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Light Emitting Diodes Technology in Public Light System of the Municipality of Rome: An Economic and Financial Analysis

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ABSTRACT

This study evaluates an investment project concerning the redevelopment of the public lighting of the Municipality of Rome. In particular, we consider the replacing of the traditional lamps of the system with light emitting diodes lamps. We consider the factors that affect this kind of project: The cost of energy, the manteinance cost, the investment cost and the weighted average cost of capital. Our results underline the reduction of energy consumption and of the maintenance costs, lower emissions of CO_2 into the atmosphere, the reduction of light pollution, the positive effects on road safety and the indipendence by incentives.

Keywords: Light Emitting Diodes Technology, CO_2 Emissions, Public Lighting
JEL Classification: H54

1. INTRODUCTION

In December 2008, the European Parliament approved the climate-energy package "Three times 20 for 2020," to achieve the objectives that the European Union (EU) has set for the year 2020: The reduction of own CO_2 emissions; the increase of 20% on the level of energy efficiency (reducing the final consumption by 20%, compared to the forecast for 2020); the increase on the share of use of renewable energy sources, reaching 20% of the total internal gross consumption of EU (European Parliament, 2008).

The EU, in its programs on energy-reduction of CO_2 emission, increases its overall efforts on the theme of energy sustainability, including the adoption of highly efficient technologies in public-lighting systems. At the moment, public lighting accounts for 2.3% of the global use of electricity, as well as up to 80% of the municipal use of electricity, and up to 60% of the municipal energy bill (Kostic and Djokic 2009; Orzáez and Díaz, 2013). As stated in a study carried out by the Andalusia Energy Agency (2011), in certain cases, the chances for consistent energy savings in the public lighting are high. These would allow the reduction in the electricity use between 20% and 50%, requiring an investment that would be amortisable in <3 years (Saunders and Tsao, 2012). The clear choice for the future of street illumination appears to be light emitting diodes (LED's) technology at the expense of incandescent light (IL) bulbs. ILs (and also halogens) is cheaper to purchase, but they are rather energy-inefficient. Typically, ILs transforms <5% of the power input into visible light, while the remainder is converted into heat. Since LEDs exhibit higher efficiency than ILs, require about 90% less electricity but also have a higher initial purchase cost. Energy-efficient lamps are also more durable than ILs. LEDs are supposed to last 25 times longer than ILs (around 1000 h). To accelerate the diffusion of energy efficient light bulbs, many countries have recently implemented bans on imports and domestic sales of IL bulbs (Koo et al., 2014; Schleich et al., 2014). However, this technology is still developing very 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 (Comodi et al., 2012; Kostic and Djokic, 2012; Rossi et al., 2015; Schleich et al., 2014).

In the scientific related literature, there are only a few papers dealing with street lighting plans. Wu et al. (2009) studied the energy saving of roadway lighting systems comparing conventional mercury, sodium lamps and the solar-powered LED. They found that solar-powered roadway lighting is economically feasible using payback method. Kostic and Djokic (2009) had some recommendations regarding the relevant influencing factors for energy saving 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. Comodi et al. (2012) analysed the reductions in energy consumption and CO_2 emissions deriving from energy plans developed by local government, including the substitution of current lamps with LED lamps. Unfortunately, they did not take into account the economic aspects of such a substitution. Orzáez and Díaz (2013) showed that high intensity discharge lamps are intended to coexist with new LED technologies in the short and medium term.

The aim of our work is to verify technical-energy-economic feasibility study of systems based on LEDs technology. In fact, we want to evaluate the impact of energy consumption and CO_2 emissions in the atmosphere on an investment project for the redevelopment of public lighting of the Municipality of Rome.

