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Economic feasibility of energy efficiency improvements in street lighting systems in Rome

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ABSTRACT

Many Italian street lighting systems are obsolescent, considering the best available technology. Energy-efficiency improvements of street lighting systems are possible using Light Emitting Diode (LED) technology, and many cities are investigating how to effectively implement LEDs in their systems. However, the initial costs of LED luminaires are considerably higher than the costs of other technologies, and investment costs may be a barrier to implementation. In this paper, it is discussed the adoption of LED luminaires to replace the conventional lamps in public-lighting systems of Rome (Italy); calculating possible savings of energy and costs. Based on this analysis, despite the cost of LED luminaires, the use of LED technology is economically advisable.

Strategic options and flexibility are introduced in the project. Specifically, it is considered the possibility of splitting LED investment into five stages, deciding whether each part should be implemented. Real options are used to evaluate the economic cost-saving of such a project, considering uncertainty of the electricity price and multi-stage investment. The economic value obtained from real option analysis is higher of that obtained from net present value because the latter does not consider some flexibilities of the project. Taking into account the sources of uncertainty, real options provide results that are more realistic.

1. Introduction

The current rhythm of human economic activities has almost irreparably damaged the environment, leading to detrimental climate changes that have culminated with recent global warming (Rossi et al., 2016). The aim of public institutions is to achieve sustainable development for global business activities and simultaneously to avoid any harmful effect on the environment. Sustainable development, in fact, entails on one hand meeting the objectives of the development of societies and on the other hand preserving the ability of natural ecosystems to provide all the resources and services that societies need.

Indeed, a new model for an economy takes into account, together with all the benefits of a certain system of production, the impacts that it has on the environment. In addition to the theme of efficiency, the theme of fairness is a component of sustainability. In fact, the United Nations' Environment Programme's annual report states "to be green, an economy must not only be efficient, but also fair. Fairness implies recognising global and country level equity dimensions, particularly in assuring a just transition to an economy that is low-carbon, resource efficient, and socially inclusive." (UNEP, 2011).

Furthermore, on national and international level, to promote the culture of energy efficiency and to reduce the consumption of energy and other resources, several initiatives are encouraged (UNEP, 2011). Additionally, to limit waste, a bundle of economic, legislative, technological and social measures are promoted. This double effort, should lead to a substantial reduction of greenhouse gas emissions and pollution on both local and global levels.

The success of such policies, however, depends on the effectiveness of the technological interventions adopted and on their effect on the economy. From a managerial perspective, on one hand, the reduction of the consumption and of the energy waste would certainly increase the efficiency of private and public companies; on the other hand, there may be doubts and confusion about the effectiveness of the exploitability of innovative energy.

In the framework of a drastic reduction of urban emissions, the European Union, in its programmes on reduction of CO2 emission, increased its overall efforts on the theme of energy sustainability,

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including the adoption of highly efficient technologies in public-lighting systems. To implement these technologies, coordinated energy planning at the national and local levels is needed. Local governments are the first governmental stakeholders involved in the implementation of energy-saving initiatives, and the right mix of centralised and decentralised approach can help identify energy-saving measures, technologies and alternative sources that are most suitable for specific territories (Brandoni and Polonara, 2012).

Currently, public lighting accounts for 2.3% of the global use of electricity, up to 80% of the municipal use of electricity, and up to 60% of municipal energy costs (Kostic and Djokic, 2009; Orzáez and de Andrés Díaz, 2013). As stated in studies conducted by the Andalusia Energy Agency (2011) and Tähkämö and Halonen (2015), in certain cases, the chances for consistent energy savings in public lighting are high. These changes would entail a 20–50% reduction of electricity use, requiring an investment that would be amortisable in 6–8 years (Beccali et al., 2015; Tähkämö et al., 2012). The clear choice for the future of street illumination appears to be LED technology because this offers great opportunities for smart lighting, high efficiency and cost efficacy with the future development of the technology (Tetri et al., 2017). However, this technology is still developing quickly and has not been sufficiently tested yet. This is why high-intensity discharge lamps are intended to coexist with new LED technologies in the short and medium term (Kostic and Djokic, 2009; Brandoni and Polonara, 2012; Rossi et al., 2016). In a context of budget restriction for local governments, finding energy efficiency measures that do not require expensive investments and can interoperate with existing technology is an alternative.

