Universidade de Aveiro Departamento de Ambiente e Ordenamento
2015

Ruben Filipe Madeira de Oliveira

Energy Efficiency and Climate Policy in the Management of Public Spaces - Public lighting

Eficiência Energética e Política Climática na Gestão de Espaços Públicos - Iluminação Pública

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Dissertação apresentada à Universidade de Aveiro para cumprimento dos requisitos necessários à obtenção do grau de Mestre em Sistemas Energéticos Sustentáveis, realizada sob a orientação científica do Drª. Myriam Lopes, Professor assitente do Departamento de Ambiente e Ordenamento da Universidade de Aveiro

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This thesis is dedicated to my family.

The jurors

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palavras-chave Alterações Climáticas, Eficiência Energética, Iluminação Pública

resumo

A Iluminação Pública é uma parte importante da vida noturna de um município. A iluminação pode ser usada para aumentar a segurança e protecção enquanto melhora a aparência estética da sua envolvente mas com a atual crise financeira mundial os sistemas de iluminação tem de ser sustentáveis também.
A maioria dos esforços para a politica climática focam-se a nivel dos países e a nível internacional, no entanto os governos não serão capazes de cumprir os seus compromissos internacionais sem acção local.
Em Portugal, a iluminação pública é responsável por 3% do consumo de energia. O problema é que a tendência é para aumentar (cerca de 4-5% ao ano), o que representa custos muito elevados para os municipios.
Em termos de números são analisados nesta tese 45 de 278 existentes em Portugal Continental o que representa apenas 16,2% dos municípios. Este são os que os municipios em Portugal que tinham um Plano de Acção de Energia Sustentável (PAES), que tinha sido aceite e disponibilizado no site do Pacto de Autarcas, até o final do ano de 2013.
É importante que o Pacto de Autarcas aumente a consciência das autoridades locais para a eficiência energética e, especialmente, a iluminação pública, porque ainda há um longo caminho a percorrer em termos de redução do consumo de energia.
Em trabalhos futuros, seria interessante ver o retorno do poste de iluminação EolGreen em um cenário real, devido ao não consumo de energia da rede permitiria ter um investimento inicial bastante elevado, mesmo com a manutenção que essas tecnologias necessitam.

keywords Climate changes, Energy Efficiency, Public Lighting

abstract

Public Lightning is an important part of municipality's nighttime landscape. Lighting can be used to enhance public safety and security while improving the aesthetic appeal of the surrounding properties but with the current global financial crisis, such lighting systems must also be sustainable.
Most climate policy efforts focus on the state and international level, however national governments won't be able to meet their international commitments without local action.
In Portugal, the Public Lighting is responsible for 3% of energy consumption. The problem is that the trend is to increase (about 4-5% per year) which represents very high costs for the municipal authorities.
In terms of numbers are analyzed in this thesis 45 of 278 existent in Continental Portugal what represents only 16,2 % of the counties. This where the local authorities in Portugal that had a Sustainable Energy Action Plan (SEAP) that had been accepted and made available in the Covenant of Mayors website until the end of year 2013.
It is important that the Covenant of Mayors will increase the local authorities awareness for energy efficiency and especially to public lighting because there is still a long way to go in terms of energy consumption reduction.
In future works it would be interesting to see the payback of the EolGreen post in a real scenario due to lack of energy consumption from the grid it would allow to have a pretty high initial investment even with the maintenance that those technologies need.

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1.Introduction

Public Lighting is an important part of municipality's nighttime landscape. Lighting can be used to enhance public safety and security while improving the aesthetic appeal of the surrounding properties but with the current global financial crisis, such lighting systems must also be sustainable (Rabaza et al. 2013; Vermont 2012). Many light fixtures were placed in service 20, 30, or even 50 year ago, and might no longer serve their initial purpose, due to changes in the areas, while having a high energy consumption. In the past, when energy was relative inexpensive, municipalities erred on the side of installing more lighting rather than less which means that many locations might also have more than necessary (Vermont 2012). In a world were energy is becoming more and more expensive, reducing energy consumption is important both to reduce costs and the environment because all energy production has associated emissions to the environment, even if indirect emissions in case of renewable energy.

Since the Industrial Revolution began around 1750, human activities have contributed substantially to climate change by adding CO_2 and other heat-trapping gases to the atmosphere. These greenhouse gas emissions have increased the greenhouse effect and caused Earth's surface temperature to rise. The primary human activity affecting the amount and rate of climate change is greenhouse gas emissions from the burning of fossil fuels (EPA 2015). In the world over 60% of greenhouse gas emissions come from energy (IEA 2015).

Most climate and energy policy efforts focus on the state and international level, however national governments won't be able to meet their international commitments without local action (Argyriou et al. 2012). Public administrations should have an exemplary role in energy and climate policies by implementing energy-saving measures capable of ensuring the greatest savings in the shortest time span, and informing citizens about the best practices in order to steer the private sector towards a low-carbon future (Comodi et al. 2012).

When it comes to climate change policy European Union (EU) has tried to be ahead of the game. The 20-20-20 climate change package, which is a set of legislation to ensure the EU meets its climate targets for the year 2020, sought to demonstrate that a fast track program of investing in current renewables complemented by the world's first large scale emissions trading scheme, would provide a template for others to follow (Helm 2014). Also the Covenant of Mayors initiative, which pretends to involve local and regional authorities to voluntarily commit to increase energy efficiency, is proving to be a great example for others. With 5917 signatories through Europe the Covenant of Mayors is set to great energy savings, and many others such as creation of skilled and stable jobs, not subject to delocalization, healthier environment and quality of life, enhanced economic competitiveness and greater energy independence (EC 2015a). In Continental Portugal there is already 79 signatories.

Public Lighting is responsible for 3% of energy consumption, and the trend is to increase (about 4-5% per year). This represents very high costs for the municipal authorities as well as indirect greenhouse gas emissions (ADENE 2015). In this context is possible to understand that public lighting is a very important part of energy consumption in municipal authorities but even a bigger part when analyzing the costs of the municipalities.

Considering the importance of public lighting, the present work intends to understand what are the causes of the differences in consumptions in public lighting as well as trying to understand the improvements that can be done to this outdated technology. The case study select for this work give an estimation of the theoretical benefits of implementing some measures in a determined location, in the particular case of city of Aveiro, together with the costs of implementation compared to the benefits of what it will produce in terms of energy reduction and consequently the municipal energy costs in electricity as well as the CO_2 equivalent that it will save.

1.1. Objectives

General Objectives

This thesis will try to determine the importance of public lighting in Portugal in terms of its contributions to total electricity consumptions of the municipalities, try to find and propose technical and management solutions to reduce this consumptions in order to reduce energy costs and CO_2 emissions.

Specific Objectives

- To analyze the implementation of the Covenant of Mayors strategy in Portugal in terms of public lighting, related energy consumptions, costs and CO_2 emissions

- To analyze a specific case study in Aveiro city.

- To improve the current public lighting and propose measures.

1.2. Methodology

To analyze the case of public lighting in Portugal it was used an available database called PORDATA.

To evaluate the importance of public lighting for Municipalities energy savings strategies the Covenant of Mayors data was used. All available Sustainable Energy Action Plans (SEAPs) for Portugal Municipalities were analyzed. Relevant data was used to build graphs (using Excel) and maps (using ArcGis).

In order to analyze a specific case study the Dr. Lourenço Peixinho Avenue in the city of Aveiro, Portugal was selected. The current situation was analyzed by consulting the department DAEO (Energy Subunit) of the Aveiro Municipality. Improvement scenarios were defined and analyzed using data supplied by Schréder and the other resources.

1.3. Organization of Thesis Paper

This report is divided into five chapters. Chapter one includes the introduction of the paper where the objectives, methodology and organization of the paper are explained. The second chapter is allocated for the literature review addressing climate and energy policy as well as public lighting for those strategies.

The third chapter focused on the analysis of Covenant of Mayors the fourth chapter presents the case study with the reference scenario and proposed improvement scenarios. The fifth and final chapter will summarize the most relevant results and present future research directions.

2. Literature Review

2.1. Energy Policy

World Energy Council (WEC 2013) sets that the world electricity production anual grown per year 76 % between 1993 and 2011. At the same time CO_2 emissions had an annual increment of 44 % in the same period of time. This shows there is a great need to reduce energy consumption that lead each country to develop energy policies to meet internal targets. Energy Policy is a major concern in the European Union (EU) (Helm 2014).

In Figure 1 is possible to view that lighting has a great contribution for electricity demand, being 19 % of the entire share and even this not representing only public lighting, which is the main subject of the thesis, it still shows that this is the second major electricity consumption sector in the world.

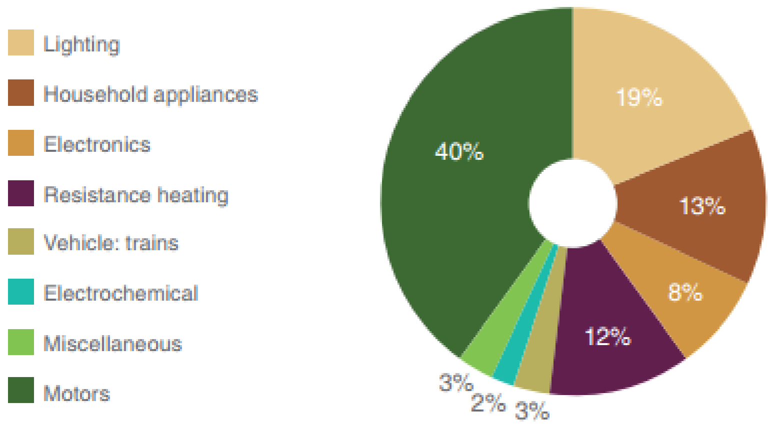

Figure 1: Global electricity demand by application in the world (WEC 2013).

2.1.1. European Policy

Increasing evidence of climate change and growing dependence on energy has underlined the EU determination to become a low-energy economy and that the energy consumed is secure, safe, competitive, locally produced and sustainable, making the EU ahead of the game when it comes to climate change policy (EU 2015a; Helm 2014). To make this possible the EU focused on the exemplary role that the public administration should have in energy policies by implementing energy-saving measures capable of ensuring the greatest savings in the shortest time span, and informing citizens about the best practices in order to steer private sector towards a low-carbon future (Comodi et al. 2012).

EU energy policy actions will always respect two main principles: first, that Member States are ultimately responsible for their national energy mix and secondly, indigenous energy resources are a national, not European, resource (Kanellakis et al. 2013).

In addition to ensuring that the EU energy market works efficiently, the EU energy policy promotes the interconnection of energy networks and energy efficiency. It deals with energy sources ranging from fossil fuels, through nuclear power, to renewables (EU 2015a).

European Parliament climate change package (20-20-20 package) aims to ensure that the EU will achieve its climate targets by 2020: a 20% reduction in greenhouse gas emissions, a 20% improvement in energy efficiency, and a 20% share for renewables in the EU energy mix (EP 2015).