The first part of the work is devoted to the analysis of the current system of public lighting of the Municipality of Rome (cost of energy, cost of maintenance, environmental impact). Then, the research analyzes a system of public lighting of the Municipality of Rome achieved by replacing the current lamps with LEDs lamps (cost of investment, cost of energy, environmental impact). Later, it's possible calculate the net present value (NPV) of the investment project taking into account the different options arising from the different regulatory frameworks (Campisi et al., 2016; Campisi et al., 2015; Morea and Poggi, 2016). This led us to assess the value of investment opportunities and to find out the relation between price level of electricity, incentives and optimal timing of investment decisions. In fact, the investments in energy systems are often irreversible, but it is possible increase their flexibility expanding new products, reducing the scale, changing the inputs and outputs and abandoning or postponing the phases of the project.

2. LED TECHNOLOGY

For more than 30 years, the LED (acronym of LED) has been used in various fields of application and, in recent years, the luminous efficiency of the white LEDs is increased to exceed 130 lumens/Watt. In addition, following the economic crisis and the necessity of having to reduce the consumption of electrical energy, there has been a high increase in sales and spread of LED bulbs, or objects that take advantage of the LED, capable of guaranteeing a bright light in exchange for low power consumption. This technological innovation has opened the door to new lighting concepts in the name of miniaturization, lifetime, efficiency and sustainability. However, the global LED lighting market has not reached its full potential, because the disposal of incandescent lamps and compact fluorescent lamps is still in progress or at an early stage in most countries (Chang et al., 2015; Koo et al., 2014; Loiselle et al., 2015; Schleich et al., 2014).

The LED is an element that belongs to the world of optoelectronics, it is constituted by a positive terminal and a negative terminal and, to function, they must be inserted in a circuit respecting this polarity. LED operation is based on the phenomenon known as "electroluminescence" (discovered more than 100 years ago), due to the emission of photons (in the visible or infrared) produced by recombination of electrons and holes when the junction is polarized with the direct way. When they subjected to a voltage to reduce the potential barrier of the junction, the electrons of the conduction band of the semiconductor is recombine with holes in the valence band releasing sufficient energy in the form of photons (Forcolini, 2008).

The LEDs are differentiated from all other semiconductors for the ability to emit light when they are forward biased, and thus, traversed by current. When the LED is forward biased, particularly thin layer, called the active layer, generates light. Unlike the incandescent lamps that emit a continuous spectrum, an LED emits monochromatic light of a specific color. Its junction, called PN, is located at equilibrium when the two areas of semiconductor, called P (excess of holes) and N (excess of electrons), are in contact. So that a PN junction can be used as the emitting device LED, it is in need of a strong recombination of the charge, so as to have a strong emission of photons. Electrons injected from the cathode head up to the junction where recombine with holes, giving rise to photons. Entering charges with a current inside the junction, it is polarized directly, allowing a high traffic charge. The LED technology show abnormal characteristics compared with conventional lamps used until now, definitely innovative, among which, the possibility to create infinite shades of color of any kind (Forcolini, 2012; 2008).

The main advantages and disadvantages of traditional lamps have been reported in Table 1 (Bierman, 2012).

The main advantages of the LED technology are the efficiency (in terms of generation of a high amount of lumens per unit of absorbed power), the duration (the same can be up to 100,000 h), the independence of switching cycles on-off on the duration, the reduced maintenance costs (replacement and periodic), the absence of infrared radiation (cold light), the structural strength, the controllability of the output light (by means of the dimmer), the ignition instant, the cold start, the absence of mercury, lead and toxic materials or gases which are harmful to health (containing only silicon powder), the total absence of light pollution (there is no saturation of the environment), the operation at very low voltage direct current, the small size of the lamps, the directionality of the light beam. Instead, the mail advantages are the decay of the luminous flux, the thermal sensitivity, the current sensitivity (Forcolini, 2008; Gallaway et al., 2010; Massa et al., 2008).

