Free dissemination

(ContractTREN/07/D3/390-2006/S07.72702)
Preparatory Studies for Eco-design Requirements of EuPs

Lot 19: Domestic lighting
Final Task Report
Task 7: IMPROVEMENT POTENTIAL

Study for European Commission DGTREN unit D3, contact: Andras Toth

Contractor:

VITO

Project performed in cooperation with:

bio Intelligence Service
Energy piano
kreios

Contact VITO: Paul Van Tichelen, info@eup4light.net

2007/ETE/R/

VITO

May 2009

Project team

VITO:
Paul Van Tichelen
An Vercalsteren
Bio Intelligence Service:
Shailendra Mudgal
Benoît Tinetti
Alexander Thornton
Energy Piano:
Casper Kofod
Kreios:
Lieven Vanhooydonck
Laborelec (reflector lamp tests):
Jean-Michel Deswert

Important disclaimer:

Important note:
This report contains the final results of research by the authors and is not to be perceived as the opinion of the European Commission.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

0 PREFACE

VITO and its partners are performing the preparatory study for the new upcoming eco-design directive for Energy Using Products (EuP) related to domestic lighting, on behalf of the European Commission (more info http://ec.europa.eu/enterprise/eco_design/index_en.htm).

The environmental impacts of Energy-using Products such as domestic lighting take various forms, including: energy consumption and the related negative contribution to climate change, consumption of materials and natural resources, waste generation and release of hazardous substances. Eco-design, which means the integration of environmental considerations at the design phase, is arguably the best way to improve the environmental performance of products.

The creation of a coherent framework for environmental product policy avoids the adoption of uncoordinated measures that could lead to an overall negative result; for example eliminating a toxic substance from a product, such as mercury from lamps, might lead to increased energy consumption, which could in total have a negative impact on the environment. A Community framework also ensures that divergent national or regional measures, which could hinder the free movement of products and reduce the competitiveness of businesses, are not taken. It is not the intention to decrease the quality of domestic lighting.

You can follow the progress of our study and find general information related to lot 19 on the project website when you register as stakeholder: http://www.eup4light.net
Please, also consult the website for timing and organisation of the tasks.

1 PRODUCT DEFINITION

For more info see website www.eup4light.net.

2 ECONOMIC AND MARKET ANALYSIS

For more info see website www.eup4light.net.

3 CONSUMER BEHAVIOUR AND LOCAL INFRASTRUCTURE

For more info see website www.eup4light.net.

4 TECHNICAL ANALYSIS EXISTING PRODUCTS

For more info see website www.eup4light.net.

5 DEFINITION OF BASE-CASE

For more info see website www.eup4light.net.

6 IMPROVEMENT POTENTIAL

For more info see website www.eup4light.net.

7 IMPROVEMENT POTENTIAL

The importance of assessing the improvement potential is addressed in Article 15 (c) of the 2005/32/EC Directive:

> '*the EuP shall present significant potential for improvement in terms of its environmental impact without entailing excessive costs, taking into account in particular the absence of other relevant Community legislation or failure of market forces to address the issue properly and a wide disparity in the environmental performance of EuPs available on the market with equivalent functionality*'.

This indicates that costs, existing Community legislation, and self-regulation as well as the environmental performance and functionality of a wider range of the existing EuP need to be assessed.

What "costs" entail is indicated in Article 15 (c), imposing that the implementing measure shall not have a significant negative impact on:

a) the functionality of the product for the user;

b) health, safety and the environment;

c) the affordability and life cycle costs to the consumer;

d) industry's competitiveness.

as well as not leading to:

e) imposing proprietary technology or;

f) an excessive administrative burden for industry.

The boundary conditions a) and b) are to be defined per product to a large extent in harmonised EN standards to provide an objective basis for assessment. Condition e) is relatively easy to assess from desk-research and discussions with stakeholders. The question of which characteristics of an implementing directive would create 'an excessive administrative burden' can only truly be established *ex-post* if one or more proposals for legislation are known. This leaves us with two conditions c) and d), which are – in part – linked and which play a key role in the methodology that will be discussed hereafter.

Chapter 7 consists of identifying the improvement design options, their monetary consequences in terms of Life Cycle Cost for the consumer, their environmental costs and benefits and pinpointing the solution with the Least Life Cycle Costs (LLCC) and the Best Available Technology (BAT). The assessment of Life Cycle Costs is relevant to indicate whether design solutions might negatively or positively impact the total EU consumer's expenditure over the product's complete life (purchase price, operating costs, etc.). The gap between the LLCC and the BAT indicates - in a case where the LLCC solution is set as a minimum target - the remaining margin for product-differentiation (competition). The BAT indicates a medium-term target that would rather be subjected to promotion measures than restrictive action. The BNAT indicates long-term possibilities and helps to define the scope and definition of possible measures in the long run.

Key improvement options have been identified on the basis of current technology development and research as described in chapter 6. Such improvement options are further elaborated in the following sub-sections, presenting their respective environmental improvement potential and associated costs when implemented in the base-cases.

Chapter 5 showed that the indirect environmental impacts due to the electricity consumption during the use-phase represents the largest share of the environmental impacts. Therefore, suggested improvement options target the reduction of electricity consumption per lumen and per hour. Possible ways to achieve this objective are to:

- increase the lamp efficacy of the base-case, or
- replace the base-case lamp with another type of lamp technology having higher lamp efficacy.

Improvement potential related to luminaires will be analysed in the scenario analysis of Chapter 8.

7.1 Improvement options with cost and impact assessment

Scope: Identification and description of design options for environmental improvement with a quantitative assessment of estimated cost impact and the environmental improvement potential using the MEEuP EcoReport.

The base-case life cycle cost is calculated using the following formula:

$LCC = PP + PWF * OE$,

where,

LCC is Life Cycle Cost,
PP is the Product Price (see also chapter 2 and 4),
OE is the Operating Expenses per year,
PWF is the Present Worth Factor according to the following formula:

$PWF= \{1 – 1/(1+ r)^N \}/r$,

where

N is the product life (see also chapter 2 and 3),
r is the discount (interest-inflation) rate (see chapter 2).

Detailed calculations of the improvement options can be found in the complementary MEEuP EcoReports (in Microsoft Excel format) that are published on the website http://www.eup4light.net for each improvement option. The input parameters are the performance and cost parameters defined in the previous chapters. Stakeholders can use these excel spreadsheets for assessing and verifying the options.

For each option, environmental impacts as well as life cycle costs are calculated per hour and per lumen allowing a fair comparison between different improvement options. These values will serve in section 7.2 for determining the LLCC and BAT options.

