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Sustainable infrastructure development: Assessing LED street lighting as a tool for sustainable development in São José dos Campos, Brazil.

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Prefeitura de SÃO JOSÉ DOS CAMPOS
Trabalho que toca a cidade

Foreword

This thesis is being written for the Master's of Science program, Sustainable Development. The author is enrolled in the International Development track of the Master's program and is also submitting the thesis as the final component of the thesis annotation entitled, Sustainable Entrepreneurship and Innovation. The research project was conducted in collaboration with the city of São José dos Campos, Brazil and was overseen by the Faculty of Geosciences of Utrecht University. The research was conducted over a ten week period and comprises of two main sections: a section on the impacts of LED (light emitting diode) street lights and a section on the case study of São José dos Campos. This first section investigates the primary and secondary effects of LED street light projects around the world. Primary effects are defined as changes in energy consumption, maintenance intensity and overall financial expenditure. Secondary effects are defined as impacts resulting from a change in the light source (LED vs. conventional). The second section focusing on São José dos Campos as a case study investigates what impacts LED street lights could have on the city and how an LED retrofit project could be implemented.

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Acknowledgments

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Abstract

This research project investigates LED street lights as a tool for sustainable development in São José dos Campos, Brazil. The project explores the energy and maintenance impacts of using LED in the place of conventional street lights by assessing the LED street light retrofit projects of eighteen case study cities. These case studies are also analyzed for the secondary impacts of LED street lights resulting from a new light source. Using an example LED street light (Lumi R-Series), projections are made for São José dos Campos on the potential energy and maintenance effects of LED street lights compared to the existing street light network. The final part of the research addresses the local municipal government's interest of how to implement a street light retrofit project in São José dos Campos while stimulating economic development through the creation of a local LED lighting company. The results show that energy and maintenance expenditures were significantly reduced in each of the eighteen case studies as a result of implementing LEDs. Data also indicated that some secondary benefits were caused by the use of these street lights including reduced criminality, increased road safety, positive public perception and reduced light pollution. The projections for São José dos Campos suggest an energy savings of at least seventy percent and a payback period of just over ten years. Finally, a project implementation strategy, via a build-operate-transfer public-private partnership, is suggested to the city of São José dos Campos as the most feasible method to achieve the city's development goals and overcome the challenges of such a significant infrastructure improvement project.

Keywords: São José dos Campos; Brazil; LED; street lighting; urban development; public-private partnership; energy efficiency

Introduction

Public lighting accounts for 19 percent of global electricity consumption and 6 percent of global carbon emissions [The Climate Group, 2012]. Around the world, city street lighting is estimated to consumed 159TWh of electricity and can account for up to 60 percent of a municipal government's electricity expenditure [CCI, 2010a]. With over 500 million street lights worldwide [CMU, 2011], and more being installed every day as urban centers grow, street lighting is increasingly a topic of relevance in the push for global sustainability. As of 2011, the European and American street lighting networks were made up of 47 and 59 percent sodium pressure lights (respectively), 32 and 20 percent mercury vapor, 3 and 5 percent metal halide, and less than one percent LED (CCI, 2010a). This highlights the relative newness of LED street lights compared to the conventional pressurized gas lamps. The global street lighting market is expected to grow by 60 percent to US$160 billion by 2020 as urban areas continue to expand [The Climate Group, 2012]. This coupled with the fact that LED street lights represent less than one percent of all street lights currently in use creates a significant economic opportunity.

In Brazil, public lighting accounts for approximately 4.5 percent of the national energy demand and 3.95 percent of the total consumption of electricity in the country [Eletrobras, 2013]. Accord to a 2008 survey conducted by the Eletrobras (national energy company), there are 15 million public lighting units installed in the country consuming 9.7 billion kWh per year [Eletrobras, 2013]. The street light system in Brazil consists of 63 percent sodium vapor, 32 percent mercury vapor; with incandescent, fluorescent and metal halide making up the remaining 5 percent.

This thesis centers around LED (light emitting diode) street lights and their applicability to the challenge of sustainable development. The research investigates the multi-dimensionality of LED street lighting technology and it's potential contribution to the sustainable development of an urban area. The project utilizes quantitative and qualitative data gathered from cities already using LED street lights to assess the primary and secondary effects of LED street lights on urban development. Primary effects are defined as changes in energy consumption and maintenance intensity of the street light network; and the associated expenditures. Secondary effects are defined as those resulting from a new light source (light from LEDs differs from light from conventional sources).

The second portion of the study examines how an LED street light retrofit project can be implemented in the city of São José dos Campos, Brazil. São José dos Campos was chosen as the focus for a hypothetical retrofit due to their interest in LED street lighting and the city's status as a technological and industrial leader in Brazil and the South American region. Projections are made for the potential primary impacts of the use of LED in São José dos Campos street light network. Finally, drawing on the results from the case study cities and projections for São José dos Campos, a project implementation strategy is researched and suggested. This final section, focusing on public-private partnerships, was requested by the Municipality of São José dos Campos as they are interested not only in the effects of LED street lights, but also in how a city with limited financial resources can bring to fruition this infrastructure improvement project.

The final part of the report focuses on creating an implementation strategy for São José dos Campos and explores various forms of public-private collaboration in the field of infrastructure projects. The research on public-private partnerships (PPPs), and resulting proposed strategy, stems from the city's desire to not only retrofit existing high pressure sodium lights with LED but to also encourage local economic development. Lighting and LED technology are industrial sectors with limited development in São José dos Campos and the city government hopes to develop these sectors further to remain on the forefront of Brazilian and South American industrial innovation. By partnering with an LED street light manufacturer and utility company, via a PPP, it is hoped the city can accomplish both goals.

Theoretical Framework

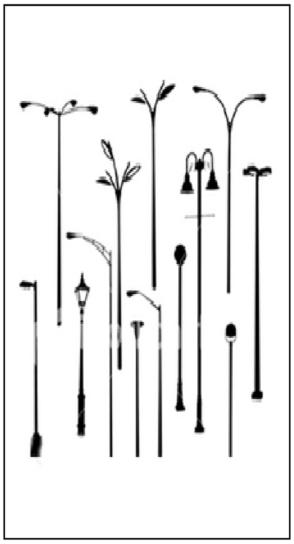
The following section explores the nature of street lighting today and presents the background information on the topic. Within this chapter the different forms of streets lights and LED technology are presented, including the technical information necessary to understand the differences between different types of street lighting. Following the background information, public-private partnerships are explained in order to recognize the conditions under which different forms of public-private collaboration occur.

Street Lights

Street lights are elevated light sources, used to illuminate roadways. Standardized street lighting was first used in Cordoba, Spain in the 10^{th} century by the Moors [CMU, 2011]. These first street lights were kerosene lanterns and street lighting has since undergone many technological changes. In the 15^{th} century, street light lanterns used wax, tallow, pith and fat wicks to create an enduring and uniform light source. In the early 19^{th} century, street light lamps burned coal gas, but by the end of the 1800s, street lights were utilizing electrified arc lamps and incandescent bulbs [CMU, 2011].

The street lighting we see today is almost exclusively electric and the most common light sources are sodium vapor, mercury vapor and metal halide luminaires. These fixtures are found in cobrahead (conventional L-shaped lights over most roads) and decorative free standing varieties (simple vertical pole). High pressure sodium, mercury vapor and metal halide are high intensity discharge (HID) lights whereas low pressure sodium is a standard discharge variety. Street lights are judged in four main categories; color rendering (the amount of spectrum colors emitted by the light source), color temperature (the temperature of the light in Kelvin), efficacy (efficiency, measured in lumens per watt) and lifetime (hours). The Color Rendering Index (CRI) indicates how closely a light source can reproduce the light spectrum produce by natural light. The higher the CRI, the more accurately it mimics natural lighting conditions, illuminating objects correctly. Correlated Color Temperature (CCT) indicates the dominant color tone in white light. CCT is measured in Kelvin and colors less than 3200K are considered 'warm' colors (yellow and red) whereas colors above 4000K are considered 'cool' (blue), temperatures in between are considered neutral [RPI, 2004]. Efficacy is a measure of lighting efficiency (measured in lm/W) and indicates how much light (lumens) is produced per watt of electrical energy. The pictures below show the two main types of street light; cobrahead and decorative fixtures. Cobrahead fixtures are by far the most common, being used in the majority of street light networks, whilst decorative fixtures tend to be used in city centers where traditional aesthetics and historical value are important.

Various street light types (Fig.1) ***Cobrahead fixture (Fig.2)*** ***Decorative fixture (Fig.3)***

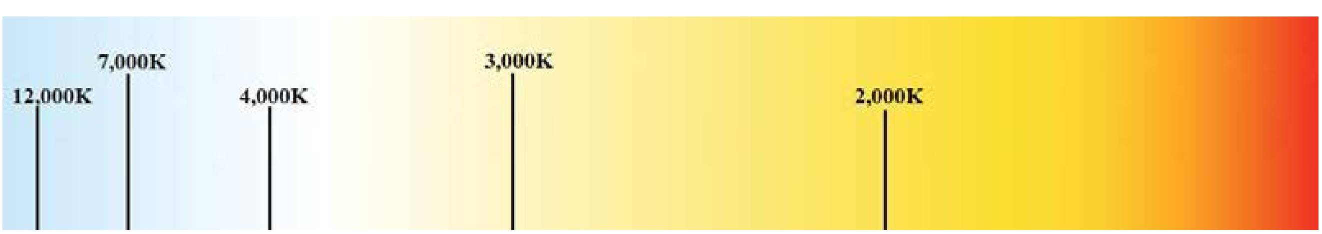


[LEDEL, 2013] [CoP, 2013] [Sternberg Lighting, 2013]

Sodium vapor lights employ sodium gas in an excited state to produce a dull yellowish light. Low pressure sodium (LPS) lights contain a solid piece of sodium metal inside a glass tube filled with neon and argon gas. When electricity is passed through, the sodium metal starts to glow pink and red until the sodium vaporizes, at which point it starts to emit yellow light. These lamps emit an almost completely monochromatic light that results in two effects [Luginbuhl, 2007]. The first is that objects are difficult to see as a result of a single color bandwidth being reflected (most objects are seen as black and white/yellow due to monochromatic light). Secondly, LPS lights cause little light pollution, making them popular around astronomical observatories. LPS lights are the most efficient street lights and have an efficacy of between 100 and 190 lm/W and a lifetime of 18,000 to 24,000 hours [Schiler, 1992].

High pressure sodium (HPS) lights are very similar to LPS lights but the sodium element is kept in a high pressure environment which results in a boarder spectrum of emitted colors. This makes color rendition easier (color recognition) and allows for better vision in dark environments due to more colors being reflected off illuminated objects. HPS street lights are the most common variety of sodium pressure lights used in street lighting and have an efficacy of 50 to 140 lm/W, a lifetime between 16,000 and 24,000 hours [DoE, 2013a] and a CCT of 2,100K [Schiler, 1992].

Correlated Color Temperature Spectrum (Fig. 4)



[DoE, 2008]

Mercury vapor lights (MV) are the oldest variety of HID (high intensity discharge) lights and use an electric arc through a tube of vaporized mercury. These lights produce around 50 lm/W, operate at 3600 to 7,000K [Schiler, 1992] and have a lifetime of 16,000 to 24,000 hours [DoE, 2013a]. MV lights are often replaced with HPS lights for greater energy efficiency.

Metal halide (MH) lights are very similar to HPS lights with the exception that metal halide gas (iodine and bromine compounds) is added to the mercury gas. This has the effect of giving MH lights the best color rendering properties and creating a bright white light at 4,500K [Schiler, 1992] as opposed to the yellowish light of mercury and sodium vapor lights. These lights produce between 75 to 100 lm/W but have much shorter lifetimes of 5,000 to 20,000 hours [DoE, 2013a].

250W HPS (Fig.5)

[Stoughton Utilities, 2010]

400W Metal Halide (Fig.6)

[Lightmart, 2013]

250W Mercury Vapor (Fig. 7)

[Munday, 2012]

Light Emitting Diode (LED) Technology

Light emitting diodes (LEDs) are semiconductors that glow when a current is applied and are used in various electronic products as indicators or light sources. The creation of LED technology is credited to Dr. Nick Holonyak of General Electric who published a paper in October 1962, defining LEDs “as visible light emitters based upon minority carrier injection and radiative recombination of excess carriers” [Bush, 2012]. Essentially, LEDs are thin wafers of silicon that emit light when a current is passed through them. By 1987, LED technology was advanced enough that the LEDs themselves could be used (in large numbers) as light bulb replacements and started to permeate the consumer goods market. Today LEDs are seen in many products such as flashlights, vehicle brake lights, television screens and other consumer products.

LED street lights were developed in the 1990s but cities and municipalities only started to deploy them in the late 2000s. This has been due to the relatively high cost of LED street lights compared to conventional street lights (HPS, HM and MV) but recent advances in technology have reduced the price considerably [Uhlenhuth, 2013]. Xcel Energy, an American Midwestern utility company, estimates that at present HPS and MH fixtures cost between $60 to $100 per fixture (in a medium volume contract) compared to $200 to $300 for basic LED fixtures [Bieging, 2013]. Today the largest manufacturers of LED street lights are Phillips, GE, Osram, BetaLED, Cree and Leotek.

The main components in LED street lights are multiple LEDs (usually about 1-2W per LED), the fixture cover and a heat sink. The heat sink is a layered piece of metal used to dissipate heat via its large surface area. These LED heat sinks are similar to other heat sinks used in computers and other consumer goods. Most LED street lights have the LEDs facing downwards, making the fixture relatively slim and streamlined compared to existing HPS, MH and MV fixtures.

120W BetaLED (Fig.8) ***96W Lumi R-Series (Fig.9)*** ***Acpaltech 50W Solar LED (Fig.10)***

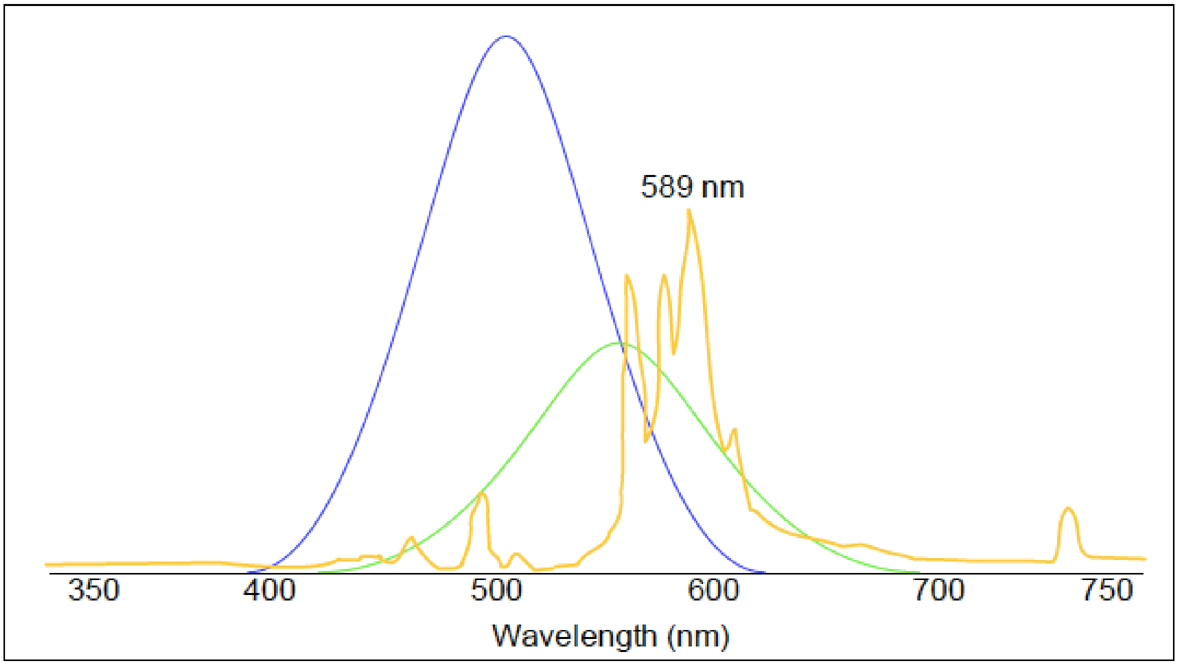
[Gleberman, 2010] [Desigence, 2013] [Acpaltech, 2013]

The LED street light used in this project for the São José dos Campos retrofit scenario is the R-Series from Lumi Group Oy (above right). The main difference between the Lumi street light and other competing LED models is the upward facing LEDs. The LEDs face upward, directing light into a orthodontist-style refracting mirror, giving the fixture a very even distribution of light on the ground below. The LED heat sink is consequently facing downwards whereas the BetaLED (far left) heat sink is above the LED fixture (above left). A relative newcomer to the street lighting market is the solar-powered LED street light. These are typically used in rural locations, military bases and in situations that require energy independence (e.g. emergency lighting).

Vision and Light Sources

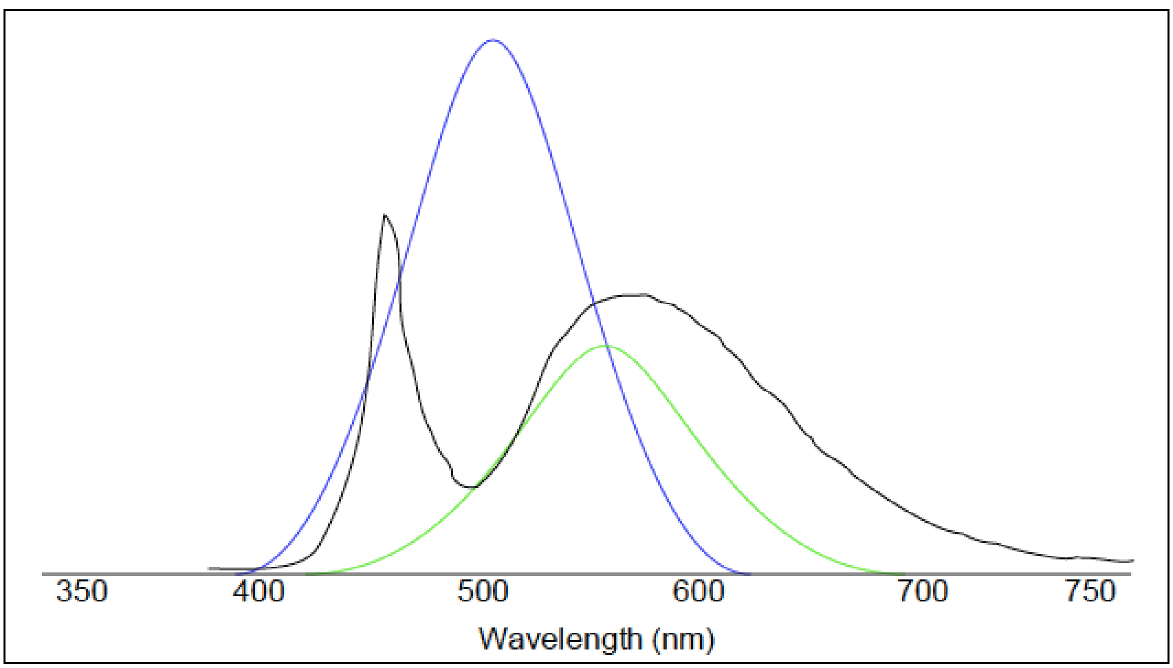
Human perception of light follows two distinct spectral response curves depending on the level of light. The photopic spectral response curve is most important during daytime, and depends on the 'cones' in human eyes, which enable us to see in color. During low light or near dark conditions, perception follows the scotopic response curve, which depends upon the 'rods' in the human eye (monochromatic light receptors). At moderately low light levels however, such as those encountered during nighttime roadway lighting, both the photopic response curve and the scotopic response curves are important as both rods and cones are active. This is known as the ‘mesopic’ range [Energy Solutions, 2008]. Figure 11 and 12 show the distribution of light from high pressure sodium and LED street lights. The blue line shows the scotopic vision spectrum, the green line shows the photopic vision spectrum and the orange and black lines show the distribution of light from HPS and LED sources respectively.

HPS light distribution (orange line) according to light wavelength (Fig.11)



[Osler, 2009]

LED light distribution (black line) according to light wavelength (Fig.12)



[Osler, 2009]

LEDs and high pressure sodium lamps emit light with different physical properties, and these properties affect the effectiveness of the light source for street lighting purposes. LEDs emit light across a broader spectrum of wavelengths than high pressure sodium lights. LEDs emit most light between 425-700nm and high pressure sodium bulbs typically produce most light between 500-625nm [Osler, 2009].

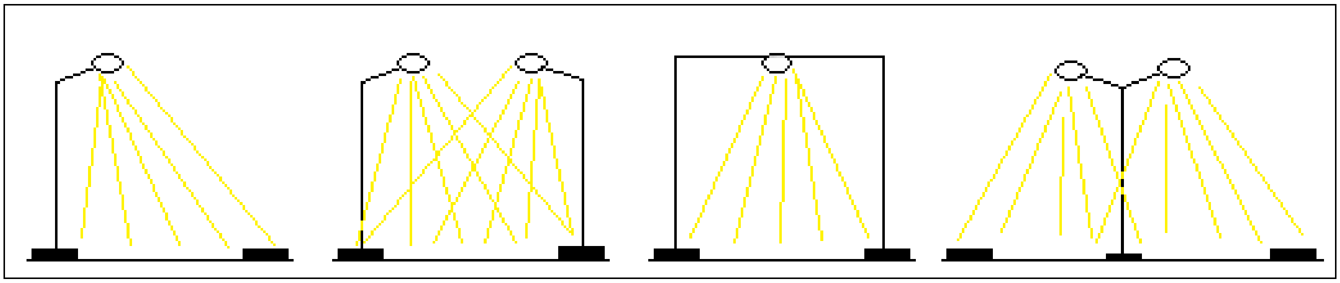
The human eye detects light between 400-626nm, with photopic vision (well-lit conditions, green line) occurring between 450-700nm and scotopic vision (low light conditions, blue line) occurring between 400-625nm [Osler, 2009]. The charts suggest that more of the light emitted by LED sources is detected by the eye than the light of HPS sources. This in turn suggests that LED street lighting is more effective at illuminating the street than HPS lights. Furthermore, due to the fact that LEDs produce more light in the scotopic visual range, vision in low light conditions may be enhanced. This could have positive effects on the surrounding urban area such as making the area more appealing to residents and increasing pedestrian and vehicle safety.

Currently, almost all photometric tests used to evaluate light output from street lighting sources are based on photopic vision, which is not representative of the human response to light under low light conditions (the conditions under which street lights operate). Photopic measurements favor 'warmer' light, such as the yellow light produced by high pressure sodium lamps. Scotopic and mesopic measurements represent a broader spectrum of light, including the 'cooler' light generated by most LEDs used in street lighting applications [Berman, 2005]. Because of these differences, many leading scientists and lighting experts believe that photopic measurements should be used for daytime and indoor lighting measurements, and scotopic and mesopic measurements should be used to evaluate nighttime lighting.

As most photometry is based on photopic measurements, a scientific conversion factor is used to create scotopic values from photopic data. Data from Dr. Sam Berman's research on light levels shows that a 50W high pressure sodium light with 4,000 initial photopic lumens provides only 2,480 initial scotopic lumens based on the 0.62 conversion factor. Conversely, a typical 4,100K light source (typically used in LED street lighting) with the identical 4,000 initial photopic lumens provides 6,642 initial scotopic lumens based on the reversed 1.62 conversion factor [Berman, 2005].

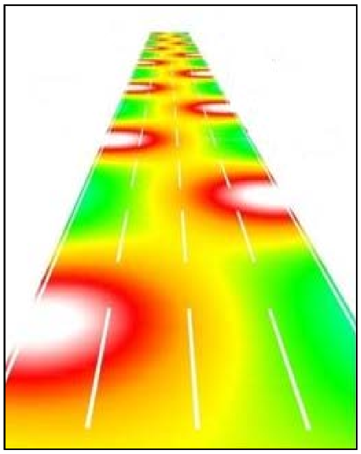
The effectiveness of street lighting is dependent on not only the light source but the arrangement of the light poles. There are five main types of street light arrangement; one-sided, even (both sides) and staggered (both sides), central overhead and dual-central lighting. One-sided lighting is used primarily on smaller roads, overhead is used mainly in city centers, central dual lighting is used for larger roads (such as highways); and even and staggered lighting on both sides of the street are the most common. The diagrams on the following page show these arrangements.

The main types of street light arrangement (one-sided, both-sided, overhead, dual central) (Fig.13)



[ANEEL, 2010]

Light distribution of staggered (both-sided) street lights as shown by a color gradient (bottom left, Fig.14) and uneven street lighting in practice (bottom right, Fig.15).



[LEDEL, 2013]

[Kligman, 2011]

The diagram above shows the light distribution of HPS street lights with white and red areas being the brightest and green areas being the dimmest. This diagram highlights the importance of proper street light placement and shows how roadways can be unevenly illuminated even when placement is uniform. Currently, standards for roadway lighting levels are currently written only for photopic levels, neglecting the scotopic spectrum, leaving much room for improvement of roadway lighting standards [IESNA, 2013].

Health and Safety

Governments around the world have primarily implemented street light improvement projects for safety reasons. This is because having a well-lit road or pathway can reduce the number of traffic accidents [ROSPA, 2013]. This is especially true for periods of adverse weather conditions (rain, fog etc) when accidents are much more probable [Wanwik, 2008]. Another safety aspect of urban lighting is it's impact on crime. Street and area lighting has been found to reduce crime by up to twenty percent in studies in the UK [Farrington & Welsh, 2004]. Similar studies on crime have found that the presence of lighting in urban areas has significantly reduced the number of emergency calls made to police [Quinet

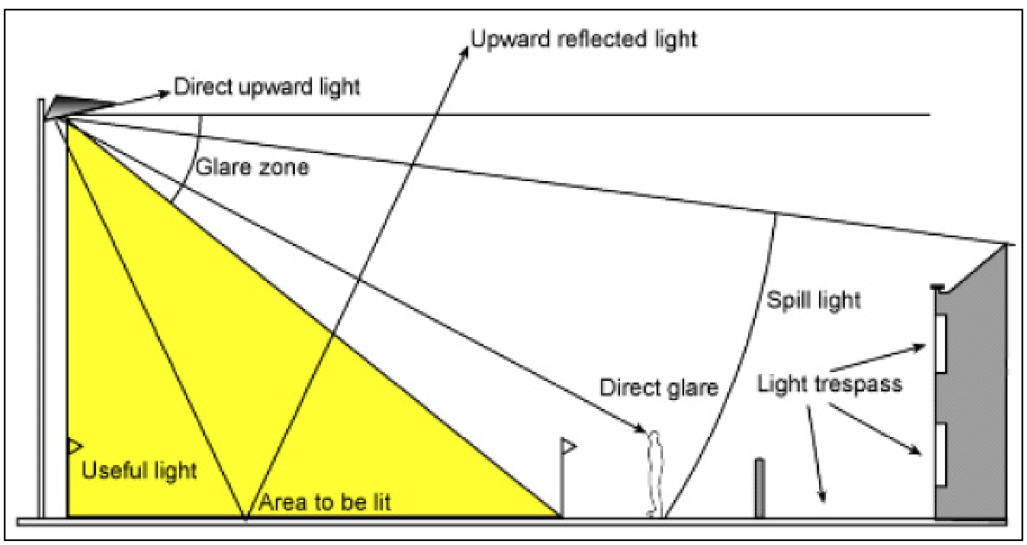
& Nunn, 1998]. This not only increases residents' safety but also reduces the time and money spent by police on redundant calls for service instigated by resident fear alone. Other studies, which contest the crime prevention effectiveness of urban lighting, have determined that the presence of light gives local residents a feeling of security and increases the pride of the community, which they deem to be a significant benefit of urban lighting [Herbet and Davidson, 1994]. This perceived safety can boost morale and pride, which is important to people's mental well-being and can help attract new residents and businesses to the area.

Light Pollution

Light pollution is detrimental to a community as it can negatively impact the amount of rest people get at night [Shi, 2010]. This affects rest duration, quality and effectiveness at work or school. Furthermore, sleep-dependent biological rhythms and cycles in our body are negatively impacted by the effects of light pollution on sleep and these have been documented to cause unhealthy hormonal imbalances [Shi, 2010]. As well as negatively affecting local human populations, light pollution negatively affects local wildlife populations, especially nocturnal species [Guynup, 2003]. In their research Hölker et al found that there is up to a twenty percent increase in artificial light sources per year, and as a result there is a need for more research on effective lighting policies and the type of technologies that can reduce the impacts of light pollution [Hölker et al., 2010].

LED street lights can also have an effect on the development potential of a community in an urban area through the light they produce. Should LED street lights illuminate the streetscape more effectively and evenly, then there may exist some implications for public safety and urban quality. If an urban area is better lit we can hope to expect positive impacts on the utility of an area and the safety of local residents. These impacts can enhance a community's development potential as a safer and more appealing urban area is more likely to attract new residents and businesses. The diagram below shows how light emitted from street lights can result in light pollution. The three types of light pollution are upward reflected light (which leads to skyglow, often a yellow haze in the night sky), light trespass or spillover (light entering private property) and direct glare.