The LED lamps, even if they have a high cost of buying and initial installation, should help to save up to 90% of electricity (for their lower nominal power), compared to conventional bulbs, for the same light output, and are expected to last 25 times longer. In addition, the LEDs have low operating costs, compared with conventional lamps, since they are constituted by a semiconductor traversed by current, and, with the substitution of traditional lamps with LED lamps, are guaranteed superior lighting performance and the saving of energy and maintenance costs up to 80%, on average compared to the current ones (Koo et al., 2014; Nakamura, 2015; Schleich et al., 2014).

2.1. The Public Lighting

The public lighting is the ideal starting point for energy saving policy, since the quality of the service is immediately "visible" to citizens and can help in a concrete way to improve environmental sustainability. About 2/3 of the sources currently installed in the EU is based on outdated technology. In October 2007, the new Italian regulations UNI 11,248 was published, completing the view on lighting road together with European standards UNI EN 13201-2/3/4, regarding the performance requirements and the test methods (McKinsey & Company, 2012).

The public lighting includes the lighting of the streets, the parks, the industrial and commercial areas as well as the works of art. In order on the type of the application of lighting, the law identifies the suitable equipment type (Table 2).

The supports most commonly used are those at stake. In urban areas, where there are buildings on which to anchor, are installed wall shelf supports. Less frequent are the supports in suspension (positioned on ropes anchored to the buildings, and centrally located above the area to be illuminated). For large areas (industrial and commercial), you have supports on "light tower" (RSE, 2012).

The light sources used in public lighting systems must have a high luminous efficiency and reliability, along with a long operating life and environmental compatibility, the latter mainly linked to the problem of the presence of harmful substances and disposal of spent sources. Moreover, the lamps must be at direct illumination, i.e. the unit is pointed towards the surface to be illuminated (Falchi et al., 2011; Gallaway et al., 2010; RSE, 2012; U.S. Department of Energy, 2015).

Using LED technology for public lighting could be expected advantages in terms of energy saving, durability (estimated useful life of more than 10 years, for a run of about 12 h in 1 day [compared to the 12 months average of traditional lamps] and flow light), light pollution, light quality (with increased security for users of the public areas), maintenance cost. The United States Department of Energy (U.S. Department of Energy, 2015) estimated that by replacing, in the U.S., over the next 20 years, the current urban and street lighting with LEDs we can:

- Decrease the consumption of electricity by 62%;
- Reduce polluting emissions of 250 million tons of carbon dioxide;
- Avoid the construction of 153 new power plants;
- Achieve financial savings to $ 115 billion, which would be necessary for the construction of such power stations.

2.2. The Incentives

The LED technology benefits from incentives, so called "White Certificates" or "Energy Efficiency Certificates." The same were born at European level to achieving the goals of reduction of primary energy set by the climate and energy package 20-20-20, next to the Kyoto Protocol (Nakamura, 2015).

Table 1: Advantages and disadvantages of traditional lamps

Type of lamp	Advantages	Disadvantages
Incandescent lamp	Low cost of purchase	Low luminous efficiency
	Excellent color rendering	Short duration of the life with reduction of luminous flux
	Ease of installation	High heat emission
	Small footprint	Great sensitivity to oscillations of voltage and current
	Time ignition and reignition null	High operating and maintenance costs
	Unity power factor	
Fluorescent lamp	Low cost of purchase	Low luminous efficiency
	Excellent color rendering	Short duration of the life with reduction of luminous flux
	Ease of installation	High heat emission
	Small footprint	Great sensitivity to oscillations of voltage and current
	Time ignition and reignition null	High operating and maintenance costs
	Unity power factor	
Induction lamp	Excellent average life	External power supply
	Good color rendering	High cost
	Instant switch	Range of color temperature reduced
	Absence of flickering of the light	Luminous efficiency lower than the competition
	Independence to voltage swings	Need for special attack