7.1.1 Base-case GLS-R

After a detailed analysis of available technologies in chapter 6, the improvement options to decrease environmental impacts of a reflective incandescent lamp aim at reducing the electricity consumption during the use phase. Each improvement option applicable to the base-case GLS-R is presented in the following paragraphs with its relative impacts on the BOM and on the product price compared to the base-case. Table 7.1 presents a summary of the proposed improvement options for the base-case GLS-R (reflective incandescent lamp).

Table 7.1: Summary of the main characteristics of the improvement options for the base-case GLS-R

Lamp cap: E27	Wattage	Average LLMF[1]	Average lamp efficacy (lm/W)	*Functional lumen output within opening angle of 90°(lm)*	LWFt[2]	Electricity consumption (Wh/h)	Lamp life time (hours)	Yearly burning hours (hours/year)	Lamp lifespan (years)	Purchase price (€)
Base-case GLS-R	50	0.965	5.16	258.14	1	50	1000	500	2.00	1.30
Option1: HL-MV-R Xenon and optimized filament design	50	0.975	8.29	416.33	1	50	2000	500	4.00	14.00
Option2: HL-MV-R with infrared coating, integrated electronic transformer, Xenon, dichroic	21	0.975	14.04	297.38	1	21	5000	500	10.00	26.00
Option3: CFLi-R	20	0.925	29.51	407.00	1.05	21	6000	500	12.00	15.00
Option4: LEDi-R	7.4	0.850	33.4	209.95	1.05	7.77	30000	500	60.00	40.00

7.1.1.1 Option 1: Replacing the GLS-R with a Xenon HL-MV-R and optimized filament design

A HL-MV-R Xenon with optimized filament design (50 W – 416 lumen) has lower environmental impacts per lumen and per hour compared to a GLS-R (50 W – 258 lumen) due to the higher lamp efficacy and thus this replacement can be considered as an improvement option as discussed in chapter 6, section 6.1.1.2.

---

[1] Lamp Lumen Maintenance Factor

[2] Total Lamp Wattage Factor

The bill of materials (BOM) as well as the packaged volume of this improvement option were assumed to be the same as the base-case HL-MV-R (50 W) (see chapter 5).

7.1.1.2 Option 2: Replacing the base-case GLS-R with HL-MV-R with infrared coating, integrated electronic transformer and Xenon

In chapter 6 (see section 6.1.1.5), a new technology for halogen lamps (mains voltage) was presented with use of infrared coating, together with an integrated electronic transformer. This technology allows enhancing the lamp efficacy as well as extending the lifetime.

7.1.1.3 Option 3: Replacing the base-case GLS-R with a CFLi-R

The third improvement option of the base-case GLS-R is to replace it with a reflective compact fluorescent lamp with integrated ballast. This type of lamp was developed in order to provide a substitution product with higher energy efficiency (i.e. lamp efficacy) for incandescent lamps. However, the CFLi-R often has a larger beam angle (80 – 120°) than its GLS-R counterparts. Considering this, the CFLi-R does not provide the equivalent directional lighting function and comfort as a GLS-R. Also the colour rendering index (CRI) value is lower.

7.1.1.4 Option 4: Replacing the base-case GLS-R with an LEDi-R

An LEDi-R of 7.4 W was chosen as it is currently the most powerful directional LED on the market. It presents a significant improvement in lamp efficacy (+547%) and lifetime (+3000%), it also has a very high cost of 40€ (+2997%), which could pose an adoption barrier. Please note that for many LED types the colour rendering index (CRI) is lower.

Note: While being a significant improvement in terms of efficacy, the HIDi-R is not identified as an improvement option as it is not a valid retrofit option because of its very high lumen output, which is almost four times higher than that of the base-case (1025 lm vs. 258 lm). Indeed, as mentioned in chapter 6, normal HID lamps are mainly available in high lumen output versions (> 1000 lm), and are rarely used in indoor domestic applications.

7.1.2 Base-case HL-MV-R

Three of the four improvement options in the base-case GLS-R are also improvement options for the base-case HL-MV-R: Xenon HL-MV-R, CFLi, and LEDi-R. The GLS-R improvement option HL-MV-R with infrared coating technology, integrated electronic transformer, and Xenon cannot be used as no retrofits currently exist. Additionally, the improvement option LEDi-R is more likely to replace the typical HL-MV-R in the long term.
The three improvement options mentioned above are compared to the base-case HL-MV-R in Table 7.2.

Table 7.2: Summary of the main characteristics of the improvement options for the base-case HL-MV-R

Lamp cap: GU10	Wattage	Average LLMF	Average lamp efficacy (lm/W)	*Functional lumen output within opening angle of 90°(lm)*	LWFt	Electricity consumption (Wh/h)	Lamp life time (hours)	Yearly burning hours (hours/year)	Lamp lifespan (years)	Purchase price (€)
Base-case HL-MV-R	50	0.975	6.34	322.73	1	50	2000	555	3.60	3.10
Option1: HL-MV-R Xenon and optimized filament design	50	0.975	8.29	416.33	1	50	2000	555	3.60	6.50
Option2: CFLi-R	7	0.925	11.19	78.63	1.05	7.35	6000	555	10.81	6.00
Option3: LEDi-R	4.7	0.850	26.35	144.5	1.05	4.94	30000	555	54.05	30.00

Options 2 and 3 cannot be considered a true replacement option as their luminous output are too low to be considered a realistic retrofit option for the base-case. A possible improvement using a LED module in a LED luminaire is discussed in section 6.1.8. For LEDi-R this might improve in future with higher lumen output (see section on BNAT in chapter 6).

As the luminous output of the base-case and Option 1 is not the same, these lamps will be analysed further on a per lumen per hour basis in section 7.2.2.

A more detailed comparison both in terms of environmental impacts and economic costs is provided in section 7.2.2.

7.1.3 Base-case HL-LV-R

The improvement options investigated for the base-case HL-LV-R are the HL-LV-R with Xenon, HL-LV-R with Xenon and infrared coating technology, and the LEDi-R. The characteristics of these substitution lamps are presented in chapter 6, section 6.1.3, and it was assumed that the BOM and the packaged volume of this improvement option are the same as those of the base-case.

Table 7.3: Summary of the main characteristics of the improvement option for the base-case HL-LV-R

Lamp caps: GU5.3	Wattage	Average LLMF	Average lamp efficacy (lm/W)	*Functional lumen output within opening angle of 90°(lm)*	LWFt	Electricity consumption (Wh/h)	Lamp life time (hours)	Yearly burning hours (hours/year)	Lamp lifespan (years)	Purchase price (€)
Base-case: HL-LV-R	35	0.975	13.07	458.25	1.11	38.85	4000	695	5.76	1.50
Option1: HL-LV-R Xenon	25	0.975	14.43	361.73	1.06	26.5	2000	695	2.88	7.00

Option2: HL-LV-R with infrared coating and Xenon	20	0.975	14.82	297.38	1.06	21.2	5000	695	7.19	7.50
Option3: LEDi-R	4.4	0.850	26.35	115.60	1.05	4.62	30000	695	43.17	30.00

As the luminous output is not the same, these lamps will be analysed further on a per lumen per hour basis later in section 7.2.3.

