Nova School of Business and Economics

WORK PROJECT

BASED ON

Energy Efficiency in Public Lighting

Business Project with EDP Distribuição

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PART 1: BRIEF CONTEXT OF THE BUSINESS PROJECT

Company: EDP Distribuição

EDP Distribuição is a company that operates in the energy distribution sector in Continental Portugal. It is the current concessionary of the national distribution network of electricity in high and medium voltage, and the majority of the distribution network of low voltage electricity, granted by municipalities. Its activity entails expansion, operation and maintenance of the network, and provision of market support (switching, metering, etc) (EDP Distribuição, 2014). In 2012, it distributed 44.7 TWh of electricity to over 6 million clients in Continental Portugal, obtaining a profit of 213 M€ (EDP Distribuição, 2012).

It is part of the EDP group, which is a vertically integrated utility, holding businesses in the production, distribution and commercialisation of electricity and gas in 13 countries (EDP, 2014). These activities generated a profit of around 1 billion euros in 2012, of which 21% are attributed to the activity of EDP Distribuição in Continental Portugal (EDP).

The Business Project Challenge: Energy Efficiency in Public Lighting

The business project consisted of the development of a business plan for EDP Distribuição to support technological change in public lighting. This change is motivated by a EU Directive requiring the phasing-out of mercury lamps, whose production will be discontinued after 2015.

For EDP Distribuição this policy change is very relevant since the company is responsible for the provision of public lighting, under the concession contract of the low voltage network. This contract establishes the payment of a concession rent to the municipalities and attributes the responsibility of investment and maintenance of the network to the concessionary for 20 years. In Continental Portugal, EDP Distribuição is the concessionary for all municipalities.

To face this requirement, EDP Distribuição is considering the substitution of mercury lamps by two options: sodium lamps or LED luminaires. Sodium lamps are now the standard solution in public lighting, but have a lower lifespan and higher power consumption than LED luminaires, which are the most energy efficient technology.

The objectives of the business project were therefore to assess the best technology to install in public lighting by evaluating its benefits and costs, as well as to analyse the relevant financing alternatives of the project, providing a recommendation (see Appendix A for a more detailed description of the modules of the business project).

Market overview: The Portuguese Electricity System

EDP Distribuição is an important player in the Portuguese Electricity System, where the public lighting sector is inserted (see Appendix B). In this system, energy producers generate electricity which is transported in a very high voltage network by REN to supply points, from which it is distributed by EDP Distribuição in a high and medium voltage network and by several distribution network operators (also including EDP Distribuição) in a low voltage network. The electricity then reaches the end-consumers, which in the case of public lighting are the municipalities. In this system, public lighting represents around 3% of total electricity consumption, but 6% of only low voltage electricity consumption.

Now considering only public lighting, municipalities pay the electricity bill to energy retailers. These retailers then pay to energy producers as well as EDP Distribuição and REN for the use of the distribution and transport networks, respectively.

Current Situation: Public Lighting in Portugal

In Portugal, there are approximately 3.5M lamps, of which 20% are mercury lamps and 80% are sodium lamps. This represents 1,4 TWh of annual electricity consumption, which is equivalent to an energy cost of 197 M€ for municipalities. For EDP Distribuição, the annual costs regarding maintenance of lamps amount to 10 M€, investment in luminaires reaches 7 M€, and the concession rent related to public lighting is 16 M€.

Main Conclusions

The business project assessed three scenarios: scenario one in which mercury lamps are substituted by sodium lamps; scenario 2 in which mercury lamps are replaced by LED luminaires; and scenario 3 in which both mercury and sodium lamps are substituted by LED luminaires. By constructing a model where the benefits and costs of each scenario were compared to the current situation, it was concluded that scenario 3 was the most attractive for the main stakeholders (EDP Distribuição and municipalities), generating an overall NPV of 115 M€ over 15 years (see Appendix C). Furthermore, it was recommended that the project is financed through an Energy Performance Contract under shared savings, with EDP acting as ESCO. This means that EDP will make the necessary investment but it will also obtain a share of the benefits from the municipalities. This sharing could be arranged as a reduction in the concession rent paid to municipalities, which should be at least 15.4% of the total concession rent as for EDP to break-even. Finally, this project can also be supported financially and technically by the EU, with the European Energy Efficiency Fund.

PART 2: SAVINGS IN CO2 EMISSIONS GENERATED BY THE PROJECT

In this part, the CO2 savings generated by EDP Distribuição's project on energy efficiency in public lighting will be presented since its calculation was not included in the business project. In addition, these savings will be translated into monetary terms by using the price of carbon. Finally, the value-added for EDP of reducing CO2 emissions will be analysed.