Source: Own elaboration

Table 2: Application type of lighting and relative equipment type

Code	Application type of lighting	Equipment type
A	Roads exclusively or mainly vehicular traffic	Road equipment
B.1	Urban areas with mixed traffic (vehicular, pedestrian and bicycle)	Equipment for urban (road and pedestrian)
B.2	Urban areas with bicycle and pedestrian traffic only and green areas	Equipment with residential areas (in public)
C	Large areas (squares, parks, etc.)	Equipment for large areas

Source: Own elaboration

Starting with the European targets, they have been introduced in Italy by the Ministerial Decrees of 20 July 2004, and subsequent amendments and additions, which provide that the distributors of electricity and natural gas annually to reach certain goals in terms of quantity of energy savings, measurable in tons of oil equivalent (TOE) saved (roughly 5300 kWh electric). A "White Certificate" (of economic value varies according to market energy, controlled by the "Energy Services Manager" [GSE]) is equivalent to saving a TOE. In essence, the "Energy Efficiency Certificates" are securities that certify the achievement of energy savings in end-use energy through actions and projects to increase the energy efficiency. The Italian legislative framework was recently modified with the publication of the Ministerial Decree of 28 December 2012, which outlines the national quantity of energy savings, increasing over time, to the distribution companies of electricity and gas for the years 2013 to 2016 and introduces new players invited to submit a plan for the release of the "White Certificates." From 3 February 2013, the aforesaid Ministerial Decree establishes the transfer to the GSE of the management activities, evaluation and certification of the savings related to energy efficiency projects undertaken as part of the mechanism of "White Certificates" (GSE, 2016).

The obtaining of "White Certificates" appears to be a very complex mechanism, not only for the technical difficulty in quantifying the energy savings achieved but also for the bureaucratic acts necessary to obtain them. Once obtained, the "White Certificates" have value for a period of 5 years and cannot be combined with other incentives (GSE, 2016).

3. MATERIALS AND METHODS

The project consists of the replacement of conventional lamps of the public lighting system of the Municipality of Rome (managed by Acea Corporate, under a 10-year service contract for the period 2005-2015, approved by Resolution of the Municipality Council n. 3/2007 and subsequently modified and extended until the date of expiration of the concession for the plants [2027] by Resolution of the Municipality Council n. 130/2010) with LED lamps.

The scheme of the complex intervention of adaptation of the existing plant is the following:

- Relief of the current plant (mapping of the typology of lamps of the current system and related nominal powers, etc.);
- Verification of the functionality and possible adjustment to the regulations of the existing electric panels, with the ability to deploy the same in different areas as well as to adjust the power;
- Verification and possible adaptation of the power lines;
- Verification and possible adaptation of the system grounding and plant protection;
- Checking and possible adjustment of the position of the poles for lighting, in order to ensure a homogeneous and efficient luminous flux;
- Replacement of existing lamps with LED lamps;
- Disposal in a center of waste the plant parts not reusable by the administration;
- Optimization of the new system.

The technical documentation made available by the municipal technical offices in comparison with the data collected during the many visits undertaken have identified the consistency of the public lighting system of the municipality of Rome (spread over approximately 1500 km^2 of the territory of Rome) at the end of 2014 and its operating characteristics, as follows:

- 7500 km of network;
- n. 193,045 traditional lamps, of which n. 10,500 used for artistic lighting;
- Type of lamps installed (and relative nominal power values [Table 3]): High pressure sodium, low pressure sodium, metal halide, fluorescent and mercury vapor;
- Start time: 4.332 h/year (approximately 11.87 h).

To evaluate the profitability of the investment, the following parameters are taken into consideration: Total cost required to build the system; annual maintenance and management costs; cost of energy; public incentives; weighted average cost of capital (WACC).