The LEDi-R does not offer enough lumen output to be considered a possible replacement option and will not be analysed further. A possible improvement using a LED module in a LED luminaire is covered in 6.1.8. For LEDi-R this might improve in future with higher lumen output (see section on BNAT in chapter 6).

7.2 Analysis LLCC and BAT

The LLCC and BAT analysis is an important step in the MEEuP where the suggested improvement options are evaluated for their environmental and economic implications extending over the complete life cycle of the product.

The objective of this sub-task is to analyse improvement options (which in turn are based on improvement potentials) using EcoReport and then prioritise them according to their life cycle costs (LCC) in order to identify the option with least life cycle cost (LLCC), as well as the option with the best environmental performance, i.e. the BAT option.

Individual options have different impacts: some generate considerable savings on running costs at hardly any extra production costs; some are more expensive and deliver modest environmental improvements providing little reduction in running costs.

For each base-case, the life cycle costs and environmental impacts of the improvement options are presented per lumen and per hour in order to allow a fair and relevant comparison and ranking.

On the basis of obtained results, following graphs show the environmental assessments for each base-case, with the GER (total energy consumption over lifetime including production phase), the GWP (Global Warming Potential) and the mercury emissions as key environmental parameters. Mercury emissions are also presented since compact fluorescent lamps contain mercury, which can be released if the end-of-life treatment is not appropriate.

7.2.1 Base-case GLS-R

Based on the inputs of the improvement options presented in section 7.1.1, Table 7.4 highlights the main results in terms of environmental impacts (GER and GWP) as well as in monetary terms (Life Cycle Cost).

Table 7.4: Key results of the improvement options analysis for the base-case GLS-R

Option	***Option description***	***Product lifetime (hours)***	***Lumen output (lm)***	***Total Energy GER (MJ)***	***GER per lumen per hour (J/lm/h)***	***Total GWP (kg CO_2 eq.)***	***GWP per lumen per hour (mg CO_2 eq/lm/h)***	***LCC (€)***	***LCC per lumen per hour (10^{-6} €/lm/h)***
0	***Base Case GLS-R***	1000	258.14	580	**2246.84**	28	**108.47**	8.74	**33.85**
1	***Replacement with Xenon HL-MV-R Xenon and optimized filament design***	2000	416.33	1105	**1327.07**	51	**61.25**	28.62	**34.37**
2	***Replacement with HL-MV-R with infrared coating, electronic transformer, Xenon, and dichroic***	5000	297.38	1158	**778.80**	53	**35.64**	40.56	**27.28**
3	***Replacement with CFLi-R***	6000	407	1382	**565.93**	63	**25.80**	32.18	**13.18**
4	***Replacement with LEDi-R***	30000	209.95	2510	**398.51**	112	**17.78**	61.48	**9.76**

Figure 7.1 shows that Option 4 leads clearly to the least life cycle cost (per lumen and per hour) and requires less energy (GER) than the other improvement options. Thus, it is both the LLCC and the BAT option. Compared to the base-case, the reduction in terms of LCC is about 71 % and about 82 % in terms of total energy consumption.

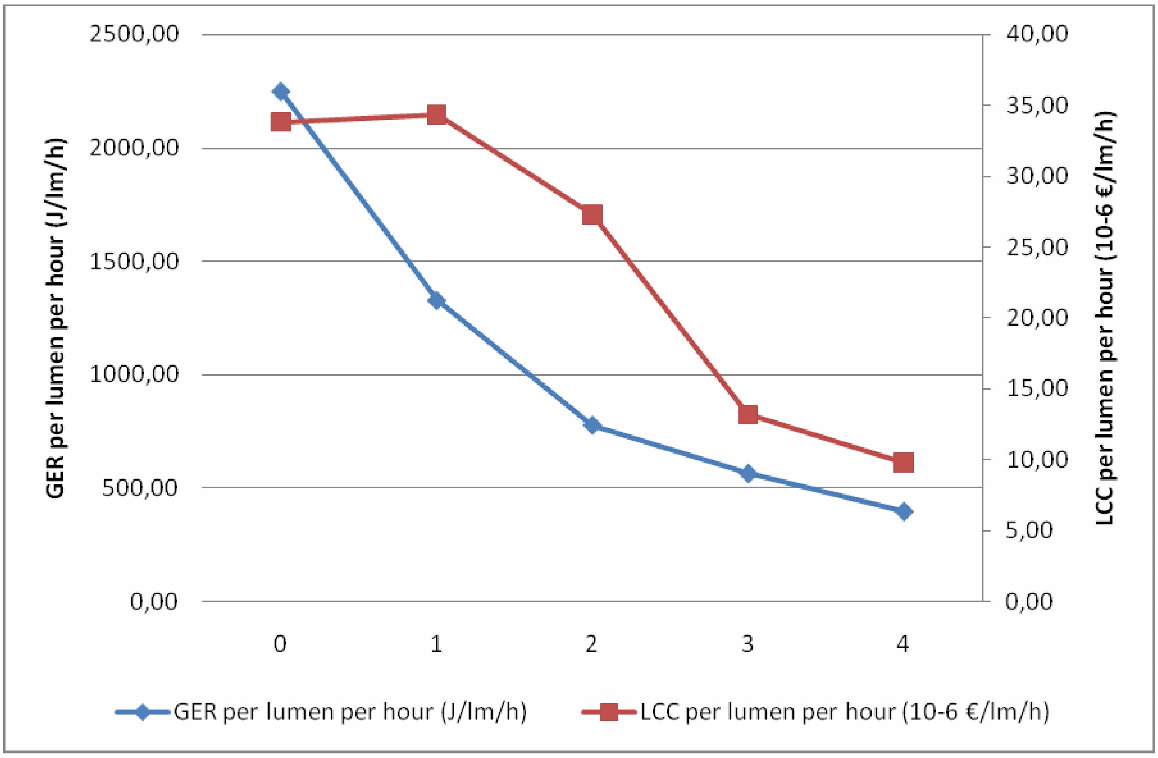

Figure 7.1: LCC curve – environmental performance expressed in total energy consumption (GER) for the improvement options for the base-case GLS-R

Figure 7.2 presents the same trend when the focus is on the global warming potential, as the energy consumed during the use phase dominates global warming emmissions. Further, the amount of mercury emissions to air over the entire life cycle (i.e. the use phase and the end-of-life) per lumen and per hour is also presented.