The assessment of the CO2 savings generated by the project is very relevant given the rising importance of climate change for both authorities and businesses. This issue first gained momentum in 1980s with several studies demonstrating the impact of the greenhouse gas (GHG) emissions (including CO2) on climate variations (Weart, 2014). This was followed by the adoption of the Kyoto Protocol in 1997, which fostered countries to reduce their GHG emissions by imposing a cap on emissions (UNFCCC Website). At the EU level, an Emissions Trading Scheme (ETS) was launched in 2005, aiming to limit CO2 emissions by 20% (compared with 1990 levels) by 2020 (European Union, 2013). Furthermore, in 2009, all EU countries took further action by committing to the 20-20-20 targets (European Commission, 2014). For Portugal in particular, these targets impose a reduction in total primary energy consumption of 25% (compared to 2005 levels), an increase in the share of renewable energy sources in final energy consumption of 31% and a limit to the increase of GHG emissions of 1% (compared to 2005 levels) for emissions from sectors not included in the ETS, until 2020 (Governo de Portugal, 2013). More recently, the Members of the European Parliament suggested a 40% cut in CO2 emissions, a 30% target for renewable energy and a 40% target for energy efficiency by 2030, under the EU's new climate change policy (European Parliament, 2014).

In particular, the issue is very relevant in the electricity sector with the majority of these targets being related to energy production and consumption. This occurs because the sector is one of the major emitters of GHG. For EU27, public electricity and heating represented 27% of all GHG emissions and 32% of CO2 emissions in 2011 (European Environment Agency).

Given the weight of electricity's contribution to CO2 emissions, the EU has developed projects to support energy efficiency, which are usually integrated in climate change mitigation policies. Thus, they require CO2 emissions reduction targets. For example, one of the objectives of the European Energy Efficiency Fund (EEEF), proposed in the business project as an opportunity to obtain financial and technical support, is to contribute to the mitigation of climate change. Thus, it requires the calculation of both energy and CO2 savings when submitting the project (EEEF Website).

Calculation of CO2 emissions

The savings in CO2 emissions depend on the type of power source that generates the electricity that is saved by implementing this project. It follows that only the pollutant sources are relevant for this calculation.

To evaluate the power sources that generate electricity in Portugal, it is necessary to analyse the wholesale market for electricity, the MIBEL (Mercado Ibérico de Electricidade), which is a joint market with Spain. In this market, electricity is supplied by different energy producers. The aggregate supply curve depends on the power portfolio, i.e., type of energy sources (conventional thermal, combined cycle, renewables, among others), including their availability and marginal costs. It is determined by merit order dispatch, that is, the power sources are ordered by bids (from lower to higher), which are made by each producer that sets the quantities supplied at a certain price. On the other hand, energy is demanded by energy retailers. An equilibrium price and quantity is reached in this market for every hour of the year. Note that the analysis of this market will focus on 2013, constituting the base year for the timeframe considered in project (15 years), as it was done for the topic about impact on tariffs included in the business project.

To determine the impact of the project in CO2 emissions, first it is necessary to evaluate the current tonnes of CO2 emitted by the public lighting sector as to have a basis of comparison. In the case of Portugal, pollutant sources of electricity encompass the conventional thermal power plants, using coal, and the combined cycle power plants, using natural gas. Analysing the energy wholesale market in 2013, these represent 25% of the electricity used in Portugal in 2013, that is, 11.8 TWh, of which 10.9TWh are produced from coal and 0.9TWh are produced from natural gas. To calculate the CO2 emissions resulting from this production, it is necessary to apply the emission factors, i.e., the tonnes of CO2 (tCO2) emitted per GWh of electricity produced from each pollutant technology. Coal is more pollutant than natural gas, emiting 930 tCO2/GWh, while natural gas emits 400 tCO2/GWh. Therefore, total CO2 emissions in 2013 from electricity produced by these two technologies were approximately 10.4M tCO2. Given that public lighting represents around 3% of total electricity in the system, this sector generated 314 thousand tCO2 by approximation (a detailed explanation of this calculation can be found in Appendix D).

Regarding the impact of the project, its implementation can lead to a reduction in CO2 emissions provided the electricity saved was in part produced by pollutant sources. Note that the total electricity saved by the execution of the project will be based on scenario 3 since this is the most attractive scenario, which was recommended in the business project. In this scenario, the reduction in electricity consumption after the completion of the project amounts to 720.8 GWh in one year (or 172 MWh in one hour, given that in one year there are 4200 hours in which public lighting is operating). CO_2 savings can then be calculated by two different methods, providing a lower and higher bound.

The first method provides the higher bound. It entails assessing the saved electricity that is produced from the two pollutant sources considered (coal and natural gas) as to estimate the CO_2 savings. However, information about the technology that produces each MWh of electricity per hour is not public. Thus, the intended value is calculated from the information about the marginal technology that sets the price in the wholesale market, i.e., the last bid to enter the market. Since the reduction in electricity consumed occurs at the margin, it is viable to assume that this decrease will occur in the technology that sets the price. By this method, the CO_2 savings are 213 thousand tCO_2, of which 7% come from combined cycle (natural gas) and 93% from conventional thermal (coal). Comparing with the current situation, it represents a reduction of 67.9% in CO_2 emissions (a detailed explanation of this method can be found in Appendix E). However, this method might be overestimating the CO_2 savings since it assumes that all the energy saved in that hour is produced by the marginal technology. Instead, part can also have been produced from clean sources, which would imply lower CO_2 savings.