The WACC is the rate that a company is expected to pay on average to all its security holders to finance its assets. The WACC is commonly referred to as the firm's cost of capital. It represents the minimum return that a company must earn on an existing asset base to satisfy its creditors, owners, and other providers of capital, or they will invest elsewhere. Companies raise money from a number of sources: Common Stock, preferred stock, straight debt, convertible debt, exchangeable debt, warrants, options, pension liabilities, executive stock options, governmental subsidies, and so on. Different securities, which represent different sources of finance, are expected to generate different returns. The WACC is calculated taking into account the relative weights of each component of the capital structure. The more complex the company's capital structure, the more laborious it is to calculate the WACC. Then, companies can use WACC to see if the investment projects available to them are worthwhile to undertaken (Campisi and Nastasi, 1993).

Methodologically, the calculation of the NPV for investment projects, incorporating the regulatory framework, involves three stages (Regan et al., 2015):

a. Identification of the regulatory frameworks;
b. Estimation of cash flows for the projects;
c. Estimation of the uncertainness for the projects.

For the evaluation of profitability and solvency of the project, the following indicators were taken into consideration: NPV and internal rate of return (IRR). See Campisi et al. (2014), Campisi and Costa (2008), Thusen and Fabrychy (1993) for a review.

To define the acceptance of a project, the following conditions were used:

$$NPV > 0 \quad (1)$$

$$IRR > WACC \quad (2)$$

In the following paragraphs, it will be calculated before energy consumption and costs of energy and maintenance of the

Table 3: Annual energy consumption and annual total cost of energy of the current lighting system of the municipality of Rome

Type of lamp	Watt lamp	Δ watt lamp (21.50%)	Total watt lamp	Hours/year	kW/year lamp	Number of lamps	Total kW/year	Unitary cost of energy (€/kW)	Annual cost of energy lamp (€)	Annual total cost of energy (€)
High pressure sodium lamp	70	15.05	85.05	4332.00	368.44	812	299,171.00	0.19	70	56,842.40
	100	21.5	121.5	4332.00	526.34	16,864.00	8,876,164.00	0.19	100	1,686,471.17
	150	32.25	182.25	4332.00	789.51	80,421.00	63,492,942.00	0.19	150.01	12,063,659.06
	250	53.75	303.75	4332.00	1315.85	59,942.00	78,874,381.00	0.19	250.01	14,986,132.39
	400	86	486	4332.00	2105.35	15,155.00	31,906,610.00	0.19	400.02	6,062,255.82
Low pressure sodium lamp	35	7.525	42.525	4332.00	184.22	172	31,686.00	0.19	35	6,020.25
	55	11.825	66.825	4332.00	289.49	37	10,711.00	0.19	55	2035.09
	90	19.35	109.35	4332.00	473.7	147	69,635.00	0.19	90	13,230.56
Metal halides lamp	70	15.05	85.05	4332.00	368.44	1672.00	616,026.00	0.19	70	117,044.94
	100	21.5	121.5	4332.00	526.34	3041.00	1,600,594.00	0.19	100	304,112.83
	150	32.25	182.25	4332.00	789.51	4879.00	3,852,005.00	0.19	150.01	731,880.88
	250	53.75	303.75	4332.00	1315.85	828	1,089,520.00	0.19	250.01	207,008.74
Fluorescence mercury vapor lamp	35	7.525	42.525	4332.00	184.22	8611.00	1,586,304.00	0.19	35	301,397.72
	125	26.875	151.875	4332.00	657.92	263	173,034.00	0.19	125.01	32,876.39
	250	53.75	303.75	4332.00	1315.85	180	236,852.00	0.19	250.01	45,001.90
	400	86	486	4332.00	2105.35	9	18,948.00	0.19	400.02	3600.15
	1000.00	215	1215.00	4332.00	5263.38	12	63,161.00	0.19	1000.04	12,000.51
Total					18,579.73	193,045.00	192,797,741.00		3530.15	36,631,570.79

Source: Own elaboration

current system of public lighting of the Municipality of Rome (paragraph 4) and, subsequently, the cost of the investment needed to replace traditional technology with the LED technology and related energy consumption and costs of energy (paragraph 5), necessary for economic and financial evaluation of the project (paragraph 7).