Light pollution resulting from street lighting (Fig.16)



[PTL, 2013]

Public-Private Partnerships

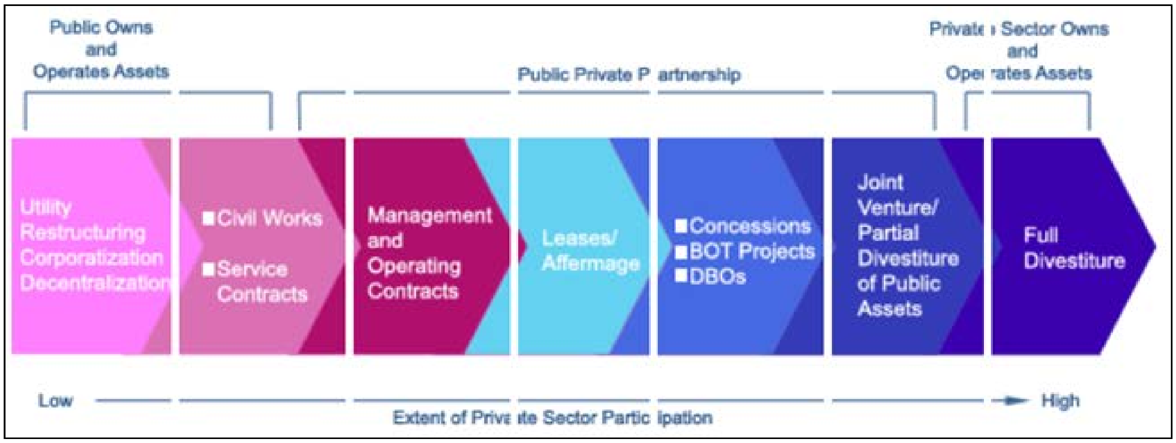
Public-private partnerships (PPPs) are joint initiatives usually carried out by a government entity and a private company in order to deliver a public good or service [PPIAF, 2012]. The European Commission defines PPPs as “the transfer to the private sector of investment projects that traditionally have been executed or financed by the public sector”. These types of partnerships exist in the industrial (product development), health care and infrastructure sectors; and often comes to fruition when a government agency is unable to achieve a desired goal (level of service provision). The reasons why a government agency may not be able to provide a necessary service is often linked to lack of expertize or financial resources. In these cases, a private firm can provide the necessary capital and expertize to facilitate a project and receives financial returns in the form of payments over time. Another reason governments enter into these agreements is to decrease the project timeline and be able to provide the necessary services on a much shorter timescale. Furthermore, since private firms are generally very knowledgeable in their field, the quality of service provision can be higher than if a government department or agency were acting alone [PPIAF, 2012]. Private firms choose to enter into these agreements because of the scale of the project or order, allowing them to receive substantial financial compensation. Furthermore, since these projects are often in the infrastructure sector, they can be in operation for decades, allowing the firm to reap the rewards for many years.

Investment in public infrastructure projects in Brazil has been of growing concern and significance since the 1970s when investment in infrastructure was 5.4% of GDP [IADB, 2007]. By 2005, that level of investment had fallen to 2%. This lack of investment, coupled with a growing economy and burgeoning middle class, have caused the national infrastructure network to fall behind growing national demand. As a result of continued Federal Government spending cuts and lack of expertize, and the resulting weakening the public sector's capacity to plan and execute new projects, it has become paramount that the private sector partake on the required infrastructure investments, either through direct investment or by joint ventures with the government [de Sa Almeida, 2004]. Today, PPPs have been used in many Brazilian states to address projects of national importance. These have not only been in the infrastructure sector (highways, sewage treatment, dams etc) but also in the healthcare, prison and public buildings sectors.

The Different Forms of PPPs

According to the World Bank's PPP in Infrastructure Resource Center there are thirteen different types of PPPs that are used in infrastructure projects. These PPP forms are shown in the figure 17, with PPPs with low levels private party involvement on the left and high private party participation on the right.

The different PPP forms according to degree of public-private collaboration (Fig.17)



[World Bank, 2011]

Utility Reform and Restructuring are defined as government efforts to increase the operational efficiency of public utilities. Reform efforts are done to increase transparency in all areas and to allow accountability to stakeholders. These area often executed when a public utility such as electricity provider has significant inefficiencies is production and distribution of energy and costs have reached unsustainable levels – rendering the public service a loss maker. Management efficiency is enhanced by creating a performance plan with measurable deliverables or creating a performance contract between the utility and the municipality or relevant agency. These types of agreements create a strategy for monitoring performance and foster institutional capacity building by training management to meet performance standards and exceed expectations by hiring new or additional human resources with necessary skills and expertise [World Bank, 2011]. These contracts use incentives (usually bonuses) to encourage the desire to exceed performance expectations .

Restructuring entails creating a separate unit (within the department or municipality) as a first step in introducing the private sector to utility and public good provision. This is done in examples where a large department or utility needs to be divided into smaller units such as distribution and maintenance units to recover operational efficiency. An example of this is water management agencies where monitoring, compliance and enforcement would become separate from customer services. This involves creating a workforce specifically allocated to the newly created utility unit. Separate accounts are drafted for the utility with clearly defined budget allocations and greater transparency regarding the actual costs of operation and maintenance. Finally, a clear reporting structure is utilized to increase transparency and to enhance operational efficiencies through the logging of accurate service information [World Bank, 2011].

Corporatization involves creating a separate legal entity and hence the transfer of control is more robust than with utility reform. Managerial and financial autonomy is also a key feature and management personnel have total control over all inputs and aspects pertaining to production of services. As the name suggests, the new legal entity adheres to company law and accounting regulations of the host country and the corporate unit has all assets and liabilities transferred to it in order for full operational independence to take place. A Board of Directors represents shareholder values, maintaining it's independent status and includes a rigid budget structure, making the organization fully accountable for its financial performance [World Bank, 2011]. This allows the company to retain excess revenues whilst holding it accountable for any losses incurred. In cases of extreme mismanagement and insolvency, liquidation represents the last solution. Examples of this are the electrical energy generation sector where a corporation may take over a large infrastructure installation such as a hydroelectric dam from the state energy company.

Civil works service contracts, management and operating agreements, usually awarded to ESCOs (Energy Service Company) in the energy sector, involve the private partner (operator) being paid a fixed fee by the municipality for executing specific tasks. This compensation does not depend on the collection of tariffs and the ESCO does not usually take on the risk of asset condition [Feslinger, 2008]. However, when management contracts become tied to performance, they tend to mandate that the operator assumes more risk – for example asset condition and replacement of equipment. These agreements tend to be short-term in nature, running from two to five years. Many of the existing LED street light projects fall under this category of public-private collaboration. These types of contracts also exist for road and utility (electricity grid etc) maintenance contracts and water and sewage treatment contracts. These types of contracts have been utilized in transitional arrangements for the gradual introduction of the private sector into managing infrastructure.

Long-term operation and maintenance contracts are increasingly popular in the water and energy sectors where more expansive and comprehensive participation by the private sector (via lease, affermage or concession) in these essential 'strategic projects' is considered to be too politically sensitive or cumbersome [Cavali, 2013]. These operations agreements tend to have limited potential for efficiency and performance improvements. However more sophisticated agreements can introduce financial incentives for improved efficiency or bill collection and in some cases a part of the remuneration is tied to the fulfillment of performance targets [World Bank, 2011]. These more multilayered contracts cover longer periods of time as more extensive monitoring is required to observe changes in operational performance. Finally, the structure of human resources remains largely unchanged as the ESCO simply adds a management layer over the existing utility workforce (this can cause problems in staff relations as existing staff sometimes look to the old management for instructions and resist the authority of the new 'over-their-head' hired management team).

Concession agreements give the operator of the utility network a long-term right to utilize existing utility assets. This also includes responsibility for operation, maintenance and investment. In these contracts asset ownership is held by the municipality or government body and control over these assets reverts back to municipal control at the end of the concession [Feslinger, 2008]. All capital investments made by the operator during the concession are handed over to the municipal body upon termination of the agreement. In most concession contracts, the operator collects revenues directly from the service consumer and thus it has a direct relationship with the consumer [World Bank, 2011]. Concessions typically last for between 25-30 years and the operator takes fully responsibility of the condition of the assets. Concessions are unique in the way that the contract emphasizes outputs, meaning the provision of a service according to contractual performance standards. By focusing on the outputs, the operator is given the autonomy to decide how to provide the agreed upon service through a range of inputs [World Bank, 2011]. Concessions exist in the mining and forestry where the contractor leases the right to use the land from the government and also gives a portion of the profits to the owner (government). These types of agreements also exist in infrastructure, such as highway projects.

A Build-Operate Transfer (BOT) project is most often used to develop, construct or refurbish an asset, and is usually a new 'greenfield' construction project (new construction). In BOTs the service company or operator typically obtains it's income stream through a fee (sometimes fixed) charged to the municipality, instead of tariffs collected from users of the service [Feslinger, 2008]. The service provider or operator finances, owns and develops the asset or system and operates and maintains it for the concession period. After the concession period, the asset is transferred to the ownership of the municipal authority. In these cases, the 'operator' or 'service provider' is a 'special purpose vehicle' (SPV), sometimes known as 'special purpose entity', which assumes the risk of the project. This is because there is usually no revenue stream from the start of the project and lenders are keen to ensure that project assets are within the authority of the SPV and that all risks associated with the project are assumed and passed on to the appropriate partner via separate contractual agreements [World Bank, 2011]. In the energy sector, Purchase Agreements (Power Purchase Agreements in energy supply contracts) define the level of output or service provided by the SPV and the fee charged to the government. For BOTs, the SPV sources funding for the project, designs and constructs the asset, and operates and maintains it for the duration of the contract period. The SPV is owned by shareholders – such as construction companies, maintenance contractors and other input suppliers. Revenues generated from the operation of the asset, fees from government, are used to cover operating and maintenance costs, repayment of debt principal, financing costs (interest and fees) and a return for the shareholders of the SPV. Investors and lenders provide non-recourse or limited recourse financing and will, therefore, bear any residual risk along with the project company and its shareholders [World Bank, 2011]. BOT projects are often power plants, water and sewage treatments facilities and even hospitals.

Design-Build-Operate (DBO) projects in the public sector own and finance the construction and development of new assets. The private sector designs, builds and operates the assets to meet certain agreed outputs [Feslinger, 2008]. The documentation complexity, in the form of contracts, for a DBO is usually simpler and more straightforward than a BOT or concession since there are no financing documents and is typically consisted of a civil works contract and an operating contract. The municipality pays the operator for the construction and development of the asset (no financial risk on the part of the operator) and will also pay an operating fee for the operating period [World Bank, 2011]. This form of relatively simple PPP is essentially a subcontract and governments often use these types of agreements where there may be little government capacity to provide services (e.g. water infrastructure, 'private' highways).

Joint ventures (partial divesture) between public and private parties involves the shared ownership of the asset in question. When there is an existing utility, shares in the utility are sold to the private sector partner. When building a new asset, the SPV will be created with a shared ownership structure. The level of government ownership will depend on whether the municipality is looking to get the project off it's balance sheet and whether the municipality desires to retain managing control of the utility. In a situation where the majority of shares are under private ownership (e.g. lack of government funding), the government can still be given management control, sometimes even in the form of a negative veto [World Bank, 2011]. In these instances of majority private ownership, the municipality will usually want to retain control of the utility for strategic reasons. If the private partner agrees to the government controlling the utility, they will want to ensure management rights over the managing structure of the government. In these joint ventures, the private operator typically is responsible for the operation and maintenance of the utility [Feslinger, 2008]. Other types of joint ventures can be in the form of a general partnership, entailing a profit sharing agreement. In these cases no separate legal entity, or SPV, is needed as both parties (public and private) share the legal accountability. In non-profit sharing partnerships, public and private partners collaborate on a specific project via a contractual consortium arrangement. Here, each party is compensated for specific services and functions provided to the consortium. Joint ventures often occur in the healthcare, research and development, education and defense sectors.

Leases and affermages between a government entity and a private firm involve the private firm gaining control of a state asset (through renting) and utilizing it to provide a public service. Leases or affermages are used when private equity and commercial debt are not available as funding options and the governing municipality aims to combine public financing with private operator efficiency. In these agreements more commercial risk lies with the private partner than in management contracts. The main difference between leases and management contracts is that the operator charges customers directly, rather than receiving a fixed fee from the government [World Bank, 2011]. A portion of these collected fees are paid to the awarding authority as the lease payment and the remaining revenues are retained by the operator. In an affermage, the private operator collects a fee from customer receipts and pays an additional surcharge (passed on to the customer) to the a municipality which is used for investments that the awarding authority deems necessary for the asset. The rental payment in leases is usually fixed regardless of the tariff level collected. This means the operator bears a risk on revenue collection and on costs incurred covering operating expenses. Operators in affermage agreements are guaranteed a fee (as long as enough revenue is collected from customers) and the municipality assumes the risk on the rest of the receipts collected from customers which cover its investment obligations [Feslinger, 2008]. Municipalities utilizing leases and affermages are responsible for financing and managing investment in the asset and part of this investment comes from the rental payments received from private operators. Leases and affermages are shorter contracts, usually running between eight and fifteen years. In order to ensure the financial viability of the partnership, lease operator will seek assurances from the awarding authority on tariff levels and increases over term of lease [World Bank, 2011]. These assurances usually include review mechanisms and compensation guarantees if tariff levels do not meet requirements. Scheduled tariff, cost and performance reviews take place every four or five years. Leases and affermages are contracts linked more to management than to new construction. These agreements can often be seen in the energy sector where a utility or asset already exists but is being run inefficiently by the government.

Potential Benefits of PPPs

Public-private partnerships have traditionally been of interest for the fiscal leveraging of projects but governments have now started to look to the private sector to help them deliver public services for a number of other reasons. PPPs can be used as a way to introduce private sector technology and innovation in providing better public services via improved operational efficiency. Project managers can use incentives to encourage the private sector to deliver projects in a timely fashion and within budget [Levinson et al., 2006]. Due to the long term nature of PPP projects, introducing budgetary certainty by establishing the present and the future costs of infrastructure projects across the timescale of the concession can stabilize the process by reducing budgetary instability.

Through joint ownership with international firms, PPPs can be used as a way of developing local private sector capabilities as well as creating subcontracting opportunities for local firms in areas such as construction, asset management, maintenance services, etc [World Bank, 2011]. Furthermore, PPPs can be utilized to expose state owned enterprises and government to increasing level of private sector participation (especially foreign). By structuring PPPs to ensure transfer of skills and knowledge to contracted entities and eventually the asset owner, the city's capacity to provide services is enhanced as it learns these capabilities from the private partners [NCPPP, 2012]. A PPP can also assist in the diversification of the economy by making the area more competitive in terms of its operational infrastructure base as well as well as boosting businesses and industries associated with infrastructure development [World Bank, 2011]. Finally, long term value for money can be achieved through the transfer of risk to the private sector over the project lifetime, including design, construction, operation and maintenance. However, with the transfer of risk comes the appropriate compensation (higher payments are received for assuming more risk).

Potential Risks of PPPs

The costs associated with PPP projects (development and ongoing costs) are often greater than for the traditional government procurement processes. In these cases the government should assess whether the greater project costs are justified considering the goals and direct and indirect impacts. Since there is a cost attached to debt, financing will only be available for projects where operating cashflows of the SPV are expected to provide a return on investment [World Bank, 2011]. Therefore, the PPP needs to not only be successful in providing the public service but remain a profitable endeavor (the cost of debt is borne by the government, customers or subsidies).

Risk sharing is a key aspect of PPP arrangements and private firms (and their financiers) will be cautious about accepting significant risks due financial liabilities. If they do assume large risks, the price of the service will reflect this risk. Allocating risk sharing is a complex process that depends on the financial inputs and roles of each partner [NCPPP, 2012]. The private sector will demand a significant level of control (often to the dismay of the city) over the project and it's operations if it is to accept significant risks. The presiding government will need to retain or develop sufficient expertise to be able to understand the PPP arrangements and carry out it's own responsibilities defined in the PPP contract [Levinson et al., 2006]. If it fails to do this, the quality of post-contract period service delivery may be jeopardized.

Private contractors will usually do no more for the project than they are paid for according to their contract. Accordingly, incentives and performance requirements need to be clearly set out in the contract in order to facilitate an efficient and measurable development process. Performance requirements should be based on outputs and relatively easy to monitor for government quality assurance contractors. This aspect of working with private contractors can jeopardize the operational efficiency benefits often sought by involving private parties. Since contactors are bound by the terms of the contract, there is sometimes no motivation to go beyond the scope of the contract to improve the public utility or service. This can stifle the development and improvement of the asset and can result in the PPP not reaching its full potential of cost savings and quality service provision. Reporting requirements imposed upon private parties need to be clear and well-defined to reduce the risk of goals not being met. Given the long contract period (usually 15-25 years) a clear legal and regulatory framework is vital to achieving a sustainable solution. Without this guiding framework; goals, responsibilities, liability and operating procedures may become blurred, creating an inefficient partnership that may results in deadlines being missed [Levinson et al., 2006]. Unseen contingencies are always a potential risk in large projects and it is likely that the contract will need to be renegotiated to accommodate these contingencies.

Contextual Framework – Brazil

The Brazilian government has created many mechanisms and programs to reduce the country's contribution to climate change. Most of these schemes focus on reducing emissions from the supply side of the energy sector such as the Brazilian Ethanol Program, PROCEL (Electrical Energy Conservation Program), PROINFA (incentives for renewable energy sources) and the Brazilian Energy Initiative (increases renewable energy use throughout Latin America) [La Rovere & Pereira, 2007]. The main goals of these programs have been to reduce Brazilian emissions from the source of electricity generation via renewable energy infrastructure and bio-fuel investments [La Rovere & Pereira, 2007]. Less emphasis has been placed on energy efficiency measures and this creates an opportunity for further emissions reductions, greater energy independence and security.

With electricity demand growing at 7.8 percent per year and hydroelectric power stations operating at capacity, the Brazilian government is struggling to find additional energy sources for its economy [The Economist, 2011]. Furthermore, the price of electricity has increased at about 3.8% per year [ANEEL, 2013]. According to international consulting firm McKinsey, Brazil has made inadequate investments in it's transport and energy infrastructure for a number of years [Yan, 2007]. This has led to widespread electricity blackouts and brownouts over the past few decades due to naturally fluctuating reservoir levels [Yan, 2007]. This has negatively impacted economic growth and threatens any future development and progress. This massive stress on energy infrastructure does not bode well for a growing economy, in a country where there is a burgeoning middle-class demanding more energy and goods. By reducing electricity consumption through efficiency measures, Brazil can help provide the economy and the population with the energy it needs to sustain economic growth and enhance quality of life.

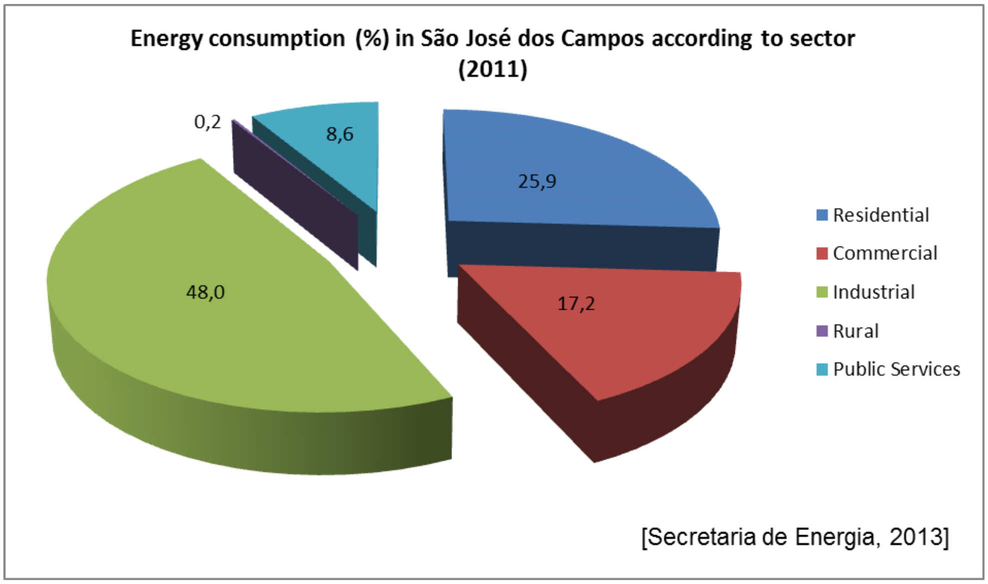
São José dos Campos, São Paulo

São José dos Campos (São Paulo state) is the hypothetical retrofit case study of this research project as energy, maintenance and cost projections are calculated for the street light network. These projections will yield an analysis of potential energy and cost savings for the city of São José dos Campos. In addition to assessing the energy and cost savings potential of an LED retrofit, the project investigates a project implementation strategy, using a public-private partnership structure, to realize a city-wide retrofit of its existing street lights to LED.

Map of Brazil showing São José dos Campos (Fig.18)

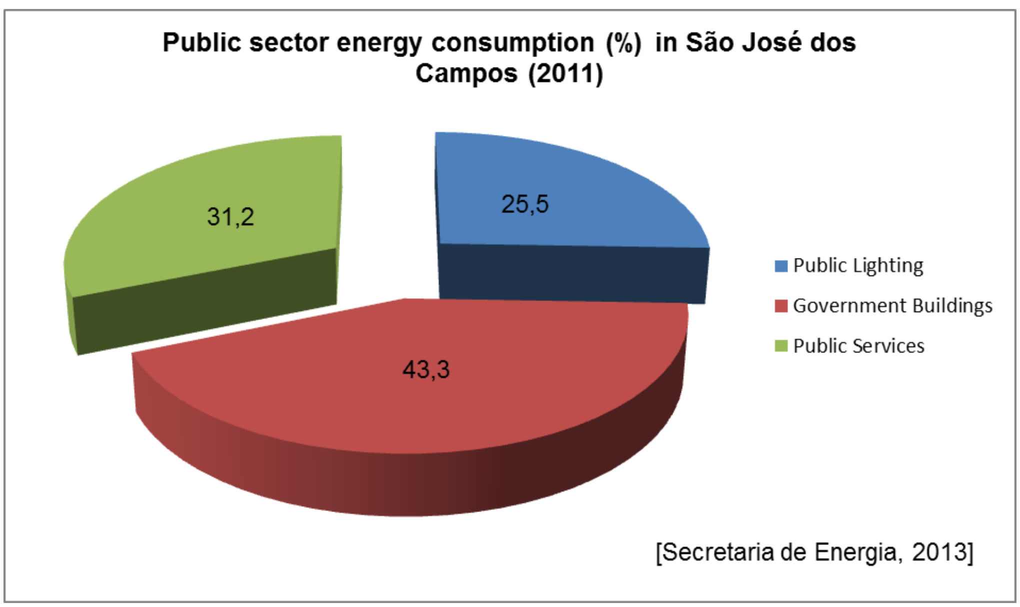
[Google Maps, 2013]

São José dos Campos is a city of approximately 645,000 people, situated in western part of São Paulo state between the city of São Paulo and Rio de Janeiro [SJdC, 2013]. The city was founded in the late 16th century by Jesuits and has since grown from a small agricultural settlement into a hub of high technology manufacturing and service-based industries. The industrial growth of São José dos Campos was initiated by the foundation of the Aerospace Technical Center in 1950 and the opening of the Via Dutra (BR-116) motorway in 1951. The main industries are aerospace, defense, petrochemical, automotive and consumer durable goods. Many large multinational firms such as Embraer, General Motors, Johnson & Johnson, LG, Panasonic, Ericsson and Monsanto have established research and manufacturing facilities in São José dos Campos to take advantage of a well-educated work force, excellent transport infrastructure and proximity to the major cities of São Paulo and Rio de Janeiro [SJdC, 2013].



(Fig.19)

São José dos Campos has a total of 55,543 street lights across the city illuminating streets and avenues [Obras, 2013]. These street lights are HPS lights (100W, 150W and 250W) with an additional 2,016 MV and MH (125W, 160W, 250W, 360W, 400W) used for area lighting of parks and squares (for this study, only the HPS street lights will be analyzed). The municipality owns the street lights but the local energy provider – EDP Bandeirantes – is responsible for installing, maintaining and providing electricity for the street lights [Obras, 2013]. The city of São José dos Campos was selected due to its nature as a high technology center in the region, well educated population and general commitment to sustainability. The city is considered to be more advanced in industrial, technological and entrepreneurial development than most cities in Brazil and could have a more realistic chance of realizing an LED street light project due to these attributes.



(Fig.20)

Brazilian Street Lighting Regulations

This section briefly covers street lighting legislation in Brazil and highlights the sections relevant to this study. Public lighting in Brazil falls under the jurisdiction of the National Agency of Electrical Energy (ANEEL) which regulates the use of street lights and the procedures of ownership and implementation by municipalities [ANEEL, 2013]. The Brazilian Association of Technical Norms (ABNT) stipulates the minimum technical requirements of street lights and their related components (as defined by ANEEL Resolution 414/2010 Article 25). ABNT legislation NBR 5101/1992 outlines general specifications for street lighting (such road classification) and NBR 15129/2004 defines the technical specifications for street lights used in Brazil [ANEEL, 2013]. Within this legislation there are multiple sub-categories for technical specifications and testing methods for different types of street lighting.

ANEEL Resolution 414/2010 is the main piece of legislation which encompasses street light implementation regulations. Article 2 (414/2000) defines public lighting as it's own tariff sub-group, resulting in municipalities being charge less per kWh for public lighting than for other uses. Article 24 (414/2000) states that street lights will be operational for eleven hours and fifty-two minutes of each twenty-four hour period (dusk to dawn) regardless of the season [ANEEL, 2010]. Article 218 of ANEEL Resolution 479/2012, an amendment to 414/2010, states that municipalities will be obliged to assume ownership and responsibility of all assets currently belonging to the public lighting energy utilities. This legislation entails the absorption of management and maintenance costs of the whole street lighting network and is predicted to result in a 40 percent increase in public lighting costs (after a 9 percent government credit on electricity price is applied) [ANEEL, 2010].

PPPs in Brazil

Investment in public infrastructure projects in Brazil has been of growing concern and significance since the 1970s when investment in infrastructure was 5.4 percent of GDP [IADB, 2007]. By 2005, that level of investment had fallen to just 2 percent. This lack of investment, coupled with a growing economy and burgeoning middle class, have caused the national infrastructure network to fall behind growing national demand. As a result of continued Federal Government spending cuts and lack of expertize, and the resulting weakening the public sector's capacity to plan and execute new projects, it has become increasingly important that the private sector partake in the required infrastructure investments, either through direct investment or by joint ventures with the government [de Sa Almeida, 2004]. Today, PPPs have been used in many Brazilian states to address projects of strategic importance. These have not only been in the infrastructure sector (highways, sewage treatment, dams etc.) but also in the healthcare, prison and public buildings sectors.

PPPs have existed in Brazil for many decades but today fall under the Federal Laws 8.987/2004 and 11.097/2004, which categorize PPPs as *Common Concession, Administrative Concession* or *Sponsored Concession* [Zaldanha, 2011]. The common feature of the three forms is the fact that PPPs enable the government to decentralize the investments in infrastructure to private companies [PPP Brasil, 2013]. A common concession is a form of PPP in which the private partner's investments are remunerated directly by customers. Systematic budgetary contributions are not required of the public partner. An administrative concession is utilized when it is not possible or inconvenient to charge users directly for the public service [PPP Brasil, 2013]. In these cases private partner compensation is in the form of regular payments from government budgetary funds. Sponsored concessions are utilized when user fees are not sufficient to cover the investments made by the private partner. Therefore the government complements the private partners project revenue from user fees via regular installments from public funds [Barral and Haas, 2007). In order to be sanctioned as a PPP, the project must be between 5 to 35 years and have a budget of over R$ 20million [GDESP, 2012].

For the hypothetical LED street light retrofit project in São José dos Campos (and resulting PPP strategy) Lumi Group Oy, a Finnish LED manufacturer is used. Lumi products are used in the retrofit analysis but as this is only an example, almost any LED street lights can be used. This startup company is also one of the private partners for the proposed PPP to help make LED street lighting a reality in São José dos Campos. Lumi Group Oy, formed in Turku in 2010, is a spinoff of parent company Oversol Oy which produces LED lighting for domestic and commercial interior spaces. Oversol was started in 2000 as a one man business, selling one product to one customer and has since grown to a team of around fifteen employees, selling LED lights to Finland, Sweden, Russia, Belgium, Spain and the Baltic states. In 2010, Oversol received funding from TEKES, the Finnish Funding Agency for Technology and Innovation, to create a spinoff to produce LED street lights (Lumi Group).

Existing Research on LED Street Lights

Due to the fact that LEDs are a technological innovation and were developed in a laboratory environment, much research has been conducted on the technology to improve it's performance and understand it's potential. This research initiated by General Electric has now become the focus of thousands of companies around the world, whose efforts are aimed at carving out a share of the LED lighting market. Since LEDs have been used in a plethora of applications, research on many of these applications of LED lighting technology is abundant. When focusing on LED street lights, research has usually been aimed at the photometric qualities of the light sources, focusing on color temperatures and light distribution. These research initiatives have been the work of both public and private entities – academic institutions, government agencies and companies.

The U.S. Department of Energy (DoE), through it's 'Gateway' program, has conducted several studies on the performance of competing LED street light models in an array of applications (parking garage lighting, public park lighting, bridge and street lighting) in cities across the country [DoE, 2013b]. Much of this research was conducted by the Pacific Northwest National Laboratory, an arm of the DoE. As a part of the Solid State Lighting (SSL) initiative, the DoE has also operated the Commercially Available LED Product Evaluation and Reporting (CALiPER) program which also supports testing of a wide range of SSL products available for general illumination. The DoE allows its test results to be distributed to the public for non-commercial, educational purposes [DoE, 2013b]. Another DoE initiative is the Municipal Solid-State Street Lighting Consortium, which shares technical information and experiences related to LED street and area lighting demonstrations. This organization serves as another objective resource for evaluating new products on the market. Cities, electricity utilities, and other stakeholders who invest in street and area lighting are invited to join the Consortium and share their experiences. The aim of this medium is to build a repository of useful information and data that will accelerate the learning curve for purchasing and operating high quality, energy efficient LED lighting [DoE, 2013c].

LightSavers is a Canadian organization founded by the Toronto Atmospheric Foundation with the aim of accelerating the development of the outdoor LED lighting market. This organization, like the U.S. DoE, tests and evaluates competing LED street light designs. Now a part of the Canadian Urban

Institute, LightSavers conducts tests in cities around the world to assess various LED street light fixtures [LightSavers, 2013].

The Lighting Research Center is part of the Rensselaer Polytechnic Institute and was founded in 1988 as a graduate studies center, offering Masters and Doctorate programs in advanced lighting sciences. This research center has produced many important publications on lighting, including an assessment of LED street lighting in the state of New York. The institute assessed the newly available 'Edge™' LED street lights installed at a business park in North Greenbush, NY [LRC, 2013].

The Climate Group, an independent non-profit group working towards a low carbon future, partnered with Philips to create a comprehensive report on the LED street light market and the business case for LED street lighting. This report, although sponsored by an LED street light manufacturer (Philips), sheds much light on the argument for LED street lighting [The Climate Group, 2013]

The Remaking Cities Institute of Carnegie Mellon University from Pittsbugh, Pennsylvania conducted a "proof of concept research project to investigate best practices of LED conversion" for the city of Pittsburgh. The research explores a potential retrofit project for the city and examines the various aspects of street lighting such as regulation, existing infrastructure, lighting design and light properties [CMU, 2011]. Students at the Mascaro Center for Sustainable Innovation at the University of Pittsburgh conducted a life cycle assessment of four different lighting technologies. This is a highly technical report focusing on the individual technical specifications of the products rather [Hartley et al., 2009].