The second method provides the lower bound. It involves calculating the average emission factor of electricity production in Portugal, which reflects the share of both non-pollutant (renewables) and pollutant technologies. Note that this method assumes that the share of technologies in one year is equal to their share at the margin, where reduction in electricity consumption will occur. By this method, the CO_2 savings obtained are 156 thousand tCO_2, representing a reduction of 49.8% when comparing with the current situation (a detailed explanation of this method can be found in Appendix F). However, this result might be underestimated given that the share of technologies in a year might not be equal to the share at the margin. Since the last technology to enter the market is the most expensive, which usually corresponds to a pollutant source, these are likely to be overrepresented at the margin, which would entail higher CO_2 savings.

All in all, the two methods provide a range of total CO_2 emissions reduction between 50% and 68%. These results are similar to the outcomes of other projects and studies that promote a technological change in public lighting (see Appendix G).

It is now possible to apply the results presented previously to the business project as to evaluate the reduction in CO_2 emissions throughout the considered timeframe (2015 – 2030).

First, note that these results correspond to the outcome when the project is completed. This only occurs in 2026 since sodium lamps are replaced over 12 years. This means that CO2 savings will increase every year until 2026 when they stabilise around the previously calculated values, as figure 1 illustrates.

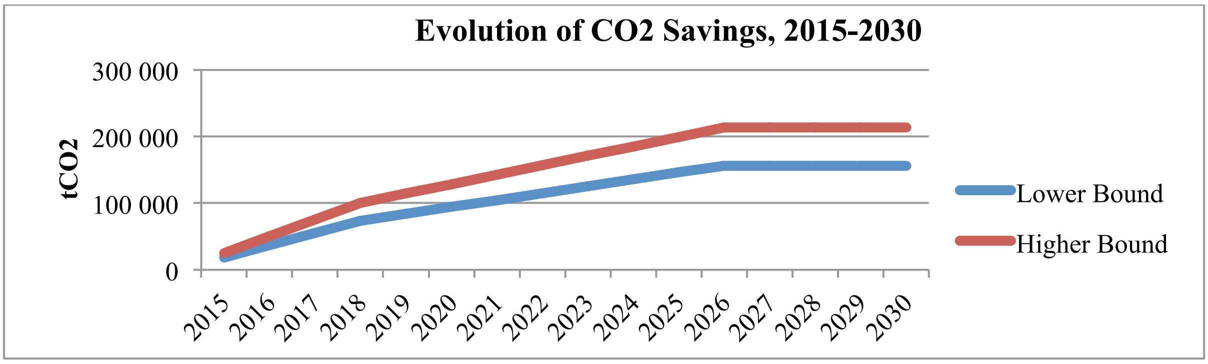

Figure 1 – Evolution of CO2 Savings, 2015-2030

CO2 Allowance Savings and the EU ETS market

It is also important to quantify this reduction in CO2 emissions by using the price of carbon from the EU Emission Trading Scheme (ETS). The ETS is a market of emissions allowances, which was launched in 2005 and is already in its third phase (2013-2020). It was the first major carbon market and it is currently the largest in the world. It encompasses the 28 EU countries in addition to Iceland, Liechtenstein and Norway. It covers around 45% of EU's GHG emissions from power plants, energy-intensive industry and commercial airlines (European Union, 2013).

The EU ETS is based on the "cap-and-trade" principle. This means that the authority sets a cap on CO2 emissions by issuing a limited number of permits that give the right to emit one tonne of CO2. These permits are received or bought by the covered companies in the ETS primary market, which can trade them among each other in the secondary market. After each year, companies must submit the necessary permits to cover their pollution (regulated by the ETS), otherwise they can be heavily fined (European Union, 2013).

It is the tradability that creates a value for the right of polluting since the decision to pollute reflects an opportunity cost (the value of the permit's sale). Firms will be willing to buy (sell) permits as long as its price is less (higher) than the marginal pollution abatement cost - investment in energy efficiency and low carbon technology, for example - they will have to incur otherwise. Therefore, the clearing price will be a reflection of the overall cost of polluting (Perman, Ma, Common, Maddison, & McGilvray, 2011). The flexibility of the market allows the reduction in CO2 to occur where the abatement cost is lower, thus the outcome is expected to be cost-effective.

Currently, the price in the EU ETS is very low due to an excess supply of emission allowances (de Vries, Richstein, Chappin, & Dijkema, 2014). This arose from a contraction in allowances' demand due to the economic crisis that generated a slowdown in economic activity, which implied less pollution. In 2013, the average clearing price of the auctions was 4.52€ (European Commission, 2013). However, in 2014 it is expected to increase to a value between 6€ and 7.5€ due to a reduction of allowances in the market (see Appendix H).

Assuming the 2013 average price of 4.52€, this entails total savings due to lower permits' purchases between 706K€ and 963K€ (lower and higher bound methods, respectively). For EDP in particular, since it holds businesses in the energy production sector covered by EU ETS, the implementation of this project also entails significant savings. Given that EDP contributes 75% for the CO2 emissions in this sector, this means allowance savings between 503K€ and 723K€ in 2013 (see Appendix I for results using the other prices).

As before, these results can be applied to the business project. Thus, the present value of the cumulative allowance savings for 15 years was calculated for EDP and in total, with a discount rate of 10% (as used in the business project). Table 1 shows this calculation, using 3 different prices given its expected evolution.