4. ENERGY CONSUMPTION AND COST OF ENERGY AND MANTEINANCE OF THE CURRENT LIGHTING SYSTEM OF THE MUNICIPALITY OF ROME

The annual energy consumption of the public lighting system of the municipality of Rome, calculated considering an average increase percentage of the rated power of the lamps to take account of the power dissipated by the accessories (igniter, reactor), estimated in 21.50%, amounts to 192,797,741 kW/year. The total annual cost of energy relative to the predicted lighting system - estimated considering an energy cost of 0.19 €/kW, based on hourly costs incurred by Municipality, inclusive of additional costs (dispatching, transport, line losses, etc.), at the cost of (pure) energy for single band issued by the Authority for Electricity and Gas, estimating an average - amounts to € 36,631,570.79 (Table 3).

We consider a period of study equal to 12 years, which is the reasonable lifetime of a LED lamp. In fact, the expected lifetime of the commercial LED lamp is 50,000 h, which translates to 12 years at a usage of 4167 h/year (daily usage of 11.4 h/day). During this lifetime in which the LED can be used, the current (traditional) lamps must be replaced 3.17 times, considering a lifetime of 12,000 h. This means that, on average, 26.4% of the traditional lamps must be replaced during a year. Therefore, the annual cost of traditional lamp substitution (considering the specific cost of a lamp) is 3,467,740 €/year.

So, the annual valued cost that will have to support the municipality of Rome for the current system of public lighting, equipped with traditional lamps, amounts to €40,099,310.79 (=€36,631,570.79 + €3,467,740), equal to €/lamp 207.72.

5. COST OF INVESTMENT, ENERGY CONSUMPTION AND COST OF ENERGY OF THE LED LIGHTING SYSTEM OF THE MUNICIPALITY OF ROME

The cost of incestiment to be incurred for the replacement of traditional lamps of the public lighting system of the municipality of Rome with LED lamps was determined by estimating, for each lamp (in relation to its type and location), the costs of interventions necessary for the removal of traditional lamps and related facilities, the supply and installation of equivalent LED lamps and their respective facilities with the installation of flow control light (dimmer function, that saves energy consumption, estimated on average in 15% for each lamp), the disposal of equipment no longer usable for the municipality, the adapting of the existing electrical installation and the manpower to carry out the aforementioned work.

By adding, for each LED lamp, the aforementioned costs, you get the cost of investment, amounted to €208,506,805 (Table 4).

The annual energy consumption of the LED public lighting system of the municipality of Rome, calculated considering an average increase percentage of the rated power of the lamps to take account of the power dissipated, estimated in 12.00%, amounts to 58,030,380.89 kW/year, with an annual energy-saving of 70%. The total annual cost of energy relative to the predicted lighting system - estimated considering an energy cost of 0.19 €/kW, based on hourly costs incurred by municipality, inclusive of additional costs (dispatching, transport, line losses, etc.), at the cost of (pure) energy for single band issued by the authority for electricity and gas, estimating an average - amounts to €11,025,772.37 (Table 5).

So, the annual valued cost that would support the municipality of Rome with a LED system of public lighting amounts to €11,025,772.37, equal to €/lamp 57.12.

6. DATA SET

The data for the economic and financial evaluation of the project are as follows:

- Cost of investiment: €208,506,805 (that we assume fully financed with equity from the municipality of Rome);
- Annual cost savings due to the reduction of the annual cost of electricity as a result of the substitution of traditional lamps with LED lamps (which leads to improved energy efficiency): €29,073,538.42 (=€40,099,310.79 - €11,025,772.37);
- Annual incentive (White Certificates"), recognized to the municipality of Rome for the first 5 years, as it is obtained a saving of 134,767,360.09 kW/year (=192,797,740.98 kW/year - 58,030,380.89 kW/year) by replacing the traditional technology with LED technology: €2,520,151.32;
- Reference time interval (equal to the estimated useful life of LED technology): 12 years (approximately 50,000 h) (Nakamura, 2015);
- WACC = 6.9%, in reference to the rates of return on investment set by the authority for electricity and gas for the 2014-2015 period.