The EU is facing unprecedented challenges resulting from increased imports and external dependence of energy, the scarcity of energy resources and the necessity to limit climate change and to overcome economic crisis. Energy efficiency is an important instrument to overcome these challenges and is supposed to increase energy efficiency in order to realize the objective of saving 20% of the EU's primary energy consumption by 2020 (EU 2012).

The control of European energy consumption and the increased use of energy from renewable sources, together with energy savings and increased energy efficiency, constitute important parts of the package of measures needed to reduce greenhouse gas emissions and comply with the Kyoto Protocol to the United Nations Framework Convention on Climate Change. In line with the energy efficiency targets it was defined that 20 % target for the overall share of energy from renewable sources and a 10 % target for energy from renewable sources in transport where possible to accomplish until 2020 (EU 2009).

Europe now faces an enormous competitiveness challenge, exacerbated by the costs it has self-imposed by putting so much priority on a short-term renewables target (Helm 2014).

Since the 1990s, several action plans have been launched to encourage a bottom-up approach to the development of energy plans such as Agenda 21, an action plan on sustainable development supported by the United Nations, which gives local government the responsibility to develop a platform for dialogue and consensus building to promote a participatory approach to sustainability (Comodi et al. 2012; PA 2015).

With Agenda 21 Europe aimed to be a globally competitive space, without jeopardizing social cohesion and environmental sustainability. Five years after its launch, the Spring European Council in February 2005, showed a moderate balance of results. The expected performance of the European economy for growth, productivity and employment has not been reached. Job creation has slowed and investment in research and development continues to be inadequate (APA 2007).

Other platform of local action is Covenant of Mayors, which is the mainstream EU movement of local and regional authorities committed to increasing energy efficiency (Comodi et al. 2012).

European Commission launched the Covenant of Mayors to endorse and support the efforts deployed by local authorities in the implementation of sustainable energy plans. Indeed, local governments play a crucial role in mitigating the effects of climate change, even more when considering that 80% of energy consumption and CO_2 emissions are associated with urban areas (EC 2015a).

2.1.2. Portuguese Policy

The Portuguese energy policy follows in general the EU policy and is based on two fundamental pillars: the economic rationality and the sustainability of energy sector. Relevant statements include the energy efficiency measures, the incentive to renewable energies use to reduce external dependence of energy and the decrease of energy costs (ADENE 2015a).

In general terms the objectives of this policy are (ADENE 2015a):

- Significantly reduce emissions of greenhouse gas effect in a sustainable manner;
- Strengthen the diversification of primary energy resources, increasing the supply security of the country;
- Increase the energy efficiency of the economy, contributing to the reduction of public spending and efficient use of resources;
- Contribute to increasing the competitiveness of the economy by reducing fuel consumption and costs associated to the operation of companies.

To achieve these results, Portugal has developed specific plans and programs aimed at boosting measures and implement them more effectively (ADENE 2015c). These programs are:

- PNAEE (National Action Plan for Energy Efficiency) – increase of 9% energy saving by 2016 in six specific areas: transports, home and services, industry, behavior and agriculture;
- PNAER (National Action Plan for Renewable Energy) – promoting the production of electricity from renewable sources should be between 55% and 60% in 2020;
- ECO.AP (Energy Efficiency Program for Public Administration) - aims to achieve an energy efficiency level of around 30% by 2020 in agencies and departments of Public Administration.

Through a solid and effective energy policy which results in the implementation of these plans and programs, Portugal has the ambition to head the list of countries with a good energy performance (ADENE 2015c).

In particular, public administrations can implement several schemes designed to fulfill this exemplary role, such as (Comodi et al. 2012):

- Improving the energy efficiency of public properties;
- Introducing street lightning energy-savings measures;
- Producing information to promote the citizens sensitivity to energy issues;
- Adopting clean technologies.

2.2. Climate Policy

Climate change has been identified as one of the greatest environmental, social and economic threats to the planet and that humanity face today. The emissions of greenhouse gas is a problem affecting several activity sectors, justifying therefore the cross-cutting nature of the climate change mitigation policies (APA 2015). In Figure 2 is possible to see the sources of greenhouse gas emissions per sector and the energy sector emerge as the biggest contributor with 29 %.

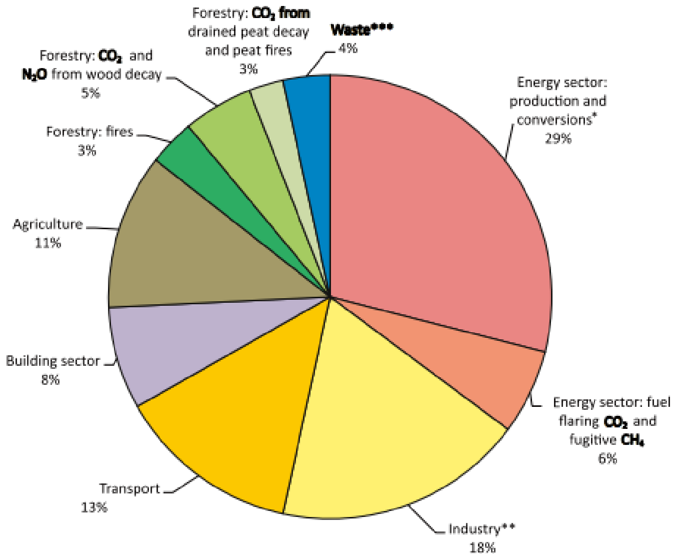

Figure 2: Shares of sources of global greenhouse gas emissions in 2010 by main sector (UNEP 2012).

This make climate change a national priority, given their future impact on our society, economy and ecosystems. More and more scientific studies and international institutions demonstrate changes in the global climate system. It is important to address climate change when talking about energy because the two are directly related. An example is the fifth report of IPCC (International Panel on Climate Change), which provides an overview of the state of knowledge concerning the science of climate change (IPCC 2014).

Energy and climate policy always meet because they have the same objectives affect the same activity sectors and normally similar measures. The main sources of man-made greenhouse gas emissions are:

- Burning of fossil fuels (coal, oil and gas) in electricity generation, transport, industry and households;
- Agriculture and land-use changes like deforestation;
- Land filling of waste;
- Use of industrial fluorinated gases.

2.2.1. European Policy

Environmental quality is considered central to health and well-being. Since 1970s, the EU and its member countries have introduced laws to ensure the careful use of natural resources, to minimize environmental impacts of production and consumption, and to protect biodiversity and natural habits. EU environment law covers aspects as wised-ranging as waste management, air and water quality, greenhouse gases and toxic chemicals (EU 2015b).

The EU integrates environmental concerns in its other policies, e.g. transport and energy, and is a major global force in pushing for tighter environmental standards and for effective action against climate change. EU decided to lead the world strategy on climate change and to craft a new international environmental order, since oil and gas prices would go even upwards (EU 2015b; Helm 2014).

There are four pillars for climate change policy in Europe, which are:

- Early action in the EU provided sufficient knowledge has been acquired;
- Integrating adaptation into EU external relations;
- Improving knowledge where there are gaps;
- Involving all stakeholders in the preparation of adaptation strategies.

Most climate policy efforts focus on the state and the international level, however national governments will not be able to meet their international commitments without local action. Municipalities are taking action for mitigation, being the reduce greenhouse gas emissions and the monitoring of carbon emissions the core parts of their local climate programs (Argyriou et al. 2012).

Mayors Adapt is the Covenant of Mayors Initiative on Climate Change Adaptation and has been set up by the European Commission to engage cities in taking action to adapt to climate change. The Mayors Adapt aims to increase support for local activities, provide a platform for greater engagement and networking by cities, and raise public awareness about adaptation and the measures needed (EC 2015b).

Right now in Europe there is a long-term climate policy which is Roadmap 2050 that establishes an objective of reducing greenhouse gas emissions in 80 %, but there is other policies such as(EU 2015b; EC 2015c):

- Reduce greenhouse gas emissions in 20% by 2020 (EC 2009a);
- Monitoring and adapting to climate change (EC 2009b);
- Extending Kyoto Protocol and convince international community to adopt new agreement. Next international meeting will be COP 21 in Paris in December 2015.

2.2.2. Portuguese Policy

Studies indicate that Portugal is among the European countries one of the most vulnerable to climate change impacts (APA 2015).

The political and institutional response regard is climate change has been updated and developed, lying mirrored in the proposals for the Strategic Framework for Climate Policy (QEPiC)(Santos et al. 2015), the National Program for Climate Change (PNAC 2020/2030) and the National Adaptation Strategy to Climate Change (ENAAC 2020) (APA 2015):

- The QEPiC sets the vision and goals of this policy, ensuring the national response to the commitments already made for 2020 and proposed for 2030 within the European Union and at national level, the commitment to green growth;
- The PNAC 2020/2030 aims to ensure a sustainable trajectory of reducing national emissions of greenhouse gases in order to achieve an emissions reduction target of -18% to -23% in 2020 and -30% to -40% by 2030 compared to 2005. Establishing guidelines for sectorial policies and measures, defines sectorial goals to reduce emissions and identifies a set of policy options and sectoral measures to develop future together with the relevant policy sectors such as transport, energy, agriculture and forest;
- The ENAAC 2020 sets out the objectives, activities and model of organization and functioning of the Strategy by 2020, in view of a country adapted to the effects of climate change through the continued implementation of solutions based on technical and scientific knowledge and best practices. For this purpose, it is proposed to improve the level of knowledge about climate change and promoting the integration of climate change adaptation in the various public policies, place a great emphasis in this strategy.

It's important to refer the vulnerability of the public lighting sector to climate changes, due to the different technologies that are prepared to deal with a determined type of climate risks and that with climate changes can be subjected to different ones that they might not be ready to supplement. Also there is a great amount of complications in public lighting due to the fragilities of the technologies that currently transport electricity.

2.3. Public Lightning

The main purpose of public lighting is to provide fast, accurate and comfortable visibility overnight. In addition to reduce crime and increase safety awareness, lighting can help authorities in the exercise of authority and compliance with the law (Zeller 2015).

The lighting reduces the number and severity of road accidents at night up to 30%. Sufficient lighting helps emergency services to carry out their duties after dark safely and effectively. Therefore, public lighting is essential for allowing life to continue safely during night time (Zeller 2015).

With the energy prices rising and the shortage of fuels throughout the world it is very important for everybody to reduce their consumptions. There is an area in which there hasn't been many changes and where there is still a big difference to be made, that is Public Lighting. It is known that public lighting accounts for 1,5%-3% of all energy consumption in the world (Comodi et al. 2012).

Public lightning represents a large electrical load and can be one of the highest costs for a municipality. By eliminating unnecessary lighting and replacing old fashion lighting technologies, municipalities have the opportunity to reduce the cost of public lighting, and consequently reducing the municipal electricity bills (Vermont 2012), while also gives the opportunity to reduce the climate impact of urban areas and in consequence the country as well.

In Table 1 is possible to see how energy consumption has constantly improved from 2001 to 2011 but has seen a slight decrease in 2012 and 2013. Also the energy fare and yearly cost had a constant increase over the years. The yearly cost even duplicated over the course of the 12 years between 2001 and 2013.