As already discussed in chapter 5, mercury emissions can have two origins:

- the use phase, due to the power generation from coal. It was assumed that, taking into account the electricity mix of Europe, 0.016 mg of mercury is emitted to air for the production of 1 kWh.
- the end-of-life phase, due to the share of non-recycled CFLi-R (assumed equal to 80 %). Therefore, for a typical CFLi-R containing 4 mg of mercury, 3.2 mg is assumed to be emitted to air at the end-of-life because it is estimated that only 20 % of the mercury content is recycled at present although EU regulation requires recycling.

Due to the lack of recycling, Option 3 (replacement with CFLi-R) does not give lower overall mercury emissions than Option 1 and 2 although the electricity consumption per lumen and per hour is lower than in Option 1 and 2. The mercury emissions of the other replacement options, like global warming potential, have a direct correlation to the energy and thus Option 4 presents the greatest reduction of 81%.

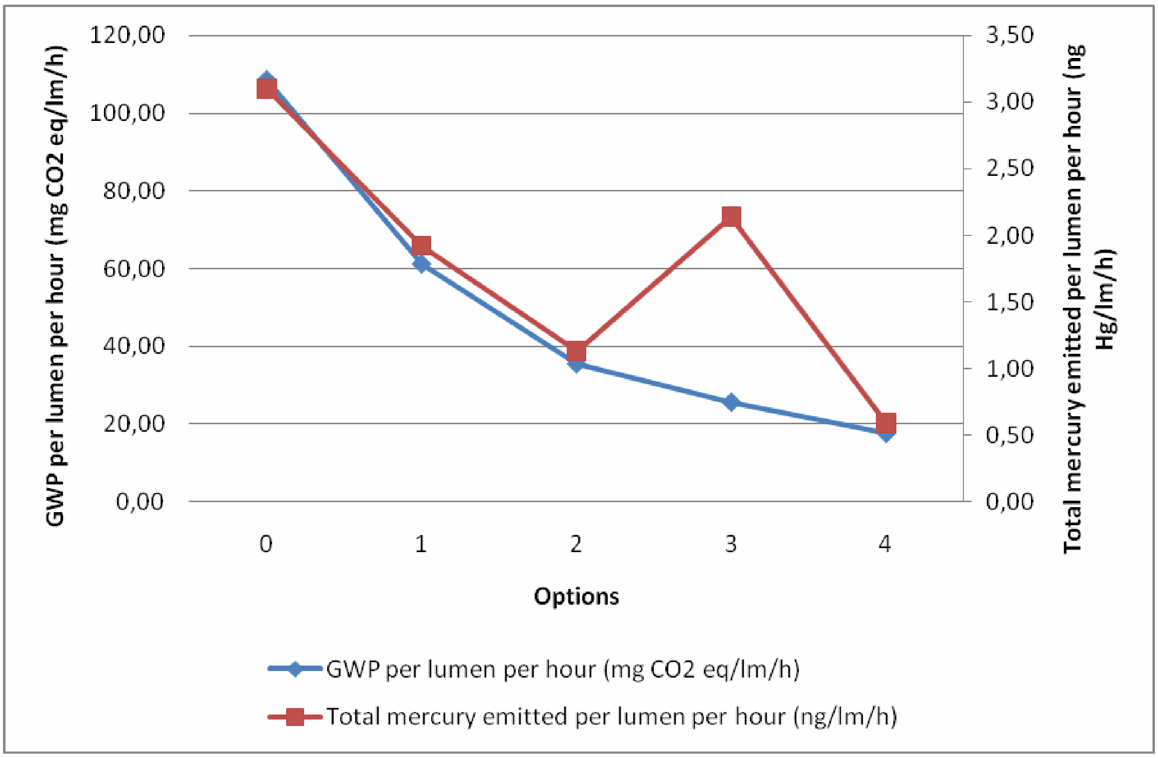

Figure 7.2: Environmental performance expressed in GWP and in mercury emissions for the improvement options for the base-case GLS-R

Electricity costs, reflecting the electricity consumption, and the life cycle cost are presented for each improvement option per lumen and per hour in Figure 7.3. The gap between the two curves represents the product price per lumen and per hour. The figure shows that the high product price is why the LCC of Option 1 is higher than that of the base-case.

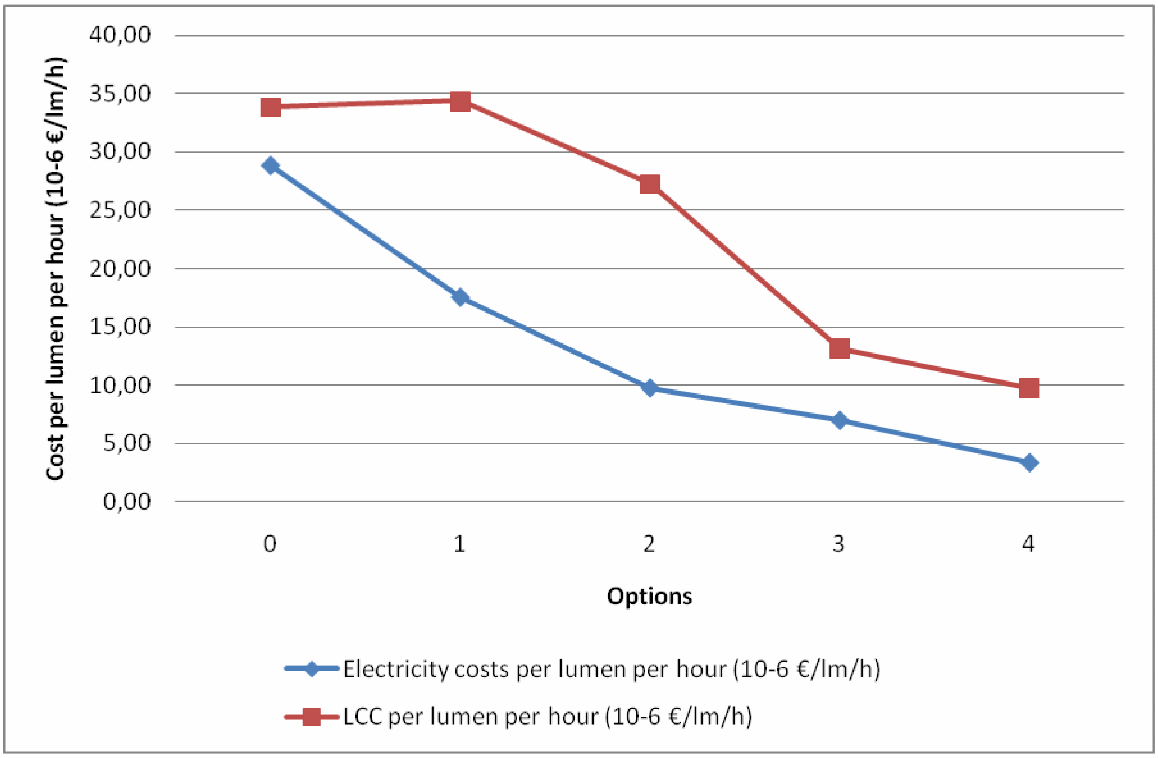

Figure 7.3: LCC curve – environmental performance expressed in total electricity costs for the improvement options for the base-case GLS-R

The complete results of the EcoReport including the different options are presented per lumen and per hour in Table 7.5 in order to allow a straightforward comparison.