Table 1 –Present value of cumulative allowance savings in total and for EDP, 2015-2030

Price	4.52€	6.00€	7.50€
Total	[3.2M€, 4.4M€]	[4.3M€, 5.9M€]	[5.3M€, 7.3M€]
EDP	[2.4M€, 3.3M€]	[3.2M€, 4.4M€]	[4M€, 5.4M€]

It is worth highlighting that the present value of cumulative allowance savings (total) can be interpreted as the social benefit of reduced CO2 emissions, translated in monetary terms. Thus, it quantifies one of the benefits of the project for the whole society. This is also a benefit for municipalities, since they have to comply with climate change mitigation policies, as previously described. For the EDP group in particular, this project generates savings in the purchase of allowances, but it also reflects a reduction in production. Nevertheless, this project generates positive impacts, which will be further developed in the next section.

Value-Added for EDP of reducing CO2 emissions

These initiatives in sustainability are becoming very relevant for businesses. A 2011 study from BCG and MIT, which surveyed more than 4000 managers of 113 countries, revealed that 67% of the respondents perceive sustainability to be essential for a business to be competitive nowadays (Haanaes, Reeves, Strengvelken, Audretsch, Kiron, & Kruschwitz, 2012). Another study conducted by these two organisations concluded that for managers the greatest benefit from pursuing these initiatives is the increase in brand reputation (Haanaes, et al., 2011). Indeed, sustainability actions can have a significant impact on brand equity as the case of General Electric (GE) shows. This company that participates in the utilities sector increased its brand value by 17% after launching "Ecomagination", which develops energy-efficient products (Rapacioli, Osborn, Thimmiah, & Richardson, 2011).

In addition, a survey conducted by TANDBERG with Ipsos MORI showed that 50% of the respondents (out of 16 823 surveyed in 15 countries) prefer to buy goods and services from a company with good environmental reputation (TANDBERG and Ipsos MORI, 2007). Thus, this type of initiatives can have a great impact on brand equity, which then contributes to attract more customers. This might be very relevant for EDP given the recent liberalisation of the electricity retail market.

An additional benefit from being a sustainable company is the improvement in the ability to attract and retain top talent. The TANDBERG/Ipsos MORI survey showed that almost 80% of global employees find that working for sustainable company is important (TANDBERG and Ipsos MORI, 2007). Moreover, a 2004 survey of MBAs concluded that 97% of them were willing to forgo 14%, on average, of the expected income to work for a social responsible company (Stanford Graduate School of Business, 2004).

All in all, it seems that sustainability initiatives are very positive for businesses. This is particularly true for utility companies, which are expected to provide sustainable services, more than in other industries (Claye, Crawford, Freundt, Lehmann, & Meyer, 2013). Accordingly, EDP has position itself as a sustainable and social responsible company, having both environmental and social objectives defined. For example, one of its goals is to reduce CO2 emissions by 70% (compared to 2008 level) by 2020 (EDP, 2013). Its commitment to minimise its environmental impact has led the company to occupy the first place in the Dow Jones Sustainability Index, in the sector of utilities worldwide (EDP, 2013).

Thus, the project is in line with the EDP's strategy. Indeed, its 2013 annual report mentions its commitment to energy efficiency initiatives and the increase in the provision of energy services in the demand side (EDP, 2013). Thus, a project that reduces CO2 emissions can be very beneficial for the EDP group.

PART 3: REFLECTION ON LEARNING

Previous knowledge learned from Masters programme

I found that the course "Global Energy Markets" I took as part of my Master's in Economics was very useful for this business project. It provided me an overview of the energy sector, which facilitated my approach to the business project's topic. Furthermore, the knowledge regarding the energy market mechanisms, which are very specific and complex, allowed me and my colleagues to develop a particular topic of the business project, the analysis of the impact of the project on tariffs. For this, it was necessary a profound understanding of supply and demand characteristics as well as the price setting mechanism, which had been introduced in this course. Thus, I was able to apply the theoretical knowledge to a real situation, which was both challenging and stimulating.

In addition, the course "Corporate Finance" I attended during my semester abroad at LSE greatly contributed to the development of the business project, in particular the construction of the excel model to evaluate the benefits and costs of the several scenarios of the project in monetary terms. This required understanding of how to identify the relevant cash flows and calculate the Net Present Value.

Also, it is worth mentioning the course "Global Supply Chain Management" whose content contributed to the understanding of the electricity system, with the flows of both electricity and money among the several stakeholders.

New Knowledge (methodologies and tools)

With this business project, I have learned much about financing in the energy sector. This was required for the final part of the business project since one of the objectives was to recommend one financial alternative. This entailed the understanding on how more common types of financing can be applied to this specific sector (eg. Leasing) as well as the learning of new financing models as is the case of Energy Performance Contracts, including their many variants.

I have also learned about new methodologies that contributed to improve the development of the work on the business project such as the MECE (Mutually Exclusive and Collectively Exhausted) principle.

In addition, I have improved my knowledge of Microsoft Excel since this business project required an extensive and advanced use of this software. Also, I have learned much about how to construct an excel model, which should be easy to use and flexible enough to change assumptions.