Research Motivation and Knowledge Gap

The motivation for this research stems from a lack of available information on the impacts of LED street lighting on the implementing communities. During the initial research phase, it was found that much research has been conducted on solid state LED lighting technology due to it's nature as a commercially viable product. As a result, many private companies have conducted numerous studies on various aspects of the technology and the potential market for it. However, barring a few studies, little research has been conducted by independent sources on the effects of LED street lights on urban development. The few academic and institutional studies that were found focus on life cycle assessments of LED lights and the photometric and technical properties of the lights. A study by the Remaking Cities Institute of Carnegie Mellon University was the lone example of a study found to briefly address the impacts of LED street lights. Furthermore, very little research material was found on the secondary (indirect, co-benefits) effects of LED street lights – effects on cities going beyond energy and cost savings. In the reports and studies that were found, these aspects were largely overlooked. Research on LED street lights was found almost exclusively from sources based in the developed world; namely the United States, Canada, the EU and Australia.

This research aims to address the gap in knowledge on the resulting effects of utilizing LED street lights in the implementing communities. Up to this point, studies have been theoretical in nature with few studies focusing on cities that have already implemented LED technology for their street light network. This study will shed light on what impacts the new street light technology has had on energy consumption, maintenance intensity and secondary effects or co-benefits in cities which have adopted LED street lights. From a regional perspective, LED street lights have not been widely adopted in Brazil and the rest of South America so a lack of know-how exists regarding how to implement such projects. As a result of a request from the city government of São José dos Campos, an implementation strategy is suggested to make LED street lighting a reality in São José dos Campos.

Research Objectives

The over-arching goal of this research project is to examine the sustainable development potential of LED street lights for São José dos Campos, Brazil. This main goal is reached by achieving a few objectives that allow the topic of LED street lighting to be properly understood. Firstly, the research aims to help create a foundation of knowledge of existing LED street light networks in order to understand their primary and secondary effects on the surrounding community. Secondly, the existing street light network of São José dos Campos is assessed and compared to projections of LED street light energy consumption, maintenance intensity and their associated effects on government spending. Thirdly, an implementation strategy is formulated in order to assist the local government in assessing the merits and costs of an LED street light retrofit project. By completing these three project components, an assessment of LED street lights networks can be made regarding their contribution to the sustainable development of a community.

Research Questions

R1: How do LED street lights directly and indirectly affect the communities they serve?

This research question aims to shed light on what is happening (and what has happened) in LED retrofit projects around the world. By doing this, an understanding of existing LED street light projects is developed and the effects of the LED street lights on the community are exposed. This in turn allows a critical assessment of the potential of LED street lights as a tool for sustainable development.

R2: What are the potential impacts of an LED street light retrofit project in the city of São José dos Campos?

Question 2 assesses the potential energy consumption, maintenance intensity and cost impacts of LED street lights on the city of São José dos Campos. This analysis helps the city government weigh the costs and benefits associated with an LED street light project, allowing them to make a more informed decision if they choose to pursue such an initiative.

R3: How could an LED street light project be implemented in São José dos Campos?

This research question is specific to the hypothetical retrofit case study of São José dos Campos and how it could make LED lighting in the city a reality. This question was developed as a result of the input of city government officials. These officials welcomed the study into LED street lights and the potential effects on the city but were especially keen to see a potential strategy for implementation. This implementation aspect is relevant to the city as a limited city budget, and limited implementation experience in the region, prevents the city from executing a street lighting retrofit.

Methodology

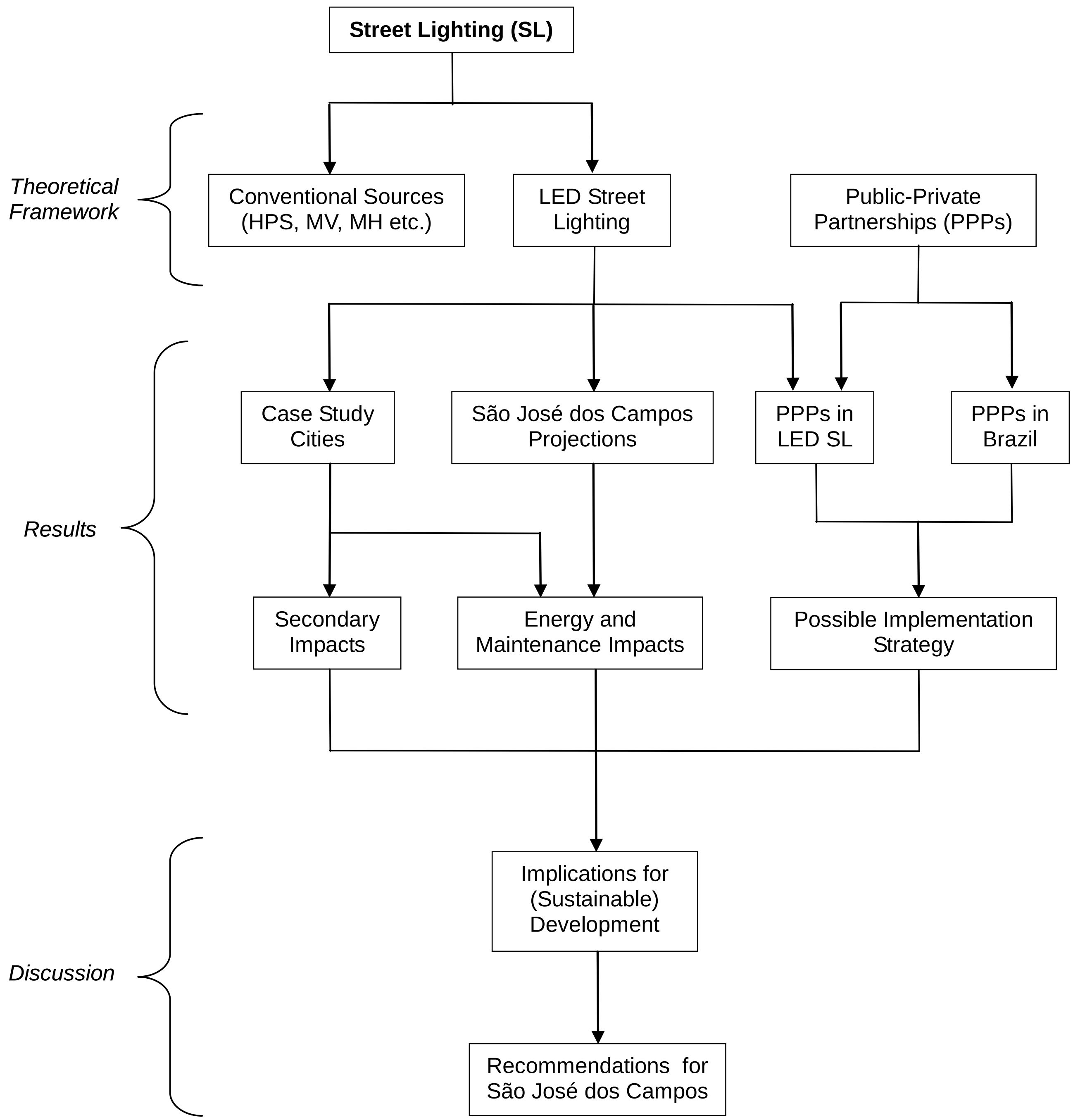
In order to determine the primary and secondary effects of LED street lighting, over 200 cities and municipalities around the world were approached for information on their projects. A wide range of projects were identified and these varied from five LED streets lights installed to over one hundred thousand units installed. These initiatives also ranged from projects still in the planning phase to nearly-completed and completed projects. For this research only retrofit projects were considered (projects were existing street lights were replaced with LED), new construction projects were not included in the study. It was found that there was a significant difference in available information on each project. Some city officials were able to furnish full reports while others were unsure of the number of lights installed and their cost. This massive discrepancy called for the exclusion of most of the identified projects from the study. It was also found that officials representing projects in non-English speaking countries were much more reluctant or unable to provide any data, this limited the study of case study cities to the United States, Canada and the United Kingdom.

The LED CSC projects were analyzed to deduce the energy and maintenance costs (primary effects) of new LED fixtures compared to previously used conventional street lighting (HPS, MH or MV). This was done to ascertain the magnitude of the effect of LED fixture use on city energy and maintenance expenditure. The CSCs were also assessed for secondary effects resulting from the implementation of LED street lights. Furthermore, these secondary effects, sometimes called co-benefits, can help planners to understand the development potential of LED street lights. The combination of assessing primary and secondary impacts of LED street lights allows an foundation of information to be created on the impact of LED street lights on urban development.

Conceptual Model

The conceptual model below outlines the structure of the research and indicates how the various components of the study are linked.

(Fig.21)



Case Study Cities – Primary and Secondary Data Components

The following data components were collected from the case study cities (CSCs) in order to build project profiles.

1. Number of street lights replaced or installed.
2. Project cost, timescale and source of funding.
3. Wattage of old street lights and new LED fixtures.
4. Change in energy use.
5. Change in maintenance use.
6. Effects on safety (road safety and crime), light pollution, public opinion and urban development.
7. Use of electricity and maintenance cost savings in city (if any are present) or area.

São José dos Campos and LED Street Lights

This research project explores the developmental benefits of implementing LED street lighting systems in São José dos Campos, Brazil. In this project, the existing street light network in the city is compared to four LED-based solutions (scenarios) are applied to the challenge of reducing energy consumption and increasing the urban quality of São José dos Campos. Below are the following data components that were collected:

São José dos Campos – Existing Street Light Network Data Components

The following data components were collected from various sources within the city government of São José dos Campos.

1. Number of street lights in operation.
2. Price in Reals (R$) of energy in kilo watt hours (kWh).
3. Different categories of street lights in operation (HPS, MH or MV)
4. Wattage of different street lights (e.g. 100W, 200W, 400W etc).
5. Electricity consumption data of existing street lights by category. This data component is not the same as above, since advertised wattage is less than actual energy consumption due to the ballast component.
6. Expected lifetime of existing street lights in hours, by category.
7. Price of existing street light unit.
8. Cost of maintenance per street light fixture.
9. Local Emissions Factor for greenhouse gas calculation.

The first proposed retrofit solution is a standard LED street light connected to the existing electrical grid. The second is a scenario utilizing an LED street light with adaptive controls. The third proposed solution is a solar-powered LED (SPLED) street light that can, but does not have to be, connected to the grid. The fourth scenario combines all three elements and is a solar-powered LED street light with adaptive controls. The first solution utilizes existing Lumi Group products while the second, third and fourth scenarios implement Lumi Group products still in development (integrated solar panel and adaptive controls). Manufacturer data was needed from LED street light manufacturer Lumi Group to produce an accurate comparison of street light performances and therefore produce an accurate projection of energy and cost savings. The data components are listed below.

Lumi Group Oy – LED Product Technical Specifications

The following data components were obtained from Lumi Group Oy and were used in the retrofit projections.

1. Different categories of LED street lights to replace existing street light categories.
2. Wattage of different LED street light models.
3. Electricity consumption (and generation) of Lumi LED streetlights (LED, LED-AC, LED-SP, LED-AC-SP).
4. Expected lifetime of street lights in hours.
5. LED luminaire Color Rendering Index (CRI), Correlated Color Temperature (CCT), light output (lumens) and efficacy (lm/W).
6. Price of LED street light unit.
7. Cost of maintenance per unit.
8. Price of LED street light unit with solar panel and battery.
9. Price of adaptive controls mechanism.

Public-Private Partnership

The data collected for the PPP portion of the research project consists of information on the partners involved in the PPP, their roles and responsibilities, and general project information. This information helps build an understanding of the structure of PPPs in general and PPPs in the street lighting sector. This information is used in conjunction with the interview data collected from interviews with São José dos Campos government officials to formulate a suggested implementation strategy for the city.

Data Collection Methods

Desktop Research

Desktop research (library literary sources and online sources) were extensively utilized in the first stages of the project to build a foundation of knowledge on LED street lights, street lights and transport infrastructure. Furthermore, CSCs were identified via internet searches and approached via email with the questionnaire below.

Questionnaires

In order to determine the possible effects of an LED street light project on an urban area, data was collected from existing LED street light projects around the world. It was understood that not all LED street light projects would yield the same results, or the same type of information, in terms of effects on urban development. Therefore, in order to understand the outcomes of such projects, it was necessary to locate the projects that have yielded relatively detailed information on the results of street light improvement projects. This was done by canvassing a large number of LED streetlight projects, requesting basic project information through the use of questionnaires via email. Once the questionnaires were analyzed, a selection of projects – which yielded detailed project information – were selected for further analysis. The questionnaire used can be found in the appendix at the end of this report.

Interviews

Once a list of selected LED street light retrofit projects was compiled, in-depth semi-structured telephone interviews were conducted with officials from each city. These officials were employees of the city government and came from various departments such as Traffic and Signals, Engineering, Public Works and Transportation. The officials were mainly project engineers, project managers and directors of the project or department.

It was through this two-tiered approach that a large amount of relevant and useful information was collected and analyzed; leading to a better understanding of the impacts of LED street light projects on an urban area. Interviews were also conducted with officials from São José dos Campos to gain insightful knowledge on the street light network in the city and the options available for the creation of a PPP.

Cities approached for information were found through extensive online research. These sources include the U.S. Department of Energy, LightSavers Canada, the Clinton Climate Initiative, the European Commission, www.newstreetlights.com, www.led-professional.com and www.lednews.org. The websites and publications list numerous cities around the world that are in various phases of LED retrofit projects (planning, installing and completed).

Data Analysis Methods

Street Light Fixture Comparison – Energy Consumption and Financial Analysis

In order to properly analyze the potential energy, maintenance and cost savings to be captured from a street light retrofit project in São José dos Campos, projections were made to compare project scenario trajectories. This included using the technical data of the different Lumi R-Series LED street light packages (solar power, adaptive controls), as well as the city street light network data, in the Department of Energy Municipal Solid State Lighting Consortium (MSSLC) Financial Analysis Tool [MSSLC, 2012]. This tool is a comprehensive analysis tool used by city municipalities to test the performance of street light technology in potential projects. The variables, outlined in *São José dos Campos – Existing Street Light Network* were entered into this analytical tool to create projections of different project scenarios for the city. These projections include projected energy use, maintenance costs, return on investment, net present value and payback period.

Case Study Cities

Data collected from CSCs included quantitative and qualitative data. The quantitative data collected from the CSCs was stored, analyzed and summarized in Microsoft Excel and is presented in the following *results* section. Here, tabulation of data was accompanied by simple calculations to facilitate the description of the results alongside qualitative data.

Public-Private Partnerships

Public-Private Partnerships were researched mainly through desktop research but also through interviews and email correspondence. Basic knowledge of PPPs was procured online and from books; whereas city specific information for São José dos Campos was obtained via interviews and email correspondence. All the information gathered was used to create a model of a PPP that could be used to implement an LED street light retrofit project in São José dos Campos. During this process United Nations PPP frameworks were compared to Brazilian PPP law and existing LED street light PPPs to create a customized PPP strategy to help São José dos Campos achieve its goal of retrofitting all of its street lights.

SWOT Analysis

A SWOT (strengths, weaknesses, opportunities and threats) analysis is a useful tool when assessing qualitative data as was done with the PPP section of the project. A SWOT analysis was used to assess the street light project as a whole and the same methodology was also used to assess the suggested PPP. The first SWOT analysis entailed assessing the findings of the primary and secondary results of the research project to assess the quality and dynamic nature of such a project. Secondly, a SWOT analysis was used to assess the PPP process itself. This is to help ascertain whether the proposed project is realistic and feasible, and what aspects to be aware of which might hinder or enhance chances of success.

Limitations

Many limiting factors were experienced during the data collection phase that affected the nature of the data collected. Firstly, it was found to be very difficult to obtain any useful data from non-English speaking countries. Even in English speaking countries, many cities where LED street lights had been installed were unable to provide detailed information on their LED projects. Projects were selected for further analysis based on the level and quality of information obtained. This meant that cities of various sizes, with LED projects of differing sizes, were compared. Whilst not ideal, it did not hamper the collection of core data on energy consumption and maintenance, the focus of the primary impacts study. Most cities were able to identify some secondary effects resulting from the use of LED street lights and similar secondary impacts were observed in cities/projects of different sizes. While comparing cities of similar sizes, projects of similar sizes, similar locations, project ages and implementation strategies would have been desirable, it was not possible simply due the lack of LED street light retrofit projects around the world as well as the length of the study and research resources available.

Results

In this section the case study city results are presented (primary and secondary effects), followed by the projections for São José dos Campos. These results have been obtained through questionnaires and interviews with city officials and project managers, and is supported by extensive desktop research.

In the first section, primary and secondary effects, the project information will be shown in tables (two table per project) with brief summaries to explain the nature of each project. The first table will contain the following information; project dates, previous street light portfolio (including lighting type and number of fixtures), LED street light information (including manufacturer and number installed), project cost, source of funding, energy savings, maintenance savings, additional savings (if applicable), payback period and the area in which the project has been conducted. The second table will show the secondary effects of LED street lights. Due to the differing nature of available information, the data collected will be present in the following manner; change, effect and description. In general, there was found to be a lack of studies and data on the secondary effects of LED, but through interviews with project managers and city officials, information was attained on the nature of secondary impacts. Having said this, some data was available from the older LED retrofit projects (those conducted several years ago) as they had had time to conduct studies on the effects of the LED street light project. Each project profile will be completed with a brief *comments* section, detailing any findings not presented in the tables. This data includes special project information and considerations that have influenced the LED street light retrofit project.

The final results section will focus on the hypothetical retrofit project for São José dos Campos, which utilizes data collected from the city departments of São José dos Campos. Here energy usage, maintenance costs and other relevant factors will be analyzed through the use of the MSSLC Financial Analysis Tool. This will quantify the potential project and allow the magnitude of potential effects to be better understood. Furthermore, from the analysis of existing LED street light projects, a summary of expected secondary results will be offered.

In the following *discussion* section, PPP projects and interviews with São José dos Campos city officials will be assessed, and a strategy for the completion of a retrofit project will be created. The overarching goal is to visualize the multidimensional aspects of retrofit project in the city of São José dos Campos. It is hoped that this research and analysis can prove to be a useful conversation starter in order to realize such a project in São José dos Campos.

Case Study Cities

For this research project over one hundred cities and municipalities from around the world were approached via telephone and email to furnish data for this study. The results below contain project profiles for fourteen cities for whom data was made available. Over twenty other cities provided some information but not enough to create project profiles or conduct useful analysis. The information and data below has principally been collected from questionnaires and interviews with city officials. Additional information was obtained from project reports and press releases. The terms in the tables below are defined as:

Project dates	*The years in which the retrofit project took place.*
Previous (E/P)	*Number of street lights in the network and type of lighting*
LED Lights	*Number of LEDs installed*
LED %	*Percentage of lights converted to LED*
Project Cost	*Total cost of the retrofit project for X number of LED SLs*
Energy Savings (ES)	*The energy savings (percent) compared to the old fixtures*
Maintenance Savings (MS)	*The maintenance savings (percent) compared to old fixtures*
Total Savings (TS)	*Total savings per year (local currency and Euros)*
Payback period (PP)	*Number of years it takes project savings to cover it's cost*
Fixture Type (C/D)	*Cobrahead or decorative fixtures*
Project Area	*The type of city area in which the project took place*

Light Pollution	*Light trespass, spillover and sky glow*
Public Safety	*Resident security and law enforcement effectiveness*
Road Safety	*Traffic safety for vehicles and pedestrians*
Public Perception of Vision	*Residents' perception of quality of vision at night*
Public Perception of Aesthetics	*Residents' perception of aesthetics of the city at night*
Area Utility	*The degree to which an area has become more utilized*

The amount of data available for each city varies widely, hence some fields are blank where no information was available. The project information in the tables relates to the number of LEDs currently in operation (not the overall project size sometimes given in the *description* column). All project statistics such as cost and maintenance savings pertain to the number of LEDs stated in the *number* column.

Anchorage, AK, USA

Project Information	*Detail*
Project dates	2008 – ongoing
Previous street lights	16,000
LED lights	6,500
Project cost	US$2.2 million
Energy savings	50%
Maintenance savings	25%
Total savings per year	US$360,000
Payback period	6.1 years
Project area	Mostly smaller rural roads, but city-wide

(Table 1) [Bourque-Parker, 2013]

Secondary Impacts	*Effect*	*Description*
Light pollution	Reduced	Less light escaping upwards and excellent control of light boundaries (less spillover)
Public safety	Enhanced	Law enforcement supports the use of LEDs as resident safety has increased as a result of decreased criminality. Residents also percieve their safety to have imorved to do better vision under LED street lights.
Resident perception of vision	Mixed	Mostly positive feedback. Residents enjoy the clear light due to long winters and extended darkness. Some residents indicated the street lights had become too bright.

(Table 2) [Bourque-Parker, 2013]

This project in Anchorage is a complete retrofit project in progress with HPS lights being replaced with BetaLED, Cree and McGraw Cooper LEDs. Funding was obtained through an Energy Efficiency and Conservation Block Grant (EECBG) and cost savings were used to offset rising costs in other departments.

Mrs. Bourque-Parker stated the reason some LEDs had been perceived as too bright was because the street lighting standards were drafted according to HPS specifications. Due to the higher performance of LEDs, more lumens per watt and clearer white light, some areas had become 'over-lit' (more light than intended). One of the greatest disadvantages was that the Illuminating Engineers Society (IES) had not come out with revised design standards for use of LEDs at the time of project initiation therefore the lighting had mainly been adopted on rural roads until the inception of new regulations.

A criticism Mrs. Bourque-Parker did have was that some of the LED lights have not lasted as long as the manufacturer’s suggested life. This had reduced the expected energy savings and slightly increased maintenance costs. However, she believes this is due to Alaska's extreme weather conditions and hope future LED street lights will be designed with these extreme conditions in mind.

Baltimore, MD, USA

Project Information	***Detail***
Project Dates	2011 – 2012
Previous street lights	88,000
LED Lights	11,000
Project Cost	US$ 4.1 million
Energy Savings	65%
Maintenance Savings	33%
Total Savings	US$ 271,875
Payback period (years)	15
Project Area	City-wide

(Table 3) [Draddy, 2013]

Secondary Impacts	***Effect***	***Description***
Light pollution	Reduced	Excellent light control ability of LED fixtures prevents light being emitted upwards, reducing sky glow. The lights produce a white light and the yellow haziness from HPS fixture has been eliminated.
Resident perception of vision	Mixed	Mostly positive but some people have complained that the LED fixture light cutoff prevents sidewalks from being properly illuminated and that they are fearful of their safety at night.

(Table 4) [Draddy, 2013]

Replacing HPS lights in Boston with LEDs resulted in costs savings of US$ 327,500 (energy) and US$ 34,375 (maintenance) per year. These cost savings were reinvested into the LED conversion program and were used to reduce the local budget deficit. Mrs. Draddy stated that there had been great difficulty in getting the project initiated due to resistance from the local utility company. As the utility company stood to lose much money on the electricity sales and maintenance service, they were opposed to the project plan. Baltimor took on government loans to proceed with the project anyway and hired an Energy Service Contractor (ESCO) to conduct the installation and maintenance of the street lights. However during the project, the ESCO failed to meet contractual performance targets and the city had to hire the original utility company to install and maintain the lights. As the second phase of the retrofit project is about to start, Mrs. Draddy explained that similar difficulties are again being experienced due to the reluctance of the energy utility. These challenges have led to significant delays in the implementation period. In spite of the delays and setbacks, the next phase of the project has been approved and will consist of 33,000 more LED street lights.

Boise, ID, USA

Project Information	*Detail*
Project Dates	2009 – 2011
Previous street lights	11,000
LED Lights	2,200
Project Cost	US$1.2 million
Energy Savings	50%
Maintenance Savings	45%
Total Savings per year	US$ 126,300
Payback period (years)	9.5
Project Area	City-wide

(Table 5) [Hedge, 2013]

Secondary Impacts	*Effect*	*Description*
Light pollution	Mixed	Light trespass has been reduced due to the excellent light cut off of the LEDs. Some over-lighting due to LED lights
Road safety	Enhanced	Police have stated they prefer LED lights for better recognition of suspects, license plates and general recollection of events.
Resident perception of vision	Mixed	Most think the lights are quite good but some think they are too bright in the historic district.

(Table 6) [Hedge, 2013]

In Boise, HPS lights were replaced with Cooper Lithonia and Inovis LEDs. The project received it's funding from an EECBG and the cost savings were used to purchase more LEDs. Mr. Hedge stated that the reason Boise achieved a longer payback than most projects (9.5 years) was due to the local price of energy. Energy prices in Boise are comparatively low as the energy comes from hydroelectric sources. In spite of the longer payback period, Boise intends to retrofit all street lights with LED.

Boston, MA, USA

Project Information	*Detail*
Project dates	2010 - 2016
Previous street lights	64,000
LED lights	30,000
Project cost	US$15,500,000
Energy savings	75%
Maintenance savings	95%
Total savings per year	US$ 1,312,500
Payback period (years)	11.8

Project area	City-wide

(Table 7) [Mayrl, 2013], [Cooper, 2013]

Secondary Impacts	***Effect***	***Description***
Light pollution	Reduced	Very even light distribution and little light trespass onto private building fronts.
Public safety	Enhanced	Police have worked closely with the Department of Public Works since the project started and indicated that burglaries, assaults and car theft has fallen by 9%
Resident perception of vision	Enhanced	Very positive feedback from the public. They prefer the bright white light of the LEDs.

(Table 8) [Mayrl, 2013], [Cooper, 2013]

Boston HPS (left) and LED (right) street lighting

(Fig.22) [Cooper, 2013]

As can be seen from the photographs, replacing orange HPS lights with white light LEDs has resulted in a more even distribution of light. The cost savings of US$ 1.3 million have been used in the city budget to avoid staff downsizing in other departments and have been invested into vehicle and building repairs.

Brentwood, CA, USA

Project Information	***Detail***
Project dates	2013
Previous street lights	5,500
LED lights	565
Project cost	US$270,000

Energy savings	56%
Maintenance savings	50%
Total savings per year	US$62,800
Payback period (years)	4.3
Project area	Suburban arterial roads

(Table 9) [Dhaliwal, 2013]

Secondary Impacts	***Effect***	***Description***
Light pollution	Reduced	More focused light from Leotek LEDs has reduced light trespass.
Resident perception of vision	Enhanced	Residents prefer the whiter light.
Resident perception of aesthetics	Enhanced	Residents have stated the neighborhoods look better and more pleasant under white light.

(Table 10) [Dhaliwal, 2013]

This ongoing project in Brentwood has seen General Electric HPS street lights replaced with Leotek LEDs. US$ 250,000 of the funding came from a zero-interest loan from Pacific Gas and Electric Company and US$ 20,000 came from a city treasury fund. Mr. Dhaliwal stated that the project had been a resounding success and that the city hope to retrofit all municipal street lights in the near future. One aspect of this project that contributed to its success was the availability of competitive financing (0% interest loan). The city's budget would not have allowed for the purchase and installation of lights as the city is experiencing budget cuts in many departments. The public in Brentwood, as in many other cities, is aware of environmental and climate change issues and as a result were quite supportive of the project in the name of energy and cost savings.

Canton, OH, USA

Project Information	***Detail***
Project Dates	2007 - ongoing
Previous street lights	8,000
LED Lights	1,100
Project Cost	US$550,000
Energy Savings	55%
Maintenance Savings	80%
Total Savings per year	US$ 60,000
Payback period (years)	9.2 years
Project Area	Downtown city center

(Table 11) [Molina, 2013]

Secondary Impacts	***Effect***	***Description***
Light pollution	Reduced	Directability of lights has reduced light trespass.
Public Safety	Enhanced	No statistics available but police have stated there is less criminal activity at night. CCTV images are clearer and residents feel safer
Resident Perception of Vision	Enhanced	Very positive, resident prefer the brighter white LEDs to the yellow light of HPS.
Resident Perception of Aesthetics	Enhanced	Residents have commented on how the new light make the area look more pleasant and appealing.
Area utility	Enhanced	The city center has become more frequented and utilized during evening hours.

(Table 12) [Molina, 2013]

Canton first started using LED technology in traffic lights and has since adopted LED street lights for use in the center of the city. HPS lights were replaced with Relume and Lumicon light fixtures and the project was funded by city, state and a federal funding (EECBG). Energy cost savings amounted to US$ 20,000 and maintenance savings totaled US$ 40,000. The city government has used these cost savings to reduce the budget deficit and it has also reinvested in more LEDs. Since the installation of the LED street lights, the city has adopted LED lighting solutions for other public lighting needs such as underpasses, walking and cycling tracks.

A decorative LED fixture in central Canton

(Fig.23) [Molina, 2013]

Chattanooga, TN, USA

Project Information	***Detail***
Project dates	2013
Previous street lights	30,000
LED lights	2,000
Project cost	US$ 2 million
Energy savings	75%
Maintenance savings	90%
Total savings per year	US$196,400
Payback period (years)	20
Project area	City-wide

(Table 13) [Davis, 2013]

Secondary Impacts	***Effect***	***Description***
Light pollution	Reduced	Excellent cut off and programmability of the LEDs has greatly reduced light pollution.
Public safety	Enhanced	Police have direct control over street lights. Officers commented on clearer vision and better facial recognition.
Road safety	Enhanced	
Resident perception of vision	Enhanced	Quality of lighting and night-time visibility has been enhanced.
Area utility	Enhanced	Many residents stated they feel safer at night and as a result stay out longer at night.