Table 7.5: Comparison of GLS-R options for each environmental indicator

		Base-case GLS-R	***Option 1***	***Option 2***	***Option 3***	***Option 4***
main environmental indicators	**unit**	**value per lumen per hour**	**value per lumen per hour**	**value per lumen per hour**	**value per lumen per hour**	**value per lumen per hour**
Total Energy (GER)	J	**2246.84**	**1327.07**	**778.80**	**565.93**	**398.51**
	variation with the base-case	*0.00%*	*-40.94%*	*-65.34%*	*-74.81%*	*-82.26%*
of which, electricity	J	**2035.29**	**1261.60**	**741.80**	**543.15**	**386.23**
	variation with the base-case	*0.00%*	*-38.01%*	*-63.55%*	*-73.31%*	*-81.02%*
Water (process)	µltr	**136.54**	**84.44**	**49.64**	**37.80**	**26.48**
	variation with the base-case	*0.00%*	*-38.16%*	*-63.65%*	*-72.32%*	*-80.61%*
Water (cooling)	µltr	**5423.44**	**3362.72**	**1977.27**	**1445.28**	**1027.30**
	variation with the base-case	*0.00%*	*-38.00%*	*-63.54%*	*-73.35%*	*-81.06%*
Waste, non-haz./ landfill	µg	**2725.53**	**1593.87**	**933.50**	**665.35**	**526.11**
	variation with the base-case	*0.00%*	*-41.52%*	*-65.75%*	*-75.59%*	*-80.70%*
Waste, hazardous/ incinerated	µg	**50.87**	**30.30**	**17.78**	**31.42**	**17.71**
	variation with the base-case	*0.00%*	*-40.43%*	*-65.04%*	*-38.24%*	*-65.19%*
Emissions (Air)						
Greenhouse Gases in GWP100	mg CO2 eq.	**107.16**	**60.77**	**35.57**	**25.63**	**17.87**
	variation with the base-case	*0.00%*	*-43.29%*	*-66.80%*	*-76.08%*	*-83.33%*
Acidifying agents (AP)	µg SO2 eq.	**572.49**	**339.94**	**199.46**	**145.56**	**102.64**
	variation with the base-case	*0.00%*	*-40.62%*	*-65.16%*	*-74.57%*	*-82.07%*
Volatile Org. Compounds (VOC)	Ng	**1029.57**	**558.94**	**326.30**	**240.53**	**172.35**
	variation with the base-case	*0.00%*	*-45.71%*	*-68.31%*	*-76.64%*	*-83.26%*
Persistent Org. Pollutants (POP)	10^{-3} pg i-Teq	**15.49**	**9.02**	**5.28**	**3.70**	**3.60**
	variation with the base-case	*0.00%*	*-41.80%*	*-65.91%*	*-76.13%*	*-76.79%*
Heavy Metals (HM)	ng Ni eq.	**47.48**	**25.76**	**15.03**	**10.59**	**7.84**
	variation with the base-case	*0.00%*	*-45.75%*	*-68.34%*	*-77.71%*	*-83.49%*
PAHs	ng Ni eq.	**14.78**	**5.66**	**3.24**	**2.16**	**1.61**
	variation with the base-case	*0.00%*	*-61.72%*	*-78.09%*	*-85.38%*	*-89.10%*
Particulate Matter (PM, dust)	µg	**28.06**	**12.89**	**7.41**	**3.92**	**5.13**
	variation with the base-case	*0.00%*	*-54.07%*	*-73.59%*	*-86.04%*	*-81.73%*
Emissions (Water)						
Heavy Metals (HM)	ng Hg/20	**14.30**	**8.55**	**5.02**	**4.84**	**3.39**
	variation with the base-case	*0.00%*	*-40.19%*	*-64.91%*	*-66.11%*	*-76.31%*
Eutrophication (EP)	ng PO4	**105.66**	**54.98**	**31.87**	**31.64**	**28.58**
	variation with the base-case	*0.00%*	*-47.97%*	*-69.83%*	*-70.05%*	*-72.95%*

Table 7.5 shows that the replacement of a GLS-R 50 W by a 7.4 W LEDi-R is the best option for almost all environmental indicators, with a decrease of 65 - 90% for all the environmental impact indicators.

The analysis of the improvement options of the base-case GLS-R shows that the LEDi-R is the "best option", as it is both the LLCC (Least Life Cycle Cost) point and the BAT (Best Available Technology) point, i.e. leading to the highest reduction of environmental impacts.

7.2.2 Base-case HL-MV-R

The main outcomes of the environmental assessment of the base-case HL-MV-R and its improvement option as well as their life cycle cost are presented in Table 7.6. Values are given per lumen and per hour allowing a comparison between the lamp types.

Table 7.6: Key results of the improvement option analysis for the base-case HL-MV-R

Option	*Option description*	*Product lifetime (hours)*	*Lumen output (lm)*	*Total Energy GER (MJ)*	*GER per lumen per hour (J/lm/h)*	*Total GWP (kg CO_2 eq.)*	*GWP per lumen per hour (mg CO_2 eq/lm/h)*	*LCC (€)*	*LCC per lumen per hour (10^{-6} €/lm/h)*
0	***Base Case HL-MV-R***	2000	322.73	1105	**1711.96**	51	**79.01**	17.77	**27.53**
1	***Replacement with Xenon HL-MV-R Xenon and optimized filament design***	2000	416.33	1105	**1327.07**	51	**61.25**	21.17	**25.42**

The environmental indicators GER, GWP and mercury emissions are plotted in Figure 7.4 and Figure 7.5. Replacing a typical HL-MV-R (50 W) with Option 1 results in the decrease of the total energy required during the entire life cycle by 22 %. The reduction is the same for the global warming potential.

Mercury emissions are not discussed for this base-case, as there is no mercury embedded within the base-case nor the improvement options.

In monetary LCC terms, Option 1 is 8% less expensive than the base-case. The small reduction is because the product price of Option 1 is 110% greater than that of the base-case.