7. RESULTS AND DISCUSSION

The financial analysis carried out shows a value of NPV =€27,494,115, much greater than zero, and an IRR = 9.53% and higher than the WACC (Table 6). Even repeating the analysis assuming no financial incentives ("White Certificates"), the results show an NPV >0 (=€23,650,910) and an IRR (=8.97%) >WACC, confirming the economic and financial compatibility of the intervention proposed with the expected savings and the indipendence by incentives (Table 7).

The analyzes carried out showed that the replacement of traditional lamps of public lighting system of the municipality of Rome with equivalent LED lamps leads to an annual reduction of energy consumption amounts to 134,767,360.09 kW/year (=192,797,740.98 kW/year [annual energy consumption with traditional lamps] - 58,030,380.89 kW/year [annual energy consumption with LED lamps]) and an annual saving of energy costs amounting to €29,073,538.42 (=€40,099,310.79 [annual cost of energy with traditional lamps] - €11,025,772.37 [annual cost of energy with LED lamps]). Moreover, since each kWh that is generated and consumed produces emissions of CO_2 in the atmosphere, in Italy estimated at about 531 g for each kWh produced, annual energy savings of 134,767,360.09 kW/year,

Table 4: Cost of investment of the LED lighting system of the municipality of Rome

Type of lamp	Watt lamp	LED lamp (equivalent)	Unitary cost €/armor	Number of LED lamps	Total cost armor (€)
High pressure sodium lamp	70	22	700	812	568,400.00
	100	30	850	16,864.00	14,334,400.00
	150	60	975	80,421.00	78,410,475.00
	250	90	1200.00	59,942.00	71,930,400.00
	400	150	1635.00	15,155.00	24,778,425.00
Low pressure sodium lamp	35	9	450	172	77,400.00
	55	15	650	37	24,050.00
	90	24	700	147	102,900.00
Metal halides lamp	70	45	850	1672.00	1,421,200.00
	100	60	975	3041.00	2,964,975.00
	150	90	1200.00	4879.00	5,854,800.00
	250	155	1635.00	828	1,353,780.00
Fluorescence mercury vapor lamp	35	20	700	8,611.00	6,027,700.00
	125	70	1200.00	263	315,600.00
	250	135	1635.00	180	294,300.00
	400	215	2000.00	9	18,000.00
	1000.00	537	2500.00	12	30,000.00
Total				193,045.00	208,506,805.00

Source: Own elaboration. LED: Light emitting diodes

Table 5: Annual energy consumption and annual total cost of energy of the LED lighting system of the municipality of Rome