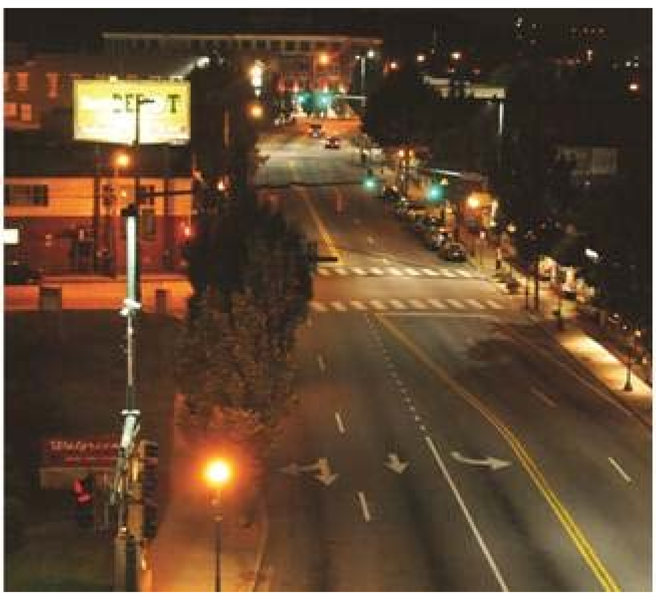
(Table 14) [Davis, 2013]

Chattanooga has replaced it's HPS lights with Global Green Lighting LEDs (GGL, a local manufacturer). Four thousand more LED street lights are to be installed as a part of the second phase of the project. Currently only phase one has been initiated but later project phases will retrofit the remaining 24,000 lights. A federal government bond of US$ 6 million has been awarded to the city for the project's first and second phases. The GGL street lights have been installed with adaptive controls and remote monitoring capabilities to enhance service provision and maintenance efficiency. Cost savings exceeding bond payments have been used to purchase more LED street lights.

Compared to other retrofit projects this is quite expensive due to the added feature of adaptive controls and remote monitoring of individual LED street lights. This system is comparatively advanced in that it has been linked to the Police Department and individual officers have control over individual street lights from their patrol cars. This allows officers to increase the lighting level in an area in which an incident has taken place or where a response is necessary. This has greatly enhanced security and residents have received it positively. Maintenance and energy savings have been better than expected due to the adaptive light control on each street light, adjusting light output according to local demand. Mr. Davis stated that lights can dim themselves down to 25% of illumination potential, in order to conserve energy and still provide the minimum level of illumination required. Furthermore, the remote monitoring feature means that street lights report themselves as broken, eliminating the need for maintenance patrols (needed to identify broken fixtures) and maintenance crew response times have been reduced.

Global Green Lighting (GGL), a local Chattanooga LED manufacturer, was chosen as the street light supplier for the following reasons. Firstly, the company worked with the city municipality to design the LED street lights according to the city's needs in ways in which other manufacturers were unable to do so. GGL added the adaptive controls and remote monitoring systems to enhance operating efficiencies and utility. The firm also designed the LED lighting elements to be individually programmable. What this means is that in an instance where light is encroaching on a private home, the strip of LEDs on the house side of the light can be disabled, preventing light spillover onto the property. Secondly, GGL is a local firm and the city wanted to support local business, retaining much of the project expenditure within city limits.

Central Chattanooga before and after LED retrofit.



(Fig.24) [CAC, 2013]

(Fig.25) [CAC, 2013]

Fallon, NV, USA

Project Information	***Detail***
Project dates	2009 – 2011
Previous street lights	11,000
LED lights	2,200
Project cost	US$1,200,000

Energy savings	50%
Maintenance savings	66%
Total savings per year	US$100,000
Payback period (years)	7
Project area	Residential and downtown city center

(Table 15) [Souba, 2013]

Secondary Impacts	***Effect***	***Description***
Light pollution	Reduced	Better light cut off due to reflector design resulting in less light trespass onto private property.
Public safety	Enhanced	Police have stated their preference for LED due to better facial and vehicle recognition by residents.
Road safety	Enhanced	Fewer accidents at intersections as driver peripheral vision has been enhanced by white LED light.
Resident perception of vision	Mixed	Some positive, some negative. Negative comments pertained to light being too bright in the historic district. Mostly positive in other districts as residents prefer bright white light.
Resident perception of aesthetics	Enhanced	Even though bright were sometimes deemed too bright in the city center, the overall consensus was it made the area more appealing.

(Table 16) [Souba, 2013]

The city of Fallon chose Cooper Lithonia LEDs to replace their existing HPS network. The project was funded by an EECBG and resulted in cost savings of US$ 60,000 (energy) and US$ 40,000 (maintenance). As a result of the successful street light retrofit project, local legislation has been changed to make LED street lights mandatory for new street light installations. This came as a result of positive feedback from the Police Department regarding the impact of LED street lights on law enforcement in the community. Officials from the local Police Department stated that clearer security camera pictures, resulting from whiter light, had enhanced the Department's ability to prosecute suspects. The city also supports the retrofit of HPS street lights due to increased road safety, especially at intersections, as drivers' peripheral vision had improved.

Jackson Township, NJ, USA

Project Information	***Detail***
Project dates	2012
Previous street lights	4,900
LED lights	506
Project cost	US$415,500
Energy savings	40%
Maintenance savings	72%

Total savings per year	US$36,900
Payback period (years)	11.3 years
Project area	Residential streets

(Table 17) [Burke, 2013]

Secondary Impacts	***Effect***	***Description***
Light pollution	Reduced	Sharper light boundaries (less spillover), less upward light emission (better direction control)
Public safety	Enhanced	The local PD have indicated they prefer LED lights due to more successful recognition/description of suspects and clearer CCTV footage.
Road safety	Enhanced	Fewer collisions at intersections.
Resident perception of vision	Enhanced	Even tho the overall light output (total lumens) per light was decreased, the lights were considered 'brighter' and people felt safer.
Resident perception of aesthetics	Positive	Residents indicated that the LED light makes the neighborhoods more appealing due to 'brighter conditions'. The fixtures themselves are also seen as more pleasing due to their slim and modern look.

(Table 18) [Burke, 2013]

The ongoing retrofit in Jackson Township has seen both cobrahead and decorative HPS street lights being replaced with General Electric LEDs. The project was funded by an EECBG and has achieved energy cost saving of US$ 6,900 per year and maintenance savings of US$ 30,000 per year. As a result of the successful street light project (showing only 3 LED fixture failures), lighting standards have been made more stringent (due to the higher performance of the LEDs). These measures included better light cut off in the fixture design and better energy consumption performance. During the street light manufacturer selection process, only American companies were consider due to a local purchasing agreement. The local utility, 1st Energy, was against the project as they stood to lose much revenue from the lower energy consumption. The project was only approved after two years of negotiations, following determined action from the Department of Public Works.

Lancashire, United Kingdom

Project Information	***Detail***
Project dates	2008 - ongoing
Previous street lights	148,000
LED lights	16,400
Project cost	GBP 5,000,000
Energy savings	45%
Maintenance savings	63%
Total savings per year	GBP 350,000
Payback period (years)	14.3
Project area	City-wide, small roads

(Table 19) [Dunwell, 2013]

Secondary Impacts	***Effect***	***Description***
Light pollution	Reduced	Light trespass and sky glow has been reduced
Resident perception of vision	Enhanced	Residents stated their night time visions has improved due to white light
Resident perception of aesthetics	Enhanced	Aesthetics have been enhanced as colors appear more vibrant under LED light

(Table 20) [Dunwell, 2013]

Lancashire County Council has initiated a self-funded street light retrofit project where Urbis Axis LEDs (with adaptive controls) replace HPS, LPS (low pressure sodium), metal halide and mercury vapor lights. Energy and maintenance cost savings of GBP 290,000 and GBP 60,000 have been reinvested into LEDs and have been used to reduce the budget deficit.

Las Vegas, NV, USA

Project Information	***Detail***
Project dates	2011 - ongoing
Previous street lights	52,000
LED lights	41,600
Project cost	US$18,000,000
Energy savings	50%
Maintenance savings	71%
Total savings per year	US$2.7 million per year
Payback period (years)	7.5
Project area	City-wide

(Table 21) [Rohleder, 2013]

Secondary Impacts	***Effect***	***Description***
Light pollution	Reduced	GE Evolve light directional control was excellent, resulting in much less light trespass.
Resident perception of vision	Enhanced	Only negative feedback came from resident who WANTED their property to be illuminated by public lighting. They had to install extra security lighting as a results of less light trespass.
Resident perception of aesthetics	Enhanced	Residents have stated their surroundings look nicer and more pleasant as a result of clearer light and enhanced illumination.

(Table 22) [Rohleder, 2013]

Las Vegas city government has started a city-wide retrofit project which replaces HPS and mercury vapor lights with General Electric LEDs. Significant cost savings of US$ 1.7 million (energy) and US$ 1 million (maintenance costs) have been used to make payments on the federal government bond which funded the project.

An interesting aspect of this project is that Crescent Electric, the local electric supply company, recycles the HPS fixtures and obtains direct credits for the purchase of LED fixtures. Mr, Rohleder stated that energy efficiency measures are essential in Las Vegas due to growing energy demand and hydroelectric installations operating at capacity. This part of the United States has an significantly higher energy consumption per capita due to high summer temperatures (requiring constant cooling of buildings) and the energy intensive nature of the local entertainment industry.

Las Vegas neighborhoods during LED conversion (white LEDs and yellow HPS)

(Fig.26) [GE, 2013]

(Fig.27) [GE, 2013]

Los Angeles, CA, USA

Project Information	***Detail***
Project dates	2009 - ongoing
Previous street lights	210,000
LED lights	143,855
Project cost	US$57 million
Energy savings	63%
Maintenance savings	34%
Carbon savings per year	48,837 tonnes
Total savings per year	US$9.85 million
Payback period (years)	6.8
Project area	City-wide

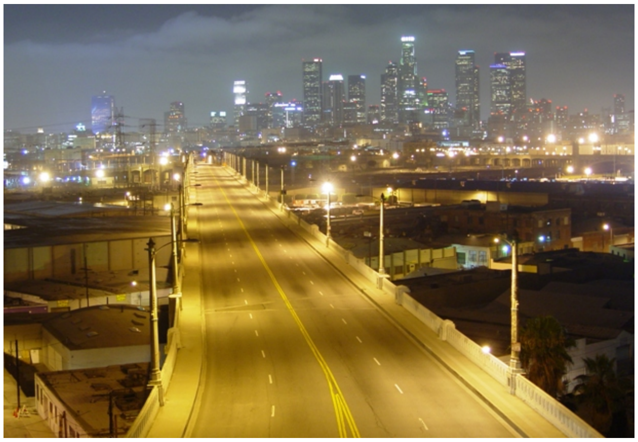
(Table 23) [BSL, 2013], [Cheng, 2013], [Ebrahimian, 2012]

Secondary Impacts	Effect	Description
Light pollution	Reduced	Significant decrease in orange glow from previous incandescent lights. Dark Sky Association has commended the city for the projects success in reducing light pollution.
Public safety	Enhanced	13.6% reduction in number of stolen cars 7.82% reduction in burglary and theft 10.9% reduction in vandalism (incidents between 19.00-07.00)
Resident perception of vision	Enhanced	Overwhelming public support. Bright white light has enhanced night-time vision. Residents feel the area is safer at night.
Resident perception of aesthetics	Enhanced	City streets and building facades look nicer as a result of the clearer white light.
Area utility	Enhanced	Due to better vision, people are out at night more frequently than before.

(Table 24) [BSL, 2013], [Cheng, 2013], [Ebrahimian, 2012]

This was the first large-scale LED retrofit project in the world and has been the model for other cities due to it's size and resounding success. This project was conducted in conjunction with the Clinton Climate Initiative which encourages the adoption of energy efficiency measures at the municipal level. This is one of the only mature LED street lighting projects in the world and has 66,145 HPS street lights left to be replaced with LEDs (of a total of 210,000). Funding was obtained from three main sources; US$ 40 million from a federal government loan and US$17 million from the Street Lighting Assessment Fund and electricity rebates. Cost savings of US$7,352,263 (energy) and US$2.5 million (maintenance) per year were used to make loan repayments. As of this summer, smaller local roads have been completed and only a few major roads remain to be retrofitted. The pictures below show the enhanced illumination distribution uniformity and reduced light pollution (sky glow).

Los Angeles 6th St. Bridge lit by HPS



(Fig.28) [Forbes, 2013]

Los Angeles 6th St. Bridge lit by LED

(Fig.29) [Forbes, 2013]

View of Los Angeles before and after LED SL retrofit (HPS left, LED right)

(Fig.30) [O'Connor, 2013]

(Fig.31) [O'Connor, 2013]

Mississauga, ON, Canada

Project Information	***Detail***
Project dates	2012-2014
Previous street lights	49,600
LED lights	5,500
Project cost	CAD 2.88 million
Energy savings	55%
Maintenance savings	50%
Total savings per year	CAD 470,306
Payback period (years)	6.1
Project area	City-wide

(Table 25) [Menezes, 2013]

Secondary Impacts	***Effect***	***Description***
Light pollution	Reduced	The directional nature of LEDs reduces sky glow and makes them dark-sky friendly.
Road safety	Enhanced	The white light of LEDs provide better visibility to both pedestrians and motorists. LED offers better clarity and an improvement in the ability to identify colors at night.
Resident perception of vision	Enhanced	97% positive reception from the public

(Table 26) [Menezes, 2013]

In 2009, the City Council of Mississauga made the decision to become a net-zero carbon city by decreasing carbon emissions within city limits. In 2004, the city became one of Canada’s first cities to retrofit it's 740 signalized intersections (traffic lights) to colored LEDs. All the city’s 49,600 HPS street lights are to be replaced with Conxcorp LEDs with adaptive controls. Cost savings achieved thus far from the installation of 5,500 LEDs have resulting in energy cost savings of CAD 336,735 and maintenance cost savings of CAD 133,571. The project realized a payback of 2.5 years (originally estimated at four years), energy savings of 85%, and improved public safety. This success with traffic lights created the momentum to start an street light conversion project.

North Bay, ON, Canada

Project Information	***Detail***
Project dates	2011-2013
Previous street lights	5,567
LED lights	5,567
Project cost	CAD2.8 million
Energy savings	37%
Maintenance savings	53%
Total savings per year	CAD 350,000
Payback period (years)	8
Project area	City-wide

(Table 27) [Korell, 2013]

Secondary Impacts	***Effect***	***Description***
Light pollution	Reduced	Residents enjoy a better quality of light, making walking and driving safer and more pleasant.
Road safety	Enhanced	Due to a better quality of light, walking and driving has become safer and more pleasant.

(Table 28) [Korell, 2013]

The project in North Bay is one of the only city-wide retrofits to have been completed. All 5,567 HPS cobrahead street lights have been replace with Philips LEDs. The project was mainly funded through the city’s budget but CAD 60,000 was received from the local power authority. Energy and maintenance cost savings amount to CAD 250,000 and CAD 100,000 respectively. A important goal of the retrofit project was to reduce the city’s energy consumption by 5% per year. Due to the fact that street lights consumed 3.32 million kWh in 2010, increasing the efficiency of the street light network would greatly support the city's aim of reducing energy consumption. Another key reason for the project's initiation was the dwindling lifetime of existing HPS street lights.

Salford, United Kingdom

Project Information	*Detail*
Project dates	2012 – ongoing
Previous street lights	27,600
LED lights	6,200
Project cost	GBP 3.1 million
Energy savings	50%
Maintenance savings	70%
Carbon savings	31%
Total savings per year	GBP 224,600
Payback period (years)	13.8
Project area	City-wide

(Table 29) [Fern, 2013]

Secondary Impacts	*Effect*	*Description*
Light pollution	Reduced	Less light trespass onto private property
Public safety	Mixed	Initial results show a decrease in criminal activity at night-time. However 26% of survey respondents indicated the area had become less safe whereas only 12% indicated the streets had become safer.
Resident perception of vision	Mixed	40% feel the light is too bright, 60% feel the light is too dim
Resident perception of aesthetics	Mixed	Many residents have complained that due to the enhanced light cutoff, their properties have not been illuminated as much as they would like. The council reminds these residents their responsibility is to only illuminate the streets and footpaths.

(Table 30) [Fern, 2013]

The main motivation to install LED street lights in the United Kingdom is the reduction in electricity consumption. Many major cities and counties in the UK have had to switch their street lights off entirely due to strained city budgets and this has havd a negative impact on crime [Fern, 2013]. In the case of Salford LED street lights have saved enough money to allow the street lights to remain operational. HPS, LPS, mercury vapor and metal halide streets lights have been replaced with LRL SAT LEDs. The funding for the retrofit of all 27,600 street lights (GBP 13.8 million) comes a government loan and the city's existing street light budget, with financial carbon credits, makes the loan repayments. Savings have exceed the repayment and these additional financial resources have been channeled into other departments facing budget cuts. Local residents and volunteer groups have recycled old street light fixture covers by using them to protect vegetable seedlings in community gardens.

Salt Lake City, UT, USA

Project Information	***Detail***
Project dates	2010 – ongoing
Previous street lights	15,000
LED lights	1,530
Project cost	US$875,000
Energy savings	50%
Maintenance savings	100%
Total savings per year	US$ 137,700
Payback period (years)	6.4
Project area	City-wide, arterial roads

(Table 31) [Barry, 2013]

Secondary Impacts	***Effect***	***Description***
Light pollution	Reduced	Better light cutoff
Public safety	Enhanced	Law enforcement have stated their preference for LEDs
Road safety	Enhanced	Better vision for drivers, fewer collisions noted
Resident perception of vision	Enhanced	Residents stated their vision has improved due to LEDs
Resident perception of aesthetics	Enhanced	Residents stated the LED light makes things look more pleasant

(Table 32) [Barry, 2013]

Salt Lake city has started it's retrofit project by replacing HPS fixtures with Lighting Science LEDs. Funding from the project came in the form of an EECBG but this funding has since run out and no more LEDs are to be installed until more funding can be obtained. Energy savings and maintenance savings have however allowed for some new LED units to be purchased as these savings amount to US$ 64,260 (energy) and US$ 73,440 (maintenance) per year. Mr. Barry explained that the first batches of LED cobrahead fixtures had an operating color of 5000K. He describes this light as 'too blue', as opposed to a clear white light around 4000K. He stated that the city evaluates new technology and intends install lights with slightly lower color temperatures to optimize the clarity of light, enhancing vision.

Seattle, WA, USA

Project Information	***Detail***
Project dates	2010 – 2014
Previous street lights	45,969
LED lights	34,969

Project cost	US$18.48 million
Energy savings	48%
Maintenance savings	43%
Carbon savings tonnes per year	7,377
Total savings per year	US$2.4 million
Payback period (years)	7.7
Project area	Residential streets

(Table 33) [SCL, 2013]

Secondary Impacts	***Effect***	***Description***
Light pollution	Reduced	Less orange glow around the city
Resident perception of vision	Enhanced	Public feedback has been very positive. Five neighborhoods were surveyed after the retrofit and 78% of respondents rated their vision as 'improved' or 'much improved'.

(Table 43) [SCL, 2013]

Local energy utility company spokesperson, Justin Foss of Alliant Energy, states one of the motivations of the LED retrofit project was to be able to better manage electricity load growth across the electricity grid. With rising demand for electricity from a growing population and higher energy consumption per capita, Foss explains that it is important to make all energy-users more efficient to help the city deal with future energy issues [Foss, 2013]. Seattle is another city with an established LED retrofit project with only 11,000 of 46,000 lights left to be replaced. This project is mainly internally funded by the city treasury but US$ 1 million was received as a part of an EECBG.

A Seattle neighborhood street under HPS (left) and LED (right) lights

(Fig.32) [Cusick, 2012]

(Fig.33) [Cusick, 2012]

Welland, Ontario, Canada

Project Information	Detail
Project Dates	2008 – 2013
Previous street lights	6,700
LED Lights	4,300
Project Cost	CAD 2.4million
Energy Savings	74%
Maintenance Savings	60%
Carbon Savings	1,627 tonnes
Total Savings per year	CAD 380,803
Payback period (years)	6.4 years
Project Area	City-wide

(Table 35) [Ferguson, 2013]

Secondary Impacts	Effect	Description
Light pollution	Reduced	The LEDs directionality reduces upward light pollution and waste
Resident Perception of Vision	Enhanced	Over 73% of interviewed residents strongly endorsed the LED project, stating their vision has improved
Resident Perception of Aesthetics	Enhanced	Residents stated that city aestheics had improved due to higher quality illumination

(Table 36) [Ferguson, 2013]

Welland has replaced its HPS street lights with ALLED LEDs with adaptive controls. Project funding came from Ontario Infrastructure and resulted in energy and maintenance savings of CAD 221,553 and CAD 159,250 respectively. Although achieving maintenance savings of 60 percent already, these savings are projected to increase to 80 percent upon the completion of the project as maintenance economies of scale are captured.

Due to difficulties in locating funding for the project, Welland city staff began discussions with several firms to form partnerships that would allow the city to move forward with a city-wide street light conversion. The city council chose ALLED Lighting Fixtures, an American LED luminaire manufacturer, as the provider of the LED street lights, and SSL Energy Solutions (affiliated distributor of ALLED) for financing the project in the form of an energy performance contract similar to those used by energy service companies (ESCOs) to install energy efficiency measures in government buildings. With assistance from SSL Energy Solutions, the city successfully obtained a low interest loan from Infrastructure Ontario. Since the implementation of LED street lighting in the downtown area of the city, the city has amended the city legislation to make LED street lights mandatory for any new construction.

Summary of Results

Primary Effects

City	LED (%)	Project Cost (EUR)	ES (%)	MS (%)	Total Savings (EUR/yr)	PP (yrs)	Fixture Type	Project Area
Anchorage, AK, USA	41	1,683,000	50	25	275,400	6.1	C	City-wide
Baltimore, MD, USA	13	3,016,300	65	33	200,081	15	C	City-wide
Boise, ID, USA	20	905,110	50	55	95,265	9.5	C	City-wide
Boston, MA, USA	47	11,424,232	75	95	967,371	12	C	City-wide
Brentwood, CA, USA	10	206,550	56	50	48,042	4.3	C	Suburban
Canton, OH, USA	14	404,604	55	80	44,138	9.2	D	City-center
Chattanooga, TN, USA	33	1,531,000	75	95	148,437	10.3	C	City-wide
Fallon, NV, USA	20	535,500	50	66	76,500	7	C	Residential
Jackson Township, NJ, USA	10	317,858	40	72	28,229	11.3	C	Residential
Lancashire, UK	11	5,759,370	45	63	403,181	14.3	C	City-wide
Las Vegas, NV, USA	80	13,770,000	52	71	2,065,500	7.5	C	City-wide
Los Angeles, CA, USA	69	43,605,000	63	34	7,535,250	6.8	C	City-wide
Mississauga, ON, Canada	11	2,119,680	55	50	346,145	6.1	C	City-wide
North Bay, ON, Canada	100	2,142,000	37	65	257,600	8	C	City-wide
Salford, UK	23	3,586,700	49	70	259,862	13.8	C	City-wide
Salt Lake City, UT, USA	10	669,375	53	95	105,340	6.4	C	City-wide
Seattle, WA, USA	76	14,137,200	55	75	1,836,000	7.7	C	City-wide
Welland, ON, Canada	64	1,766,400	74	92	280,271	6.4	C	City-wide
Minimum - Maximum	**10 - 100**	**206,550 - 43,605,000**	**37 - 75**	**25 - 95**	**28,229 - 7,535,250**	**4.3 - 14.3**	**N.A.**	**N.A.**
Mean	**36**	**5,976,660**	**55.5**	**65.9**	**831,812**	**8.9**	**N.A.**	**N.A.**

(Table 37) Currency rates (CAD, Euro, GBP, US$), [XE, 2013]

Secondary Effects

City	Light Pollution	Public Safety	Road Safety	PP of Vision	PP of Aesthetics	Area Utility
Anchorage, AK, USA	Reduced	Enhanced		Mixed		
Baltimore, MD, USA	Reduced			Mixed		
Boise, ID, USA	Mixed		Enhanced	Enhanced		
Boston, MA, USA	Reduced	Enhanced		Enhanced		

Brentwood, CA, USA	Reduced			Enhanced	Enhanced	
Canton, OH, USA	Reduced	Enhanced		Enhanced	Enhanced	Enhanced
Chattanooga, TN, USA	Reduced	Enhanced	Enhanced	Enhanced		Enhanced
Fallon, NV, USA	Reduced	Enhanced	Enhanced	Mixed	Enhanced	
Jackson Township, NJ, USA	Reduced	Enhanced	Enhanced	Enhanced	Enhanced	
Lancashire, UK	Reduced			Enhanced	Enhanced	
Las Vegas, NV, USA	Reduced			Enhanced	Enhanced	
Los Angeles, CA, USA	Reduced		Enhanced	Enhanced	Enhanced	Enhanced
Mississauga, ON, Canada	Reduced		Enhanced	Enhanced		
North Bay, ON, Canada	Reduced		Enhanced			
Salford, UK	Reduced	Mixed		Mixed	Mixed	
Salt Lake City, UT, USA	Reduced	Enhanced	Enhanced	Enhanced	Enhanced	
Seattle, WA, USA	Reduced			Enhanced		
Welland, Ontario, Canada	Reduced			Enhanced	Enhanced	Enhanced
Enhanced	**0**	**7**	**8**	**13**	**9**	**4**
Reduced	**17**	**0**	**0**	**0**	**0**	**0**
Mixed	**1**	**1**	**0**	**4**	**1**	**0**
Response Rate	**100%**	**44%**	**44%**	**94%**	**56%**	**22%**

(Table 38)

São José dos Campos Street Light Retrofit Projections

The following section presents the results of the projections of multiple scenario street light retrofit projects in São José dos Campos. These scenarios will include a baseline (current situation), LED scenario (LED street lights), LED-AC (LED SLs with adaptive controls), LED-SP (LED SLs with solar panel) and LED-AC-SP (LED SLs with adaptive controls and solar panel). For this analysis the Municipal Solid-State Street Lighting Consortium Financial Analysis Tool is used in conjunction with the typical variables of such a project.

Lumi Group Oy, R-Series Street Light

The Lumi R-Series street light (available in 29W, 51W, 75W and 96W) tested for this research was the 29W model, technical information is in the table below.

Light source	29 x 1W LEDs
Rated power	29W
Operating voltage	100-240V
Temperature operating range	-40°C – 50°C

Color temperature	4200K
Efficacy	83 lm/W
Lumen depreciation	30% after 60,000 hours (25°C)
Dimensions	940mm x 520mm x 210mm
Weight	12.5kg
Installation height	5 – 11m
Pole distance	33 – 51m
Guarantee	Light components 5 years, body and reflector 10 years

(Table 39) [Lumi Group, 2013]

(Fig.34 left, Fig.35 top-right, Fig.36 bottom-right) [Kivimäki, 2013]

Lumi R-Series Street Light and Solar Panel Testing

During the fieldwork period, a 30W solar panel attached to the top of the R-Series street light, was tested to determine the power supply potential. The maximum solar potential (during mid-day, no clouds or rain) was measured at 1310 W/m^2 and the maximum solar panel output achieved during one day was 0.203kW (this equates to 7hrs, of required 11hr52min [ANEEL, 2013] of lamp life for the 29W LED street light). The solar panel projections below contain this best-case figure, 0.203 kWh, as the energy savings from utilizing the panel. Due to rapid advancements in photovoltaic technology, it is assumed that the battery charging capacity of solar panels continue to increase.

MSSLC Financial Analysis Tool Variables

Variable	Value/Unit	Source
Street light operating hours	4331/year	ANEEL, 2013
Electricity rate	R$ 0.17/kWh	Obras, 2013
Annual change in electricity rate	3.8%	ANEEL, 2013
Sales tax	18%	KPMG, 2011
Maintenance cost per street light	R$ 16.20/year	Obras, 2013
Annual change in maintenance rate	16.3%	Obras, 2013
Installation vehicle rate	R$ 100/hour	EDP, 2013
Installation labor rate	R$ 25/hour	EDP, 2013
Annual change in labor rate	3.4%	ILO, 2013
Finance nominal discount rate	5%	Obras, 2013
Emissions factor	0.093 kg CO2 e/kWh	Brander et al, 2011
Installation time per Unit	30 minutes	Obras, 2013
First year of installation	Year 1	Kivimäki, 2013
Last year of installation	Year 6	Kivimäki, 2013
Solar panel max daily energy generation	0.2 kWh/day	Kivimäki, 2013
Adaptive controls energy savings	20%	Poplawski, 2013
HPS fixture failure rate per year	6%	DoE, 2012
LED fixture failure rate per year	1%	Lumi Group Oy, 2013
LED fixture cleaning rate (half-life)	7.2%	MSSSLC, 2012
Solar panel cleaning rate (once per year per unit)*	100%	Solar Daily, 2013

(Table 40)

*Solar panels sometimes need to be cleaned in order to ensure energy generation does adversely affect energy generation. However, a study in California showed that over a 145 day period with no rain (and no cleaning) solar panels lost only 7.4 percent of their generation capacity [Solar Daily, 2013]. Rain can effectively clean solar panels as long as they are installed at an angle to allow the rainwater to wash off dust. São José dos Campos is located in an area which receives an average of 1269 mm of rain per year, with July being the driest month (25mm, winter dry season) and January being the wettest (221mm, summer rainy season) [Climate Data, 2013]. It is worth noting that solar panel efficiency is heavily dependent on local environmental conditions as differing dust levels, bird populations (excrement) and rainfall affect the energy generation potential of solar panels. In the following projections for São José dos Campos the solar panel cleaning rate is not included as rainfall should keep the panels clean enough for effective operation. Projections including the solar panel cleaning rate were created and this variable eliminated the scenarios using solar panel as economically feasible. In these scenarios with each solar panel being cleaned once per year, a payback was not achieved and the street light network would incur losses.

Product Prices and Specifications

The following variables show the performance data for each type of street light.

AC *Adaptive Controls (smart dimming)*
SP *Solar Panel (integrated into light cover)*
AC – SP *Adaptive Controls with Solar Panel*

In these conversion projections, 100W HPS are replaced with 29W LED, 150W HPS replaced with 56W LED and 250W replaced with 96W LED. The fixture prices depend on the volume of the purchase, with larger orders capturing the greatest discounts. Lumi street lights are priced in five volume categories (500-999, 1000-4999, 5000-9999, 10000-19000, 20000-50000). In the case of Sao Jose dos Campos, 29W Lumi street lights capture the greatest discount as they form the largest part of the retrofit order (39,188 units). The other light categories (56W, 96W) will account for 3,307 and 13,262 units respectively. It is important to note that these figures represent the prices of street lights manufactured in Finland and not in the proposed manufacturing facility in São José dos Campos (to be elaborated upon in later sections).