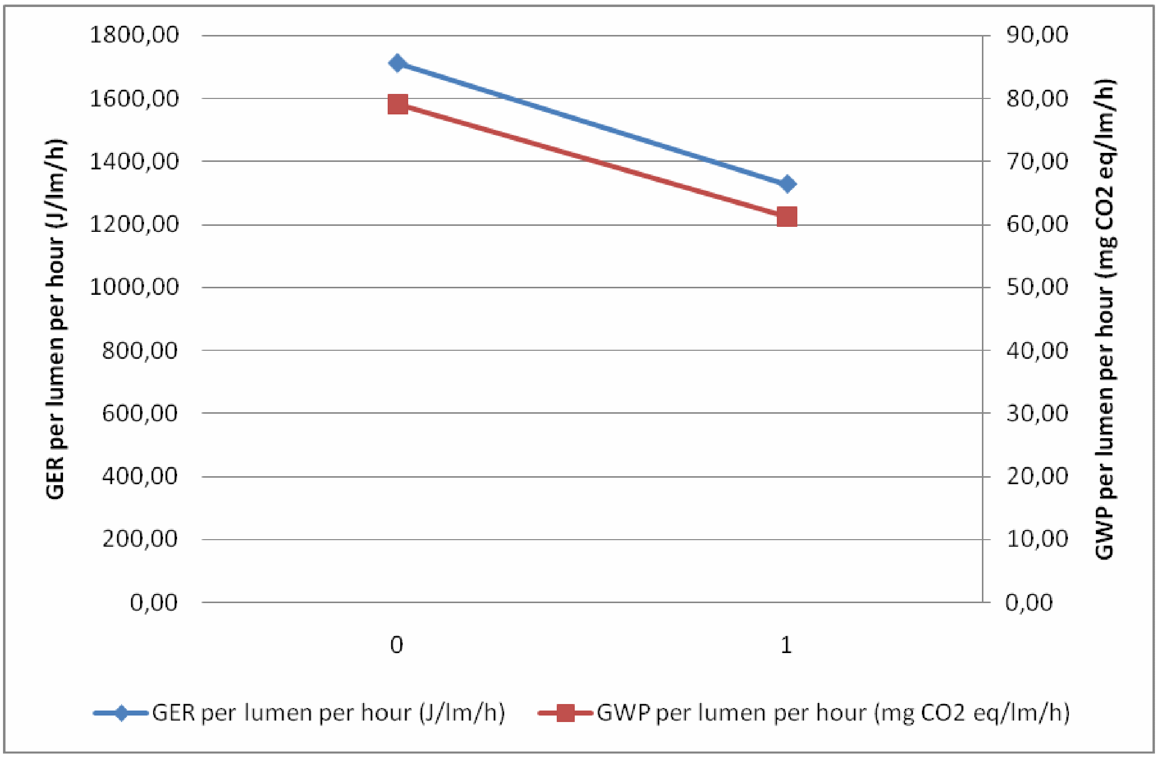

Figure 7.4: Environmental performances expressed in GER and in GWP for the improvement option for the base-case HL-MV-R

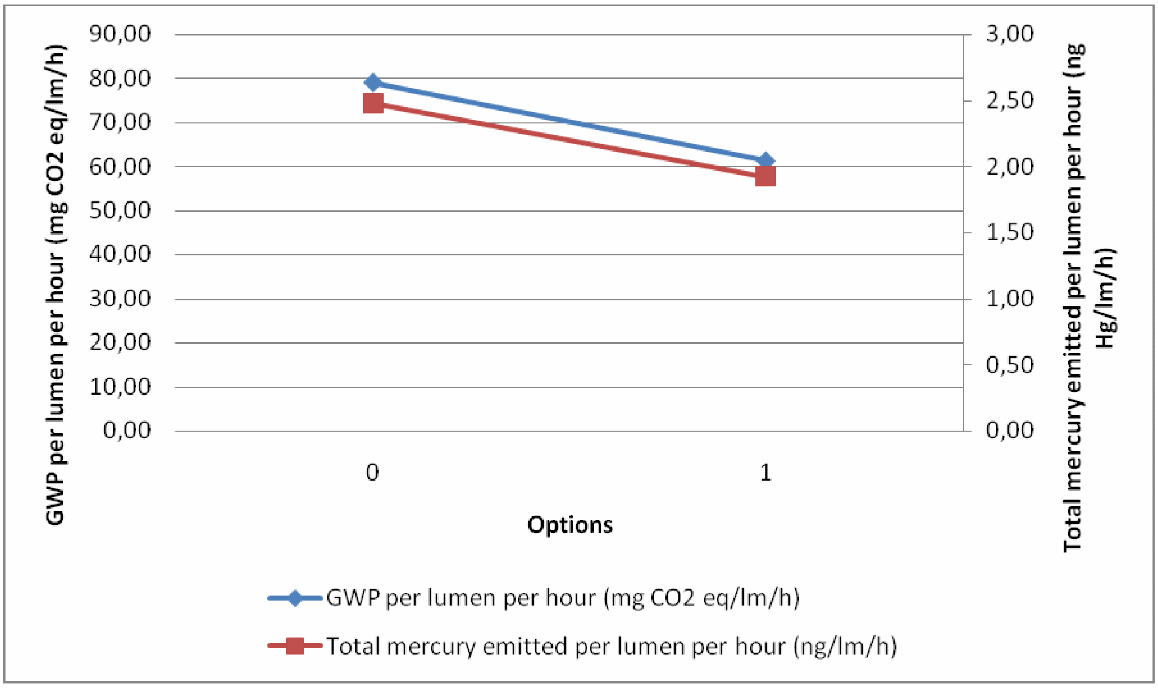

Figure 7.5: LCC curve – environmental performance expressed in total electricity costs for the improvement options for the base-case HL-MV-R

Table 7.7 presents the EcoReport outcomes per lumen and per hour as well as the difference of the improvement options results compared to those of the base-case.

Table 7.7: Comparison of HL-MV-R options for each environmental indicator

		Base-case HL-MV-R	***Option 1***
main environmental indicators	**unit**	**value per lumen per hour**	**value per lumen per hour**
Total Energy (GER)	J	**1712.35**	**1327.38**
	variation with the base-case	*0.00%*	*-22.48%*
of which, electricity	J	**1627.49**	**1261.60**
	variation with the base-case	*0.00%*	*-22.48%*
Water (process)	µ ltr	**108.92**	**84.44**
	variation with the base-case	*0.00%*	*-22.48%*
Water (cooling)	µ ltr	**4338.00**	**3362.72**
	variation with the base-case	*0.00%*	*-22.48%*
Waste, non-haz./ landfill	µ g	**2056.13**	**1593.87**
	variation with the base-case	*0.00%*	*-22.48%*
Waste, hazardous/ incinerated	µ g	**39.09**	**30.30**
	variation with the base-case	*0.00%*	*-22.48%*
Emissions (Air)			
Greenhouse Gases in GWP100	mg CO2 eq.	**78.40**	**60.77**
	variation with the base-case	*0.00%*	*-22.48%*
Acidifying agents (AP)	µ g SO2 eq.	**438.53**	**339.94**
	variation with the base-case	*0.00%*	*-22.48%*
Volatile Org. Compounds (VOC)	ng	**720.73**	**558.69**
	variation with the base-case	*0.00%*	*-22.48%*
Persistent Org. Pollutants (POP)	10^{-3} pg i-Teq	**11.63**	**9.02**
	variation with the base-case	*0.00%*	*-22.48%*
Heavy Metals (HM)	ng Ni eq.	**33.23**	**25.76**
	variation with the base-case	*0.00%*	*-22.48%*
PAHs	ng Ni eq.	**7.30**	**5.66**
	variation with the base-case	*0.00%*	*-22.48%*
Particulate Matter (PM, dust)	µ g	**16.57**	**12.85**
	variation with the base-case	*0.00%*	*-22.48%*
Emissions (Water)			
Heavy Metals (HM)	ng Hg/20	**11.03**	**8.55**
	variation with the base-case	*0.00%*	*-22.48%*
Eutrophication (EP)	ng PO4	**70.92**	**54.98**
	variation with the base-case	*0.00%*	*-22.48%*