Regarding the presentation of information, I gained insights about written form as well as oral presentation. I now realise the importance and usefulness of using action titles, for example. Due to the many presentations held at EDP Distribuição, weekly with the business advisory and monthly with other employees of the department, I have learned about how to present to a different kind of audience.

Personal Experience: strengths and weaknesses, and areas of improvement

From having participated and contributed to this business project, I realised that I am particularly strong at organising information and creating "storyline". Also, I am strong in the creative process by coming up with new forms to explore the issue and new ways to present it. Furthermore, I am strong in the rigour of my analysis and attention to detail.

Nevertheless, there are areas in which I am weak and could therefore be improved. I understand that I become quite stressed in more critical times. This could be improved by better scheduling and planning of the work. Also, another one of my weaknesses is oral presentations. To develop this, I plan to practice more, in front of different audiences as well as attend seminars that improve communication skills.

Benefit of hindsight

I believe that what added most value to this business project was the strong relationship with the business advisor and the company. Having weekly meetings with him (some weeks even two days) and monthly steering meetings with other employees of the department, including the director, was very helpful and contributed greatly to improve our work. We were able to check if what we were developing was in line with what was expected and it also served as a way to keep us on track in terms of time and deadlines.

Also, the support of the academic advisor was very important, especially having meetings with him after the meeting with the business advisor.

In addition, I felt that this project was very important for EDP and that it would be useful in the future, which contributed to increase the group's motivation.

One aspect that could have been done differently was the organisation of the final report. I feel that we did not dedicate as much time as we could have to the summarisation of our conclusions.

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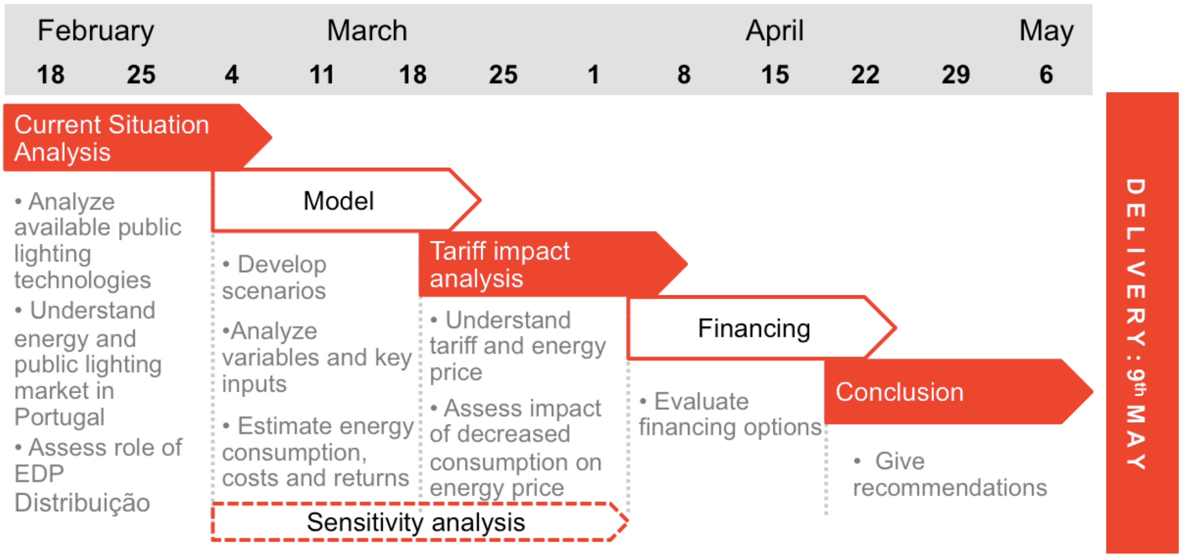
APPENDICES

Appendix A

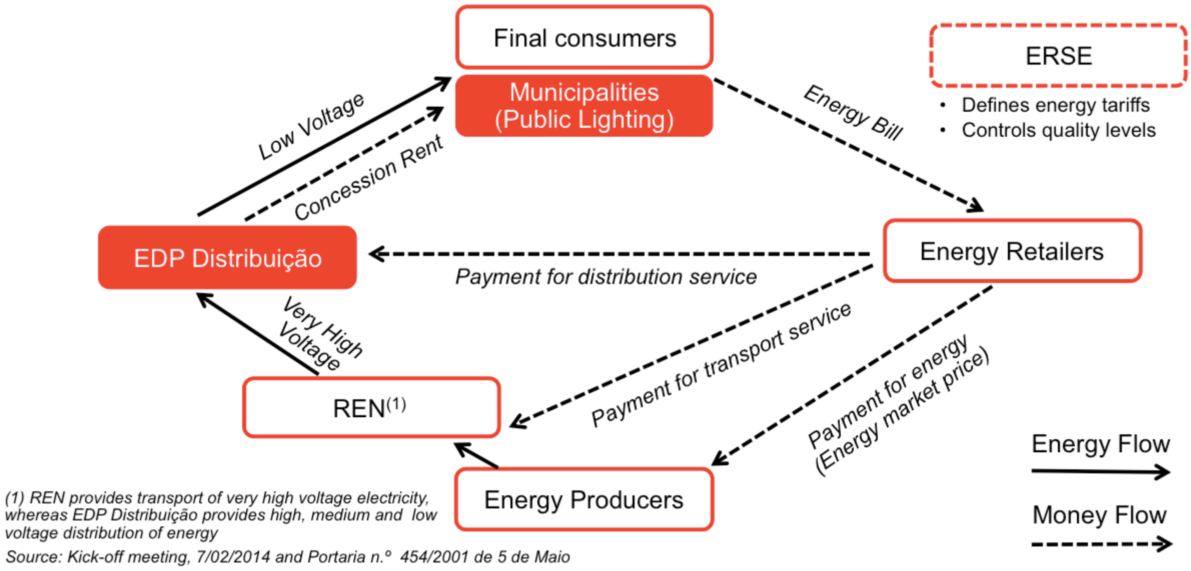
Detailed workplan of the business project