Table 1: Variation of energy consumption and energy cost in public lighting for Portugal (PORDATA 2015; Melhor 2015).

Year	Consumption (MWh)	Fare (€/kWh)	Yearly cost (M€)
2001	1144,18	0,0893	102,17
2002	1200,46	0,0920	110,44
2003	1331,95	0,0945	125,87
2004	1318,20	0,0965	127,21
2005	1409,63	0,0988	139,27
2006	1511,18	0,1011	152,78
2007	1571,27	0,1077	169,23
2008	1642,51	0,1143	187,74
2009	1673,48	0,1211	202,66
2010	1661,70	0,1285	213,53
2011	1671,18	0,1326	221,60
2012	1554,67	0,1393	216,57
2013	1469,93	0,1405	206,53

2.3.1. Public Lighting Evaluation Criteria

When designing street lighting is important to follow some criteria for evaluating where light is needed and what levels of light are needed. Some evaluation criteria include (Vermont 2012):

- Security requirements

A common misconception is that providing more light will improve safety and security, and reduce crime. On the contrary, more light can actually reduce safety and security by creating glare, reducing the eye's ability to see objects in the periphery, and improving visibility for those that commit crimes.

- Pedestrian safety

Well-designed public lighting can help increase visibility of people and objects along the side of the road in areas of high traffic or pedestrian use. Crosswalks are key areas where sufficient lighting is needed to prevent accidents.

- Traffic safety

Public lightning can help increase the visibility of vehicles to avoid collisions. In general, there should be sufficient street lighting to improve the view in each intersection of major public roads where there is significant vehicular traffic. Areas where lighting can be valuable for traffic safety include high-traffic streets, high – volume intersections, and dangerous or blind curves.

- Convenience

Public lighting can also be used as a convenience in residential areas, such as illuminating sidewalks at night. In general, there should be street lights sufficient to illuminate sidewalks in residential areas where there are significant numbers of pedestrians.

2.3.2. Regulation of Public Lighting

In Europe and also in Portugal, the public lighting is regulated by the norm EN 13201. This norm is divided into four parts that refer to:

- EN 13201-1: choice of lighting classes;
- EN 13201-2: recommended photometric parameters;
- EN 13201-3: photometric parameters calculation;
- EN 13201-4: photometric performance methods of measurement.

There is also the Reference Document for Public Lighting (ADENE 2011), that not being legislation it's an important tool to consider measures that can be taken into account for a public lighting project in particular with respect to energy efficiency requirements and all the relevant parameters to be considered.

To ensure energy efficiency gains in terms of public lighting a regulation has to be created that will allow for analysis, control and close monitoring of this type of systems to improve the economic and environmental sustainability of Municipalities (ADENE 2015b).

2.3.3. Energy Efficiency and Cost Reduction Measures

ADENE (2015b) compiled some interventions showing that energy efficiency is already a reality in public lighting:

- Installation of luminous flux regulators;

- Replacement of inefficient ballasts or lamps;
- Installation of control technologies;
- Management and monitoring of public lighting;
- Replacement of lamps with LED technology.

In addition to these there are other measures that can be applied to reduce the public lighting costs:

- Turn off unnecessary lighting;
- Adjustment of working hours;
- New lighting plans (location, number and type of lighting).

2.3.4. Lighting Technology

Public lighting technology involves a combination of technology and equipment namely: lamps, luminous flux regulators, ballasts, control systems and even innovative technologies such as EolGreen.

Some details about lighting related technologies are presented in this section.

2.3.4.1. Lamps

In Table 2 is presented a comparison of different lamps types in order to investigate the best technologies.

Table 2: Lamps technology comparison (GRAH 2015).

Light Technology	Lifetime	Luminous efficiency (lm/W)	Ignition time	Considerations
Incadescent	1.000 - 5.000	11 - 15	instant	very inefficient, short life time
Mercury vapour	12.000 - 24.000	13 - 48	up to 15 min	very inefficient, ultraviolet radiation, contains mercury
Metal halide	10.000 - 15.000	60 - 100	up to 15 min	high maintenance UV radiation, contains mercury and lead, risk of bursting at the end of life
High pressure sodium	12.000 - 24.000	45 - 130	up to 15 min	low CRI with yellow light, contains mercury and lead
Low pressure sodium	10.000 - 18.000	80 - 180	up to 15 min	low CRI with yellow light, contains mercury and lead
Fluorescent	10.000 - 20.000	60 - 100	up to 15 min	UV radiation, contains mercury, prone to glass breaking, diffused non-directional light
Compact fluorescent	12.000 - 20.000	50 - 72	up to 15 min	low life / burnout, dimmer in cold weather (failure to start), contains mercury
Induction	60.000 - 100.000	70 - 90	instant	higher initial cost, limited directionality, contains lead, negatively affected by heat
LED	50.000 - 100.000	70 - 150	instant	relatively higher initial cost

Through the analysis of the table above it becomes evident that LED (Light Emitting Diodes) technology emerges as the best technology at the present regarding public lighting lamps. This happens because LED has the better lifetime, luminous efficiency and ignition time between existing technologies.

LED's are rapidly developing in light output, color rendering, efficiency, and reliability. Achieving good maintenance-free thermal management in an often hostile environment while keeping competitive product is the largest challenge, which only few manufacturers managed to achieve. This latest high quality LED technologies are already exceeding all other available technologies by all technical parameters (GRAH 2015).

The only initial disadvantage of LEDs relatively to other technologies is the higher initial cost of the LEDs.

According to its numerous advantages, even higher initial cost quickly pays for itself due to vastly reduced cost of electricity and maintenance. But to fully benefit from outstanding advantages it is important to educate and recognize the difference between low quality and latest state of the art of LED technologies, since low quality LED alternatives have quickly spread all over the world (GRAH 2015).

In short the general benefit of LED lights are:

- Less energy consumption;
- Higher efficiency;
- Long life;
- Great operating characteristics;
- Reducing carbon footprint;
- Lower environmental impact when used up.

2.3.4.2. Luminous Flux Regulators

Luminous flux regulators with voltage stabilization systems are centralized systems that are installed at the head end of the street and road lighting supply and in Figure 3 is possible to see some examples. They perform two functions (Iberdrola 2015):

- Stabilize the voltage supplied;
- Regulate the luminosity of all the lights connected.

Figure 3: Example of luminous flux regulators (Stabilux 2015).

Luminous flux regulators reduce energy usage and light pollution, adapting the lighting level to pedestrian and vehicle traffic (Iberdrola 2015). This allows a great reduction in the electric consumption.

2.3.4.3. Ballasts

The ballast regulates the current to the lamps and provides sufficient voltage to start the lamps. Without a ballast to limit its current, a fluorescent lamp connected directly to a high voltage power source would rapidly and uncontrollably increase its current draw. There are three types of ballasts: magnetic, electronic and hybrid. A brief comparison is made in Table 3.

Table 3: Brief comparison between the different types of ballasts (Thankur 2015).

	Magnetic Ballast	Hybrid Ballast	Electronic Ballast
Number of lamps operated	1–4	1–3	1–4
Starting mode*	PH, IS, RS	RS	IS, RS, PS
Weight (lbs)	3.5	3.5–3.7	0.4–5.0
Lamp operating frequency	60 Hz	60 Hz	20,000–60,000 Hz
System efficacy	Lowest	Higher	Highest
Ballast factor	0.63–0.99	0.80–0.95	0.73–1.30
Ballast efficacy factor (for 4-ft, 2-lamp system)	0.90–1.40	1.10–1.40	1.15–1.56
Total harmonic distortion (%)	most <20, some >20	<20	some <5, most 5–20, some >20
Power factor	most >0.9	>0.9	>0.9
Lamp current crest factor	<1.7	<1.7	<1.7
Lamp flicker index	0.04–0.07	0.04–0.07	<0.01
Operating electrode voltage, rapid-start T8 (V)	2.5–4.4	NA	2.5–4.4
Rated life (years)	10–15	10–20	10–20
Sound rating	A–D	A–B	A–B
Dimming available?	Yes	No	Yes

NA = not applicable
1 lb = 0.45 kg
*IS = instant-start; PH = preheat; PS = programmed-start; RS = rapid-start.

Analyzing the table above it becomes clear that the electronic ballast is the best option of the three, presented especially for the ballast factor. Ballast factor is the measured ability of a particular ballast to produce light from the lamp it powers. This indicate the ballast efficiency, which it is one of most important factor for the evaluation of the luminaire efficiency.

2.3.4.4. Control Systems

Control systems allow the authorities to control the entire public lighting from a computer, turn it on and shut it down as well has to see the current consumption allowing to see if there is any problem in the installation and when to do maintenance.

Intelilight (2015) states that with the use of a control system energy costs are immediately reduced with up to 35% through intelligent on/off switching while overall operational costs come down by up to 42% by detailed maintenance and preventive grid interventions based on system generated reports. This systems can:

- Turn the lights on and off;
- Dimming the lights;
- Communicating through the grid;
- Sensing the city;
- Control the infrastructure;
- Reporting and maintenance scheduling.

2.3.4.5. EolGreen

EolGreen is a public lighting project with an innovative technology, which pretends to make public lighting self-sustainable by implementing renewable energies into the posts making this a zero emissions and zero energy cost technology.

The post has a fifty-eight hours autonomy without sun or wind with the batteries charged and don’t need to be connected to the grid. Figure 4 is an image of the EolGreen post.

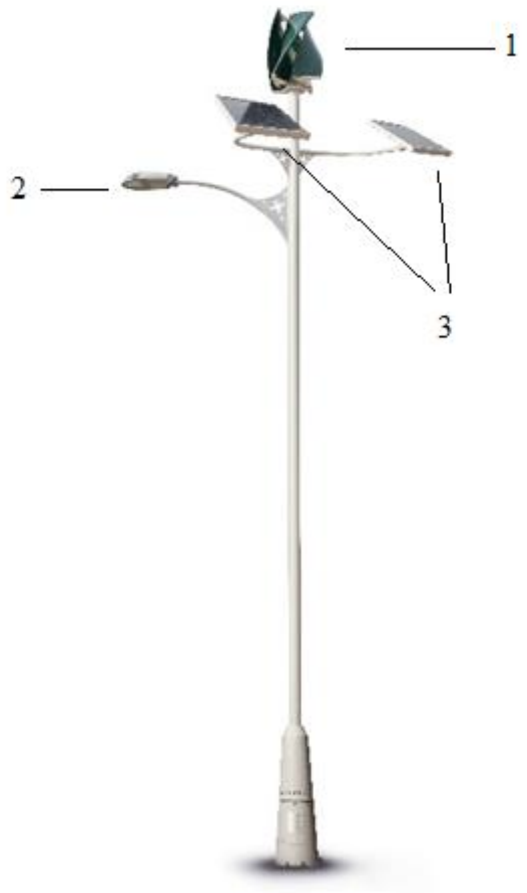

Figure 4: EolGreen Post (EolGreen).