As the BOM of the base-case and improvement option is the same but the energy use of Option 1 is less, there is a uniform 22.48% reduction of environmental impacts.

7.2.3 Base-case HL-LV-R

The key environmental and monetary results from the EcoReport of the base-case HL-LV-R are presented in Table 7.8.

Table 7.8: Key results of the improvement option analysis for the base-case HL-LV-R

Option	*Option description*	*Product lifetime (hours)*	*Lumen output (lm)*	*Total Energy GER (MJ)*	*GER per lumen per hour (J/lm/h)*	*Total GWP (kg CO_2 eq.)*	*GWP per lumen per hour (mg CO_2 eq/lm/h)*	*LCC (Euros)*	*LCC per lumen per hour (10^{-6} €/lm/h)*
0	***Base-Case HL-LV-R***	4000	458.25	1686	**919.97**	76	**41.43**	23.87	**13.02**
1	***Replacement with Xenon HL-LV-R***	2000	361.73	611	**844.71**	29	**40.12**	14.82	**20.49**
2	***Replacement with HL-LV-R with infrared coating and Xenon***	5000	297.38	1168	**785.26**	53	**35.85**	22.57	**15.18**

Similar to previous base-cases, all of the improvement options result in a decrease of energy use and global warming potential. As shown in Figure 7.6, Option 2 reduces GER by 15% and GWP by 13%.

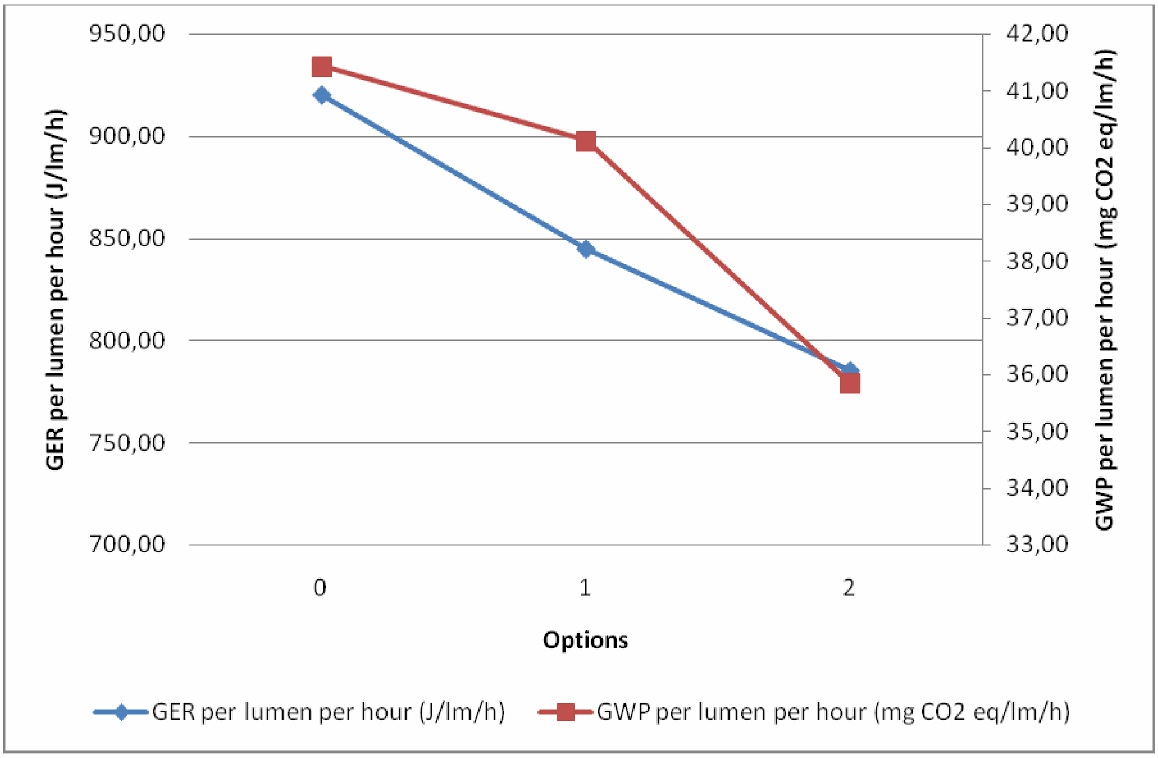

Figure 7.6: Environmental performances expressed in GER and in GWP for the improvement option for the base-case HL-LV-R

All improvement options increase lifecycle costs, shown in Figure 7.7. As HL-LV-R had the lowest LCC of the base-cases, it is reasonable to understand that improvement options would have less of an impact. The LCC of Option 1 is impacted by a significantly shorter lifetime (-50%), while Option 2 has a lower lumen output than the base-case. Judging from the figure, it appears that product price is the reason for the increase of LCC for option 1 and 2.