Source: Business Project Final Report, slide 6

Appendix B

Electricity Supply Chain



Source: Business Project Final Report, slide 10

Appendix C

Main results from the three scenarios, comparing with current situation:

Cumulative monetary flows[1] over 15 years: 2015 – 2030

	S0	S1	S2	S3
Energy consumption (in TWh)	23.1	22.6	21.0	15.0
Cost of energy (M€)	3 572	3 491	3 237	2 278
		-81	*-334*	*-1 293*
Maintenance costs (M€)	175	141	115	38
		-35	*-59*	*-137*
Investment (M€)	113	171	282	972
		+58	*+169*	*+858*
Public lighting Rent (M€)	281	280	277	265
		-1	*-4*	*-16*

Source: Business Project Final Report, slide 21

[1]Sum over 15 years: 2015 – 2030: cumulative monetary flows are not discounted
S0 – current situation
S1 – scenario 1: replacement of mercury lamps by sodium lamps
S2 – scenario 2: replacement of mercury lamps by LED luminaires
S3 – scenario 2: replacement of mercury and sodium lamps by LED luminaires

NPV[2] over 15 years: 2015 – 2030

Scenario	NPV (M€)
Scenario 1	15
Scenario 2	65
Scenario 3	115

Source: Business Project Final Report, slide 25

[2] NPV calculated with a discount rate of 10% and taking into account inflation

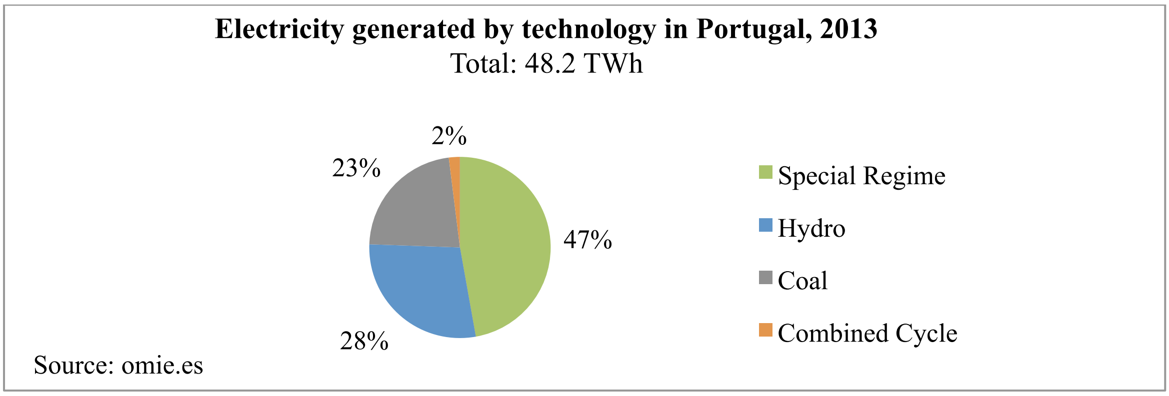
Note that this NPV is calculated with differential cash flows (relatively to scenario 0) and for the project as a whole (main stakeholders: EDP Distribuição and municipalities). Thus, it only included the following cash flows: energy consumption savings (except payment for distribution service) and maintenance costs savings as positive cash flows, and investment as negative cash flow.

Appendix D

Detailed explanation of the calculation of the current tonnes of CO_2 emitted by the public lighting sector

To calculate the current tonnes of CO_2 emitted in Portugal, it is necessary to analyse the energy wholesale market in 2013. The following figure illustrates the share of technologies that generated electricity in Portugal in 2013:

Electricity generated by technology in Portugal, 2013



According to this figure, the pollutant sources of electricity generated in Portugal are coal and natural gas, which represent 25% of the electricity used in 2013, that is, 11.8 TWh, of which 10.9TWh are produced from coal and 0.9TWh are produced from natural gas.

To calculate the CO_2 emissions resulting from this production, it is necessary to apply the emission factors: the tonnes of CO_2 (tCO_2) emitted per GWh of electricity produced from each pollutant technology. These are shown in the following figure:

Emission Factors of power sources

	gCO_2/KWh	$kgCO_2$/MWh	tCO_2/GWh
Coal: Other bituminous coal	860	860	860
Coal: Sub-bituminous coal	925	925	925
Coal: Lignite	1 005	1 005	1 005
(Average) Coal[1]	930	930	930
Natural Gas	400	400	400

[1]The emission factor used for coal is an average of the emission factors of the most common types of coal.