This posts come with:

- Wind turbine (Figure 4 - 1);
- Regulator;
- Control system;
- Luminaire (Figure 4 – 2);
- Photovoltaic panels (Figure 4 – 3);
- Generator;
- Batteries.

Besides not being yet a commercial product, still in implementation tests, EolGreen is a good reference for what current technologies can mean to public lighting right now. With this technology it is possible to cut down electric consumption in public lighting to zero and it is a very good technology to analyze in a future scenario.

3. Covenant of Mayors – Public Lighting

The Covenant of Mayors is the mainstream European movement involving local and regional authorities, voluntarily committing to increasing energy efficiency (EC 2015a). By their commitment, Covenant signatories aim to meet and exceed the European Union 20% CO_2 reduction objective by 2020 (EC 2015a).

After the adoption, in 2008, of the EU Climate and Energy Package, the European Commission launched the Covenant of Mayors to endorse and support the efforts deployed by local authorities in the implementation of sustainable energy policies. Indeed, local governments play a crucial role in mitigating the effects of climate change, when considering that 80% of energy consumption and CO_2 emissions is associated with urban activity (EC 2015a).

In Figure 5 are shown the steps that a local authority need to take when signing in the Covenant of Mayors, which includes a step when the Covenant of Mayors is signed, step 2 where the Sustainable Energy Action Plan (SEAP) has to be prepared, implemented and submitted and finally a step 3 with regular submission of implementation reports.

Figure 5: Covenant of Mayors steps (EC 2015a).

Figure 6 shows visually the signatories from Covenant of Mayors in the different regions of Europe. Till this moment 5917 local authorities have signed Covenant of Mayors being 79 located in Continental Portugal.

Figure 6. Signatories map from Covenant of Mayors (EC 2015a).

The Sustainable Energy Action Plans (SEAP's) available in Covenant of Mayors and the information include on PORDATA database were used to produce a review on public lightning for the local authorities located in Portugal and to analyze the data were made maps using ArcGis software.

Data extracted from SEAP include:

- Public lighting consumptions per year;
- Percentage of public lighting consumption in total electricity consumptions;
- Measures to reduce public lighting consumptions.

To complement this study and to make more comparisons between the municipal authorities, data from PORDATA (accessed in November 2014, and all data relative to the year of 2013) were collected, namely:

- Municipal Revenues;
- Population;
- Area.

The results of this diagnosis regarding the plans and measures for public lighting in Portugal are presented following.

3.1. Data Analysis

Through analysis of the data refer above one thing became clear, the quantity of data wasn't enough to do an extrapolation for the rest of the country, so it is important to refer that the conclusions made in this paper could be different if there was full data to analysis.

Quantitatively in this work are analyzed 45 of 278 existent municipalities in Continental Portugal what represents only 16,2 % of the counties. This is the percentage of the local authorities in Portugal that had a Sustainable Energy Action Plan (SEAP) and that had been accepted and made available in the Covenant of Mayors website until the end of year 2013. Since then there has been some local authorities that had SEAP's accepted by the Covenant of Mayors but most of them were not from Continental Portugal but yes from the islands (Azores and Madeira).

3.1.1. Data relative to public lighting

Figure 7 shows the inventory done regarding the existence of measures in each SEAP for public lighting, for Portugal.

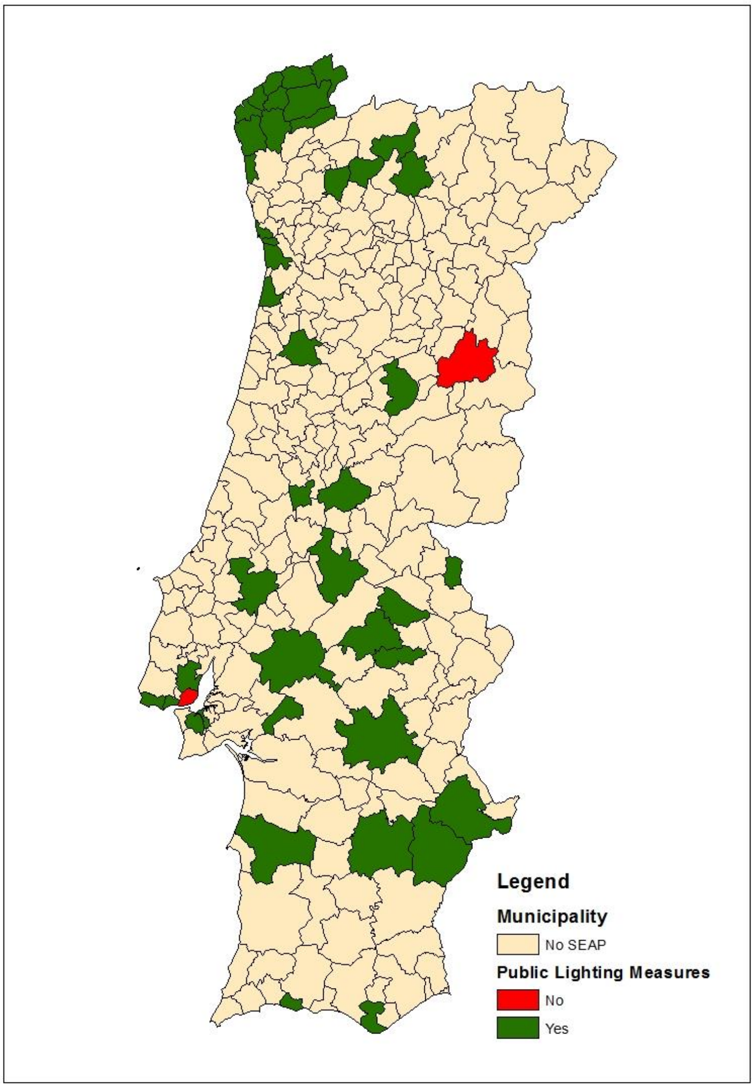

Figure 7: Map of Continental Portugal with the representation if there is data relative to public lighting in SEAP.

In the figure the counties in the red are the one's without data in SEAP relative to public lighting. It is important to say that only two municipal authorities doesn't have any data, being them Lisbon and Guarda. That represent only a percentage of a little more than 4 % of all de municipal authorities signatories what can lead to the conclusion that public lighting is an important subject when we are talking about energy efficiency and consequently about energy policy.

3.1.2. Public lighting consumptions

Information about public lighting consumptions was taken from the SEAPs, and the annual consumes are presented in Figure 8.

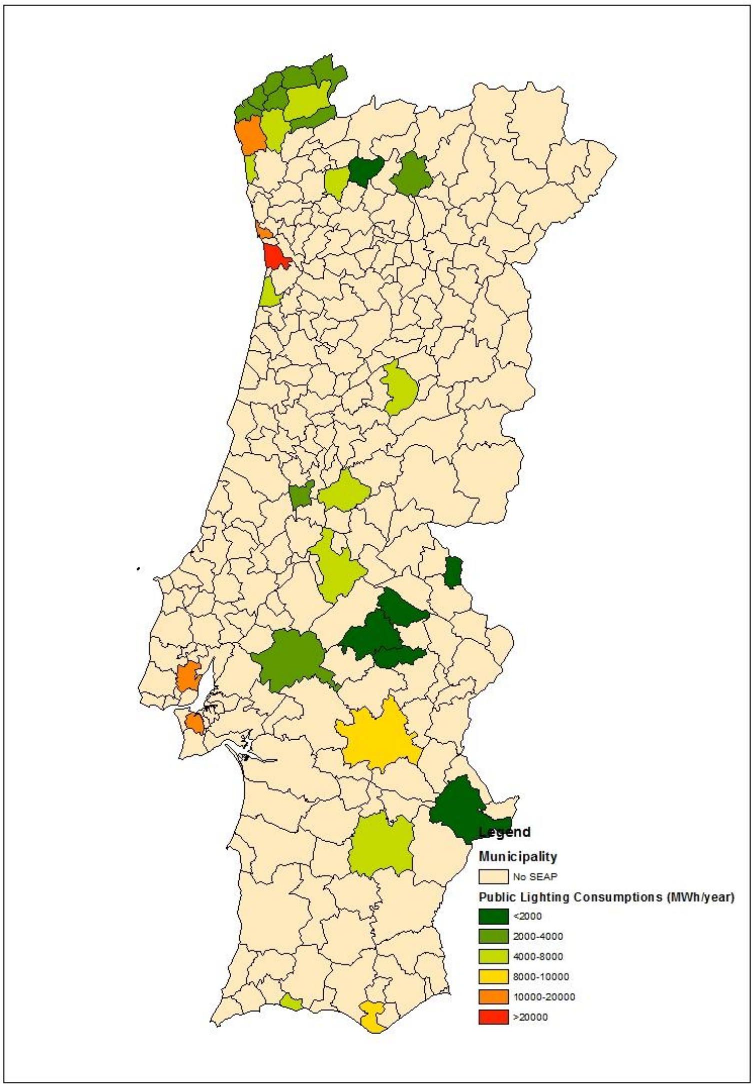

Figure 8: Public lighting consumptions per year (MWh).

Analyzing this figure is possible to see that there is a higher consumption (above 10 000 MWh/year) in the coast area and inferior consumptions are found in the interior of the country.

In average a Portuguese local authority spends around 6337 MWh/year in public lighting. Assuming that the authorities pay 0,12 €/kWh it represents a total cost of 760 440 €/year.

3.1.3. Percentage of public lighting in total electricity consumptions

In Figure 9 shows the percentage of public lighting consumption in total electricity consumptions of the local authorities.

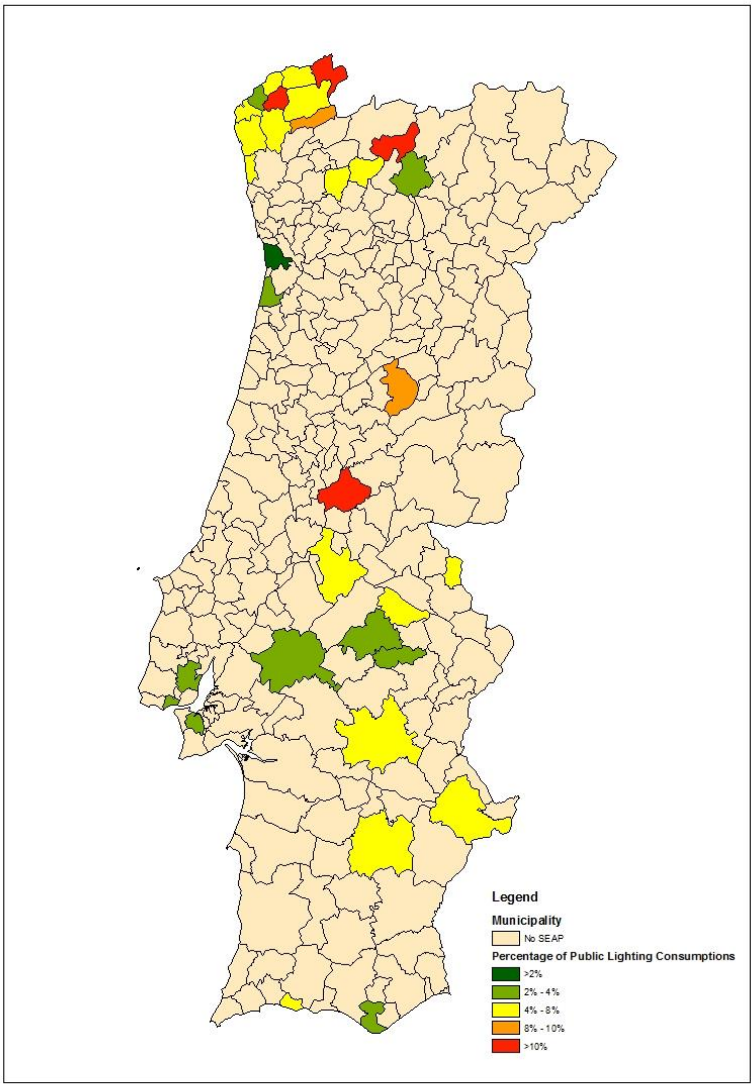

Figure 9: Percentage of public lighting in total electricity consumptions.