The problem of political choice can be turned in a double-decision problem:

i) Is investment in LED technology currently feasible?
ii) Should the decision-maker use a multi-stage approach[1]?

This is not a purely academic problem because investment in an energy saving measure can result in many benefits, which would include a longer life of the luminaire, the reduction of future maintenance and operation costs and the lowering of energy costs (Schmidt, 2012).

Local governments can accelerate the implementation of LED technologies, acting as regulators that can develop building codes and issue construction permits with high-efficiency criteria, and as public infrastructure owners, they can reduce energy consumption by developing innovative initiatives. Furthermore, local authorities' promotion of renewable energy sectors may attract new investors, resulting in an incentive for private investments towards a sustainable society (Brandoni and Polonara, 2012).

However, municipalities have encountered several obstacles in adopting, implementing and managing energy efficiency projects. Although an energy saving project is economically profitable, it could not be approved due to various barriers such as transaction costs, capital constraints and behavioural and organizational issues (Pätäri and Sinkkonen, 2014; Aasen et al., 2016; Polzin et al., 2016; Testa et al., 2016). Aasen et al. (2016) and Polzin et al. (2016) in their qualitative studies discussed exhaustively the perceived barriers and they emphasize the use of energy performance contracts in facilitating the development and of the diffusion of energy saving technologies.

In the scientific literature, few papers address street lighting plans. Wu et al. (2009) studied the energy savings of roadway lighting systems compared to conventional mercury and sodium lamps and solar-powered LEDs. They found that solar-powered roadway lighting is economically feasible using the payback method. Kostic and Djokic (2009) had some recommendations regarding relevant influencing factors for saving energy in street lighting. Radulovic et al. (2011) examined the energy-efficient management of public lighting, including the substitution of mercury lamps with high-pressure sodium lamps in the city of Rijeka. Brandoni and Polonara (2012) analysed reductions in energy consumption and CO2 emissions from energy plans developed by local governments, including the substitution of current lamps with LED technology. Unfortunately, they did not take into account the economic aspects of such a substitution. Tähkämö et al. (2012) discussed life cycle costs of replacing high-pressure mercury lamps with high-pressure sodium lamps or with LED luminaires in Finland. They found that the changes to LED luminaires is not economic for low electricity price.

Orzáez and de Andrés Díaz (2013) showed that high-intensity discharge lamps are intended to coexist with new LED technologies in the short- and medium-term. Beccali et al. (2015) studied a street lighting efficiency project in Comiso. They proposed three scenarios of system upgrade and performed energy assessments using lighting simulations. The economic performance of the systems was evaluated using a simple payback time. al Irsyad and Nepal (2016) estimate the national benefits arising from energy efficiency improvements on street lighting systems based on a pilot project in Jakarta. Tähkämö and Halonen (2015) compared the environmental performance of two common outdoor lighting technologies: the high pressure sodium (HPS) lamps and LED luminaires, in the life cycle assessment. Polzin et al. (2016) realised a survey of local German authorities to study the governance modes for adopting LED street lighting. Tetri et al. (2017) discussed the different factors of outdoor lighting energy efficiency, including safety, visibility, and environmental and economic aspects.

This article discusses the adoption of LED luminaires to replace conventional lamps in public lighting systems of Rome, Italy. Possible savings of energy, costs and environmental emissions are computed. The economic feasibility of LED technology in street lighting is discussed and the development of the project in stages is evaluated. Using real options analysis (Fernandes et al., 2011), it is determined the value of such replacement, by taking into account different uncertainties associated with the life cycle.

The paper is organized in six sections. Section 2 compares traditional methodologies and real option methodology. The third section focus on the case study: the renovation and maintenance work for the public-lighting system of the municipality of Rome, consisting of the replacement of traditional lamps with LED luminaires. Sections 4 and 5 address the evaluation of the alternative numerical simulations of the substitution project. Finally, Section 6 summarizes the main results and contains concise recommendations for future research efforts.

2. Methodologies

The economic evaluation of energy investment has been widely discussed in the literature. Several authors have applied traditional methodologies such as net present value (NPV) or internal rate of returns (IRR) to analyse the viability of projects in energy sectors. Life cycle cost analysis (LCCA) use NPV to evaluate all the costs associated with the project during its lifetime, allowing a

[1] Multi-stage approach refers to several investment decisions. The decision-makers have the option to invest in stages. Heavy investment is redesigned into a series of options to invest, with each option being independent on the early options.