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Preparatory Studies for Eco-design Requirements of EuPs

Lot 19: Domestic lighting- Part 2
Directional lamps and household luminaires
Interim Task Report
Task 7: IMPROVEMENT POTENTIAL

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Important note:
This report contains the updated draft results of research by the authors and is not to be perceived as the opinion of the European Commission.
This is an updated draft document intended for stakeholder communication.

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 represent 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 in years, taking into account the rated lamp life and the average annual operating hours (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 all base-cases and improvement options, the colour rendering index is accepted to be greater than 80 and the correlated colour temperature around 2700 K, as explained in Task 6.

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).

Based on technical data, certain improvement options could last for 20+ years. However, considering consumer behaviour that often remodels and replaces the lamp in a shorter time frame, it is assumed the behavioural lifetime is limited to 18 years. A sensitivity analysis is conducted on this limit in Chapter 8.

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

Lamp cap: E27	**Lamp wattage (W)**	**LWFt[1]**	**Electricity consumption (Wh/h)**	**Average LLMF[2]**	***Average functional lumen output within opening angle of 90° (lm)***	**Average lamp efficacy (lm/W)**	**Lamp life time (hours)**	**Yearly burning hours (hours/year)**	**Lamp lifespan[3] (years)**	**Purchase price (€)**
Base-case GLS-R	50	1	50	0.965	258	5.16	1000	400	2.5	1.30
Option1: Halogen reflector lamp, R63, E27 (B22d), xenon	42	1	42	0.975	241	5.75	2000	400	5.0	3.00
Option2: Halogen reflector lamp, PAR20, E27 (B22d), xenon +optimized filament wire design	40	1	40	0.975	289	7.22	2000	400	5.0	11.00
Option3: Halogen reflector lamp, PAR20, E27 (B22d), xenon +optimized filament wire design + dichroic/silver + anti-reflective	40	1	40	0.975	331	8.29	2000	400	5.0	15.00
Option4: Halogen reflector lamp, PAR20, E27 (B22d) transfo inc	20	1	20	0.975	263	13.65	5000	400	12.5	22.00
Option5: Halogen reflector lamp, PAR20, E27 (B22d) transfo inc + IRC	20	1	20	0.975	295.43	14.72	5000	400	12.5	24.00
Option6: Halogen reflector lamp, PAR20, E27 (B22d) transfo inc + IRC + dich/silv + anti-refl	20	1	20	0.975	319	15.99	5000	400	12.5	27.00
Option7: LED retrofit reflector lamp, R63, E27 (CCT 2700 K)	7.4	1.05	7.77	0.85	210	27.04	30000	400	18.0	40.00

[1] Total Lamp Wattage Factor
[2] Lamp Lumen Maintenance Factor
[3] Maximum 18 years based on consumer behaviour

7.1.1.1 Option 1: Replacing the GLS-R with HL-MV-R with xenon

From the analysis of base-cases in Chapter 5, an HL-MV-R with xenon (42 W – 5.75 lm/W) generally has lower environmental impacts per lumen and per hour compared to a GLS-R (50 W – 5.16 lm/W) due to the higher lamp efficacy. Thus this replacement can be considered as an improvement option as discussed in chapter 6, section 6.1.1.2.

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-LW (50 W) (see chapter 4).

7.1.1.2 Option 2: Replacing the GLS-R with HL-MV-R PAR20 with xenon and optimized filament wire design

In chapter 6 (see section 6.1.1.4), a new technology for halogen lamps (mains voltage) was presented with use of an optimised filament design and xenon in a PAR20 reflector. An optimised filament in a PAR20 reflector – made of pressurized borosilicated glass - allows for a more efficient and improved light output over traditional filaments placed in blown reflectors.

7.1.1.3 Option 3: Replacing the GLS-R with HL-MV-R PAR20 with xenon and optimized filament wire design with dichroic/silver coating and anti-reflective coating

This option has all of the advantages gained in option 2, as well as coatings to improve light transmission through the glass to increase efficacy.

7.1.1.4 Option 4: Replacing the base-case GLS-R with HL-MV-R with integrated transformer

As discussed in section 6.1.1.6, an integrated transformer and low voltage halogen lamp are combined with the E27 cap, which improves efficacy over a traditional HL-MV-R.