Source: International Energy Agency. (2012). CO2 Emissions from Fuel Combustion: Highlights. Retrieved 05 19, 2014, from International Energy Agency: http://www.iea.org/co2highlights/co2highlights.pdf

CO2 emissions from electricity production in Portugal can then be calculated. The following table presents the current tonnes of CO2 emitted in total and by the public lighting sector in Portugal in 2013:

CO2 emissions by source, total and public lighting in 2013 for Portugal

C02 emissions from:	tCO2
Conventional Thermal (coal)	10 090 500
Combined Cycle (natural gas)	381 600
Total CO2 emissions[1]	10 472 100
Public lighting CO2 emissions[2]	314 163

[1]Total CO2 emissions are the sum of CO2 emissions from conventional thermal and combined cycle productions.

[2]Public lighting CO2 emissions represent approximately 3% of the total CO2 emissions

Appendix E

Detailed explanation of the calculation of the higher bound of CO_2 savings

This method provides the higher bound. It comprises assessing the saved electricity by the project that is produced from the two pollutant sources considered (coal and natural gas) as to estimate the CO_2 savings. However, information about the technology that produces each MWh of electricity per hour is not public. Thus, the intended value is calculated from the information about the marginal technology that sets the price in the wholesale market, i.e., the last bid to enter the market. Since the reduction in electricity consumed occurs at the margin, it is viable to assume that the reduction will occur in the technology that sets the price.

This assumption allows the calculation of the number of hours in 2013 in which the technology that sets the price is pollutant. Note that it is only relevant within the hours in which public lighting is working (11.5 hours per day, 4200 hours in a year). The following tables present the results for combined cycle and conventional thermal marginal technologies:

Numbers of hours in 2013 in which the marginal technology is combined cycle (natural gas):

	One[1]	Half[1]	One third[1]	One quarter[1]	One fifth[1]	One sixth[1]
January	30	3	-	7	4	-
February	6	2	5	5	-	-
March	4	-	2	28	9	-
April	5	5	2	13	1	1
May	19	4	-	-	-	-
June	6	6	-	-	-	-
July	22	6	1	-	-	-
August	11	2	3	-	1	-
September	8	-	2	-	-	-
October	8	4	-	-	1	-
November	4	5	1	-	-	-
December	34	11	5	10	3	5
TOTAL	157	48	21	63	19	6

Total hours in which the marginal technology is combined cycle (natural gas)	**314**

Numbers of hours in 2013 in which the marginal technology is conventional thermal (coal):

	One[1]	**Half[1]**	**One third[1]**	**One quarter[1]**	**One fifth[1]**	**One sixth[1]**
January	102	10	-	7	4	-
February	74	10	6	5	-	-
March	46	2	35	48	13	-
April	12	4	51	30	2	1
May	91	6	1	-	-	-
June	95	1	-	-	-	-
July	112	12	1	-	-	-
August	126	14	4	-	1	-
September	133	7	1	-	-	-
October	145	8	2	-	1	-
November	101	11	9	-	-	-
December	94	6	7	10	3	5
TOTAL	1131	91	117	100	24	6

Total hours in which the marginal technology is conventional thermal (coal)	**1469**

Total hours in which the marginal technology is pollutant	**1783**
Percentage in total hours of public lighting	42.5%

It is concluded that 43% of the total lighting hours of public lighting (1783 hours) have a marginal technology that is pollutant.

Given the reduction in consumption in one hour (172MWh) generated by the project, the electricity saved that is produced from pollutant sources can be obtained. These results are shown in the following tables:

Electricity saved that is produced from combined cycle (natural gas) in 2013

	One[1]	Half[1]	One third[1]	One quarter[1]	One fifth[1]	One sixth[1]
Electricity (MWh)	26 943	4 119	1 201	2 703	652	172

Electricity saved that is produced from combined cycle (natural gas) in MWh	**35 789**

Electricity saved that is produced from conventional thermal (coal) in 2013

	One[1]	Half[1]	One third[1]	One quarter[1]	One fifth[1]	One sixth[1]
TOTAL	194 090	7 808	6 693	4 290	824	172

Electricity saved that is produced from conventional thermal (coal) in MWh	**213 876**

Electricity saved that is produced from pollutant sources in MWh	**249 665**
Percentage in total electricity saved	34.6%

It is concluded that the electricity saved that is produced from pollutant sources represents 35% of the total electricity savings generated by the project (250GWh).

Assuming this number, the emission factors (in appendix D) can be applied to calculate the CO2 savings. The following tables illustrate these results:

CO2 savings, by power source and in total

CO2 Savings from:	Tonnes CO2
Combined Cycle (natural gas)	14 316
Conventional Thermal (coal)	198 905
Total CO2 Savings	213 221

CO2 savings generated by the project, compared to current situation's total CO2 emissions

	Tonnes CO2
Total CO2 Savings	213 221
Total CO2 emissions[2]	10 472 100

Savings in % of the total CO2 emissions	**2%**

CO2 savings generated by the project, compared to current situation's public lighting CO2 emissions

	Tonnes CO2
Total CO2 Savings	213 221
Public lighting CO2 emissions[2]	314 163

Savings in % of the public lighting CO2 emissions	**67.9%**

In total, 213 thousand tCO2 are saved, of which 7% come from combined cycle generation (natural gas) and 93% from conventional thermal generation (coal). Comparing with the case with no project, it represents a reduction of 67.9% in CO2 emissions.