The analysis of these results is complex since the comparison depends on other factors, such as population, area and type of business. Nevertheless it is possible to conclude that public lighting represents, in average, 2-10% of the total energy consumption of municipalities. In average 5,6 % of the local authorities electricity consumptions are from public lighting, which is a significant part with potential to be reduced.

3.1.4. Relation between public lighting consumptions and municipal area

Figure 10 shows the public lighting consumptions per municipal area.

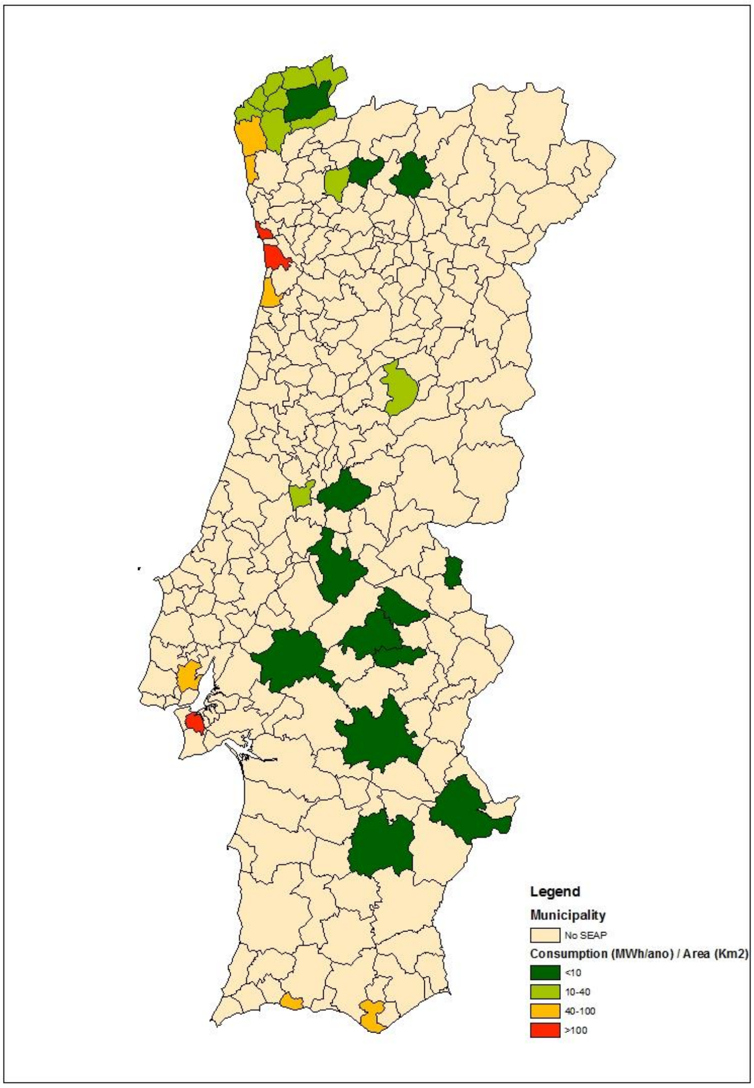

Figure 10: Relation between public lighting consumptions and municipal area.

Analyzing this figure is possible to see that there is a greater consumption per area in the coast area, which can be justified due to the highest density of population and in Figure 11 is possible to conclude that there isn't a direct connection between public lighting consumptions and municipal area.

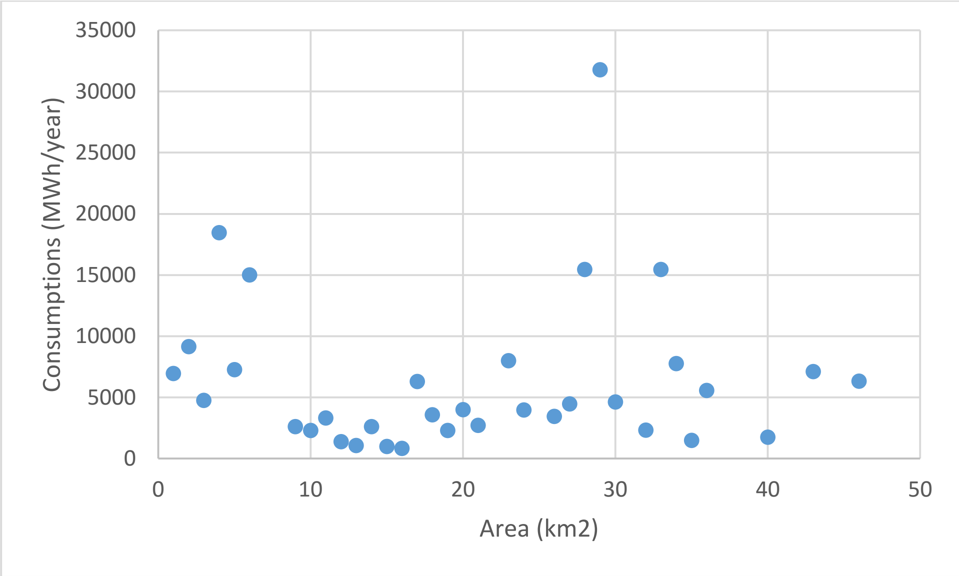

Figure 11: Relation between public lighting consumptions and municipal area.

In the municipalities located in the interior the consumption per area are mostly below 10 (MWh/year)/km^2 while the main urban municipalities have higher than 100 (MWh/year)/km^2.

3.1.5. Relation between public lighting consumptions and population

Figures 12 and 13 shows the relation between public lighting consumptions and population in the municipal area.

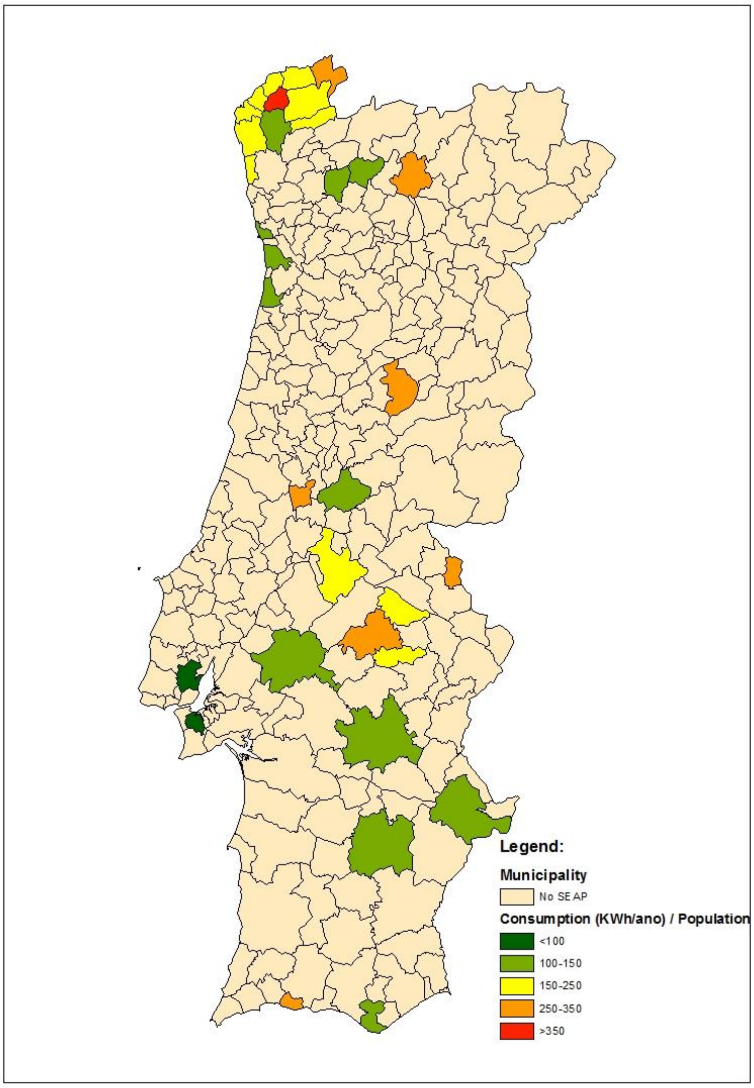

Figure 12: Public lighting consumptions per capita.

Through the figure is possible to see that some of the municipalities have a ratio between public lighting consumptions and population three times higher than others.

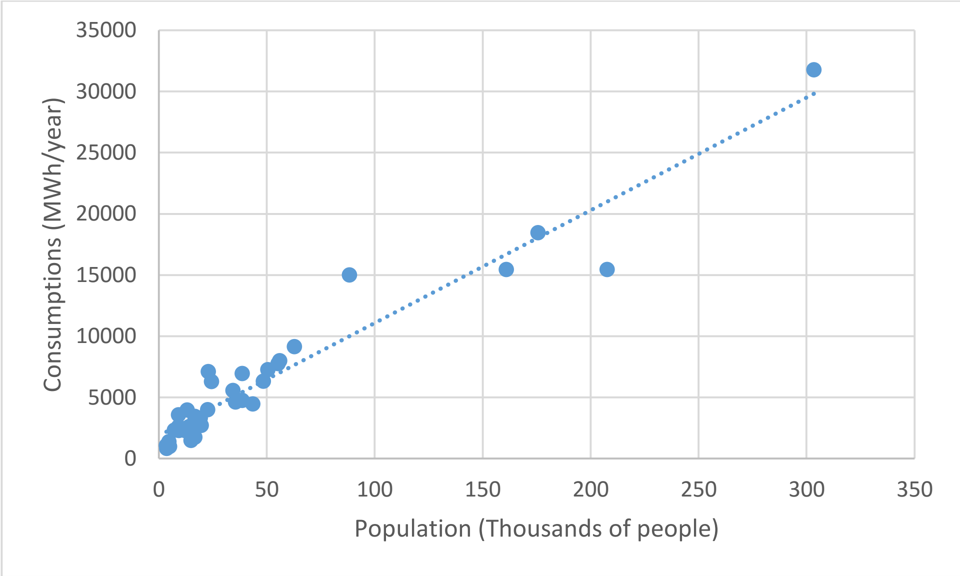

Figure 13: Relation between public lighting consumptions and population.