Lumi Group Street Light Prices (Euros)

Quantity (units)	500 – 999	1000 – 4999	5000 - 9999	10000 – 19999	20000 - 50000
29W	€ 298	€ 292	€ 283	€ 272	€ 258
56W	€ 323	€ 317	€ 307	€ 295	€ 280
96W	€ 377	€ 369	€ 358	€ 344	€ 327
29W AC	€ 348	€ 342	€ 333	€ 322	€ 308
56W AC	€ 373	€ 367	€ 357	€ 345	€ 330
96W AC	€ 427	€ 419	€ 408	€ 394	€ 377
29W SP	€ 447	€ 438	€ 425	€ 408	€ 387
56W SP	€ 485	€ 476	€ 461	€ 443	€ 420
96W SP	€ 566	€ 554	€ 537	€ 516	€ 491
29W AC-SP	€ 497	€ 488	€ 475	€ 458	€ 437
56W AC-SP	€ 535	€ 526	€ 511	€ 493	€ 470
96W AC-SP	€ 616	€ 604	€ 587	€ 566	€ 541

(Table 41) [Lumi Group, 2013]

In the following table, *system wattage* shows the actual wattage across the whole street light system. In the HPS systems, this system wattage his higher than the lamp wattage as the ballast component requires energy to function. In the LED systems, the system wattage is actually lower because of the lack of a ballast component and the additional savings captured from utilizing adaptive controls and the solar panel.

Existing General Electric HPS street light vs. Lumi R-Series street light

Manufacturer	Model	Lamp (W)	System (W)	Lifetime (hours)	Daily Usage (kWh)	Approx. Fixture Cost (R$)
GE	HPS	100	117.00	20,000	1.39	200.00
GE	HPS	150	171.00	20,000	2.03	225.00
GE	HPS	250	279.00	20,000	3.31	250.00
Lumi	LED	29	29.00	60,000	0.34	773.23
Lumi	LED	51	51.00	60,000	0.61	950.05
Lumi	LED	96	96.00	60,000	1.14	1030.97
Lumi	LED-AC	29	23.20	60,000	0.28	923.08
Lumi	LED-AC	51	40.80	60,000	0.48	1099.90
Lumi	LED-AC	96	76.80	60,000	0.91	1180.82
Lumi	LED-SP	29	11.90	60,000	0.14	1159.84
Lumi	LED-SP	51	33.90	60,000	0.40	1425.07
Lumi	LED-SP	96	78.90	60,000	0.94	1546.45
Lumi	LED-AC-SP	29	6.10	60,000	0.07	1309.69
Lumi	LED-AC-SP	51	23.70	60,000	0.28	1574.92
Lumi	LED-AC-SP	96	59.70	60,000	0.71	1696.30

(Table 42) [Lumi Group, 2013], [SJdC, 2013]

An implementation period of 6 years is used for replacing all 55,757 fixtures. A best-case installation period of 4.86 years does not include delays of any kind, therefore 6 years is used to account for these setbacks. A fifteen year analysis period is used in the MSSSLC forecast tool as this is represents a period of time slightly longer than the rated 60,000 hour LED lifetime (60,000hrs at 4,331hours/year is 13.85 years).

Retrofit Work Schedule

4	Installation crews (2 technicians per crew)	SJdC, 2013
44	Hours per work week	Surrey, 2013
228	Work days per year	Mercer, 2010
1,433	Work hours per year	Kivimäki, 2013
30	Minutes per fixture installation (2 fixtures per crew per hour)	SJdC, 2013
11,464	Fixtures installed per year (maximum efficiency, no delays)	Kivimäki, 2013
4.86	Years (minimum time needed) for all fixtures to be installed	Kivimäki, 2013

(Table 43)

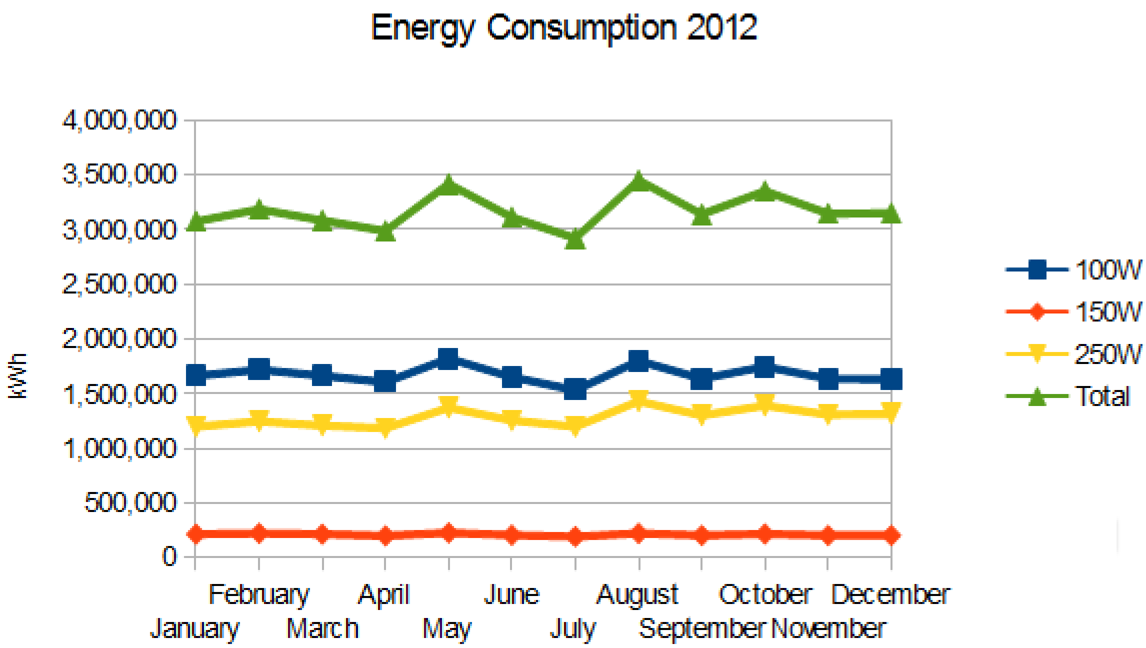
**Non-energy O&M savings (below) refers to operating and maintenance savings captured*
** All '$' values are in Brazilian Reals

Baseline Scenario (existing street lights)

The baseline is what is in place today in São José dos Campos. For this study the three major street light categories (96.5% of all street and area lights in the city) were used for analysis. For the analysis below, the year 2012 was used as it is the most recent full year with data available. As of January 2013 (directly after the analysis period) the city had 39,188 100W, 3,307 150W and 13,262 250W high pressure sodium street lights (55,757 total) [Obras, 2013].

Quantity	*Number of street lights in the light category*
kWh	*Number of kWh used by each lighting category for the period*
R$	*Total cost of energy consumption in Brazilian Reals.*
Period	*Number of days in billing period*
Start	*Start date of billing period*
End	*End date of billing period*
kWh R$	*Price of energy per kWh in Brazilian Reals.*

(Fig.37) [Obras,



(Fig.37) [Obras, 2013]

Street light energy consumption in São José dos Campos by street light category (2012)

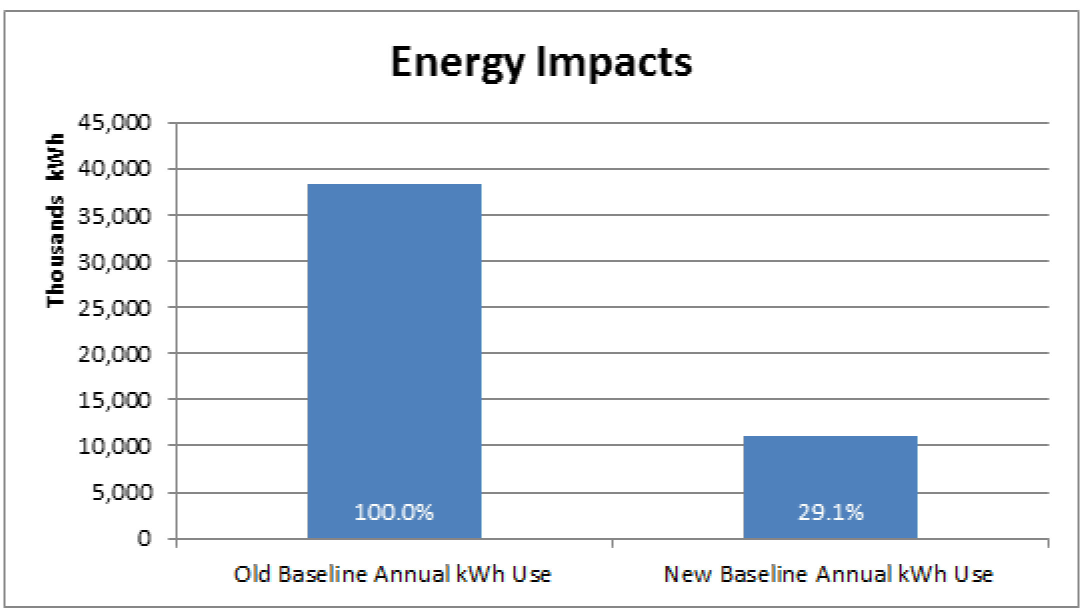
2012	January			February			March		
Light Type	**Quantity**	**kWh**	**R$**	**Quantity**	**kWh**	**R$**	**Quantity**	**kWh**	**R$**
HPS 100W	39,899	1,663,163	382,791.49	39,935	1,719,100	401,533.58	39,943	1,663,559	396,519.54
HPS 150W	3,497	212,883	48,996.88	3,497	219,979	51,380.93	3,497	212,883	50,741.98
HPS 250W	12,122	1,197,930	275,714.04	12,141	1,245,741	290,970.19	12,147	1,207,014	287,699.23
Total	**55,518**	**3,073,976**	**707,502**	**55,573**	**3,184,820**	**743,885**	**55,587**	**3,083,456**	**734,961**
	Period	30		**Period**	31		**Period**	30	
	Start	28/12/11		**Start**	27/01/12		**Start**	27/02/12	
	End	27/01/12		**End**	27/02/12		**End**	28/03/12	
	kWh R$	0.18		**kWh R$**	0.18		**kWh R$**	0.18	
	April			**May**			**June**		
Light Type	**Quantity**	**kWh**	**R$**	**Quantity**	**kWh**	**R$**	**Quantity**	**kWh**	**R$**
HPS 100W	39,836	1,605,235	373,981.68	39,806	1,821,964	423,801.91	39,471	1,651,823	385,277.75
HPS 150W	3,359	197,666	46,051.49	3,367	225,138	52,441.89	3,353	204,288	47,648.94
HPS 250W	12,348	1,183,227	275,663.83	12,454	1,371,032	318,953.74	12,835	1,255,450	292,826.14
Total	**55,543**	**2,986,128**	**695,697**	**55,627**	**3,418,134**	**795,198**	**55,659**	**3,111,561**	**725,753**
	Period	29		**Period**	33		**Period**	30	
	Start	28/03/12		**Start**	26/04/2012		**Start**	29/05/12	
	End	26/04/12		**End**	29/05/2012		**End**	28/06/12	
	kWh R$	0.18		**kWh R$**	0.18		**kWh R$**	0.18	
	July			**August**			**September**		
Light Type	**Quantity**	**kWh**	**R$**	**Quantity**	**kWh**	**R$**	**Quantity**	**kWh**	**R$**
HPS 100W	39,297	1,532,601	344,179.34	39,298	1,800,381	423,659.98	39,338	1,637,351	378,999.15
HPS 150W	3,353	190,509	42,802.83	3,285	220,527	51,893.72	3,307	200,895	46,501.35
HPS 250W	13,055	1,197,874	269,427.00	13,064	1,429,784	336,452.26	13,096	1,301,064	301,158.49
Total	**55,705**	**2,920,984**	**656,409**	**55,647**	**3,450,692**	**812,006**	**55,741**	**3,139,310**	**726,659**
	Period	28		Period	33		**Period**	30	
	Start	28/06/12		Start	26/07/12		**Start**	28/08/12	
	End	26/07/12		End	28/08/12		**End**	27/09/12	
	kWh R$	0.18		**kWh R$**	0.18		**kWh R$**	0.18	
	October			**November**			**December**		
Light Type	**Quantity**	**kWh**	**R$**	**Quantity**	**kWh**	**R$**	**Quantity**	**kWh**	**R$**
HPS 100W	39,316	1,747,104	416,467.32	39,260	1,635,880	439,301.42	39,222	1,633,543	440,313.42
HPS 150W	3,307	214,738	51,188.34	3,307	201,317	54,061.94	3,307	201,317	54,264.00
HPS 250W	13,119	1,390,317	331,417.94	13,175	1,308,282	351,327.81	13,222	1,314,127	354,216.42
Total	**55,742**	**3,352,159**	**799,074**	**55,742**	**3,145,479**	**844,691**	**55,751**	**3,148,987**	**848,794**
	Period	32		**Period**	30		**Period**	30	
	Start	27/09/12		**Start**	29/10/12		**Start**	28/11/12	
	End	29/10/12		**End**	28/11/12		**End**	28/12/12	
	kWh R$	0.19		**kWh R$**	0.21		**kWh R$**	0.21	

(Table 44) [Obras, 2013]

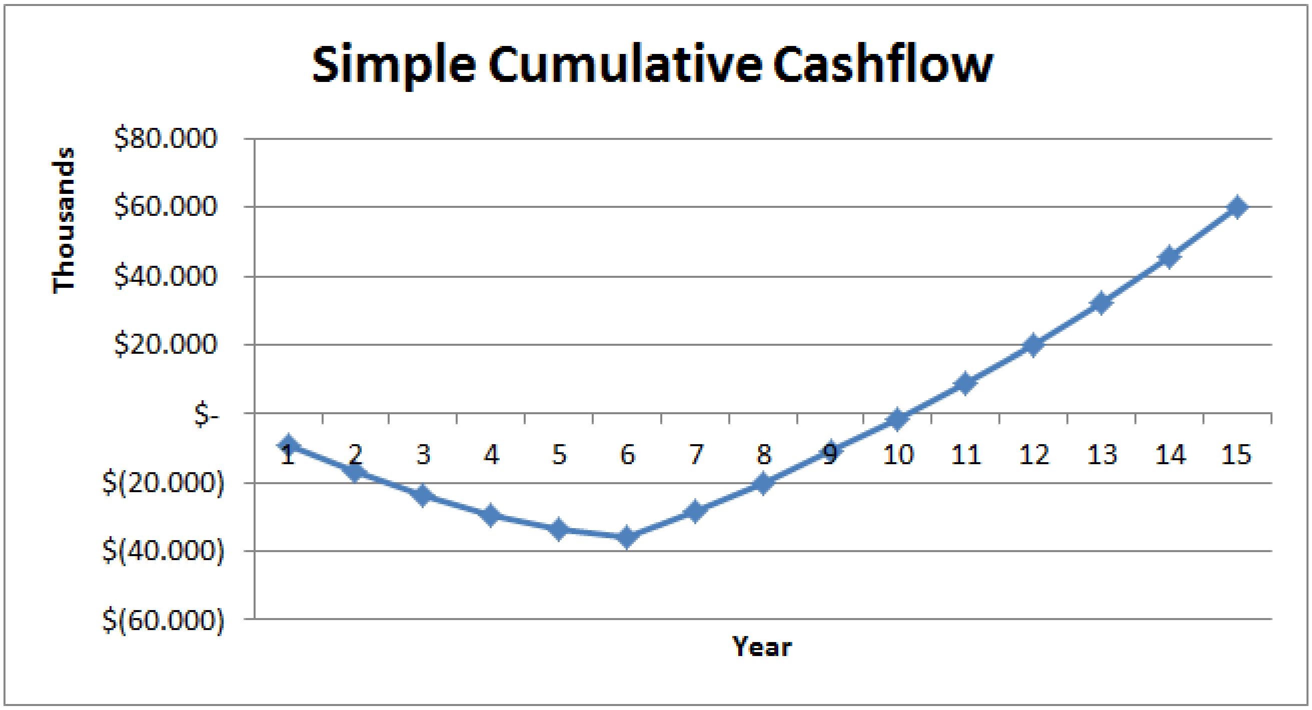
LED Scenario

# of Fixtures Installed		**55.757**
Implementation Period (years)		**6**
Analysis Period		**15**
Simple Payback (years)		**10,1**
15-Year Unlevered IRR		**12,43%**
15-Year Unlevered NPV ($)	**$**	**23.893.849**
15-Year Capital Expenditure ($)	**$**	**59.143.544**
15-Year Cap. Ex. $/kWh Saved	**$**	**0,1742**
15-Year Cap. Ex. $/ton CO2e Saved	**$**	**1.879,9600**
Annual kWh Savings		**27.167.531**
Annual Energy Cost Savings ($)	**$**	**4.618.480**
Annual GHG Savings (tCO_2e)		**2.517**
Old Baseline Annual kWh Use		38.334.830
Old Baseline Annual Energy Cost ($)	$	6.516.921
Old Baseline Annual GHGs (tCO_2e)		3.551
New Baseline Annual kWh Use		11.167.299
New Baseline Annual Energy Cost ($)	$	1.898.441
New Baseline Annual GHGs (tCO_2e)		1.035
First-Year Avg. Capital Expend. per Unit ($)	$	1.060
First-Year Avg. Material Cost per Unit ($)	$	997
First-Year Avg. Labor Cost per Unit ($)	$	13
First-Year Avg. Vehicle Cost per Unit ($)	$	50

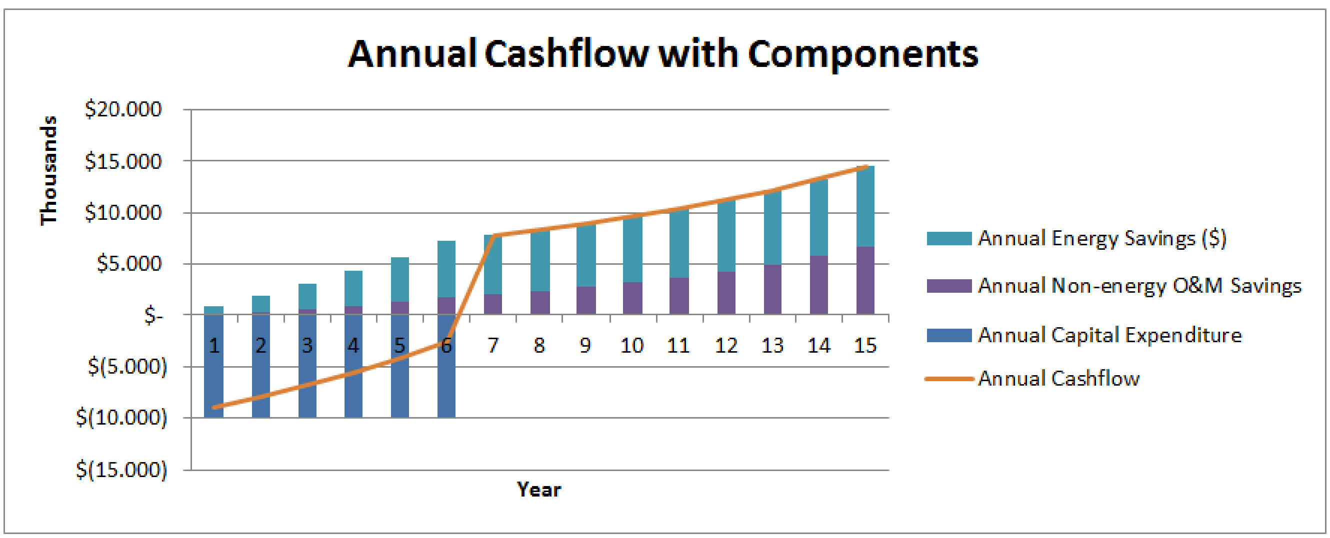
(Table 45)



(Fig.38)


Simple Cumulative Cashflow
Thousands
$80.000
$60.000
$40.000
$20.000
$-
$(20.000)
$(40.000)
$(60.000)
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Year

(Fig.39)

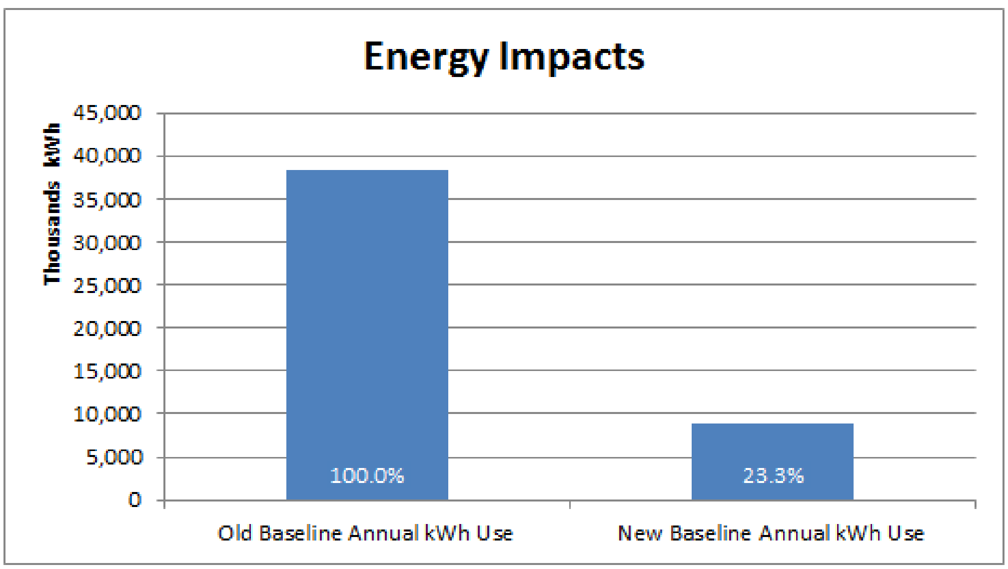

Annual Cashflow with Components
Thousands
$20.000
$15.000
$10.000
$5.000
$-
$(5.000)
$(10.000)
$(15.000)
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Year
Annual Energy Savings ($)
Annual Non-energy O&M Savings
Annual Capital Expenditure
Annual Cashflow

(Fig.40)

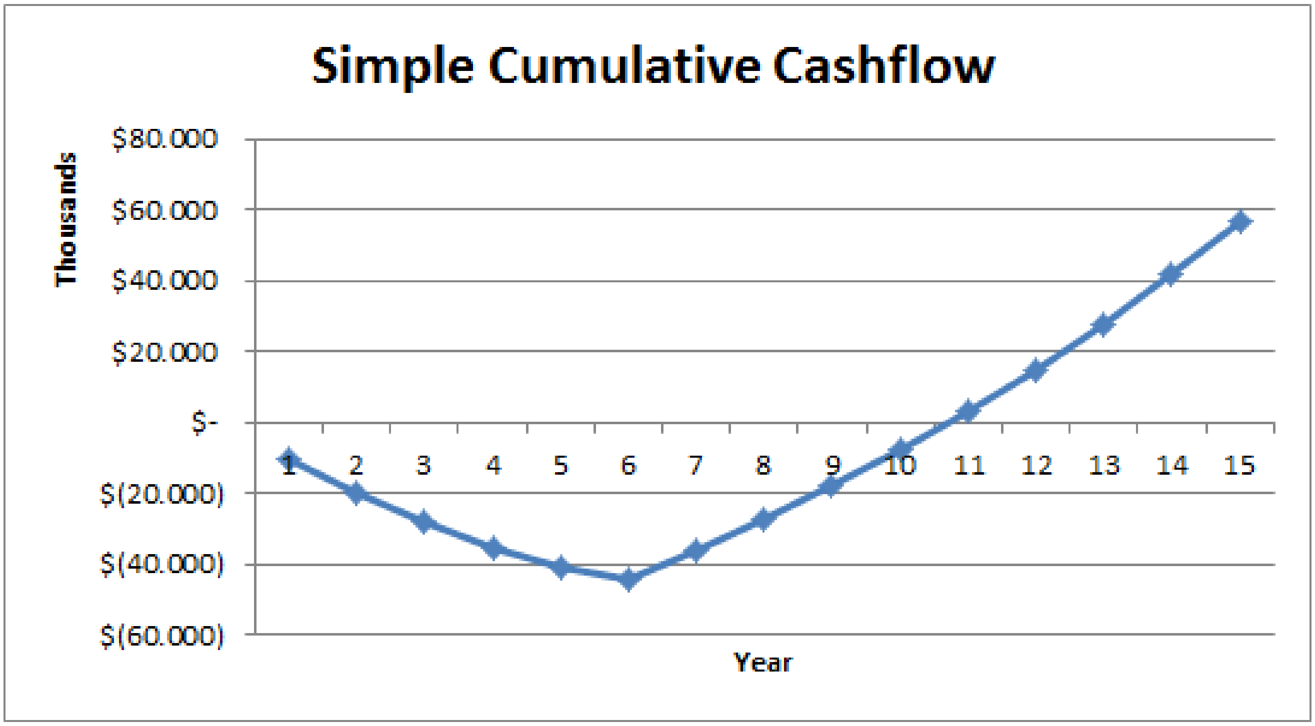
LED with Adaptive Controls (AC) Scenario

# of Fixtures Installed		**55.757**
Implementation Period (years)		**6**
Analysis Period		**15**
Simple Payback (years)		**10,7**
15-Year Unlevered IRR		**10,39%**
15-Year Unlevered NPV ($)	**$**	**19.642.821**
15-Year Capital Expenditure ($)	**$**	**69.002.664**
15-Year Cap. Ex. $/kWh Saved	**$**	**0,1879**
15-Year Cap. Ex. $/ton CO2e Saved	**$**	**2.027,8981**
Annual kWh Savings		**29.384.017**
Annual Energy Cost Savings ($)	**$**	**4.995.283**
Annual GHG Savings (tCO_2e)		**2.722**
Old Baseline Annual kWh Use		38.334.830
Old Baseline Annual Energy Cost ($)	$	6.516.921
Old Baseline Annual GHGs (tCO_2e)		3.551
New Baseline Annual kWh Use		8.950.813
New Baseline Annual Energy Cost ($)	$	1.521.638
New Baseline Annual GHGs (tCO_2e)		829
First-Year Avg. Capital Expend. per Unit ($)	$	1.236
First-Year Avg. Material Cost per Unit ($)	$	1.174
First-Year Avg. Labor Cost per Unit ($)	$	13
First-Year Avg. Vehicle Cost per Unit ($)	$	50

(Table 46)

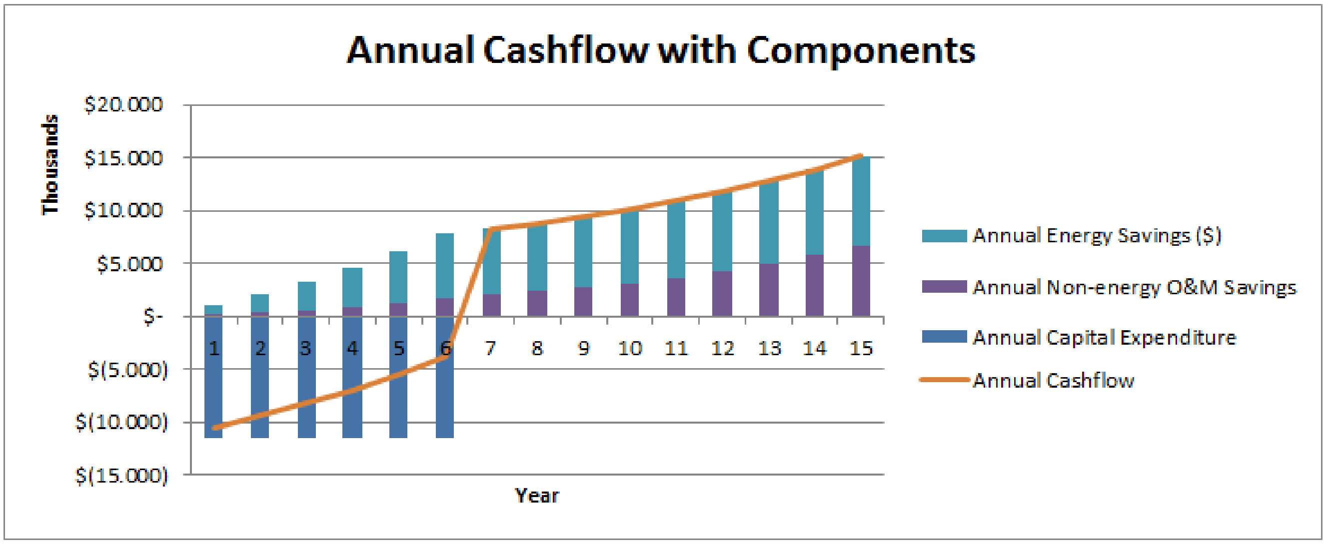


(Fig.41)



Simple Cumulative Cashflow
Thousands
$80.000
$60.000
$40.000
$20.000
$-
$(20.000)
$(40.000)
$(60.000)
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Year

(Fig.42)



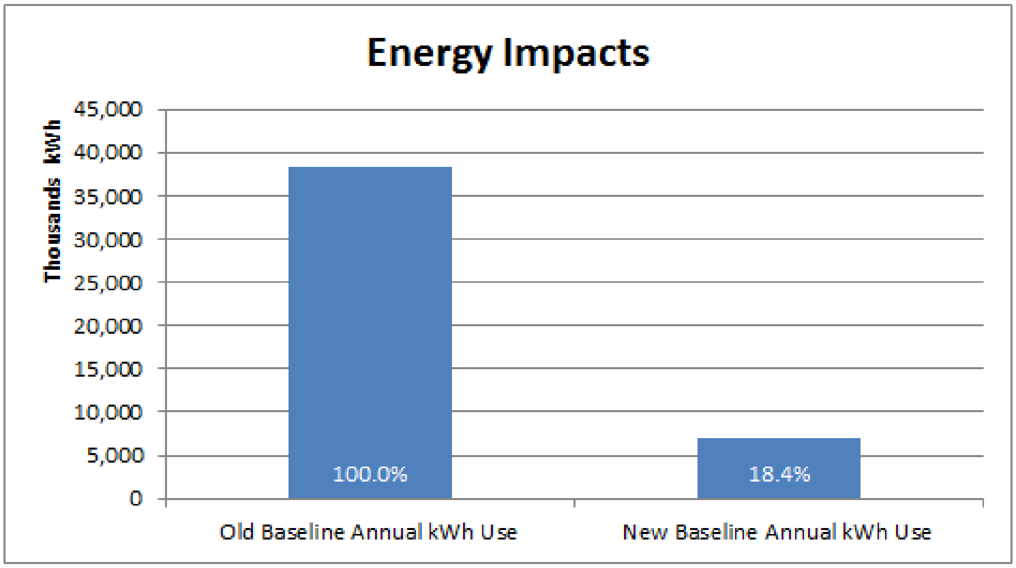
Annual Cashflow with Components
Thousands
$20.000
$15.000
$10.000
$5.000
$-
$(5.000)
$(10.000)
$(15.000)
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Year
Annual Energy Savings ($)
Annual Non-energy O&M Savings
Annual Capital Expenditure
Annual Cashflow

