Extended Abstract

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Energy is at the core of sustainable urban development. And energy efficiency has been emerging as a key strategy for the environment, economy and society, given the pressures caused by the growing evidence of the challenges of climate change, the need to increase energy security and reduce local pollution, in addition to opportunities around cost savings. When the amount of energy losses is assessed, where more than half of the global energy produced is wasted by the time it reaches its final use and when the need to promote social inclusion is considered, where 1.1 billion people do not have access to electricity, the more critical this strategy becomes - to reduce losses, to increase the efficiency of conversion processes close to its maximum yields, and also to introduce disruptive changes to the conversion processes, increasing its theoretical yields.

Given the relevance of the lighting industry in the context of electricity consumption (about 15% of global consumption), this study analyzes the introduction of LED (Light Emitting Diode) technology in the street lighting sector (3% of electricity consumption in Brazil). It is an example of innovation technology that brings in a new paradigm of electricity conversion, which is nine times more efficient than conventional incandescent lamps, with the potential to be twice as efficient as high sodium vapor lamps. In addition, LED technology will enable street lighting to be a multi-dimension system, that goes beyond providing adequate lighting levels, but promoting connectivity, communication, monitoring and big data management.

In this street lighting application, cities have been identified as the main transformational drivers for this technology revolution, along with other stakeholders, national governments, industries, development banks and organizations of civil society. When designed and implemented properly, it promotes various benefits such as contribution to mitigate climate change, with
negative GHG emissions abatement costs, energy security increases and enhances quality of living for the population.

The literature review demonstrates the complexity of lighting engineering and the need to consider the investigation of new technologies through an integrated approach that includes characteristics of the lighting source, the fixture and its power, while also considering other diverse areas such as health, social, behavioral and ecology in addition to engineering, physics and material sciences.

Lighting pollution is one of those intricate examples, where street lighting, if not well planned, can have adverse environmental, social and economic impacts (with electricity losses as high as 30% being reported). It was evidenced that addressing this challenge by only specifying fixtures is not enough. Other aspects of the projects such as luminous intensity can also have significant effects, as well as the quality of the wavelength of the lighting source.

The other major source of complexity is the very new solid state lighting technology. There has been a change in the culture of design, requiring the adoption of absolute photometry (as opposed to relative) and the introduction of new laboratory and field tests. The innovation of blue light LED, which brought significant gains in efficiency and enabled increased LED application versatility, has also brought the need for additional research regarding photometry evaluation, including scotopic and mesopic performance, as well as assessments of the effects of short wavelength on health (circadian rhythm) and biodiversity in general. The research identified cities that specify fixtures with color temperature up to 4.000K and researchers and civil society organizations, on the other hand, claim that values should be even lower than that and / or backed by more in-depth scientific research.

Given the potential of this technology, the billionaire global market has been growing at quite significant rates and the United States has been identified as the country where most incentives and research programs have been implemented to promote the solid-state lighting industry, or at least it is the country that mostly disseminates data and makes it public. Brazil and Latin America are out of this innovation map.

The Los Angeles case study, a pioneer in converting their street lighting system to LED, was investigated in this study. The case study was rebuilt through the use of an economic and finance modeling tool which is publicly available for
download at the US DOE website. The tool proved to be simple and user friendly, albeit formulas could not be edited or customized. Simulation results confirmed economic/financial and environmental benefits.

As the literature review of several other international experiments indicated, Los Angeles also benefited from a significant reduction in maintenance costs (over 60%), as well as a reduction in energy costs. The successful implementation of this project was based on three main pillars: (i) adequate planning and engagement of various city departments; (ii) attractiveness of the financial analysis, highlighting the successful negotiation with the energy and water distribution companies, which granted a significant discount for each kwh saved in the system and the loan structure to complement equity, that would be repaid through energy and maintenance savings over the loan term and finally (iii) the technical capacity and leadership of the city staff – that had already been testing LED street lights for over 4 years and developed, in collaboration with other stakeholders, a very robust process of qualifying LED suppliers and approving products, which included catalogue assessment, laboratory testing and extensive field testing program that included the active participation of the population. Field tests were essential, since not all pre-approved products in catalog and laboratory assessments have demonstrated adequate performance in the field.

Important to note that the DOE reports that despite the promise of long life, there is no standard way to rate the lifetime and reliability of LED products. Various failures can occur such as in the management of the optical system, thermal management and driver controls. Inefficient power supply networks can also adversely affect the project investment results, (if the LED is not properly designed). Those challenges can be addressed by negotiating warranties with the suppliers, contracting insurance products, among other contractual modeling options.