Notes:

[1] These titles inform whether the marginal technology was the only one to set the price (one) or if there were other technologies that were also setting the price: one half (two technologies), one third (three technologies), one quarter (four technologies), one fifth (five technologies), one sixth (six technologies). This means that the electricity saved is equally produced by all technologies that set the price.

[2]Before the project is implemented

Source: Omie.es

Appendix F
Detailed explanation of the calculation of the lower bound of CO2 savings

This method provides the lower bound. It involves calculating the average emission factor of electricity production in Portugal, which is given by the ratio between total CO2 emissions from electricity in Portugal and the total electricity consumed. The following table shows this result:

Calculation of average electricity emission factor

Total CO2 emissions (tCO2)	10 472 100
Total electricity produced (GWh)	48 293
Average electricity emission factor (tC02/GWh)	217

It is, therefore, an average emission factor that reflects the share of both non-pollutants (renewables) and pollutants technologies. Thus, it can be applied to the variation in energy consumption in one year (720.8 GWh in one year). Note that this assumes that the share of technologies in one year is equal to their share at the margin, where reduction in electricity consumption will occur. The following tables show the CO2 savings obtained by this method:

CO2 savings in total

Electricity emission factor (tC02/GWh)	217
S3 electricity savings (GWh)	720.8
Total CO2 Savings (tCO2)	156 293

CO2 savings generated by the project, compared to current situation's total CO2 emissions

	Tonnes CO2
Total CO2 Savings	156 293
Total CO2 emissions[1]	10 472 100

Savings in % of the total CO2 emissions	**1.5%**

CO2 savings generated by the project, compared to current situation's public lighting CO2 emissions

	Tonnes CO2

Total CO2 Savings	156 293
Public lighting CO2 emissions[1]	314 163

Savings in % of the public lighting CO2 emissions	**49.8%**

[1]Before the project is implemented

The CO2 savings obtained with this method are 156 thousand tCO2, representing a reduction of 49.8% when comparing with the situation with no project.

Appendix G

Comparison of CO_2 savings among different projects that promote the installation of LED technology in public lighting

	Lower Bound	Higher Bound	Climate Group	Manchester	East Dunbartonshire Council	UK Green Investment Bank	Clinton Climate Initiative
CO2 Savings	50%	68%	[50%, 70%]	60%	50%	Up to 80%	50%

Sources:

The Climate Group. (n.d.). LED Lighting. Retrieved 05 19, 2014, from The Climate Group: http://www.theclimategroup.org/what-we-do/programs/led/

Manchester City Council . (2014). Street Lighting LED Retrofit Programme . Manchester: Manchester City Council .

Scottish Future Trust. (2012, 11). Street Lighting Energy Efficiency Outline Business Case, East Dunbartonshire Council . Retrieved 05 19, 2014, from Scottish Future Trust: http://www.scottishfuturestrust.org.uk/files/publications/East_Dunbartonshire_Council_Street_Lighting_Business_Case.pdf

UK Green Investment Bank. (2014, 02). *Low energy streetlighting: making the switch.* Retrieved 05 19, 2014, from Green Investment Bank: http://www.greeninvestmentbank.com/userfiles/files/GIB-Market-Report---Low-Energy-Streetlighting---Feb-2014.pdf

Clinton Climate Initiative. (n.d.). *Street Lighting Retrofit Projects: Improving Performance, while Reducing Costs and Greenhouse Gas Emissions.* Retrieved 05 19, 2014, from Outdoor Lighting Program: http://www.dvrpc.org/energyclimate/eetrafficstreetlighting/pdf/CCI_EE_Streetlighting_White_Paper.pdf

Appendix H
(Expected) prices of allowance in the EU ETS

	2013 (EU auctions report)	2014 (Reuters)	2014 (Bloomberg)
Price of Allowance	€ 4.52	€ 6.00	€ 7.50

Sources:

European Commission. (2013). *Auctioning, Auction reports.* Retrieved 05 20, 2014, from European Commission, Climate Action: http://ec.europa.eu/clima/policies/ets/cap/auctioning/documentation_en.htm

Garside, B. (2013, 12 10). *European Parliament votes to cut carbon permit supply*. Retrieved 05 19, 2014, from UK Reuters: http://uk.reuters.com/article/2013/12/10/eu-parliament-carbon-idUKL6N0JP2AT20131210

Bloomberg New Energy Finance. (2014, 06 08). *Value of the world's carbon markets to rise again in 2014*. Retrieved 05 19, 2014, from Bloomberg New Energy Finance: http://about.bnef.com/press-releases/value-of-the-worlds-carbon-markets-to-rise-again-in-2014/

Appendix I
Allowance savings in one year, using different prices

	2013 (EU auctions report)	2014 (Reuters)	2014 (Bloomberg)
Price	4.52€	6.00€	7.50€
Total Allowance Savings	706 053€	937 757€	1 172 196€
EDP's Allowance Savings	530 007€	703 938€	879 922€