Looking at Figure 13 is possible to see almost a direct correlation between public lighting consumptions and population. This was expected due to the high need of public lighting in high density residential areas to improve da security of the citizens at night. There is two major outliners in the graph which are Loures and Viana do Castelo, this happens because of the situation in those municipalities. Loures has a great population but because doesn't have a great amount of public lighting for that amount of population it but Viana do Castelo have less than half of the population of Loures but has the same amount of public lighting consumptions due to is great municipal area to cover in terms of roads.

In remote areas without population there isn't a need for public lighting, being only restricted to risk roads.

3.1.6. Relation between public lighting consumptions and municipal revenues

In Figure 14 we can see the relation between public lighting consumptions and municipal revenues.

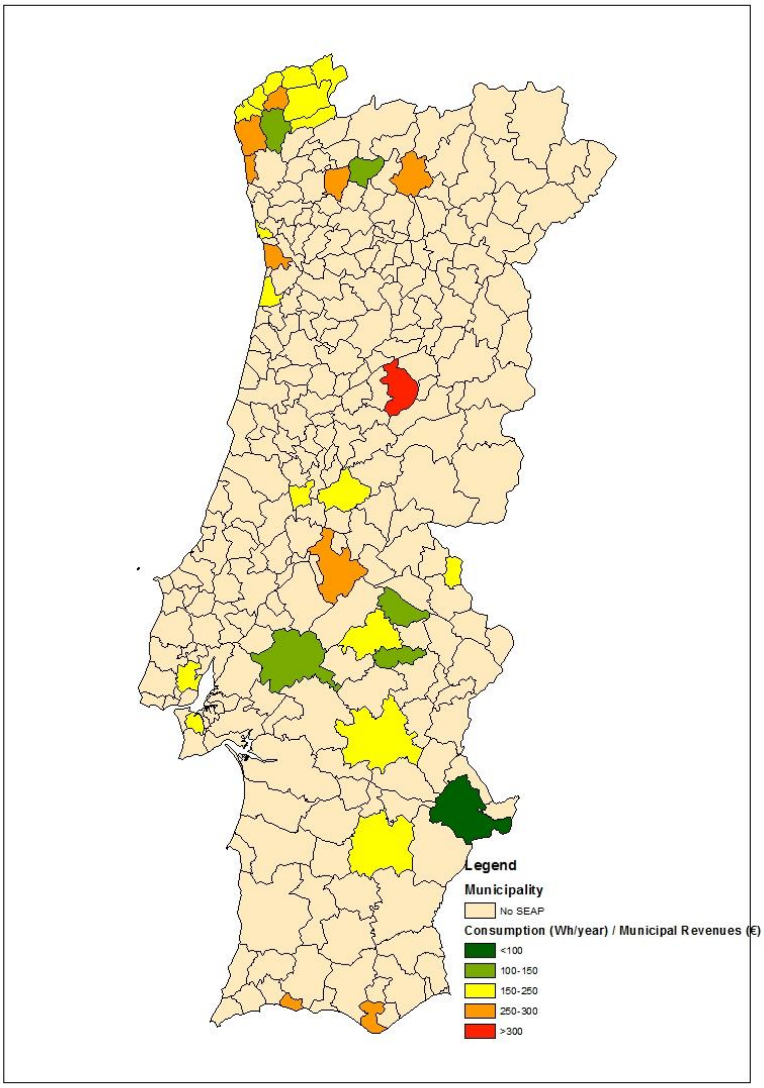

Figure 14: Relation between public lighting consumptions and municipal revenues.

There are municipalities with the ratio between consumption and municipal revenues 3 times higher than others.

3.1.7. CO_2 equivalent

In Figure 15 there is a representation of the CO_2 equivalent from the public lighting energy consumption of the municipal authorities It is also important to refer that on average in Portugal the emissions for public lighting energy consumptions are 3754,74 tons of CO_2.

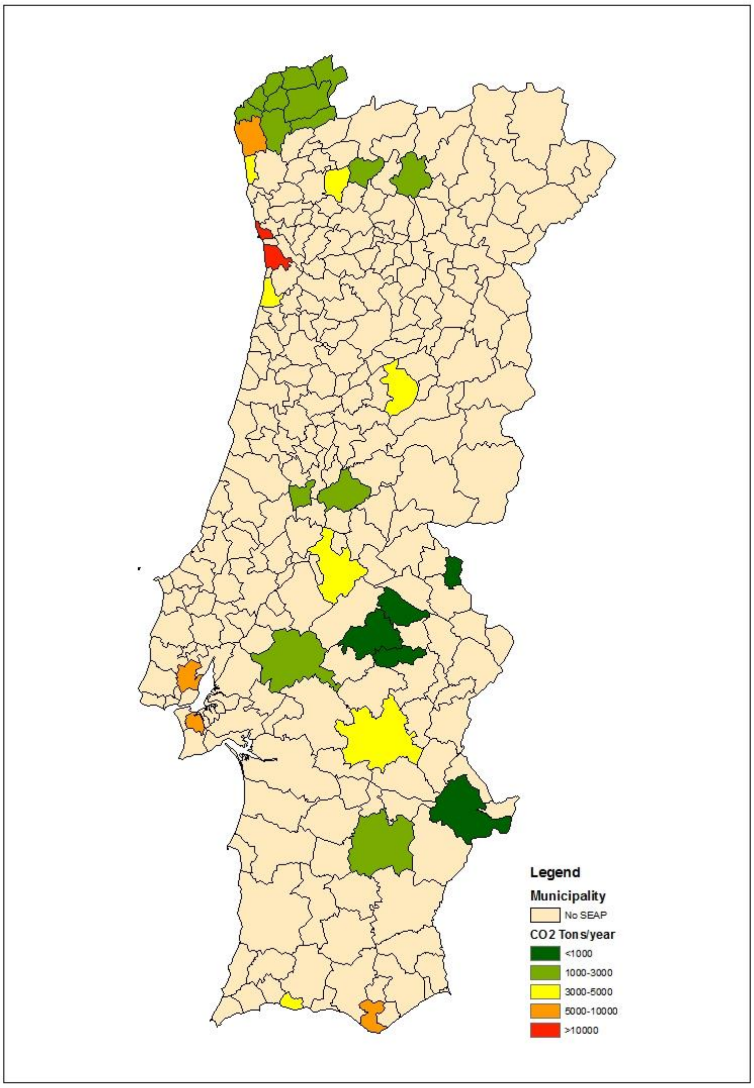

Figure 15: CO_2 equivalent

3.1.8. Measures to reduce public lighting consumptions

From the compilation made using the SEAPs, a list was identified:

- Use of luminous flux regulators;
- More efficient ballasts;
- Timers adjustment;
- More efficient lamps;
- Turn off unnecessary lighting.

It is possible to see that almost all of these measures are simple to introduce and that can be highly profitable in terms of energy reduction and associated costs for the municipal authorities. This inventory of measures will be used to support and develop the case study presented in the next chapter.

4. Case Study

The case study presented focused in the public lighting of Avenue Dr. Lourenço Peixinho in the city of Aveiro, Portugal. This avenue has aproximately 1 km long and is situated in the center of the city being considered one if not the most important avenue in the city, full of commerce and companies offices. In Figure 16 is possible to see the location of the avenue in the city of Aveiro

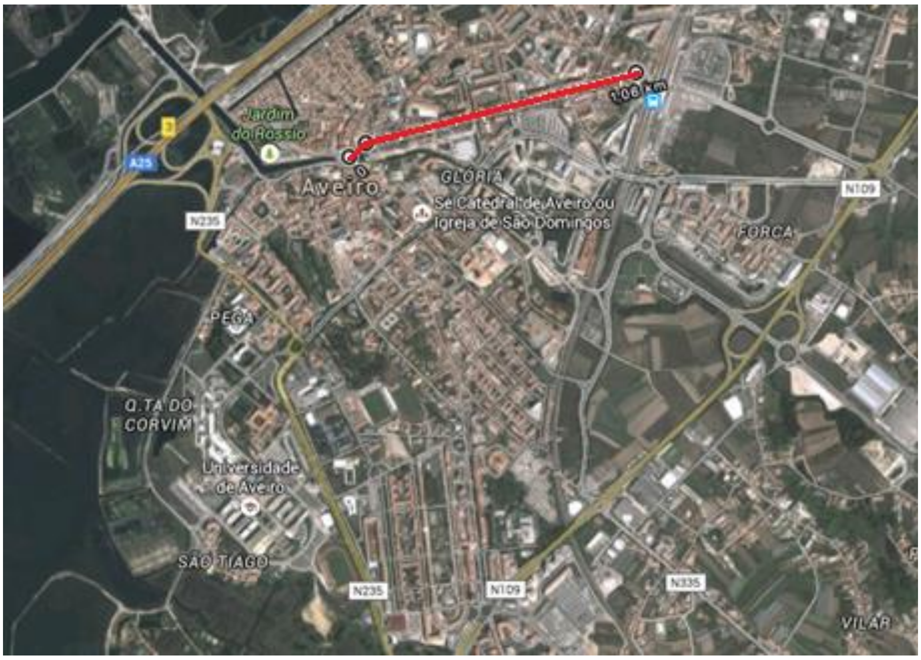

Figure 16: Location of Avenue Dr. Lourenço Peixinho.

This case study has the objective of evaluating the current situation of public lighting in the Avenue in order to determine ways to reduce the consumptions of energy as well as the electricity costs for the city. This study was done in three steps, namely:

- Fieldwork (taking pictures and assess the situation) and data acquisition (contacts with the city hall of Aveiro);
- Study of possible improvements to be implemented (search for technologies and prices);
- Calculation of the energy consumptions in the different scenarios and comparison of the scenarios to draw conclusions.

The objective is to improve the technologies present in the avenue in order to reduce energy consumption and consequently the cost reduction to the municipal authority. We will start by describing the present situation in the reference scenario and then two improvement scenarios, namely:

1) Replacement of the 250 W lamps with existing 150 W;
2) Replacement of the lamps with LED technology.

4.1. Reference scenario

In Figure 17 we have the map representation of the public lighting posts present in the Dr. Lourenço Peixinho Avenue (the posts are represented by the red dots).

Figure 17: Map of the electric posts present in Dr. Lourenço Peixinho Avenue.

At the present the avenue has 71 posts (see in Figure 15), these posts are of two different kinds that are:

- 250 W high pressure sodium lights (10 meters high marmorette posts with ferromagnetic ballasts) which are 54 and are represented with the red dots in Figure 16;
- 150W high pressure sodium lights (10 meters high aluminum posts with ferromagnetic ballasts) which are 17 and are represented in Figure 16 with blue dots.

Regarding the type of the lamps, there are 54 of 250 W and they are represented in Figure 18 a) and b) and Figure 19 a). 150W high pressure sodium lights are in a smaller number, being only 17 installed on a newer side of the avenue. In both Figures 18 c) and 19 b) we can see the 150 W lamp and post.