(Fig.43)

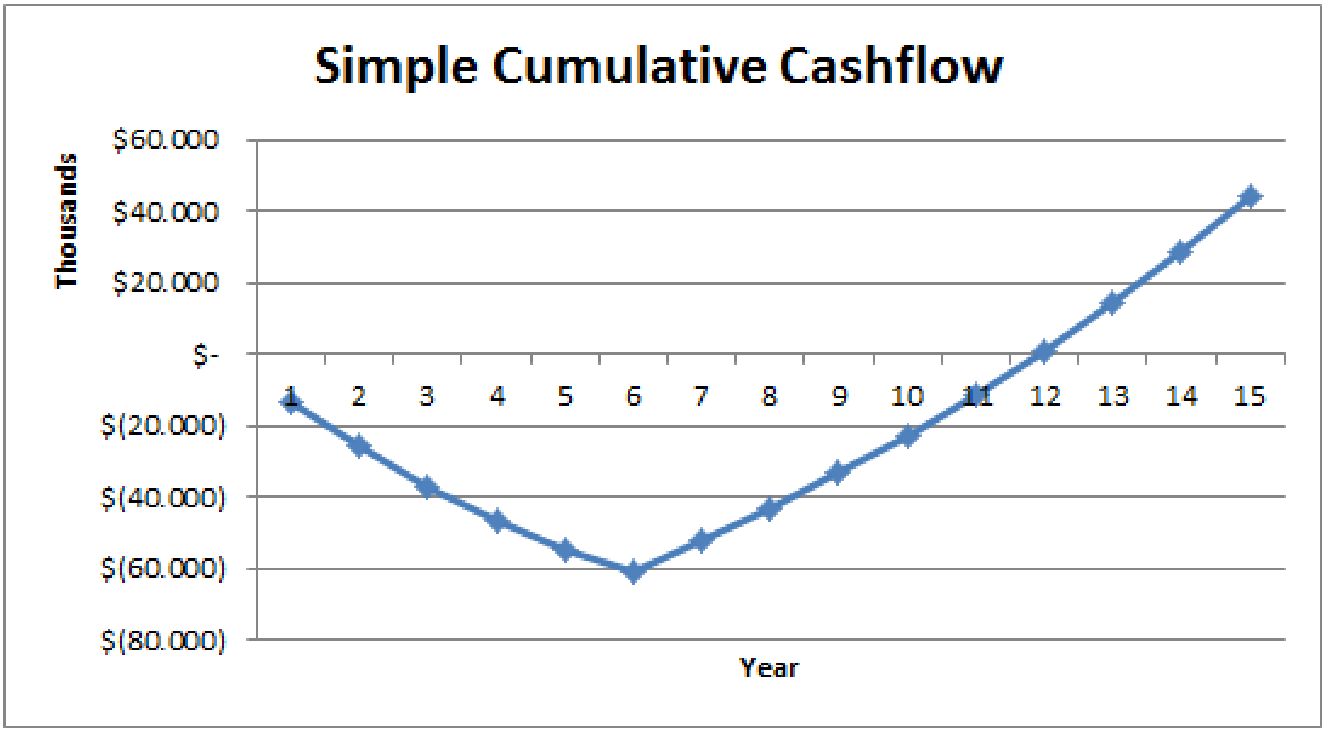
LED with Solar Panel (SP) Scenario

# of Fixtures Installed		**55.757**
Implementation Period (years)		**6**
Analysis Period		**15**
Simple Payback (years)		**11,9**
15-Year Unlevered IRR		**6,83%**
15-Year Unlevered NPV ($)	**$**	**7.997.149**
15-Year Capital Expenditure ($)	**$**	**86.941.582**
15-Year Cap. Ex. $/kWh Saved	**$**	**0,2222**
15-Year Cap. Ex. $/ton CO2e Saved	**$**	**2.398,9063**
Annual kWh Savings		**31.297.215**
Annual Energy Cost Savings ($)	**$**	**5.320.527**
Annual GHG Savings (tCO_2e)		**2.899**
Old Baseline Annual kWh Use		38.334.830
Old Baseline Annual Energy Cost ($)	$	6.516.921
Old Baseline Annual GHGs (tCO_2e)		3.551
New Baseline Annual kWh Use		7.037.616
New Baseline Annual Energy Cost ($)	$	1.196.395
New Baseline Annual GHGs (tCO_2e)		652
First-Year Avg. Capital Expend. per Unit ($)	$	1.558
First-Year Avg. Material Cost per Unit ($)	$	1.496
First-Year Avg. Labor Cost per Unit ($)	$	13
First-Year Avg. Vehicle Cost per Unit ($)	$	50

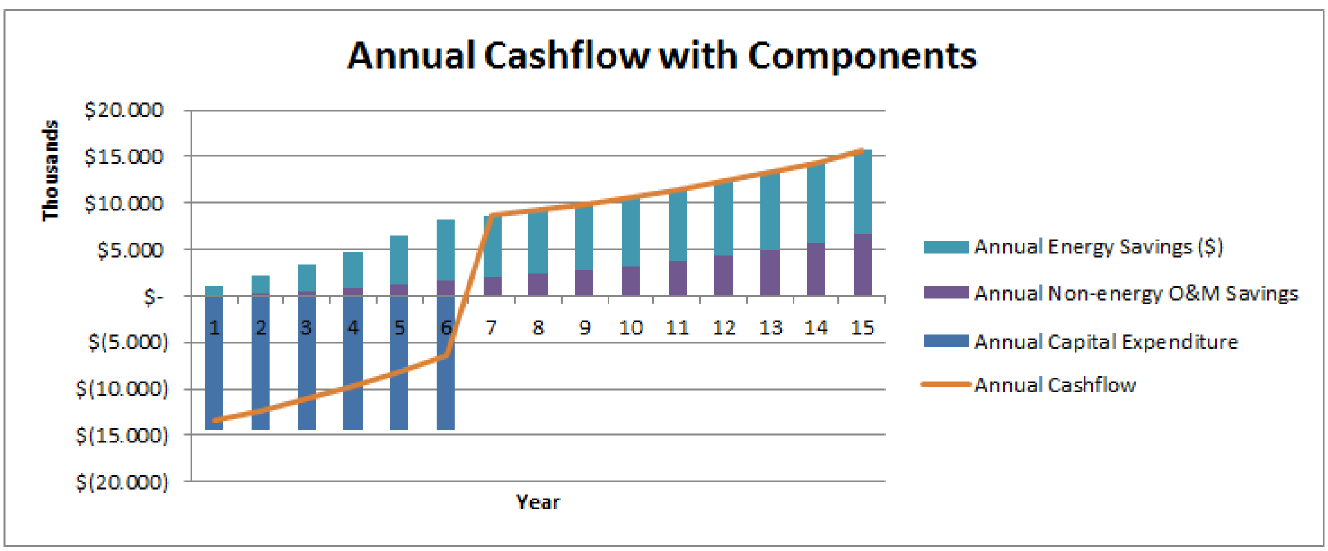
(Table 47)



(Fig.44)


Simple Cumulative Cashflow
Thousands
$60.000
$40.000
$20.000
$-
$(20.000)
$(40.000)
$(60.000)
$(80.000)
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Year

(Fig.45)


Annual Cashflow with Components
Thousands
$20.000
$15.000
$10.000
$5.000
$-
$(5.000)
$(10.000)
$(15.000)
$(20.000)
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Year
Annual Energy Savings ($)
Annual Non-energy O&M Savings
Annual Capital Expenditure
Annual Cashflow

(Fig.46)

LED with Adaptive Controls and Solar Panel (AC-SP)

# of Fixtures Installed		**55.757**
Implementation Period (years)		**6**

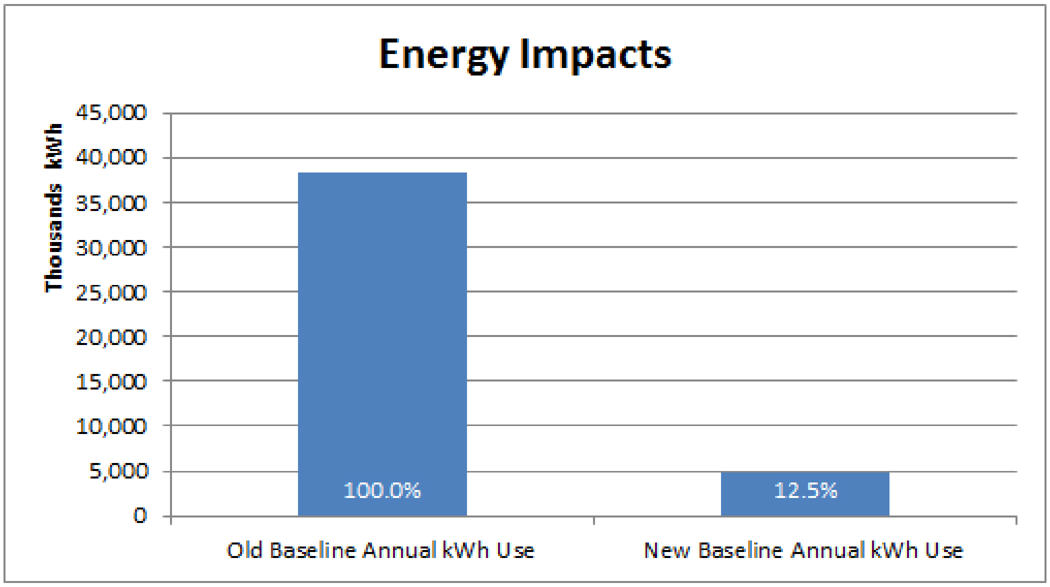
Analysis Period		**15**

Simple Payback (years)		**12,3**
15-Year Unlevered IRR		**5,79%**
15-Year Unlevered NPV ($)	**$**	**3.786.831**
15-Year Capital Expenditure ($)	**$**	**96.800.702**
15-Year Cap. Ex. $/kWh Saved	**$**	**0,2309**
15-Year Cap. Ex. $/ton CO2e Saved	**$**	**2.492,6523**

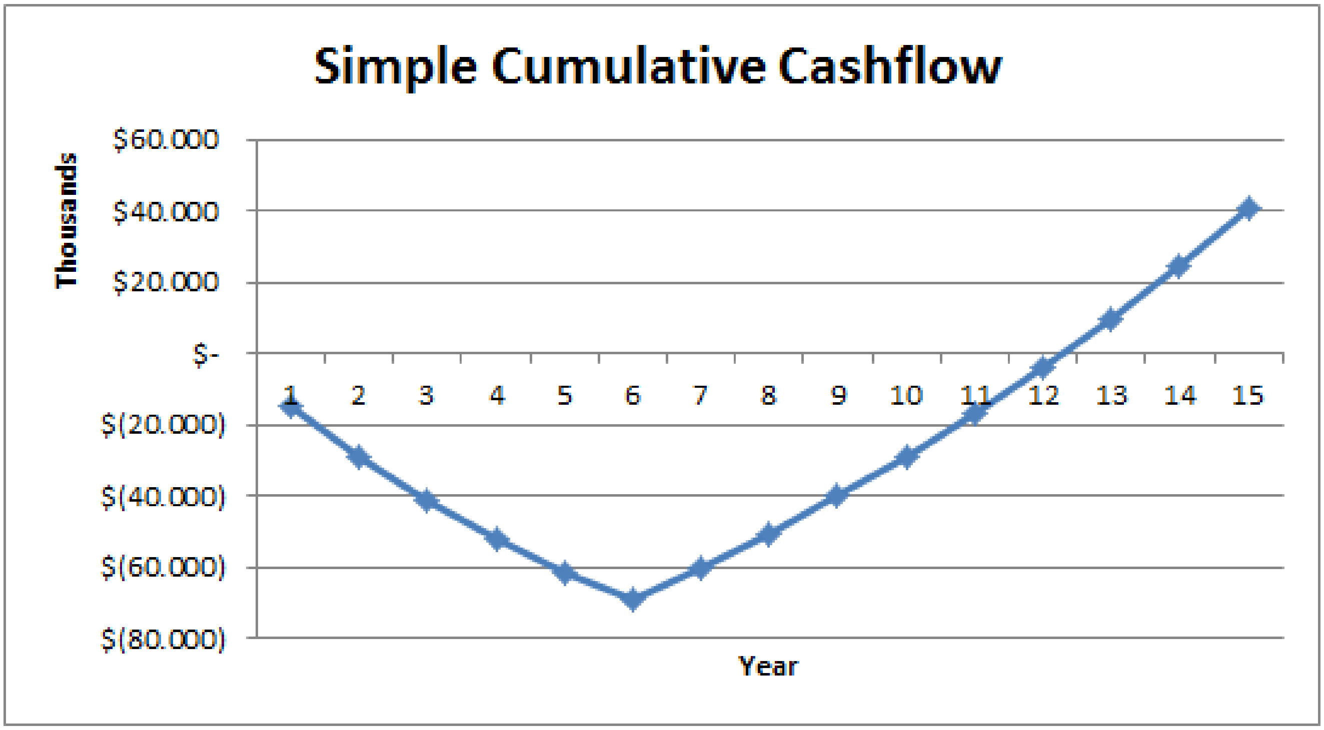
Annual kWh Savings		**33.535.767**
Annual Energy Cost Savings ($)	**$**	**5.701.080**
Annual GHG Savings (tCO_2e)		**3.107**
Old Baseline Annual kWh Use		38.334.830
Old Baseline Annual Energy Cost ($)	$	6.516.921
Old Baseline Annual GHGs (tCO_2e)		3.551
New Baseline Annual kWh Use		4.799.064
New Baseline Annual Energy Cost ($)	$	815.841
New Baseline Annual GHGs (tCO_2e)		445

First-Year Avg. Capital Expend. per Unit ($)	$	1.735
First-Year Avg. Material Cost per Unit ($)	$	1.673
First-Year Avg. Labor Cost per Unit ($)	$	13
First-Year Avg. Vehicle Cost per Unit ($)	$	50

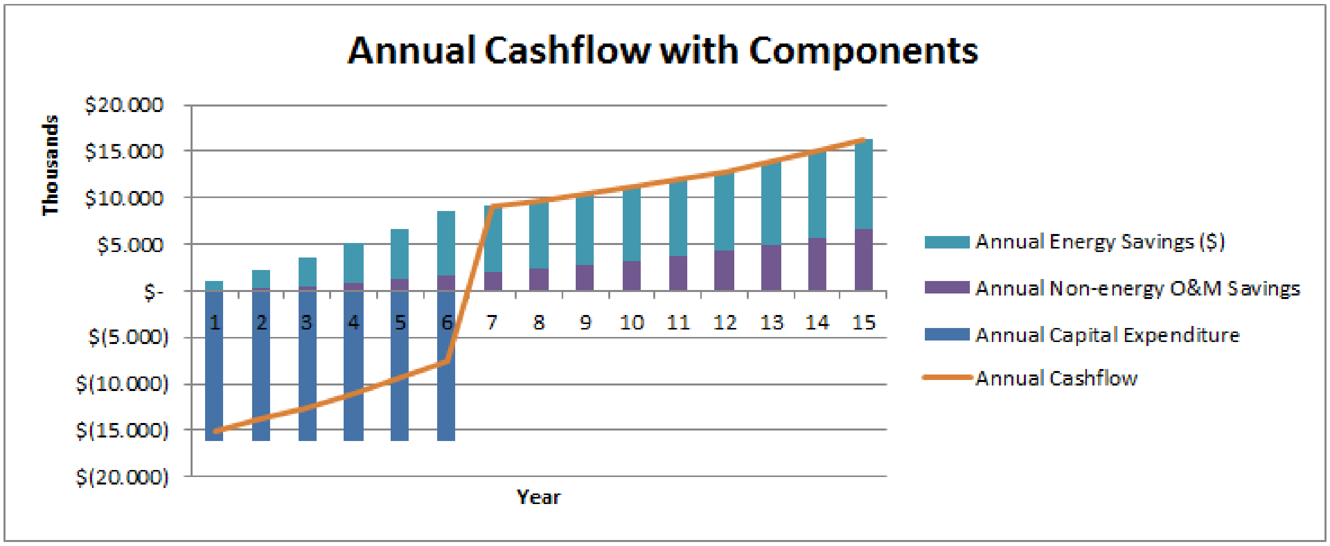
(Table 48)



(Fig.47)


Simple Cumulative Cashflow
Thousands
$60.000
$40.000
$20.000
$-
$(20.000)
$(40.000)
$(60.000)
$(80.000)
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Year

(Fig.48)


Annual Cashflow with Components
Thousands
$20.000
$15.000
$10.000
$5.000
$-
$(5.000)
$(10.000)
$(15.000)
$(20.000)
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Year
Annual Energy Savings ($)
Annual Non-energy O&M Savings
Annual Capital Expenditure
Annual Cashflow

(Fig.49)

Summary of São José dos Campos Energy Projections

In the table below the projections for the various LED street lighting scenarios are summarized.

15yr CE (R$) — *15 year Capital Expenditure*
15yr UL IRR (%) — *15 year Unlevered Internal Rate of Return*
15yr UL NPV (R$) — *15 year Unlevered Net Present Value*
AES (kWh, %)Annual — *Energy Savings (year 15)*
AECS (R$) — *Annual Energy Cost Savings (year 15)*
ANEOMCS (R$) — *Annual Non-Energy Operation and Maintenance Cost Savings (year 15)*
PP (years) — *Simple Payback Period*

Scenario	15yr CE (R$)	15yr UL IRR (%)	15yr UL NPV (R$)	AES (kWh, %)	AECS (R$)	ANEOMCS (R$, %)	PP (years)
LED	59,143,544	12.43	23,893,849	27,167,531 (70.9)	7,785,061	6,704,741 (89.6)	10.1
LED-AC	69,002,664	10.39	19,642,821	29,384,017 (76.7)	8,420,212	6,704,741 (89.6)	10.7
LED-SP	86,941,582	6.83	7,997,149	31,297,214 (81.6)	8,968,453	6,704,741 (89.6)*	11.9
LED-AC-SP	96,800,702	5.79	3,786,831	33,535,766 (87.5)	9,609,927	6,704,741 (89.6)*	12.3

(Table 49)

* Solar panel cleaning rate not included in the presented projections due to rainwater's ability to clean solar panels [Solar Daily, 2013]. However, it is likely that occasional cleaning (once per year) is required and when the cleaning rate is included in the projections, ANEOMCS fall to R$ 4,524,542 per year for the solar fixtures – rendering the option economically unfeasible as the retrofit would not achieve a payback as the street light network incurs large loses.

Public-Private Partnerships in LED Street Lighting

Street light PPPs were sought and researched in order to help create a realistic strategy for São José dos Campos. While few street light PPPs were able to provide information on their projects, a few PPPs were able to shed some light on how PPPs are implemented in the street lighting sector. Two examples are outlined below.

Croydon & Lewisham, United Kingdom

Skanska Infrastructure Development is a leader in the global PPP market. The business unit invests in, develops and operates roads, hospitals, schools, power plants and other public infrastructure in collaboration with public sector clients.

In 2011, a PFI (private finance initiative) contract between the London Borough Councils of Croydon and Lewisham and Skanska was signed to carry out a transportation development project, including the retrofit of 42,200 street lights (including installation of adaptive controls and central management system), installation of 20 subway lights and reflective traffic bollards. This bulk of this project includes the replacement of 38,200 street light fixtures and the refurbishment of 4,000 fixtures on a ward by ward, road by road basis. Skanska, along with it's 50/50 partner John Laing, formed a Special Purpose Vehicle (SPV), Croydon and Lewisham Lighting Services Ltd, to execute the project. This SPV funded the project with an installation period, CIP (Core Investment Programmer), of 5 years and total contract period of 25 years [James, 2013]. This project installation was initiated in 2011 and has an estimated completion date of 2015, with the operation and maintenance contract running until 2036. The total value of the contract is GBP 74 million (approx. EUR 86.1 million) [XE, 2013]. The operating and maintenance costs are approximately GBP 2 million, roughly GBP 47.62 (EUR 55.37) per fixture per year. The Skanska-Laing consortium is responsible for the design, construction, finance and operation of the lighting for the duration of the 25 year contract, as well as maintaining the existing infrastructure stock during the CIP. The clients, Croydon and Lewisham Boroughs, pay for the project via operating and maintenance savings [James, 2013].

The new fixtures being installed in this project are Philips Iridum 2 HID and LED street lights, both producing white light. An innovative Central Management System (CMS) is also installed to remotely monitor and control the street light fixtures. The CMS, in combination with the street lights adaptive controls, automatically dim and brighten the street lights according to environmental conditions and local user demand. This enhances the system’s ability to save energy while providing a appropriately lit street-scape [Laing, 2011].

The motivations for this street light retrofit project included; reducing criminal activity in high crime areas, reduced energy cost, the poor condition of the existing street light network, improved information management via CMS and the benefits of the new equipment itself (including white light, even light distribution and flexible remote control). Another motivation of the clients was to decommission the existing CCS which has grown organically since the 1900s according to city growth. This system, while relatively reliable, is vulnerable to large blackouts when failures occurs in the feeder columns (electricity distribution units) and is characterized by the inefficient spacing of street light poles, creating a 'cluttered' street-scape [James, 2013].

To ensure the timely success of the project, an independent certifier was commissioned to oversee the project. The role of this entity is to ensure timely payment by the Borough Councils and the quality of service provided by the contractor. The Borough Councils negotiated contractual milestones with Skanska to keep the project on the agreed upon timetable. Furthermore, there is a continual consultation process between the clients and the contractor to assist with modifications to the original plan, successful coordination with other transportation services and to assess and respond to public feedback [Laing, 2011].

Surrey, United Kingdom

Skanska-Laing conducted a similar street light retrofit project in Surrey, a county in the southeast of England. The project involves replacing or refurbishing nearly 89,000 LPS streetlights with HPS and fluorescent street light fixtures. Approximately 70,000 street lights will have both the column and the light fixture replaced and the remaining 19,000 will have just the light fixture replaced [Disley, 2013]. The installation will take place throughout Surrey during the first 5 years of the concession (2009 - 2014) and then operating and maintaining the street light will take place until 2034. Individual lighting columns will be remotely controlled, with adaptive controls, from a new control center near the town of Guildford, improving the level of service. The operating and maintenance costs are approximately GBP 4.2 million and the total contract value is to the Skanska-Laing consortium is GBP 79.6 million

[James, 2013].

One of the main partners in the project, the Department of Transport, has provided a GBP 148.4 million grant in the form of PFI credits. The PFI grant covers all of the costs associated with the light fixtures and columns, and its installation – including demolition of old columns, re-wiring and re-paving (this extra work is the reason for the high project cost). The County Council does not need to repay this grant, making the project possible. The operation and maintenance costs of the street light will be covered by Surrey County Council's existing annual street lighting budget. The fixed fee paid by the council transfers all risk and liability on repairs and maintenance during the 25 year contract period to the contractor [Disley, 2013]. The project is expected to save council taxpayers at least GBP 12 million over the life of the contract [Surrey, 2013]. All recyclable fixtures will be handled by Surrey County Council's nominated cast iron disposal company, Fenori, and all funds raised will return to the PFI fund.

PPPs in São José dos Campos

One of the principal environmental concerns in São José dos Campos is the solid waste situation. Currently, the city produces 700 tonnes of domestic rubbish per day and disposes of this waste in traditional landfills [Cortez, 2013]. In January 2013, the city of São José dos Campos commissioned a study to research possible waste-to-energy incineration solutions to address the growing concern of solid municipal waste. The São Paulo State Government has ruled out the development of new landfills for domestic and municipal rubbish and with only twelve years of landfill capacity remaining, the city has started to explore future disposal options [Cortez, 2013]. Options that have been discussed include exporting the waste or incineration. Currently, firms from the Netherlands and Germany have been working with the city municipality on facility options. Due to public resistance to incineration, stemming from air pollution concerns, the city has approached firms operating in Europe as they must comply with the European Union's strict air pollution standards.

This project was designated as an administrative concession with the operator constructing the facility and maintaining responsibility of the energy recovery system from the processing of municipal solid waste. The municipality was responsible for expropriation costs and financing based online Environmental Sanitation and Water Resources of the BNDES (Brazilian Development Bank) [Seixas, 2013]. The facility operator pays for solid waste supplied by Urbam, the city's urban waste disposal contractor [Pita, 2013]. The concession period is 30 years and has prospects for return on initial investment in eight years.

According to the secretary of the environment, André Miragaia, the public-private partnership was chosen to prevent the municipality having to increases taxes on residents. Moreover, according to Mr. Miragaia the private partner has experience in business and is able to provide high quality services [Pita, 2013]. The performance assessment of the PPP is audited by an independent verifier commissioned by City Hall and by the concessionaire. In this process, the utility clears the results according to criteria established in the bidding process, and this result is sent to the independent verifier [Seixas, 2013].

Proposed Street Light PPP in São José dos Campos

One of the key, and most logical, aspects of São José dos Campos' interest in exploring a possible LED street light retrofit project was the simple question of *how are we going to make this happen?* Considering not only the magnitude of the investment required (approximately EUR12.6 million) and the timescale of the project (6 year installation, 7.8 year payback) but also the local political situation, it becomes clear that many challenges stand in the way of such a project coming to fruition.

In São José dos Campos, a new government was elected following the municipal elections at the end of 2012. The newly elected governing party, the *Partido dos Trabalhadores* (PT, left-leaning Workers Party), faces many socio-economic challenges such as the rising cost of living, growing population, informal settlement expansion, air pollution, municipal solid waste capacity and healthcare system capacity [Cortez, 2013]. All of these issues require public spending to address the challenges, meaning funding allocations are tighter than ever.

Another influential facet of the local political environment is the fact that the PT has replaced the long-standing PSDB *(Partido da Social Democracia Brasileira,* right-leaning neo-liberals), which has created much distrust and suspicion among civil servants in the municipal government departments. This is attributed to the fear that new Department Directors will instigate structural and human resource changes in the departments, thus reducing the cooperation between civil servants of different political leanings [Villaca, 2013]. During the interviews, it was found that most civil servants were quite unwilling to discuss these issues, and while these political games are always in play, they are more evident immediately before, during and after elections.

In order to advance the sustainable development of São José dos Campos, through the use of LED street lights, a feasible strategy must be found to move such a project forward. During the literature review and interview portions of this project, it became evident that in order to realize a project of this magnitude, a collaborative effort that brings together the various influential interest groups was the most likely to be successful [Vernice, 2013]. This section combines the research on various public-private partnership mechanisms in Brazil, São José dos Campos and infrastructure projects around the world with the local conditions and expectation. The aim of this is to present a potential strategy that offers a framework from which to further discuss the possibility of an LED street light retrofit project.

São José dos Campos as a city municipality is interested in adding LED street light technology to it's portfolio of sustainable development initiatives. The various motivations behind this interest stem from the desire to increase energy efficiency across the city, reduce costly maintenance practices of existing street lights, potential urban development benefits resulting from better urban lighting and the city's continued desire to remain at the forefront of Brazilian industrial innovation [Cavali, 2013]. These interests come from multiple departments within the city government and while this increases the complexity of the solution needed to meet the various goals, it enhances the overall chances of success through networking and collaborative action.

Currently, the city owns the street lights but has contracted installation and maintenance services to the local energy provider, EDP Bandeirantes [Villaca, 2013]. The Department of Public Works has stated that if any new street lights were to be installed, they must be owned by the city [Vernice, 2013]. More flexibility is given to the source of maintenance services but it is preferred that the Department of Public Works' maintenance crews adopt service responsibilities in the future. As in most infrastructure projects, a bidding system is in place to allow private companies to compete for construction and maintenance contracts. Due to the longstanding operation and maintenance contract (including installation of new fixtures) with EDP Bandeirantes, the city is unable to execute any construction or installation phases in any street lighting project. In São José dos Campos, the city attempts to give preference to local companies competing in the bidding process as long as reasonable financial conditions are met. This is done to support the local economy and to foster the local development of solutions to municipal challenges. This aspect, coupled with the city's desire to generate more jobs and tax revenue, has created an opportunity for the city to participate in the foundation of a local lighting company. This lighting company, a possible subsidiary of Lumi Group, could utilize the street lighting technology already developed in Finland and manufacture it locally; avoiding import tariffs on foreign goods and therefore reducing the capital expenditure costs.

As a result of the wishes expressed by city officials, including limited financial resources, limited maintenance capabilities and desire to own the utility asset, a BOT (build-operate-transfer) partnership mechanism appears to be the most practical for the city. This coupled with the fact that street lighting is a municipal service and members of the public are not charged directly for it, the project would be deemed an administrative concession under Brazilian PPP law. Finally, according the LED street light projections for São José dos Campos outlined in the results section, the project would have a minimum total budget for capital expenditure, operation and maintenance of over R$ 55 million and a project timeline of between eight and fifteen years, fulfilling the general conditions (stipulated in Brazilian law) required to be classified as a PPP.

Proposed PPP Partners and Roles

City Government of São José dos Campos

Department of Public Works

Department of Economic Development, Science and Technology

The Department of Public Works is responsible for general oversight, monitoring and payment of the project since they will be handed control of the street lighting asset at the end of the contract period [Vernice, 2013]. Concession agreement payments will be made from the existing street lighting budget. The Department is also the project's point of contact to the Federal Government, keeping them informed of progress and ensuring all relevant regulations and laws are being met. The Department of Public Works should also lobby the São Paulo state government for funding as they have R$ 3.76 billion allocated to PPP projects per year [GDESP, 2012]. Additionally, Department officials will familiarize themselves with, and develop, the various aspects of managing a street lighting network. As the overall client, the Department will also be responsible for the identification and hiring of an inspector or guarantor who will be charged with monitoring and reporting the progress of PPP.