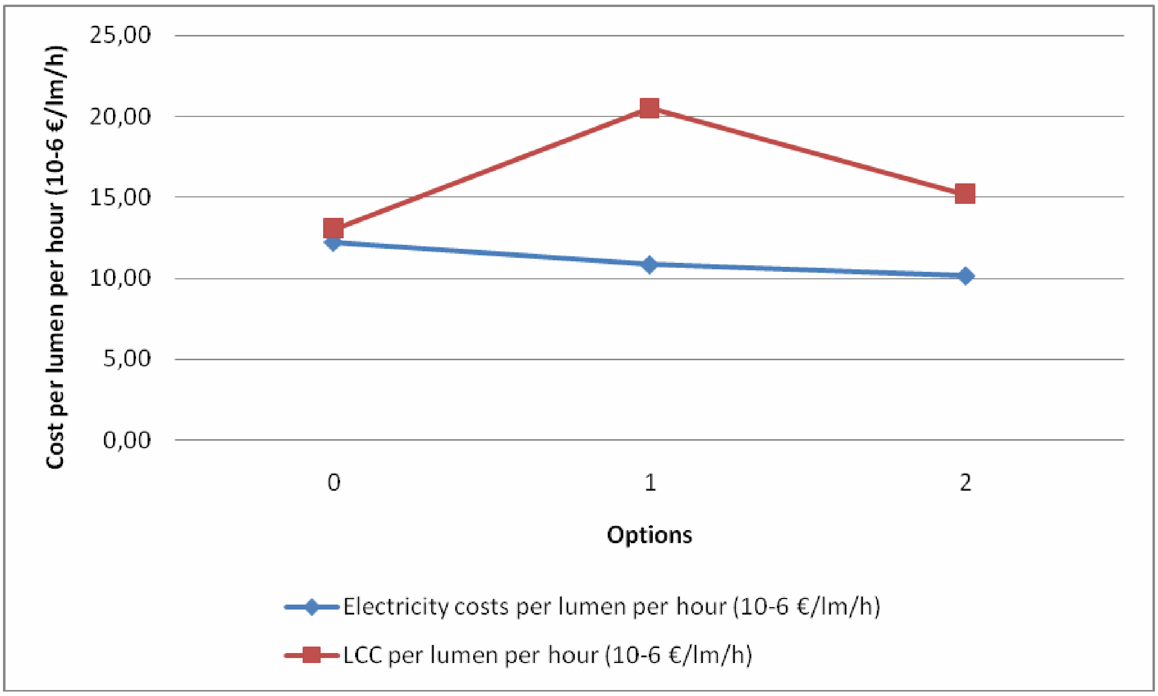

Figure 7.7: LCC curve – environmental performance expressed in total electricity costs for the improvement option for the base-case HL-LV-R

Mercury emissions are not discussed for this base-case, as there is no mercury embedded within the base-case nor the improvement options.

Outcomes of the LCA carried out with the EcoReport tool for both the base-case and its improvement options are provided in Table 7.9. Option 2 provides the biggest improvements on environmental indicators, reducing most categories by around 15%, but increase PAH emissions by 2%. It is important to note that while improvement Option 1 decreases GER and GWP, many environmental indicators increase, particularly PAHs (+62%) and particulate matter (+40%). This is due to the shorter lifetime of Option 1 (-50%), which creates the need to replace lamps more often. These replaced lamps translate into greater environmental impacts from production.

Table 7.9: Comparison of HL-LV-R option for each environmental indicator

		Base-case HL-MV-LW	***Option 1***	***Option 2***
main environmental indicators	**unit**	**value per lumen per hour**	**value per lumen per hour**	**value per lumen per hour**
Total Energy (GER)	J	**919.97**	**844.71**	**785.26**
	variation with the base-case	*0.00%*	*-8.18%*	*-14.64%*
of which, electricity	J	**890.39**	**769.76**	**748.80**
	variation with the base-case	*0.00%*	*-13.55%*	*-15.90%*
Water (process)	µltr	**59.48**	**51.63**	**50.07**
	variation with the base-case	*0.00%*	*-13.20%*	*-15.82%*
Water (cooling)	µltr	**2373.81**	**2051.26**	**1996.10**
	variation with the base-case	*0.00%*	*-13.59%*	*-15.91%*
Waste, non-haz./ landfill	µg	**1082.79**	**1020.27**	**930.36**
	variation with the base-case	*0.00%*	*-5.77%*	*-14.08%*
Waste, hazardous/ incinerated	µg	**21.08**	**19.15**	**17.94**
	variation with the base-case	*0.00%*	*-9.12%*	*-14.86%*
Emissions (Air)				
Greenhouse Gases in GWP100	mg CO2 eq.	**41.43**	**40.12**	**35.85**
	variation with the base-case	*0.00%*	*-3.18%*	*-13.47%*
Acidifying agents (AP)	µg SO2 eq.	**236.05**	**215.38**	**201.17**
	variation with the base-case	*0.00%*	*-8.76%*	*-14.78%*
Volatile Org. Compounds (VOC)	ng	**372.21**	**383.32**	**327.46**
	variation with the base-case	*0.00%*	*2.98%*	*-12.02%*
Persistent Org. Pollutants (POP)	10^{-3} pg i-Teq	**6.14**	**5.81**	**5.28**
	variation with the base-case	*0.00%*	*-5.37%*	*-13.98%*
Heavy Metals (HM)	ng Ni eq.	**17.05**	**17.70**	**15.03**
	variation with the base-case	*0.00%*	*3.81%*	*-11.83%*
PAHs	ng Ni eq.	**3.19**	**5.16**	**3.25**
	variation with the base-case	*0.00%*	*61.67%*	*1.75%*
Particulate Matter (PM, dust)	µg	**7.24**	**10.17**	**7.01**
	variation with the base-case	*0.00%*	*40.46%*	*-3.23%*
Emissions (Water)				
Heavy Metals (HM)	ng Hg/20	**5.89**	**5.33**	**5.01**
	variation with the base-case	*0.00%*	*-9.39%*	*-14.93%*
Eutrophication (EP)	ng PO4	**33.45**	**39.06**	**30.51**
	variation with the base-case	*0.00%*	*16.77%*	*-8.79%*

For the time being, there is no wide proposed improvement option for the base-case HL-LV-R in monetary terms, as the LCC of the base-case is the lowest one. However, using Xenon as filling gas andr IRC technology allow reducing main environmental impacts, of which GER and GWP. One can expect that the price of this lamp will decrease in a near future.

7.3 Conclusions

As presented in this chapter, the improvement potential of each of the 3 base-cases is significant. The EcoReport analysis show that most of the 17 environmental impact indicators, as well as mercury emissions to air, decrease by implementating animprovement option, due to their electricity saving potential.

However, the Least Life Cycle Cost option currently corresponds to the Best Available Technology option only for the base-cases GLS-R and HL-MV-R. Indeed, the “low” increase of the lamp efficacy of the improvement options for the base-case HL-LV-R does not offset the high increase of the purchase price. The differences in LCC are very small and the base case product prices could be underestimated in chapter 4 and the prices for improvement options in chapter 6 overestimated.

The cost of purchasing the lamp could prevent a significant barrier to the implementation of one or several options, most notably replacement with LEDi-R. Indeed, without any life cycle thinking the buyer would most likely not purchase an improvement product instead of an average one (base-case) due to the higher product cost. For example, LEDi-R costs 40 €, which is almost 2600% more expensive than a simple GLS-R. However, judging from previous experience with CFLi-R prices which shows that prices can quickly be reduced, it is safe to assume that the same will happen with LEDi-R prices over the next decade.

The assessment of the improvement potential of each base-case will be further investigated in chapter 8 when defining scenarios until the year 2020. These scenarios, based on relevant assumptions, will evaluate the energy savings potential for the whole EU market of domestic lamps which are in the scope of this study.