Figure 18: Luminaries of the different posts with the 250W a) with protection cover and b) without protection cover and c) the 150W luminaire.

It is possible to see that the lamps are in really bad shape and that had been degraded over the years. On the Figure 18 b) is possible to see that the lamp doesn't have is protective cover and in Figure 18 a) it still has it, but is possible to see that is in a really bad shape already, even being in good state when compared with most of the protective covers in the rest of the street. Is possible to see from this the 150 W lamps are in a much better shape than the 250 W. Through this is assumed that this lamps have a better lumens per Watt ratio that were putted at 80 lm/W. This means that each lamp will produce 12000 lm. Figure 18 let us see the entire composition of the post and Figure 20 gives us a view of the light active at night.

Figure 19: Posts installed in the avenue, a) 250W and b) 150W.

Due to the degradation that is clearly possible to see it will be assumed that the lamps currently have a very low rate of lumens per Watt, 45 lm/W, and producing 11250 lm in total (per lamp).

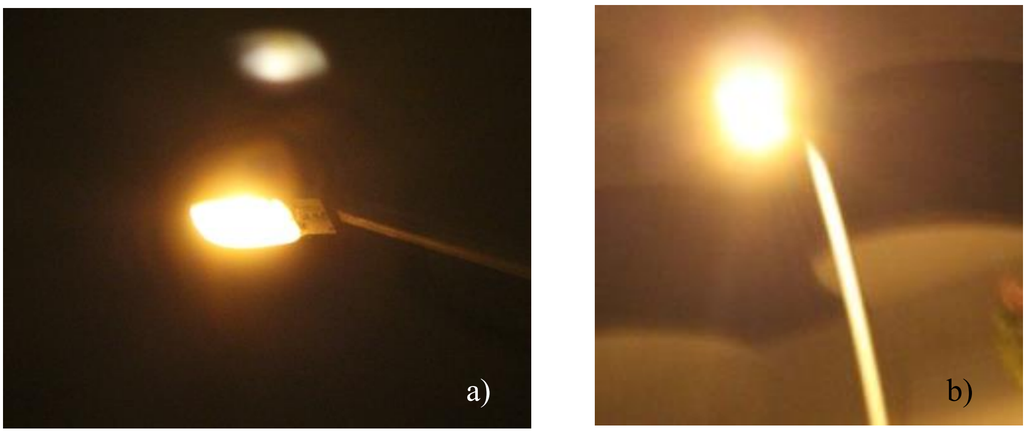

Figure 20: Luminaires by night a) 250W and b) 150W.

According to the responsible at the municipality of Aveiro, the lamps are working since sundown till one hour before sunrise and that means an average of 10,8 hours per day. Figure 21 is a chart representing the average time per day in the different months that the lamps are on which were determined using the duration of darkness table for one year corresponding to the location of Aveiro (USNO 2015).

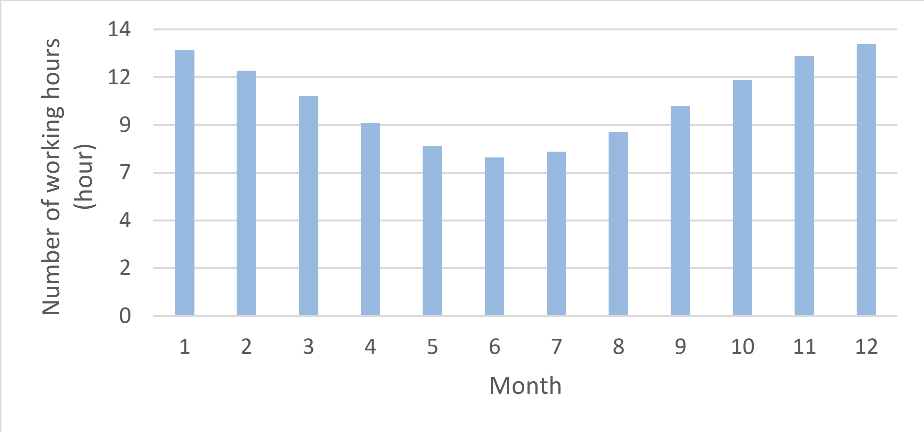

Figure 21: Lamps working time per month

Consumption is determined by equation 1:

$$Consumption\ (W) = lamp\ power\ (W) \times (1 + Ballast\ losses) \quad (1)$$

So,

$Consumption\ 250W\ (W) = 250 \times (1 + 0{,}2)$ = 300 W

$Consumption\ 150W\ (W) = 150 \times (1 + 0{,}2)$ = 180 W

To calculate Energy is used equation 2:

$$Energy\ (kWh/year) = Consumption\ (W) \times Quantity\ \times Time\ (hours) \times \frac{1}{1000} \quad (2)$$

Using it we get,

$$Energy\ 250\ W\ (kWh/year) = 300 \times 54\ \times 3942 \times \frac{1}{1000} = 63860\ kWh/year$$

$$Energy\ 150\ W\ (kWh/year) = 180 \times 17\ \times 3942 \times \frac{1}{1000} = 12063\ kWh/year$$

Time is calculated from an average amount of hours that were calculated that lead to an average of 10,8 hours per day that multiplied by the 365 days in a year (3942 hours per year).

To determine the associated cost is used equation 3:

$$Cost\ (€/year) = Energy\ \left(\frac{kWh}{year}\right) \times Energy\ fare\ \left(\frac{€}{kWh}\right) \tag{3}$$

So,

$Cost\ 250W\ (€/year) = 63860 \times 0{,}1405 = \ 8972{,}39€/year$

$Cost\ 150W\ (€/year) = 12063 \times 0{,}1405 = \ 1694{,}78€/year$

The CO_2 tons are calculated using equation 4:

$$CO_2\ (tons) = Energy\ \left(\frac{kWh}{year}\right) \times\ CO_2\ conversion\ rate\ (\frac{CO_2}{Energy}) \tag{4}$$

$CO_2\ 250\ W(tons) = 63860 \times\ 0{,}0005925 = 37{,}84\ tons\ CO_2/year$

$CO_2\ 250\ W(tons) = 12063 \times\ 0{,}0005925 = 7{,}15\ tons\ CO_2/year$

Lifetime of the lamps is calculated using equation 5.

$$\text{Lifetime of the lamps (years)} = \frac{Lifetime\ of\ the\ lamps\ (hours)}{Lamps\ working\ time\ (\frac{hours}{year})} \tag{5}$$

That leads to,

$\text{Lifetime of the lamps (years)} = \frac{16000}{3942} \cong 4\ years$

The characteristics of the reference scenario are summarized in Table 4.

Table 4: Reference scenario characteristics.

	250W	150W	Total
Quantity	54	17	71
Consumption (W)	300	180	-
Energy (kWh/year)	63860	12063	75922,92
Cost (€/year)	8972,39	1694,78	10667,17
CO_2 (tons/year)	37,84	7,15	44,98
Lifetime of the lamps (years)	-	-	4

4.2. Scenario 1

Scenario 1 considers the hypothesis of not making a complete renovation in the public lighting present in the avenue, replacing only the 250 W posts with 150W posts like the ones that are already installed. This change implies the change of the lamps and the luminaires and those costs are not considered in this study because there wasn't data to allow that evaluation.

Table 5 shows the results of the study of this scenario and the respective energy consumption (using the same calculations described for the reference scenario).

Table 5: Scenario 1 characteristics.

	Scenario 1
Quantity	54
Consumption (W)	180
Energy (kWh/year)	38316
Cost (€/year)	5383,43
CO_2 (tons/year)	22,7
Savings (€/ year)	3588,95
Lifetime of the lamps (years)	4

Analyzing Table 5 is possible to conclude that this solution will allow a significative energy reduction comparing to the base case. In the reference scenario energy consumption in the 250 W lamps was of 63860 kWh/year and now it has been reduced to 38316 kWh/year which is a 40% reduction in the energy consumption. Also there is a reduction of 15,14 tons of CO_2/year and a economic saving over 3500 €/year to the city.

This is a very interesting scenario to the municipal authority because it didn't require any kind of changes in terms of maintenance since the structure of the city is already prepared to change the lamps in the 150 W posts that are implemented in the avenue.

Also important to refer that it wasn't possible to determine a payback for this scenario due to the lack of knowledge on how much does each post cost, which do not allow the complete analysis of viability of this scenario.

4.3. Scenario 2

Scenario 2 considers the replacement of the current lamps and respective posts for LED technology. For this replacement will be used technology from the company Schréder specially the Yoa Maxi. This choice was made because it would allow to fulfill the lighting requirements of the avenue and due to the availability of the data such as the price of the posts.

In the configuration used the Yoa Maxi has 64 LEDs and emits 12600 lm which is already an improvement in terms of illumination compared to the technologies installed which are considerably degraded. This technology has a lifetime of the lamps of about 100000 hours that means a big improvement compared to the current technologies.

The Yoa Maxi is represented in Figure 22 and 23. Figure 23 allows to see the kind of support used to install Yoa Maxi which is Tressa the standard for lateral installation.

Figure 22: Yoa Maxi.

Figure 23: Yoa Maxi with Tressa (lateral standard).

Table 6 shows the results for this scenario regarding the energy consumptions, as well as the payback of the entire project.

Table 6: Scenario 2 characteristics.

	Scenario 2
Quantity	71
Consumption (W)	101
Energy (kWh/year)	28268
Cost (€/year)	3971,67
CO_2 (tons/year)	16,75
Savings (€/year)	6695,51
Payback (years)	10
Lifetime of the lamps (years)	25
IRR (%)	9

For scenario 2 the savings are over 6500 €/year, representing approximately 63%. This would allow the city to save over 18 € per day with the lighting of only one avenue.

Nevertheless, for a complete analysis of this scenario it is necessary to take into account the cost of each post being in 944,76€, which makes a total investment of over 67000€, with an amortization of 10 years.

Also the investment presents an Internal Rate Return (IRR) of 9%, which it's still positive and show that in terms of money this would be an investment with return in the long run.

Comparing these technologies in terms of the lifetime of the lamps it's possible to evaluate how much lamp replacements it would take on the lifespan of the project. With a lifetime of 25 years and without any destruction by any other means it would take only one light change to complete the lifespan of the project with the LED lamps, while the current lamps with a lifetime of only 4 years it would take 7 to 8 light changes to complete the lifespan of the project.

This cannot be calculated to see how it affects the payback of the project because the maintenance of public lighting in the city of Aveiro is a concession. Nevertheless, this is a major difference in both cases with one of the technologies barely needs any kind of maintenance while the other needs a lot of lamp replacements throughout the lifespan of the project.

4.4. Scenarios Comparison

Table 7 allows comparing between the different scenarios and evaluating the implementation of each one. It is clear that both scenario 1 and 2 allow the city municipality to reduce their energy consumptions, energy costs and CO_2 emissions since they are all correlated.

Table 7: Comparison between the different scenarios.

