per month per lamp	USD 3.09
O&M- modernized lamps	R$ 6 per month per lamp	USD 1.85

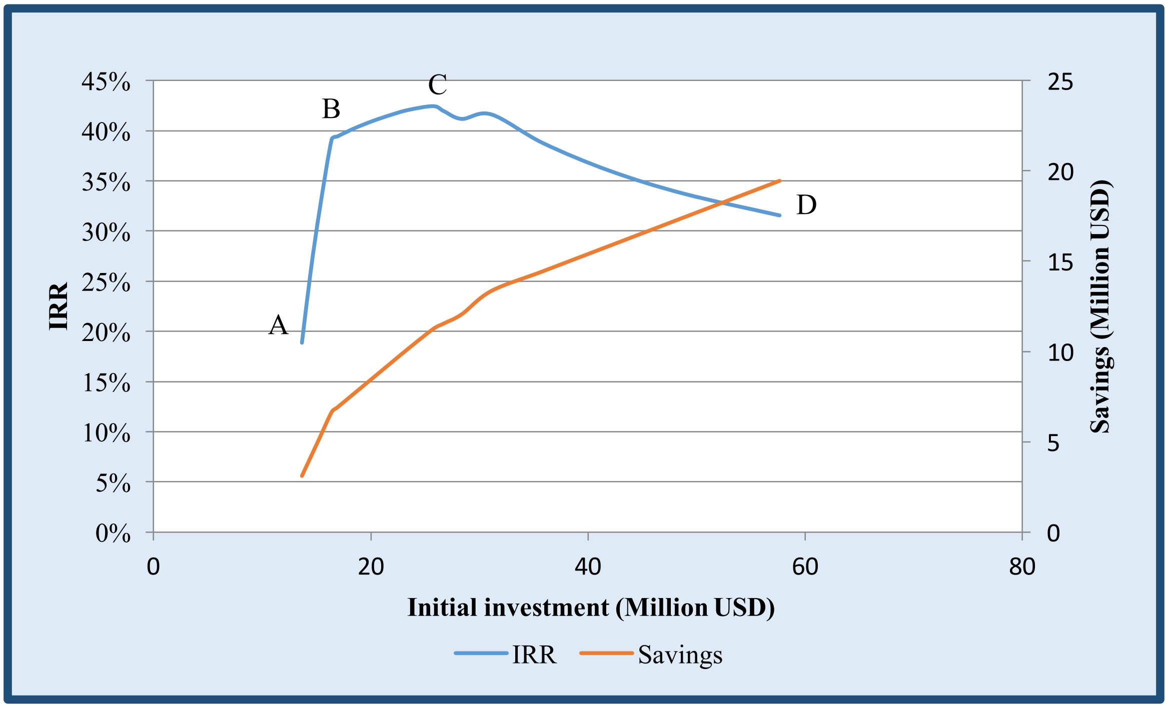
Appendix D: Additional Lighting Models

Alternative Case 1: HPS Prices are Half of LED Prices



Scenario	Lights Replaced				Investment (USD)	IRR	Simple Payback (years)	Savings (USD)
	70W	150W	250W	400W				
A	100,000	0	0	0	$13,646,623	25%	3.6	$3,765,993
B	33,045	66,955	0	0	$16,385,218	44%	2.2	$7,418,653
C	0	66,955	19,437	13,608	$25,756,147	47%	2.1	$12,460,088
D	194,806	66,955	34,767	13,608	$57,676,918	0	3	$22,139,330

Alternative case 2: HPS Prices are One Third of LED Prices



Scenario	Lights replaced				Investment (USD)	IRR	Simple Payback (years)	Savings (USD)
	70W	150W	250W	400W				
A	100,000	0	0	0	$13,646,623	19%	4.4	$3,129,150
B	33,045	66,955	0	0	$16,385,218	39%	2.5	$6,654,009
C	0	66,955	19,437	13,608	$25,756,147	42%	2.3	$11,258,135
D	194,806	66,955	34,767	13,608	$57,676,918	0	3	$19,447,741

Endnotes

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