The Department of Economic Development, Science and Technology utilizes it's extensive business and industry network to locate additional funding sources (private equity) for the project and to assist Lumi Group in the foundation of a lighting subsidiary to serve the local market [Cavali, 2013]. This involves locating private equity funding sources to finance the construction of a street light assembly facility. Furthermore, the Department's local business knowledge will prove to be very useful in the identification of subcontractors who will manufacture the street light components for the Lumi Group assembly facility [Fonseca, 2013]. Additionally, the department will be fundamental in the survival and ultimate success of the subsidiary through the awarding of the Urban Land and Property Tax exemption (2 – 12 years, Complementary Municipal Law 256/03), reduction of the ISSQN (service tax rate) and the reduction of tax placed upon production industries to the minimum of two percent [SJdC, 2011]. Additionally, the Department will facilitate Lumi Group's integration into the city's technology park and innovation cluster – where new start-ups are established in close proximity to other innovative companies and strategic assets [SJdC, 2013]. Again, the Department's network connections will be used to secure Lumi Group complementary assets and facilitate relationships with firms developing appliance controls (adaptive controls) and/or photovoltaic technology [Cavali, 2013].

LED Manufacturer

Lumi Group Oy

Lumi Group's role in the PPP consortium is to help EDP Bandeirantes plan and design the street lighting project. Lumi's expertize in LED technology will allow the plan to illuminate São José dos Campos' streets effectively – creating optimum illumination levels without unacceptable light trespass onto private property and upward light pollution. Lumi will be responsible for establishing and operating the street light manufacturing facility as well directing research efforts with other technology firms and universities in adaptive controls and integrated solar panels for the LED street lights.

Financiers

BNDES
FINEP
State Government of São Paulo
Private Equity

The Brazilian Development Bank (BNDES), the Funding Authority for Studies and Projects (FINEP) and the State Government of Brazil will be the most likely funding partners. They have a wealth of experience in PPP projects and also have access to wide networks of business and industry specialists that may provide useful assistance to the retrofit project. Private equity firms will be approached for funding for the Lumi Group subsidiary and the assembly facility construction (these contracts are outside the core PPP structure). This results in the subsidiary being partially owned by Lumi and private equity sources as Lumi does not have the financial resources to establish themselves in Brazil.

Utility Company

EDP Bandeirantes

EDP Bandeirantes will design the street light project, install the new fixtures, supply the electricity and maintain the street lights during the contract period. Their participation is a prerequisite for success as they are the current contracted ESCO for the city and will be needed for the implementation, operation and successful transfer of the assets back to the city.

Research and Development

University of São Paulo, Institute of Energy and the Environment
Federal University of Santa Catarina, Solar Energy Laboratory
National Institute for Space Research

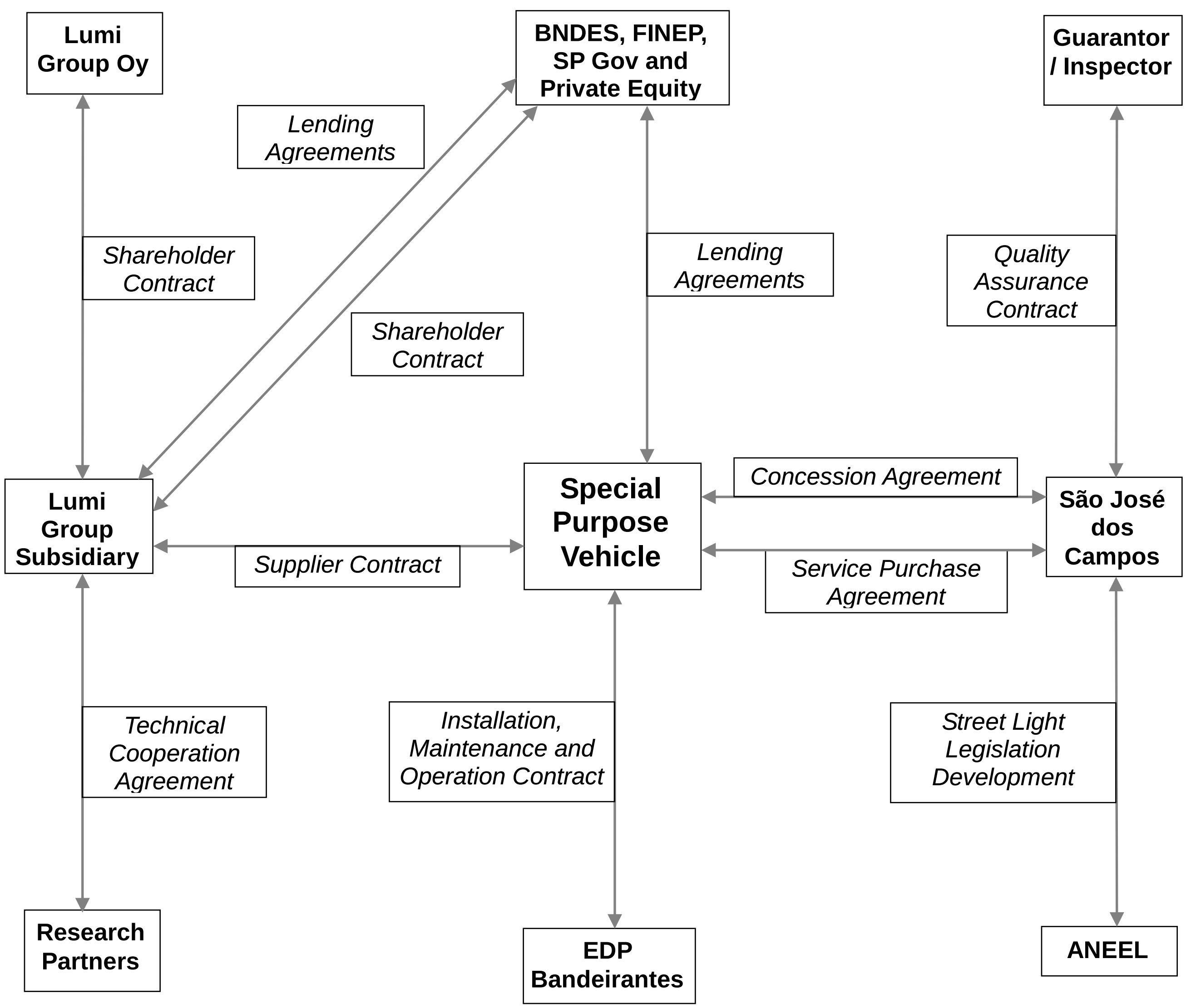
These academic and scientific partners, as indicated by the Department of Economic Development, Science and Technology will assist in the continued development of Lumi street lights, adaptive controls and integrated solar panel [Cavali, 2013].

Brazilian Federal Government

National Agency for Electrical Energy (ANEEL)

Currently, there are few regulations governing street lights (ANEEL Resolution 414/2010) and none covering LED street lights. São José dos Campos has been proactive in starting to develop legislation for street lights and these measures include clauses for; pole distance, pole height and light output according to road classification [Villaca, 2013]. By manufacturing the LEDs in São José dos Campos and continuing to improve their performance through collaborative research with universities, the PPP consortium can help the municipality further their efforts to establish appropriate street lighting regulations for São José dos Campos.

Proposed PPP Structure - Contracts and Relationships (Fig.50)



The diagram above depicts the relationships within a possible PPP created to bring an LED street light retrofit project to fruition in São José dos Campos. The proposed PPP would take the basic form of a concession agreement, as outlined in Brazilian PPP law, with a few added partners to create the inclusive solution desired by São José dos Campos.

Instead of purchasing LED street lights from multinational corporations (e.g. Philips, Osram etc) with domestic Brazilian manufacturing facilities, the city municipality hopes to encourage local economic development and technical innovation through the creation of a local LED lighting company. Part of the motivation for this is the creation of a new industry for the city, in the form of high efficiency lighting, to further the economic and technological innovation of the city by creating jobs and generating tax revenue. [Vernice, 2013]. In order to achieve this, as well as address the 'strategic project' (project of great significance to the city) of municipal street lighting, the city invites an LED manufacturer (Lumi Group) to create a local subsidiary.

Lumi Group is seen by São José dos Campos as a potential partner for the following reasons. Firstly, it is a small company without extensive corporate structure, allowing a tailor-made subsidiary to be created for local business conditions. This also allows for the Department of Economic Development, Science and Technology to assist in the identification of local partners and employees, creating more local employment. Secondly, Lumi Group has a range of turn-key street light solutions already in use throughout Europe – streamlining the process of implementing a street light retrofit. Thirdly, Lumi Group is an innovative company that actively designs new street lighting solutions such as the street light with built-in solar panel and adaptive controls. This is seen as an excellent opportunity for collaboration with local universities and research laboratories to further develop Lumi products for local conditions. Fourthly, Lumi Group is itself a subsidiary of Oversol – the parent company which produces a range of interior LED lighting solutions for commercial and residential applications. This industry expertise is a notable advantage in bringing not only the street lighting sector to the city but the high efficiency lighting industry in general.

For the PPP project to move forwards, Lumi group would establish a local LED subsidiary with funding from private equity investors. This LED subsidiary would supply the street lights via a *special purpose vehicle* company that is created to provide the LED street light solution, operation and maintenance to the city. The LED subsidiary would subcontract the manufacture of the LED street light components to local manufacturers in the state of São Paulo and assemble the components in the facility established in São José dos Campos. The Department of Economic Development, Science and Technology will assist in the identification of subcontractors through their extensive economic network. By subcontracting the manufacture of components, the subsidiary greatly accelerates the project implementation process. The special purpose vehicle subcontracts operation and maintenance to the existing energy utility and maintenance company, EDP Bandeirantes in order to make use of their existing grid network and maintenance crews. During the contract period, the Department of Public Works will develop their own maintenance capabilities as they will be the owner and operator of their own street light network at the end of the contract period. During the concession period, the city pays the special purpose vehicle from the existing street light budget. The SPV then pays the LED subsidiary for the street lights, EDP Bandeirantes for electricity and maintenance, and investors for their capital expenditure funding. During this contract period, the city hopes to develop and pass legislation to create standards for LED street lighting. This will further increase the effectiveness of the street lighting network as pole distances, pole heights, lumen output per street type, light cutoff and smart dimming functions will be optimized by the local subsidiary and it's research and development partners. This is seen as a necessary step as street illumination is currently very irregular, resulting in under-lit and over-lit areas.

Discussion

The following section discusses the results collected during the fieldwork stage. The chapter starts with primary and secondary impacts of LED street lights in the case study cities and assesses potential impacts for a hypothetical retrofit project in São José dos Campos. Following from this, SWOT analysis is used to analyze the strengths, weaknesses, opportunities and threats of both LED street lighting in general and the proposed implementation strategy (public-private partnership for São José dos Campos). The chapter goes on to present LED street lighting's implications for sustainable development after which the original research questions are addressed. Finally, research limitations are discussed and further research is suggested.

Primary Impacts of LED Street Lights

Energy Consumption

As seen in the primary results section, all of the case study cities (CSCs) reduced their municipal energy consumption as a result of switching to LED street lights. The amount of savings varied from 37 to 75 percent and the level of savings realized depended upon the wattage difference between the replaced technology and the new LEDs. In most cases, the LED wattage currently being used by the case study cities is about one third of the wattage of the old street lights. The reason why actual savings sometimes exceeded two thirds (in cases where LEDs of one third wattage were used) was due to the difference between lamp wattage and system wattage. A street light fixture system with a 100W rated HPS bulb often has a system wattage of more than 100W (about 15 percent more) due to additional energy consumption in the ballast component. This is also seen in the São José dos Campos case study where existing 100W, 150W and 250W rated street light bulbs are actually part of fixtures that had system wattages of 117W, 171W and 279W. What these results show is that as a result of implementing street lights, a municipality can reduce it's energy consumption, which in turn reduces greenhouse gas emissions (in most cases) as fewer kilowatts are used.

Only three of the eighteen case study cities achieved energy savings of less than 50 percent and in these cases the city officials and engineers stated that there was in fact 'over-lighting' of the street scape. This 'over-lighting' was explained by Mrs. Bourque-Parker (Anchorage, Alaska) to be attributed to a lack of LED street light specific planning guidelines. This lack of LED street lighting standards meant that LEDs were installed in the same pattern (usually on the same poles) as previous street lights and due to the higher performance of LED (more lumens per watt and greater, further distribution of light) the streetscape had become over-lit. In these cases, it was suggested that fewer LED street lights were needed due to their superior performance and that the spacing between street lights should be increased. This has important implications for São José dos Campos as Brazil has few street lighting planning regulations in place. If a retrofit project were to be completed in São José dos Campos there exists a risk of over-lighting as the existing HPS fixtures would be directly replaced by LED (on the same poles, maintaining existing pole height and spacing). In the different LED street light scenarios projected for São José dos Campos, a baseline of 70.9 percent energy saving was achieved using LED lights, with no adaptive controls or integrated solar panels. This energy savings was greater when adaptive controls and solar panels were used; 76.7 percent (LED-AC), 81.6 percent (LED-SP) and 87.5 percent (LED-AC-SP). It is clear that most of the energy savings are due to the

LED technology and not the adaptive controls or solar panel. The adaptive controls saved an additional 5.8 percent (over the basic LED), the solar panel 10.7 percent and the adaptive controls with solar panel combination saving and additional 16.6 percent. Although these energy savings are desirable, the higher unit prices make justifying their use more challenging in cases where financial resources are a limiting factor.

Maintenance Intensity

The maintenance results from the case study cities (CSCs) show that an average of 69.5 percent cost savings were achieved as result of the LED street lights requiring fewer repairs. City engineers indicated that these cost savings were the result of fewer man hours, fewer vehicle hours and fewer replacement parts being needed per unit per year. The reasons given as to why the LEDs required less attention was due to the longevity of the lighting element (50,000 – 70,000 hours, in most cases about three times longer than existing bulbs), the robust nature of LED street lights and lower out-of-box and first-year failure rates (failure due to faulty technology from the manufacturer upon installation or during the first year of use). When considering maintenance costs it is important to remember that when a bulb, or any other component, in an HPS, MV or MH street light is replaced, the cost incurred to the municipality is not only the cost of the bulb itself (usually less that EUR 20.00 per unit), but also the cost of technician work hours and the work vehicle rate (these non-capital expenditure items are far more costly than the bulb component itself). Therefore by having more reliable and longer lasting components, not only are component costs savings captured but significant savings on human resources and repair vehicle usage are also achieved. This can allow city engineering services to spend less time on street lights, saving money or redirecting their efforts elsewhere. By having a more efficient street light network, not only does street lighting improve but other city services can be enhanced as a result of additional financial and human resources being available.

Another source of maintenance savings resulted from the automatic remote monitoring of street lights (e.g. Seattle). Adaptive controls and remote monitoring systems are self-governing software packages that change the performance of a street light according to local environmental conditions and user demand (motion sensors and/or timed dimming). In the case of automatic dimming, street lights reduce their power consumption (and therefore emitted light) by responding to the environment around – i.e. ambient light levels and frequency of local street use. In these instances, LED street lights are dimmed to around 80 percent of maximum light output during times of low vehicle and pedestrian traffic. This not only saves energy but can also reduce light pollution as the street lights are dimmed. LED technology can facilitate this added control of light due to it's near instant power up (lights do not require time to warm up and desired light output is instantaneous). This is not possible in most conventional street lights as they use a ballast component which requires time to heat up the elements inside the bulb. Furthermore, intelligent LED street lights can be remotely monitored from a street light control center using real-time data and the street lights themselves will indicate when there is a fixture failure. In many cases this has eliminated the need for night-time scouting patrols by maintenance crews looking to identify broken street lights. Moreover, this enables street lights to be attended to much more rapidly than waiting for a member of the public to report it broken or having it identified by a night-time patrol. Here, the use of self-governing technology has not only reduced energy costs (active dimming) and maintenance costs (fewer man hours), but has also increased the quality of service provision as each broken light is 'out' or not working for a shorter period of time, thus maintaining a superior level of illumination.

Product Design

During the research phase some technical problems were found to exist with LED street lights. While investigating LED street light projects, San Antonio, Texas (although not a focus case study city) was found to have had a significant problem with LED street lights failing due to rainstorms. During the installation of the first 2,000 street lights (of a total of 25,000 to be replaced), a series of fixture failures resulted from a mechanical design fault where fixture gaskets allowed water into the lighting elements, causing short circuits [Wright, 2012]. The project was suspended and all 25,000 Greenstar/Toshiba units were returned to the manufacturer. One drawback of LED lighting technology, noted during unit testing in Brazil, was the technology's vulnerability to lightning strikes. During the Lumi street light and solar panel testing, one street light fixture was damaged due to a lightning strike during a thunderstorm and rendered unusable for further testing. These vulnerabilities to local weather conditions are product characteristics that should be addressed to properly serve markets in high precipitation and lightning activity areas.

LED technology was found to suitable for sustainable development in areas other than energy and maintenance intensity. Most of the CSCs indicated that their LED street lights were recyclable (aluminium often used in casings) and contained no heavy metals (mercury or sodium). This makes disposal safer and some of the capital investment can be recouped through recycling of the fixtures. Recycling of fixtures not only reduces the impact of street lights on the waste management system but it also creates an economic opportunity for local recycling firms. Adaptive controls can have a positive effect on the lifetime of an LED street light as running the fixture at a lower power level (in instances of low user demand) reduces the stress on the LEDs, extending their lifetime [Davis, 2013 and Ferguson, 2012]. Furthermore, due to the superior performance of LEDs in illuminating the street, fewer street lights may be needed (e.g. Anchorage, Alaska). This could allow the city to remove some of the existing street lights, reducing the amount of poles and creating a less cluttered urban environment. This has positive implication for pedestrian traffic flow as well as the general aesthetics of the streetscape.

In the projections for São José dos Campos, Lumi Group R-Series street lights were used. Lumi street light technical specifications compare favorably to HPS specifications (not only energy and maintenance related) as color temperature is neutral white (4,200K) compared to the warm yellow glow of HPS (2,100K) [Lumi Group, 2013]. This can more effectively illuminate the streetscape as residents in the case study cities indicated that their vision had improved when LED street lights with color temperatures between 4,000-5,000K were used. Furthermore, the R-Series street lights emit more light within the mesopic and scotopic light spectrums, suggesting an enhancement in nighttime vision.

Financial Aspects

Reductions in energy consumption have decreased operational expenditures for all of the case study cities (CSCs). These savings combined with diminished maintenance schedules have helped all the CSCs realize substantial (EUR 28,229 – 7,535,250 per year) cost savings. This has helped twelve of the CSCs to achieve payback periods of less than ten years. In the cities that had longer payback periods (e.g. Chattanooga, Salford, Lancashire), street lights had been installed with adaptive controls for added energy and maintenance efficiencies. In Chattanooga's case (10 year payback), the city opted to partner with a local LED manufacturer to develop streetlights and adaptive controls specifically for the city's needs. Mr. Davis, of Chattanooga Public Works, explained that the higher capital expenditure in their project was due to the level of customization of their street light network solution. The customized product was the result of extensive consultation with the local Police Department – allowing in LED street to be controlled by police officers from their patrol vehicles.

As many cities face financial hardship, budgets are often reduced – jeopardizing the quality of public services in the affected departments. By using fewer resources in one department, a city can redirect public spending to the sectors most at risk of not maintaining desired service levels. The CSCs of Anchorage, Lancashire and Salford used cost savings to offset rising costs in other departments to avoid reduced service delivery in those sectors. Another use of cost savings was reinvestment in LED street lights. Chattanooga, Salt Lake City and Lancashire used cost savings to invest in more LED street lights to expand the scale of their projects. In these cases, city officials indicated that the street light retrofit had been successful enough to justify expanding the project. This self-perpetuating cycle is beneficial to the community as the level of services provision increase without investment exceeding the original street lighting budget. As more LEDs are installed, the energy and maintenance savings increase accordingly and this can be seen clearly in the annual cashflow projections for São José dos Campos.

Secondary Impacts of LED Street Lights

Light Pollution

Overall light pollution was reported to have decreased in each of the eighteen case study cities (CSCs) and this was attributed to the high degree of control of light distribution in LED fixtures. Skyglow (upward light emission) and light trespass (light spillover onto areas where no lighting is desired) were reduced due to the precise direction of light by the fixtures. In instances where private property had become over-lit as a result of the new LED fixtures, maintenance crews were able to adjust the fixtures and redirect the light patterns (Fallon and Boston). The Bureau of Street Lighting in Los Angeles has received positive feedback from the International Dark Skies Association (a light pollution reduction advocacy group), residents, community groups and the Police Department, confirming that light pollution, sky glow and light trespass have been reduced [Ebrahimian, 2013]. It is worth noting that in Boise, Idaho light pollution may have increased in some areas as residents mentioned streets lights being too bright. This can be a result of, as in the case of Anchorage, a lack of LED specific regulations guiding the implementation of the new streets lights. A lack of regulations has led to some street lights in Anchorage being too powerful for their road category and street light poles being too close together – because of regulations being set for conventional light sources.

Public Safety

Just under half (seven of eighteen) of the CSCs reported enhancements in public safety resulting from the LED street lights. This was due to the clearer, whiter light emitted from LED fixtures, creating an illumination very similar to that of day-time natural light. Enhanced public safety was attributed to clearer vision which has a variety of positive effects on public safety. Firstly, clear vision enhances people's perception of their safety, allowing them to make more use of streetscapes at night-time [Wolf, 2010]. As more people are out at night time, people feel less vulnerable and criminals are less likely to commit offenses [Cordner, 2010]. Secondly, clearer vision allows people to avoid danger more effectively as they can recognize a threatening situation sooner and take evasive action. Thirdly, clearer vision allows law enforcement to be more effective as facial and vehicle recognition is easier for police officers and the general public [Burke, 2013]. This is also the case for video footage from CCTV security cameras and in both cases, prosecution of criminals is more effective and reliable. In Chattanooga, Fallon, Jackson Township and Salt Lake City it was found that the Police Department had developed a closer working relationship with Departments of Public Works as a result of LED street lights projects. This was attributed to increased collaboration between city departments in the design phase of street light projects and as a result, police officers encourage further adoption of LED street lights.

In Boston, police statistics show that burglaries, assault and car theft fell by nine percent in LED street light project areas after the lights had been installed. The Boston Police Department and it's officers are now strong advocates for LED lighting according to Mr. Cooper of the Public Works Department. In Los Angeles, car theft fell by 13.6 percent, burglary and theft by 7.82 percent and vandalism by 10.9 percent (incidents between 19.00-07.00) after LED street lights were installed [BSL, 2013]. Los Angeles, with comparatively high crime rates, has become a supporter of LED street lights and regularly updates project reports and resulting effects. It must be noted that where statistics are available for public safety, reductions in crime may have occurred due to other factors such as increased police presence and increasing quality of life in the city. However, the Public Wrks and Police Department officials from Boston and Los Angeles were quite certain that LED street lights had a role to play in the reduction of crime.

Road Safety

Road safety was a secondary effect for which few results were found. Only eight of the CSCs reported any effect on road safety and in these cases the white LED light had reduced the number of vehicle collisions at intersections (i.e. Fallon, Jackson Township) due to better peripheral vision. Accident data was unavailable for the researched cities due to a lack of studies on the topic but city officials stated that emergency services had noted a decrease in collisions at intersections where LED lighting had been installed [Souba, 2013; Ebrahimian, 2013 and Burke, 2013]. LED lighting was suggested to also have a positive impact on driver safety in normal and adverse driving situations.

Public Perception

The perception of the public regarding LED street light retrofit projects was very positive in most of the CSC projects. Mississauga reported positive responses from 97 percent of people interviewed while Seattle had 78 percent of respondents indicating their vision have improved as a result of the new street lights. For many of the cities which did not have statistics available on public perception, the interviewed project managers and officials did note that the overwhelming majority of public responses received in online and paper feedback forms had been positive about the LED street lights. In a minority of cases (Anchorage, Fallon and Salford) the Department of Public Works (or it's local equivalent) had received a small number of negative responses. In the case of Fallon and Anchorage, the negative responses were limited to a specific fixture (too much light falling onto a specific property) and not the network as a whole. In Jackson Township, one elderly resident interestingly enough complained how the LED street light had reduced the amount of light falling onto her front garden.

Finally, during the initial research of potential CSCs, many pilot projects were studied. In the majority of these cases (e.g. London, Sydney, New York) public perception studies were conducted and showed a strong preference for LED lighting.

São José dos Campos Projections

The projections for São José dos Campos produced promising results for both energy and maintenance savings as a result of implementing LED street lights. However, the business case for each scenario was different due to the differences in capital expenditures. While all scenarios achieved energy savings of at least 70 percent and maintenance savings of almost 90 percent, only the basic LED scenario and LED with adaptive controls achieved and internal rate of return greater than 10 percent. With an IRR of 12.43 percent the LED-only scenario achieved a payback period of 10.1 years and the LED-AC scenario achieved a payback of 10.7 years. The added energy savings resulting from adaptive controls and solar panels are marginal and probably do not justify the added cost at this stage. However, adaptive controls and remote monitoring have other benefits associated with them including better public safety (street lights can be controlled by police officers), reduced light pollution (lights are dimmed when no users around) and very efficient maintenance practices (automatic reporting of faults by the street lights). When deciding which option to use in an retrofit scenario, a municipality must decide how valuable the added benefits of adaptive controls and solar panels are. These added benefits should be taken into account during cost-benefit analysis when deciding on the viability of an LED street light retrofit project. LEDs with adaptive controls are not far off the financial performance figures of the LED-only scenario and have a IRR of 10.39 percent (2.04% less than that of basic LED). With a few more years of product development and decreasing unit costs, they should become a financially viable option for all LED street lights projects.

With street light energy consumption in São José dos Campos at 25.9 percent of public sector energy use and 2.2 percent of the whole city's energy consumption, reducing the energy consumption of the street light network by 70.1 percent (LED-only scenario) would decrease overall energy consumption in the city by 1.54 percent. Energy consumption in the area is growing at 2.1 percent per year [Luna, 2013], a decrease in consumption of 1.54 percent represents 73 percent of the additional energy demanded. By supplying most of the additional energy need through energy savings, the city can more easily fulfill energy requirements. This in turn reduces the amount of investment needed in obtaining additional energy, increasing the city's capacity to continue developing.

Due to the restrictive financial situation in São José dos Campos, and the difficulty in obtaining external funding, the added unit cost of solar panels makes solar LED street lights an unlikely choice for the city. Furthermore, if each panel requires to be cleaned once per year, the associated maintenance costs negate any cost advantage captured by the LED energy and maintenance savings, making it economically unfeasible. These solar-powered LED scenarios also require more design work as the solar panels would probably be selling electricity to the grid (during the day) and this would increase the cost of the planning the project and installing the lights. It is therefore likely that solar panel street lights are not a viable option for São José dos Campos and exist as a street lighting solution for isolated communities or installations.

SWOT Analysis – LED Street Lighting

During the research, few studies were found to have been conducted on the secondary impacts of LED street lighting. This was mainly attributed to the fact that LED street lighting is a relatively new piece of transport infrastructure and many LED retrofit projects around the world are still in their infancy. This lack of data on secondary impacts, or 'co-benefits', meant that mainly qualitative data was collected from the city officials and project managers regarding secondary effects. SWOT analysis is a tool useful when assessing qualitative data as it analyzes the strengthens, weaknesses, opportunities and threats of the study focus. In this instance LED street lighting, as investigated in this research study, is assessed with a SWOT framework as a combination of quantitative and qualitative data was collected.

Strengths

From the research, LED street lights were found to be much more energy efficient than their high pressure sodium, mercury vapor and metal halide counterparts. This was due to the LEDs technology’s ability to produce similar lighting levels with less energy. Similarly, LED street lights require far less maintenance, in the form of labor hours and spare parts, than conventional street lights. Reductions in both energy and maintenance intensity result in significant cost savings for the street light network operator. Cost savings allow a city or municipality to invest in other public services and assets, improving other aspects of the urban environment while maintaining (and in many cases, improving) the street lighting service. These cost savings result in either the city enhancing it's own development potential by having more development capacity (i.e. financial resources), or embarking on additional development as a result of more available funding (new projects and initiatives). In some of the CSCs cost savings were found to have been redirected into other government departments to prevent budget cuts. This reallocation of financial resources has allowed these CSCs to prevent a reduction in service provision in these other departments. Had these budget cuts gone through (had LED street lights not been installed) the affected departments would have had diminished capacity to provide services, resulting in a reduction in the city's own capacity to provide a sustainable urban environment to it's residents.

Light pollution comes in the form of skyglow (orange glow emanating from urban areas), light trespass (light illuminated areas where no illumination is desired) and over-lighting (illumination is too bright for the environment). While no data was available on the different types of light pollution, light pollution was reported to have been reduced in each of the CSCs after switching to LED street lights. Reduced light pollution has many potential benefits for the community and surrounding nature. Firstly, reducing skyglow means that the night sky is much more visible, allowing astronomical observations to be made more successfully than when the sky has an hazy orange glow. Secondly, nocturnal animals are less likely to be affected in an LED lit community because fewer lumens are needed to illuminate the area to desired levels. Furthermore, LED street lights were reported to have excellent directional control over the light, meaning light boundaries are clearer which results in less light illuminating areas where no light is desired. As explained in the introduction, light pollution has negative effects on humans' sleep schedules and hormone balances resulting in health issues and reduced productivity.

Public and road safety are also indicators on which LED street lights are seen to have a positive impact. This is attributed to the light emitted by LEDs, more of which is in the detectable wavelength range of the human eye's rods and cones. Although no accident data was found pertaining to LED street lights, it is suggested that being able to see more clearly at nighttime means drivers have better reaction times reducing the likelihood of accidents. Criminality was found to have been reduced in LED street light lit areas and desktop research supports the notion that urban areas are safer at nighttime when properly lit. In some of the CSCs Police Departments had stated that due to LED street lighting facial, vehicle and color recognition among victims and witnesses had improved. Furthermore, security camera footage became clearer, improving the quality of evidence. It is important to remember than while LED street lights are not designed to reduced crime, crime may be reduced as a byproduct of improving the illumination of the area via LED.

Even though LED street lights are, as a whole network, an expensive fixed asset, the fact that individual units can be purchased and used, means that replacing existing street lights can occur at the rate at which funding is available. Anywhere from a few units to tens of thousands of lights can be installed and they will immediately start producing cost savings. Street lights are also a flexible asset because they are easy to transport, install, maintain and dispose of. Street lights also have comparatively small installation/construction costs and timelines when compared to other infrastructure projects. Installation and maintenance can be achieved with a few well trained crews with 'cherry-picker' trucks (maintenance vehicles with cranes). One of the main reasons why LED street lights are easy to put into operation is the fact that most LED street lights are installed on an existing infrastructure network of cables and poles – although this sometimes has undesired effects such as over-lighting.