Scenario	Reference	1	2
Quantity	71	54	71
Consumption (W)	-	180	101
Energy (kWh/year)	75923	38316	28268
Cost (€/year)	10667,17	5383,43	3971,67
CO_2 (tons/year)	44,98	22,7	16,7
Savings (€/year)	-	3588,95	6695,51
Payback (years)	-	-	10,0
Lifetime of the lamps (years)	4	4	25

It is impossible to fully analyze both improvement scenarios due to the lack of data to calculate a payback for scenario 1, but it is expectable that this would be an easier and costless solution. Scenario 1 implicates only the replacement of the most degraded posts installed with 150 W posts, which would lead to no changes besides the substitution of the posts.

Scenario 2 involves a more long-term solution with a long payback time in 10 years, allowing to reduce in a great scale the energy consumption which will lead to a significant reduction of the energy costs and CO_2 emissions while there isn't a need to worry on the replacement of the lamps because they have a very long lifetime, reducing maintenance with public lighting in the avenue.

In order to determine the influence of the energy fare in terms of payback time a study was made in which the growth of energy fare was analyzed through 2001 and 2013. It was possible to determine that the fare had a normal growth of about 4 % being the minimum growth value of 1 % and the maximum of 7 %.

Using this values and a timeline of 15 years was possible to determine the expected payback times for the growth values. For the minimal growth of 1 % each year a payback time between 9 and 10 years were determined, the average growth of about 4 % per year lead to a payback time of 8 to 9 years and the maximum growth of 7 % each year had the minimum payback time, as expected, between 7 and 8 years.

This allow us to realize how much this projects are dependable on the energy cost and being impossible to prevent accurately the variation of the energy cost, this payback times can have some changes through the years, becoming the investment more rentable as the energy price goes higher.

5. Conclusion

The initial objectives for this paper were to determine the importance of public lighting in Portugal and find and propose technical solutions to reduce the energy consumptions and so is possible to conclude that both of the objectives were achieved. For this was used the analysis of the SEAPs from Covenant of Mayors and the case study from Avenue Dr. Lourenço Peixinho in Aveiro.

The data analysis showed that the quantity of data/information wasn't enough to do an extrapolation for the rest of the country, so it is important to refer that the conclusions addressed could be different if a complete database would be available.

The local authorities in Portugal that had a Sustainable Energy Action Plan (SEAP) that had been accepted and made available in the Covenant of Mayors website until the end of year 2013 were analyzed. A total of 45 of the 278 existent in Continental Portugal what represents only 16,2 % of the counties.

Since then there has been some local authorities that had SEAP's accepted by the Covenant of Mayors but most of them were not from Continental Portugal but from the islands (Azores and Madeira).

With the data that was analyzed it is possible to take the conclusion that public lighting represents an important part on local authorities costs and in the energy consumption of a country (3% of energy consumptions). Besides the great importance to have public lighting to have safety and comfort at night it is also important to have an energy responsibility especially when there is already technology to improve public lighting.

The analysis showed that public lighting has a direct correlation to the population density and no correlation with the municipalities revenues.

The analysis of the case study, in Avenue Dr. Lourenço Peixinho in Aveiro, it was possible to conclude that the current situation of the avenue in terms of energy consumption is very high compared to what it could be. As is shown the savings per year in either one of the improvement scenarios is very high, being one over 3000 € and the other 5718,58 €, with one we can save 8 € per day while with the second this correspond to a 15 € per day saved in one single avenue.

Comparing both scenarios is clear to see that the second is the best in terms of energy saving and CO_2 equivalent, but it needs to be really analyzed because of the payback presented being very high. But when you consider maintenance and a lifespan of 30 years the second scenario with the LED only need to change their lamps once while with the sodium vapor lights in the first scenario it will need probably 7 to 8 lamps change in the same period, this is a pretty big difference for the maintenance of the public lighting in the avenue.

One thing important to refer is the fragility of the public lighting infrastructure in Portugal, with every single year problems due to nature events, specially the wind which brings down posts and lead to the lack of public lighting leading to problems with the safety of the population and an important problem that needs solutions.

In future works it would be interesting to see the scenario of the payback of the EolGreen post. Due to the lack of energy consumption from the grid it would allow to have a significant high initial investment and also high maintenance. Also it would be very interesting to analyze the situation of Avenue Dr. Lourenço Peixinho with the program DiaLux Evo and extend these scenarios analysis.

It is important that the Covenant of Mayors will increase the local authorities awareness for energy efficiency and especially to public lighting because there is still a long way to go in terms of energy consumption reduction.

References

ADENE, 2011. Documento de Referência.

ADENE, 2015a. Energy Policy. Available at: http://www.adene.pt/politica-energetica [Accessed April 8, 2015].

ADENE, 2015b. Iluminação Pública | ADENE - Agência para a energia. Available at: http://www.adene.pt/iluminacao-publica [Accessed October 11, 2015].

ADENE, 2015c. Planos e Programas | ADENE - Agência para a energia. Available at: http://www.adene.pt/planos-e-programas [Accessed September 21, 2015].

APA, 2015. Agência Portuguesa do Ambiente. Available at: http://www.apambiente.pt/index.php [Accessed October 6, 2015].

APA, 2007. *Guia Agenda 21 Local Um Desafio Para Todos*,

Argyriou, I., Fleming, P. & Wright, A., 2012. Local climate policy: Lessons from a case study of transfer of expertise between UK local authorities. *Sustainable Cities and Society*, 5, pp.87–95. Available at: http://dx.doi.org/10.1016/j.scs.2012.06.001.

Comodi, G. et al., 2012. Local authorities in the context of energy and climate policy. *Energy Policy*, 51, pp.737–748. Available at: http://dx.doi.org/10.1016/j.enpol.2012.09.019.

EC, 2009a. 406/2009/EC of the European Parliament and of the Council of 23 April 2009 on the effort of Member States to reduce their greenhouse gas emissions to meet the Community's greenhouse gas emission reduction commitments up to 2020. *Off J Eur Union*, 140, pp.136–148.

EC, 2015a. Covenant of Mayors - The Covenant of Mayors. Available at: http://www.covenantofmayors.eu/about/covenant-of-mayors_en.html [Accessed September 21, 2015].

EC, 2009b. Directive 2009/31/EC of the European Parliament and of the Council of 23 April 2009 on the geological storage of carbon dioxide and amending Council Directive 85/337/EEC, European Parliament and Council Directives 2000/60/EC, 2001/80/EC, 2004/35/EC, 2006/. *Offical Journal of the European Union*, L140/114(June 2006), pp.114–135.

EC, 2015b. Mayors Adapt. Available at: http://mayors-adapt.eu/ [Accessed November 6, 2015].

EC, 2015c. Roadmap 2050. Available at: http://www.roadmap2050.eu/project/roadmap-2050 [Accessed November 6, 2015].

EolGreen, 2015. EolGreen. Available at: http://www.eolgreen.com/ [Accessed October 12, 2015].

EP, 2015. European Parliament seals climate change package. Available at: http://www.europarl.europa.eu/sides/getDoc.do?pubRef=-//EP//TEXT+IM-PRESS+20081208BKG44004+0+DOC+XML+V0//EN [Accessed November 6, 2015].

EPA, U., 2015. Causes of Climate Change. Available at: http://www3.epa.gov/climatechange/science/causes.html#greenhouseeffect [Accessed November 20, 2015].

EU, 2009. Directive 2009/28/EC. *Official Journal of the European Union*, 140(16), pp.16–62.

EU, 2012. Directive 2012/27/UE. *Jornal Oficial da União Europeia*, pp.1–56.

EU, 2015a. Energy policy. Available at: http://eur-lex.europa.eu/summary/chapter/energy.html?root_default=SUM_1_CODED%3D18,SUM_2_CODED%3D1801&obsolete=false [Accessed March 5, 2015].

EU, 2015b. Environment Policy. Available at: http://eur-lex.europa.eu/summary/chapter/environment.html?root_default=SUM_1_CODED=20 [Accessed March 5, 2015].

GRAH, 2015. Street lighting technology comparison. Available at: http://www.grahlighting.eu/learning-centre/street-lighting-technology-comparison [Accessed October 12, 2015].

Helm, D., 2014. The European framework for energy and climate policies. *Energy Policy*, 64, pp.29–35. Available at: http://dx.doi.org/10.1016/j.enpol.2013.05.063.

Iberdrola, 2015. Luminous flux regulator. Available at: https://www.iberdrola.es/customers/companies/efficiency/lighting/dimmers/flow-regulator [Accessed October 12, 2015].

IEA, 2015. International Energy Agency. Available at: http://www.iea.org/ [Accessed November 20, 2015].

intelilight, 2015. Inteligent Street Lighting. Available at: http://intelilight.eu/intelligent-street-lighting-control/ [Accessed October 12, 2015].

IPCC, 2014. *Climate Change 2014: Synthesis Report*. *Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*,

Kanellakis, M., Martinopoulos, G. & Zachariadis, T., 2013. European energy policy-A review. *Energy Policy*, 62, pp.1020–1030. Available at: http://dx.doi.org/10.1016/j.enpol.2013.08.008.

Melhor, P., 2015. Preços da electricidade 2001-2013 » Poupar Melhor. Available at: http://www.pouparmelhor.com/noticias/precos-da-electricidade-2001-2013/

[Accessed November 6, 2015].

PA, 2015. Agenda 21 Local - Portal do Ambiente. Available at: http://ambiente.maiadigital.pt/cidadania/agenda21/agenda-21-local [Accessed November 20, 2015].

PORDATA, 2015. Consumo de energia eléctrica por tipo de consumo. Available at: http://www.pordata.pt/DB/Portugal/Ambiente+de+Consulta/Tabela [Accessed November 6, 2015].

Rabaza, O. et al., 2013. A simple method for designing efficient public lighting, based on new parameter relationships. *Expert Systems with Applications*, 40(18), pp.7305–7315. Available at: http://dx.doi.org/10.1016/j.eswa.2013.07.037.

Santos, E. et al., 2015. Quadro Estratégico da Política Climática (QEPiC). , p.33.

Stabilux, 2015. Stabilux luminous flux regulators. Available at: http://www.irem.it/ENG/groups/lighting/stabilux_luminous_flux_regulators.html [Accessed October 23, 2015].

Thankur, A., 2015. Types of Electronic Ballast. Available at: http://www.engineersgarage.com/sites/default/files/imagecache/Original/wysiwyg_imageupload/4214/Types-of-Electronic-Ballast.gif [Accessed October 12, 2015].

UNEP, 2012. *The Emissions Gap Report 2012, A United Nations Environment Programme (UNEP) Synthesis Report*,

USNO, 2015. Duration of Daylight/Darkness Table for One Year. Available at: http://aa.usno.navy.mil/data/docs/Dur_OneYear.php [Accessed November 6, 2015].

Vermont, E., 2012. *Improving Efficiency - in Municipal Street and Public Space Lighting*,

WEC, 2013. World Energy Resources. *World Energy Council Report*, p.468.

Zeller, A. Van, 2015. Iluminação pública eficiente em Portugal.