Type of lamp	Watt lamp	LED lamp (equivalent watt)	Δ watt LED lamp (12.00%)	Total watt LED lamp	Hours/year	kW/year LED lamp	Saving for presence of dimmer function (15.00%)	kW/year LED lamp with dimmer function	Number of LED lamps	Total kW/year	Unitary cost of energy (€/kW)	Annual cost of energy LED lamp (€)	Annual total cost of energy with LED lamp (€)
High pressure sodium lamp	70	22	2.64	24.64	4332.00	106.74	16.01	90.73	812	73,672.28	0.19	17.24	13,997.73
	100	30	3.6	33.6	4332.00	145.56	21.83	123.72	16,864.00	2,086,446.46	0.19	23.51	396,424.83
	150	60	7.2	67.2	4332.00	291.11	43.67	247.44	80,421.00	19,899,681.06	0.19	47.01	3,780,939.40
	250	90	10.8	100.8	4332.00	436.67	65.5	371.17	59,942.00	22,248,417.99	0.19	70.52	4,227,199.42
	400	150	18	168	4332.00	727.78	109.17	618.61	15,155.00	9,375,028.49	0.19	117.54	1,781,255.41
Low pressure sodium lamp	35	9	1.08	10.08	4332.00	43.67	6.55	37.12	172	6,384.05	0.19	7.05	
	55	15	1.8	16.8	4332.00	72.78	10.92	61.86	37	2,288.86	0.19	11.75	1,212.97
	90	24	2.88	26.88	4332.00	116.44	17.47	98.98	147	14,549.70	0.19	18.81	434.88
	70	45	5.4	50.4	4332.00	218.33	32.75	185.58	1672.00	310,294.58	0.19	35.26	2,764.44
Metal halides lamp	100	60	7.2	67.2	4332.00	291.11	43.67	247.44	3041.00	752,476.72	0.19	47.01	
	150	90	10.8	100.8	4332.00	436.67	65.5	371.17	4879.00	1,810,917.74	0.19	70.52	58,955.97
	250	155	18.6	173.6	4332.00	752.04	112.81	639.23	828	529,282.37	0.19	121.45	142,970.58
	35	20	2.4	22.4	4332.00	97.04	14.56	82.48	8611.00	710,246.30	0.19	15.67	344,074.37
	125	70	8.4	78.4	4332.00	339.63	50.94	288.68	263	75,924.02	0.19	54.85	100,563.65

Source: Own elaboration. LED: Light emitting diodes

Table 6: Financial analysis in the presence of the incentive ("White Certificates")

Data	Value
NPV (€)	27,494,115
IRR (%)	9.53

NPV: Net present value, IRR: Internal rate of return

Table 7: Financial analysis in the absence of the incentive ("White Certificates")

Data	Value
NPV (€)	23,650,910
IRR (%)	8.97

Source: Own elaboration. NPV: Net present value, IRR: Internal rate of return

resulting from the introduction of LED technology, involves significant savings in terms of CO_2, equivalent to 71,561.47 tons.

The significance of this study is related to different aspects: We have estimated the value of LED technology in the public lighting of the municipality of Rome; we have provided an reliable methodology for investors and policy-maker, and, from this point of view, this approach should be considered an integrated system that could be used to evaluate different projects of energy investments. A possible plan for implementing the redevelopment of public lighting system of the municipality of Rome would be to not introduce additional budgetary expenditure and to change the destination of the items of expenditure for energy and maintenance of the old lighting system.

8. CONCLUSIONS

The transition from the old technology of the public lighting to the innovative LED technology is a great opportunity, with benefits safe and quantifiable: The economic growth of an important industrial sector, the reduction in public spending, the reduction of energy consumption and the reduction of the environmental pollution (Bierman, 2012; Falchi et al., 2011; Koo et al., 2014; Schleich et al., 2014). According to the prestigious McKinsey & Company, the global lighting market, which in 2010 was worth 69 billion Euro, in 2020 could reach 108 billion Euro (McKinsey & Company, 2012).

The Italy has spent a lot of money for public lighting and, in view of the spending review, the redevelopment of its plants would achieve significant savings in energy consumption and maintenance costs, along with significant reductions of CO_2 into the environment.

The study, regarding the replacement of traditional lamps of the lighting system of the municipality of Rome with LED lamps, highlighted the economic and financial viability of the aforesaid redevelopment, with its return of cash flows and other related key advantages, such as:

- The reduction of energy consumption and of the maintenance costs;
- The safeguarding of the environment with lower emissions of CO_2 into the atmosphere;
- The reduction of light pollution, thanks to the directionality of LEDs;
- Positive effects on road safety, thanks to the advanced features of LED technology, which allow better visibility;
- The indipendence by incentives.

Although LED technology is becoming a cost effective solution for lighting projects, the investment costs are still a major barrier to their spread use and adequate evaluation models are necessary in order to encourage investments in this field.

In this work we are not taken into consideration the flexibility of the project, the uncertainness due to price of the electricity and the modularity of the project. This is left to further studies.

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