7.1.1.5 Option 5: Replacing the base-case GLS-R with HL-MV-R with integrated transformer and infrared coating

Option 5 carries the benefits of option 4 with increased light transmission efficiency from the infrared coating (IRC).

7.1.1.6 Option 6: Replacing the base-case GLS-R with HL-MV-R with integrated transformer, infrared coating, dichroic/silver coating, and anti-reflective coating

This is considered best not yet available technology, as the various coatings are common in different lamp applications but not yet for HL-MV-R specifically. All contribute to allowing more efficient light production. It is considered an improvement option as manufacturers are planning on bringing these features to the market soon.

7.1.1.7 Option 7: 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-HW

Two improvement options are initially considered for base-case HL-MV-R-HW, as seen in Table 7.2.

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

Lamp cap: E27	Lamp wattage (W)	LWFt	Electricity consumption (Wh/h)	Average LLMF	*Average functional lumen output within opening angle of 90° (lm)*	Average lamp efficacy (lm/W)	Lamp life time (hours)	Yearly burning hours (hours/year)	Lamp lifespan (years)	Purchase price (€)
Base-case HL-MV-R-HW	100	1	100	0.975	1054	10.53	2000	450	4.44	13.50
Option1: HID retrofit reflector lamp. PAR38. E27 (average of all presented in Chapter 6)	25	1.05	26.25	0.81	846	33.86	9000	450	18.00	40.00
Option2: Compact fluorescent reflector lamp. PAR38(R120). E27	23	1.05	24.15	0.925	658	27.22	10000	450	18.00	27.00

As the luminous output is not the same, these lamps will be analysed further on a per lumen per hour basis later in section 7.2.2.

7.1.3 Base-case HL-MV-R-LW

Six improvement options are presented for base-case HL-MV-R-LW, seen in Table 7.3.

Table 7.3: Summary of the main characteristics of the improvement options for the base-case HL-MV-R-LW

Lamp cap: GU10	**Lamp wattage (W)**	**LWFt**	**Electricity consumption (Wh/h)**	**Average LLMF**	***Average functional lumen output within opening angle of 90° (lm)***	**Average lamp efficacy (lm/W)**	**Lamp life time (hours)**	**Yearly burning hours (hours/year)**	**Lamp lifespan (years)**	**Purchase price (€)**
Base-case HL-MV-R-LW	50	1	50	0.965	315	6.29	1500	450	3.33	3.60
Option1: Halogen reflector lamp, MR16, GU10, xenon	42	1	42	0.975	278	6.63	2000	450	4.44	7.00
Option2: Halogen reflector lamp, MR16, GU10, xenon + optimized filament wire design	40	1	40	0.975	339	8.48	2000	450	4.44	7.00
Option3: Halogen reflector lamp, MR16, GU10, xenon + optimized filament wire design + silver	40	1	40	0.975	367	9.17	2000	450	4.44	7.70
Option4: Halogen reflector lamp, MR16, GU10, xenon + optimized filament wire design + silver + Anti-Reflect	40	1	40	0.975	388	9.75	2000	450	4.44	8.10
Option5: Compact fluorescent reflector lamp. R50. GU10	11	1.05	11.55	0.925	124	10.31	15000	450	18.00	18.00
Option6: LED retrofit reflector lamp, MR16, GU10 (CCT 2700 K)	4.7	1.05	4.94	0.85	145	29.22	30000	450	18.00	35.00

Although it is foreseen to improve in the future, Options 5 and 6 currently have the maximum lumen output among CFLi-R and LEDi-R with GU10 cap. Because of this, **Options 5 and 6 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 is not the same, these lamps will be analysed further on a per lumen per hour basis later in section 7.2.3.

7.1.4 Base-case HL-LV-R

The improvement options initially investigated for the base-case HL-LV-R are the HL-LV-R with Xenon, HL-LV-R with Xenon and infrared coating technology, HL-LV-R with infrared coating and silver/dichroic, HL-LV-R with infrared coating, silver/dichroic, and anti-reflective coating, and lastly an 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 the halogen improvement options are the same as those of the base-case. The options are listed in Table 7.4.