Weaknesses

One of the main weaknesses of LED street light technology is the relatively high cost of the light fixtures themselves. Currently, LED street lights are about twice as expensive as conventional street lights but this does vary according to the quality and features of the LED fixture. Capital expenses are the main hurdle to the adoption of LED street lights according to the responses by LED project managers and city officials. With many city budgets under strain due to rising costs and budget reductions, obtaining the funding for a retrofit project remains a serious challenge. In most of the American CSCs studied, the main funding source was the EECB grant, a part of President Obama's economic stimulus plan. Without this funding many of the CSC would not have implemented the LED street lights. Since the commencement of this study, EECBG funding has largely run out and many LED retrofits have been unable to continue. Only a few of the CSCs were able to finance the project internally emphasizing the critical importance of external funding.

One potential weakness of LED street lights is the general newness of the technology. Since it is still in the early adopter phase of the product life-cycle, there may be a general unwillingness to embark on such a costly project on a large scale. During the LED street light and solar panel tests in Brazil, one of the LED street lights failed after being struck by lightning. This indicates that the technology could be better adapted to local conditions to ensure the investment is worthwhile.

Opportunities

There are many opportunities for LED street lights in general that may contribute to it's selection as an urban infrastructure upgrade. Firstly, rising energy and maintenance costs (3.8% and 16.3% respectively in São José dos Campos) means that operating street lights is more expensive every year. Secondly, LED street light production costs are falling every year, making them more accessible to cities and municipalities around the world. Thirdly, additional energy and cost savings can be achieved by installing adaptive controls and solar panels to the street lights. Although adaptive controls are already in use in some LED street lights, their additional cost represents a hurdle. Furthermore, due to high cost of solar-powered street lights, these varieties are used mainly in remote locations and in those areas where lighting is considered essential even in emergency situations (i.e. military bases).

The potential market for LED street lights is massive as less than one percent of all street lights are LED [CMU, 2011]. In Brazil alone there are over 15 million street lights consuming 3.9 percent of the national total energy consumption, representing an opportunity for significant energy savings [Gregorio, 2013]. The fact that LED street lights are gaining in popularity and the number of utilizing cities is small means that there is a significant economic opportunity available to firms wanting to access this market. As is a focus of this study, creating an LED manufacturer in the area or region where it is needed can create jobs and generate income for firms and municipalities alike (profit and taxes respectively). Due to the simplicity of LED street lighting technology and the fact that the technology is improving rapidly means that there are few barriers to entering the market. The Brazilian and South American markets are of particular to the city of São José dos Campos and creating a new industry in the city in the form of LED lighting can help make the city more competitive.

Another interesting opportunity pertains to solar-powered street lights and entails the street light network being an electricity grid energy consumer and producer. The street light solar panels would produce energy during the day and sell it to the grid when the street lights are not in operation. At night time the street lights would turn on and use energy purchased from the grid. The opportunity depends on electricity tariffs with electricity being more expensive during the day than at night. This is the case in São José dos Campos and Mr. Vernice (Director of Public Works) indicated that this would be an attractive opportunity to explore. In this scenario the street lights would not have internal (or local) batteries to store energy for their own use. They would use energy from the grid and the solar panels would act as a renewable energy source for the city as a whole and not just the street lights. The disadvantage of this option is that the street lights do not maintain energy independence and the additional cost of the solar powered street lights would have to be compared against producing the energy from traditional renewable energy installations such as dedicated solar panels and wind mills.

LED street lights, when turned on at night, are quite noticeable installations compared to certain other infrastructure projects (out of sight projects such as cables, pipes, water treatment facilities etc). The public's perception of LED street lights in the CSCs studied was generally quite positive and many locals indicated that their vision had improved. This suggests that LED street lights can draw attention to energy efficiency measures and sustainability measures as a whole, helping to garner support for other energy savings measures and investments. Similarly, if the street light replacement program is executed through a PPP, where public-private collaboration is seen to succeed, then additional visibility and trust is created for this type of collaborative initiative. These additional benefits can be seen as opportunities to inform the public on sustainability challenges and garner support for future projects. Furthermore, as a technological and industrial hub, São José dos Campos would benefit as they would be seen nationally as an innovator in sustainable infrastructure and technology.

Threats

During the research of the CSCs it was found is that in some cases (e.g. Jackson Township), the local utility company contracted to sell electricity to the city had resisted the use of LED street lights. In each case this was attributed to the fact that the utility company stood to lose much revenue from electricity sales. In Tampa, Florida LED street lights have been on the agenda for a number of years but successful lobbying efforts by the local utility company have prevented the city from adopting the technology. This pressure from invested parties presents a significant challenge to communities wanting to adopt LED street lights.

Another threat to the adoption and success of LED street lights could be the lack LED specific (or any) street light regulations. A lack of regulation could discourage city planners from adopting a technology that may become regulated in the future and risk non-compliance after implementation. Another consideration is the fact that LED street lights are usually installed on existing street lighting poles or brackets which may be spaced or located in ways that hinder the performance of the LED street lights. This may happen in situations where LEDs are installed too close to each other, preventing the use of the full potential of the lights. Moreover, installing the street lights too close together can cause light spillover onto private property and/or too much illumination for the area (over-lighting). This can create glare and dazzle pedestrians and drivers, creating an less desirable and potentially unsafe environment.

A major threat to infrastructure projects of any kind is a lack of city, state or national government funding. While identifying cities for further assessment it was found that public funding was often not available for cities wanting to convert their street lights. As was mentioned in the *weaknesses* section above many of the CSC projects were dependent on government grants for project financing. In an ever changing political and economic climate, municipalities wanting to replace their street lights should remain open to creative, collaborative solutions to funding, implementation and management challenges.

SWOT Analysis – Proposed Public-Private Partnership

Strengths

One of the strengths of using a PPP framework for this project is the expertize available from the participating partners. Each partner is selected for their skills, knowledge and available assets, and is responsible for one aspect of project delivery. With each partner focusing on one portion of the overall service, roles and responsibilities are clearly defined. Furthermore, the project utilizes a proven technology and partners have clearly identifiable roles which should make funding easier to obtain due to the clarity of the strategy and limitation of unseen risks.

With a few funding sources contributing to the upfront costs of the project, the financial burden and risk born by each funding partner is reduced. This can make it easier to find partners willing to participate as less is required of each partner. The creation of a special purpose vehicle (SPV) simplifies the operation and management of the project as it connects the four main partners; the city, the lighting subsidiary, the energy utility and the funding sources. By doing this, the number of relationships is limited and clearly defined, streamlining the process and giving it the best chance of success. Cost savings from PPP projects are often captured in the long term, due to the magnitude of the initial investment. As a result of high capital costs (and the need for external funding) the public sector shares the risks and responsibilities associated with the project with the private sector – meaning rewards are also shared. Furthermore, the long term planning measures used in the development of a PPP project can lead to additional cost savings over traditional procurement as operations are designed for long-term success [NCPPP, 2012].

Traditional procurement for infrastructure projects normally entails the development of a project, hiring of advisors to issue public debt, and after securing funds, the appointment of a contractor to execute the project. Upon completion of the construction phase, the public entity responsible for street lighting assumes control of operations and maintenance. The operational and maintenance costs then become subject to annual appropriations debates, exposing the project to potential budget cuts, deferred maintenance and repairs, and the political system. This process usually occurs in sequence, with operation and maintenance often financed only after construction is complete. Conversely, the PPP option can sometimes consider the design, finance, construction, operation, and maintenance phases of a project in a single procurement contract. Decision makers are obliged to approach project delivery from a long term macro-perspective, instead of assessing each phase individually [NCPPP, 2012]. Additionally, public-private partnerships retain a high level control of the whole project without privatizing the assets in question. Finally, the PPP would use the existing energy and maintenance contractor, EDP Bandeirantes, to not only provide services in the first stages of the contract but also to help the municipality to gain the required maintenance know-how – allowing for a smooth transition to municipal asset ownership.

One of the principal strengths of this proposed PPP strategy is the creation of a local LED lighting company which would serve local lighting needs and eventually access the rest of the Brazilian and South American markets. By establishing a local lighting firm, the local community and economy is included in the creation of a solution to a sustainability challenge. One of the advantages of this is that the street lights can be designed according to local needs, leading to better service delivery. By initiating a locally sourced LED retrofit project the city aims to develop a new industry (high efficiency lighting) which not only involves local firms and institutions in the retrofit project but enhances the competitiveness of local firms in the overall lighting market.

Weaknesses

One of the potential weaknesses is the number of active partners in the PPP agreement. Even though the central partner (SPV) is responsible for the execution of the project. There still remain many partners active in the planning, construction and operation phases of the contract. Having many project partners can cause confusion, miscommunication and disagreements which can lead to rising costs and time delays.

Another weakness of the proposed PPP is how the lights are supplied to the PPP project and the city. The fact that Lumi is not currently established in Brazil and would need to export their business model to Brazil and start manufacturing street lights according to a set schedule presents a potential weakness of the initiative. Not having an established local LED manufacturer as a supplier partner poses many potential problems, paramount of which are cost and time. The cost and time associated with establishing an assembly facility and subcontractor network could prove to cause delays. Furthermore, it is likely that the city would want to install the new street lights before an assembly facility and contractor network had been established. In this instance the city would need to either import Lumi LEDs from Finland or select another LED street lighting firm to supply the fixtures. In the case of importing the lights from Finland, the municipality could face a dramatic increase in costs if import taxes on foreign goods (60 percent) are not waived. If another manufacturer was chosen, developing relationships with this established firm could hinder the development of the local lighting company.

Opportunities

A successfully executed LED street light project can draw attention to the mechanism by which it was brought to fruition. The PPP strategy suggested above calls for the participation of many partners whose collaboration can garner support for other PPPs and government efforts in infrastructure, energy efficiency and sustainability.

By forming a local lighting subsidiary and manufacturing the product locally, the project opens the door for collaboration with educational and research institutions as well as other innovative firms. This collaboration could come in the form of further development of adaptive controls and solar panel solutions for the street lights in the innovation clusters in São José dos Campos (partnering with other start-ups). These added product developments increase energy saving potential, improve service provision and offer interesting research and business opportunities for the local research partners. Moreover, establishing a local lighting subsidiary would create an entirely new industry for the city. This in turn could lead to a multiplier effect where many other businesses and jobs are created to serve this new sector. Furthermore, creating a local lighting subsidiary would entail the transfer of technical knowledge and expertise from Finland to Brazil as the Lumi designs are used in São José dos Campos. This diffusion of know-how is often vital in the development of new economic opportunities as a working model is transplanted and then developed further. This introduction of new knowledge can initiate the development of local capabilities along the trajectory of the introduced knowledge (in this case the lighting sector). One of the aims of the PPP is to foster collaboration among firms and research institutions to develop the Lumi street light into a model perfectly suited to local environmental conditions.

As mentioned in the *contextual framework* São José dos Campos has a well-educated workforce and education levels among Brazilians in general are rising steadily [Cortez, 2013]. In order to strengthen the city's position as a technological and industrial leader, São José dos Campos needs to provide employment opportunities to these well-educated residents. The creation of a local lighting company, and all the related business activities and research and development opportunities, can provide more employment opportunities to the local community, encouraging the competitive workers to stay in the area.

Threats

Government bureaucracy in many countries can be an obstacle to the success of almost any type of transaction. If government fails to facilitate an environment which supports the collaboration of public and private entities, then the PPP process will likely run into difficulties. It is essential that the local government acts as an enabler in the project by ensuring straightforward permitting processes and on-time payments to the SPV from the existing street lighting budget. Additionally, the government departments can help reduce the threat of the lighting subsidiary failing – and putting the project in jeopardy – by supporting it in the establishment of the assembly facility, location of subcontractors and location of funding sources. The more efficient and effective the collaboration is between project partners, the more likely the project will be within (or close to) the allocated budget and time period.

By choosing LED over conventional street lighting, the municipality may negatively affect the development and operations of firms producing these conventional street lighting components. However, this should also be seen as an opportunity as the local economy gears itself to make more reliable, efficient and innovative products. The growing trend of utilizing LED for street lighting, combined with legislation banning low efficiency street lighting types (EU Ecodesign Directive 2005/32/EC), suggests that companies are better suited to pursuing new technologies rather than proceeding with technologies soon to become obsolete [EU Business, 2009].

The local lighting subsidiary may encounter problems establishing the facility or working with subcontractors. Subcontractors may be difficult to locate, their prices may be uncompetitive and they may be unreliable. Manufacturing the lights in Brazil will most likely prove to be significantly more expensive than buying street lights from established manufacturers. If the city decides to pursue a PPP project with a newly formed subsidiary in order to boost local economic development then the city is taking a calculated risk in signing a purchasing agreement with the SPV and lighting subsidiary. Should the lighting subsidiary fail to meet the terms of the concession agreement (agreed unit price, delivery schedule etc.) then the SPV would need purchase the lights from a secondary supplier.

Transaction costs are always a potential threat to any new project. In the case of the PPP in São José dos Campos transaction costs could be very high in the initial phases as the local lighting company is established. Furthermore, negotiating with the various interested parties and participating partners could be a lengthy and expensive process as each participant looks to get the best deal. It is likely that the transaction costs associated with a traditional procurement process would be lower than that of creating a PPP and local lighting company. This is because large multinational corporations are already manufacturing LED street lights in Brazil (e.g. Philips in Minas Gerais) and can undoubtedly supply the street lights faster and at a lower cost.

Implications for Sustainability

From the research into primary and secondary impacts of the utilization of LED street lights, a number of impacts on sustainable development can be noted.

The increased efficiency of LED street lights, compared to conventional lighting sources (sodium vapor, mercury vapor and metal halide), leads to a substantial reduction in energy consumption (37 – 75 percent in the case study cities researched). This reduced energy consumption leads to decreased energy expenditure as fewer kilowatt hours are needed to illuminate the streets. These cost savings are relevant for sustainable development as financial health is a prerequisite for any sustained development. Without financial viability, municipalities cannot provide the services residents of the community depend upon leading to emigration the city as people look for more favorable conditions to live and work. A recent example of municipal financial mismanagement is the default of the city of Detroit, Michigan on July 18th 2013 [Susman and Pearce, 2013]. This follows a number of Californian cities experiencing similar difficulties after 2010. By reducing expenditure on street light energy consumption, a municipality can reduce existing budget deficits (e.g. Salford, United Kingdom), reinvest in more energy saving street lights (e.g. Salt Lake City, Utah and Lancashire, United Kingdom) and invest in other departmental programs to prevent future budget cuts and reductions in service delivery (e.g. Anchorage, Alaska). These three actions, among a plethora of other uses for cost savings realized (investment in other clean technologies, environmental education etc.), enable a city or municipality to utilize available financial resources more efficiently and effectively for the community's sustained development.

The long life span (typically three times longer) and reduced maintenance intensity (65.9 percent less) per street light adds to the annual cost savings achieved by this technology. In addition to the reduced expenditure on maintenance of street lights, the ability of municipal works departments to perform their range of responsibilities is enhanced. This is due to the fact that fewer labor hours are need per street light, allowing maintenance crews to perform other necessary tasks sooner, leading to higher quality municipal service provision in the form of reduced non-functioning (or partially functioning) public works. One of the main benefits of smart management systems (adaptive controls and remote monitoring) is that street lights in need of maintenance report this need automatically. This feature eliminates the need for night-time patrols to identify broken street lights and allows maintenance crews to be dispatched only when a specific need arises (reducing costs and maintaining street light functionality, ensuring proper illumination of the urban environment).

The quality of the urban environment can be enhanced by the use of LED street lights as streets are more effectively illuminated. Many of the cities researched indicated that illumination had improved due to the white light and more even distribution of light from LED street lights. By improving the illumination of urban areas, not only does vision improve, but this improved vision leads to further benefits for residents of the community. Two cities (Jackson Township, New Jersey and Salt Lake City, Utah) indicated a reduction in vehicle collision in intersections and general lighting theory shows that improved illumination increases road safety for vehicles and pedestrians alike [ROSPA, 2013]. This is an important consideration for sustainable development as road accidents diminish the quality of life of those affected. Therefore, the development of a city cannot be considered sustainable if community members are being injured or killed on the roads in high numbers. According to the World Health Organization (WHO), 1.3 million people are killed every year in traffic accidents. The ten worst countries for road safety are China, Russia, India, Mexico, Brazil, Vietnam, Cambodia, Egypt, Kenya and Turkey; and they account for nearly half of all road deaths [Khazan, 2013]. The WHO report also projects that road traffic fatalities will become the fifth leading cause of death by 2030. While not all of these deaths can be attributed to poor lighting, improving road illumination can play a significant role in reducing accident rates by improving driver vision and therefore reaction times.

Crime is another aspect of urban quality that can be influenced by street lighting. In two of the case study cities (Los Angeles, California and Boston, Massachusetts) crime in LED street light retrofit areas has been reduced by 10.8 percent and 9 percent respectively. Law enforcement officials in seven of the case study cities also indicated that criminality had been reduced as a result of the installation of LED street lights. This decrease in criminality was attributed to better illumination of the streets which gives residents more opportunities to avoid trouble and gives fewer opportunities for criminals to conduct illegal activities. Another aspect is that better lighting of the streetscape enhances residents perception of safety, meaning they frequent the streets more often during low light conditions. Crime theory states that more people in a given space enhances public safety as there are more witnesses to intervene in and report illegal activities [Wolf, 2010]. The United States Department of Justice states that "*individuals often choose where to live, shop, and socialize based on their perceptions of the relative safety of different cities, towns, and neighborhoods*" [Cordner, 2010]. This has important ramifications for the economic and social development of a city as a city perceived to be unsafe is less likely to attract new residents and businesses. LED lighting can also be used to promote a more vibrant atmosphere at night. By properly illuminating the areas where businesses are located, city planners can positively influence commercial activity.

By creating a PPP to provide an LED street light network for the city, the municipality of São José dos Campos is fostering a collaborative effort between public and private partners. This collaborative effort benefits all of the parties involved and provides the city with an local in-house solution to a sustainable development challenge.

There are many benefits to the sustainable development of the city resulting from the creation of an LED street light PPP. First, local employment (approximately twenty jobs) is generated through the establishment of an LED lighting company [Lumi, 2013]. Second, subcontractors in the area will receive large orders for street light components (totaling over R$ 15 million), increasing their business output and generating tax revenue [Cavali, 2013]. Third, since the concession contract is a build-operate-transfer agreement, the city accrues total ownership of the utility asset, enhancing their independence as a municipality [Villaca, 2013]. Fourth, during the concession period the city will develop the capacity to conduct maintenance independently after the conclusion of the contract – again strengthening municipal independence through accrued expertize and capabilities. Fifth, the manufacturing of LED street lights uses few toxic materials (unlike sodium and mercury vapor in conventional street lights), reducing the environmental impact of the manufacturing process [Lumi, 2013]. Sixth, local and domestic research partners are engaged for the development of advanced street lighting systems. This furthers knowledge in the field of LED lighting and gives local academic, scientific and business partners the opportunity to participate in innovative solutions and business opportunities [Vernice, 2013]. Seventh, legislation covering street lights can be developed further as a new technology is introduced. The RP8 LED lighting guidelines from the Illuminating Engineers Society should be used in the development of LED specific legislation to ensure the effective and efficient implementation of LED street lights. The legislation will improve the quality of service provision of street lights and ensure uniformity and quality of any future installations [Villaca, 2013]. Furthermore, the Department of Public Works should work closely with the Police Department to ensure high crime areas are lit properly. Finally, as a result of assisting in the establishment of a new and foreign technology firm, through financial incentives and networking expertise, the city further enhances it's reputation as a hub for technological, industrial and sustainable innovation. This in turn helps to attract more businesses and skilled workers seeking a favorable economic climate [Cortez, 2013].

When considering the value of an LED street light project the city must assess the other needs of the community and decide if financial resources should be channeled elsewhere. A useful reference point is Maslow's Hierarchy of Needs [McLeod, 2007] and this delineation of needs (in order of importance; basic, safety, social, self-esteem and self-actualization needs) according to importance should be implemented when assessing investments in community development. Physiological (or basic) needs are the most important of the *needs* outlined by Maslow and these can be translated into water, food and energy security in a city. When considering LED street lights along this train of thought it becomes clear that LED street lights are not a physiological need but closer to a safety or social need. São José dos Campos is a relatively affluent city in Brazil and has few of the problems associated with developing countries (such as food shortage and violence). Due to it's position as a wealthier community the city can afford to explore development initiatives corresponding to the *higher* needs of the community as most of the basic elements of a functioning city are in order.

Research Questions Revisited

R1: How do LED street lights directly and indirectly affect the communities they serve?

LED street light were found to decrease energy consumption by 37 to 75 percent and maintenance savings were between 25 to 95 percent. Total cost savings realized from implementing LED street lights were between EUR 24.46 and EUR 83.73 per street light fixture, with an average of EUR 47.79 per fixture. This resulted in payback periods of between 4.3 and 14.3 years.

LEDs also influence urban quality by improving illumination through higher correlated color temperature (light similar to natural daylight) and more uniform light distribution. This results in improved visibility which has had positive effects on crime reduction, road safety and enhanced urban space utilization. Furthermore, light pollution is reduced when switching to LED street lights as the directional control of the emitted light is superior to conventional street lights; reducing light trespass onto private property and upward sky glow.

R2: What are the potential impacts of an LED street light retrofit project on the city of São José dos Campos?

In the case of São José dos Campos, energy savings from utilizing LED street lights would amount to at least 70 percent, with maintenance savings reaching almost 90 percent. It was found that the only financially viable options were the LED-only and LED-AC retrofits due to their lower unit costs. In addition to the cost savings achieved, LED street lights could also reduce light pollution and criminality while enhancing road safety and area utilization. These effects in conjunction with cost savings enhance the development potential of urban areas through the financial sustainability of the utility asset and the urban quality resulting from improved street lighting. Additionally, creating a locally developed street lighting solution via a build-operate-transfer (BOT) PPP generates employment, tax revenue, research and development, and enhances municipal independence.

R3: How could an LED street light project be implemented in São José dos Campos?

LED retrofit projects have been executed through a few different types of PPP arrangements, including concessions, build-operate-transfer, build-design-operate, and management and operating contracts. Considering the goals and financial constraints of the municipality of São José dos Campos, an administrative concession BOT is the most feasible PPP arrangement. This public-private collaboration model is used because it provides the necessary funding, complementary assets of participating partners, and end goal of utility asset ownership. It is the cooperation between public and private partners, and sharing of assets, that enables each challenge of a street light retrofit project to be overcome.

Limitations

Several challenges and limiting factors were encountered during the research. The number of case study cities (CSCs) studied was defined by the response rate of CSCs to emails sent and phone calls made. Over two hundred cities with LED street light projects in various stages were approached for data. Many potential case study cities (around fifty) provided some information on their projects. However, only eighteen provided enough information on primary and secondary effects to create project profiles. During the interview phase, detailed questions on project financing and implementation were asked but few were able to respond. Although net present value was desirable data, only more basic economic data was made available. Although CSCs in many different countries (including developing countries) were approached, responses were only received from English speaking countries. The CSCs used came from the United States, the United Kingdom and Canada and while these generally provided good data, they are not in the economic, political and geographic areas similar to the São José dos Campos case study. This can potentially limit the applicability of conclusions drawn from the data collected from the developed country case studies. However, energy and maintenance savings are dependent on the technology alone and therefore the results can be seen as useful when considering a potential project in São José dos Campos.

Secondary effects were studied in order to assess the potential co-benefits of using LED street lights. While these co-benefits are not usually the motivation for LED street light projects (motivations were cost savings), they have been shown to add value to the community they serve other than the aforementioned energy and maintenance savings. A limited number of studies on the secondary effects of LED street lights affected the nature of the data collected. While some quantitative data on crime was found for Los Angeles and Boston, other CSC data on secondary effects was limited to observations made by the city officials and project managers. This opens the secondary data to one source of potential bias, the interviewees (city officials and project managers responsible for the project). However, it was found during the research process that those interviewed were very careful not to respond to questions for which they had no answers or data. Interviewees did not speculate on possible effects, rather they gave as specific answers as possible with some supporting evidence (i.e. public perception surveys, comments from other departments, reports etc). Having said this, secondary data was not available for all effects (as showed by blank spaces in the secondary data tables) in all cities. Furthermore, it is worth noting that LED street lights are a relatively recent development and most street light retrofit projects are incomplete. This partial data on secondary effects also points to the fact that not all effects are experienced in all cities as all contexts and environments are different. This makes it very difficult to project possible secondary effects on São José dos Campos as a result of switching to LED street lights.

Information on PPPs in the street light sector was very difficult to obtain. Many projects furnished some basic project data (i.e. costs, energy savings etc) but were unable to provide specific information on the structure of the PPP, roles, responsibilities, risk sharing and contractual details. This made it quite challenging to propose a strategy for the suggested PPP in São José dos Campos. The resulting PPP strategy was the result of extensive desktop research on PPP forms, contractual relationships, Brazilian PPP law and interviews with the officials in São José who are proponents of the scheme (the strategy was formulated according to their needs).

Other limitations include that the solar panel power generation figure (0.203kWh per day) represents a best-case-scenario (i.e. full sun). There are inevitably many days in the year that the solar panels will not generate the energy indicated in the projections due to clouds or rain. This negatively affects the solar LED street lights' net energy consumption and reduces its' competitiveness compared with the other scenarios. Another limitation pertains to the PPP portion of the project as the cost of project financing was not considered in the projections. This is because it was not possible to obtain all the necessary data from all potential PPP partners to create a financial model. It is understood that the cost of the PPP project will be higher than indicated in the projections as there will inevitably be additional costs associated with project planning not included in the model.

Conclusions

LED street lights offer an effective and increasingly cost effective solution to the development challenge of municipal energy consumption, street light network expenditures and urban quality. Through the research conducted on LED retrofit case study cities it was found that energy and maintenance savings are real and these are the main motivations for why cities conduct LED street light projects. However, many secondary effects, or co-benefits, also arise from the use of LED street lights and they represent the added value of LED street lights. In the cities researched, secondary effects resulting from improved lighting included reduced criminality, enhanced road safety, positive public perception and urban revitalization. These secondary effects are important when assessing LED street lights as not only an energy saving tool, but a tool for sustainable development, as street lights can affect many other indicators of urban quality.

Public-private partnerships were found to be a useful method of implementing street light infrastructure projects as the collaboration of public and private partners enabled projects to go ahead due to the different inputs, assets and qualities of the partners. In most cases, funding (for the municipality) is a major obstacle for these projects but the necessary expertise exists to design, construct and operate these retrofits. It is the combination of funding from private sources and higher government authorities (state and federal) as well as the expertise of existing street lighting departments and private contractors that create the conditions for success in these projects. Without private partners, many cities are unable to fund these projects due lack of available government funds.

LED street lights also have positive development potential for developing countries as many experience high urban crime and traffic accident rates, in addition to the strained budgets seen in many developed nations. The benefits of LED street lights in these areas can help contribute to many development challenge solutions at once. While by no means being a solution to all urban problems, LED street lights can be a useful tool for urban planners looking to enhance the capacity of communities to meet the challenges of urban growth and development. The United Nations Development Programme defines *capacity building* as *“the process through which individuals, organisations, and societies obtain, strengthen, and maintain the capabilities to set and achieve their own development objectives over time”.* It can be deduced that through the long-term financial sustainability of LED street lights, cities can enhance their capacity building by reducing municipal expenditure. Furthermore, by improving the lighting quality in urban spaces, city planners can contribute to the development goal of improved urban environments – making the city a more livable and successful place.

Street lighting is a municipal service that exists in virtually every city and town across the world and LED street lights account for only 1 percent of that global street lighting market [CCI, 2010a]. Since street lighting is to be provided by the local government, serious consideration should be given to the implementation of LED street lights as the financial incentives coupled with development co-benefits make LED street lights a credible tool for sustainable development. The most effective solutions to sustainable development challenges are often developed in the location of implementation due to the intimate knowledge of the area and the challenge at hand. Therefore, developing LED street light solutions locally for local conditions and needs further enhances a community’s development capacity and the effectiveness of this tool in meeting today's urban development challenges. In order for a potential solution to meet the needs of a sustainability issue it must be socially inclusive, environmentally responsible and financially viable – through the research conduct in this study, it is concluded that when carefully and thoughtfully implemented LED streetlights meet these conditions and is a tool worthy of consideration in any urban development plan.

Further Research

In order to further our understanding of LED street lights and their impacts on urban development it is necessary to have access to more data on the secondary effects of LED street lights. This would entail studies by each LED street light implementing community into these effects. Once accurate data is available for accident and crime indicators (before LED and after LED), the results can be assessed for a more detailed view into the development potential of LED street lights and the magnitude of the effects. Once this is fully understood, the implementation of street lights can be more effective as the street lighting network is geared to maximize these co-benefits. More research could be conducted on individual LED street light projects to identify opportunities for cost reductions and improved service delivery. Additional research on street lighting public-private partnerships would be useful as understanding the pitfalls of such projects could increase the likelihood of success of future projects.

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Appendix

Questionnaire

1. When was the project started and when is it’s estimated completion date?

2. What is/are the brand(s) of existing street lights and what brand(s) of LEDs are used?

3. What is the number of existing luminaires replaced with LED luminaires?

4. What is the unit cost of the existing luminaire and unit cost of LED luminaire used?

5. What is/was the total cost of project and the source of funding?

6. What were the energy savings achieved?

7. What were the maintenance savings achieved?

8. Please state the Net Present Value, Real Discount Rate, Cost Escalation (labor and energy), luminaire installation cost per unit of the project.

9. What have been the main benefits of the LED street light project, other than energy and cost savings?

10. Has there been any change in crime levels in the project area?

11. Has there been any change in crime patterns in the city? (i.e.more/less crime in the LED project area as to non-LED areas)

12. Has there been any change in light pollution? If so, who has noticed this change and how was it measured?

13. Has there been any change in the number of traffic accidents in the project area?

14. What has been the public reaction to the change in lighting? What is their perception of the project?

15. Has the project area become more utilized/frequented by residents and/or tourists as a result of the LED street lights?

16. How have the energy cost savings been utilized by the city (i.e. budget deficit reduction or additional funding for other departments/projects)?

17. Have there been any additional advantages associated with the LED project? (please state, however minor they may seem).

18. Have there been any disadvantages or negative effects resulting from the LED project?