Based on the analysis of international case studies and particularly considering the Los Angeles experience, the potential energy savings with the introduction of LED street lighting in Brazil was investigated. Excel spreadsheets were created to model three different scenarios: (i) technical potential, which is a theoretical potential, if there were no technical or economic constraints for lamp replacements; (ii) implementation under municipality's investment point of view,
where a city makes the investment and (iii) implementation under the utility’s investment point of view, where it is assessed if an investment to enhance the street lighting system can generate savings that reduce the need to expand the electricity system and/or reduce operational costs. From the calculated technical potential savings (6,108 MWh), 76% of this savings would be feasibly achievable, considering the implementation under the municipality’s investment point of view. The Northeast region, that has low electricity tariffs, considering the adopted price scenario for the LED fixture (R$ 1,360) and the modeling assumptions, was the only region in which it was not economically viable. From the utility’s investment point of view, using the ANEEL methodology to calculate RCB, the projects were not economically viable, unless significant cost reduction of LED fixtures is obtained (from R$ 1,900 to less than R$ 1,000). Considering the limitations and simplifications of the model, it is not possible to assure that in no Brazilian city would the LED street light project not be an investment case, but it indicates that – in general – it is not attractive. One of the factors that contribute to this difference between the two scenarios (municipality’s and utility’s investments views) is that savings with the reduction of maintenance costs are not considered in the calculation of RCB. This suggests that governmental programs that aim to support energy efficient street lighting projects in Brazil should develop other indicators or criteria to assess investments, for example, adopting the ones that were used in this research (ROI, payback and NPV). The reduction of maintenance costs, which is dependent on the reduction of labor costs, had a strong influence over project feasibility. Therefore, it is recommended that municipalities strengthen their knowledge of cost management and that the impact of labor costs reduction be investigated to maximize economic benefits while also guaranteeing social benefits (eventually supporting capacity building programs for skilled labor to maintain their employability in other sectors of the economy).

In spite of the potential benefits of LED technology, there are various challenges that prevent its large scale global adoption and particularly in Brazil the following points have been mapped: i) technological risk posed by the lack of minimum technical specifications and standards in an environment of rapid LED market innovation, and in applications where specifications are available (such as traffic lights), various gaps and opportunities of improvement have been identified, compared to international standards; (ii) lack of infrastructure,
laboratories and technical capacity to conduct evaluation tests, mainly field tests in cities, especially considering that the solid state lighting technology has promoted a deep change in the project culture; (iii) financial constraints (high cost products, low local production scale); (iv) lack of specific funding lines for LED in street lights or traffic signals and (v) challenges that go beyond the LED technology, which are independent of this technology, but that need to be investigated to maximize the application of LED. Among the latter, it was highlighted (v.a) the need for cities to optimize the street lighting management system, to meet NBR 5101: 2012 specifications; (v.b) creation, maintenance and update of street light lamp inventory, a challenge which has been deepened through the ANEEL Resolution No. 414 of 2010, and (v.c) implementation of an effective public tracking system to monitor mercury lamp recycling, since those lamps will be replaced by LEDs.

The regulation of the market (creation of norms and technical specifications for LED street lights), the intensification of capacity building programs and knowledge dissemination (with virtual and in presence meetings, computational tools), the creation of a collaborative ecosystem between municipalities, organizations that promote energy efficiency policies, research centers, universities and the private sector, in addition to the creation of programs to enhance finance access, were some of the proposed suggestions to tackle the challenges to introduce LED technology in Brazil.

Last but not least, reflections about the interdependence and connection between individuals and between individuals and the planet are included. This interdependence was demonstrated in this study through the discussion and analysis of the use of LED in streetlight, the importance of light and its technologies and its important role in promoting sustainable development.

This unequivocally demonstrates that effective solutions to the great challenges of humanity (energy efficiency and climate change, for example) will be effective once an integral and not fragmented approach is applied. That is, when the solution covers all spheres and dimensions of sustainability – the social, economical and environmental, in an integrated approach that considers all aspects of the project throughout its life cycle.

The complexity of lighting science, to be effective, needs to embrace various areas of knowledge. Energy efficiency innovations do not need to be
contradictory, where a solution occurs at the expense of, for example, human health or environmental and biodiversity damage, taking just a single requirement as condition. The optimal solution would meet all spheres and dimensions of sustainability, not excluding the economic, of course.

The development and use of LED technology has led to an acceleration of these reflections on the possible integration of different boundary conditions, which has been perceived as seemingly contradictory. The potential successful experience of the integration of these different boundary conditions - environmental, social and economic - can serve to enhance the replication process in other technological areas.

**Keywords**

Energy efficiency; LED; cities; public lighting; climate change.