Table 7.4: Summary of the main characteristics of the improvement option for the base-case HL-LV-R

Lamp caps: GU5.3	**Lamp wattage (W)**	**LWFt**	**Electricity consumption (Wh/h)**	**Average LLMF**	***Average functional lumen output within opening angle of 90° (lm)***	**Average lamp efficacy (lm/W)**	**Lamp life time (hours)**	**Yearly burning hours (hours/year)**	**Lamp lifespan (years)**	**Purchase price (€)**
Base-case HL-LV-R	35	1.11	38.85	0.975	392	10.08	3000	500	6	2.40
Option1: Halogen reflector lamp, MR16, 12V, GU5.3, xenon	25	1.06	26.50	0.975	358	13.52	2000	500	4	6.80
Option2: Halogen reflector lamp, MR16, 12V, GU5.3, IRC + xenon	25	1.06	26.50	0.975	358	13.52	5000	500	10	7.00
Option3: Halogen reflector lamp, MR16, 36°, 12V, GU5.3, IRC + silver/dichroic	20	1.06	21.20	0.975	329	15.54	5000	500	10	7.50
Option4: Halogen reflector lamp, MR16, 36°, 12V, GU5.3, IRC + silver/dichroic + Anti-Refl	20	1.06	21.20	0.975	350	16.56	3500	500	7	8.00
Option5: LED retrofit reflector lamp, MR16, GU5.3 (CCT 2700 K)	4.4	1.17	5.15	0.85	116	22.52	30000	500	18	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 7.2.4.

The LEDi-R does not offer enough lumen output to be considered a possible replacement option and will not be analysed further, despite having the maximum light output among LEDi-R GU5.3 on the market. A possible improvement using a LED module in a LED luminaire is covered in section 6.1.8.

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, the 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 and metal halide 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 7.5 highlights the main results in terms of environmental impacts (GER and GWP) as well as in monetary terms (Life Cycle Cost).

Table 7.5: Key results of the improvement options analysis for the base-case GLS-R

Option	Option description	Product lifetime (hours)	Average 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	580.1	**2247.06**	27.7	**107.20**	8.71	**33.72**
1	***Option1: Halogen reflector lamp, R63, E27 (B22d), xenon***	2000	241	937.3	**1946.02**	43.3	**89.85**	15.17	**31.50**
2	***Option2: Halogen reflector lamp, PAR20, E27 (B22d), xenon +optimized filament wire design***	2000	289	895.3	**1551.11**	41.4	**71.80**	22.59	**39.14**
3	***Option3: Halogen reflector lamp, PAR20, E27 (B22d), xenon +optimized filament wire design + dichroic/silver + anti-reflective***	2000	331	895.3	**1354.36**	41.4	**62.69**	26.59	**40.22**
4	***Option4: Halogen reflector lamp, PAR20, E27 (B22d) transfo inc***	5000	263	1131.6	**859.74**	51.9	**39.42**	35.57	**27.03**
5	***Option5: Halogen reflector lamp, PAR20, E27 (B22d) transfo inc + IRC***	5000	295	1131.6	**766.10**	51.9	**35.13**	37.57	**25.44**
6	***Option6: Halogen reflector lamp, PAR20, E27 (B22d) transfo inc + IRC + dich/silv + anti-refl***	5000	319	1131.6	**709.87**	51.9	**32.55**	40.57	**25.45**
7	***Option7: LED retrofit reflector lamp, R63, E27 (CCT 2700 K)***	7200	210	673.7	**445.69**	32.3	**21.40**	47.25	**31.26**

Figure 7.1 and Figure 7.2 show that Option 7 leads to the lowest energy use (GER[4]) and global warming potential on a per lumen per hour basis. Compared to the base-case, both energy use and global warming potential are reduced 80%. However, Option 7 only offers a reduction of 7.3% in LCC over the base-case. The LLCC option is option 5, which has an LCC 25% lower than that of the base-case.

Also, it is interesting to note that Option 2 leads to increased life cycle costs (+ 16 %), despite improved luminous efficacy and lifetime over the base-case. This cost increase is due to the much higher price of Option 2 over that of the base-case (+ 746 %).

[4] GER represents the Gross Energy Requirements (GER) of primary fuel consumed for a particular service (usually measured in Joules)

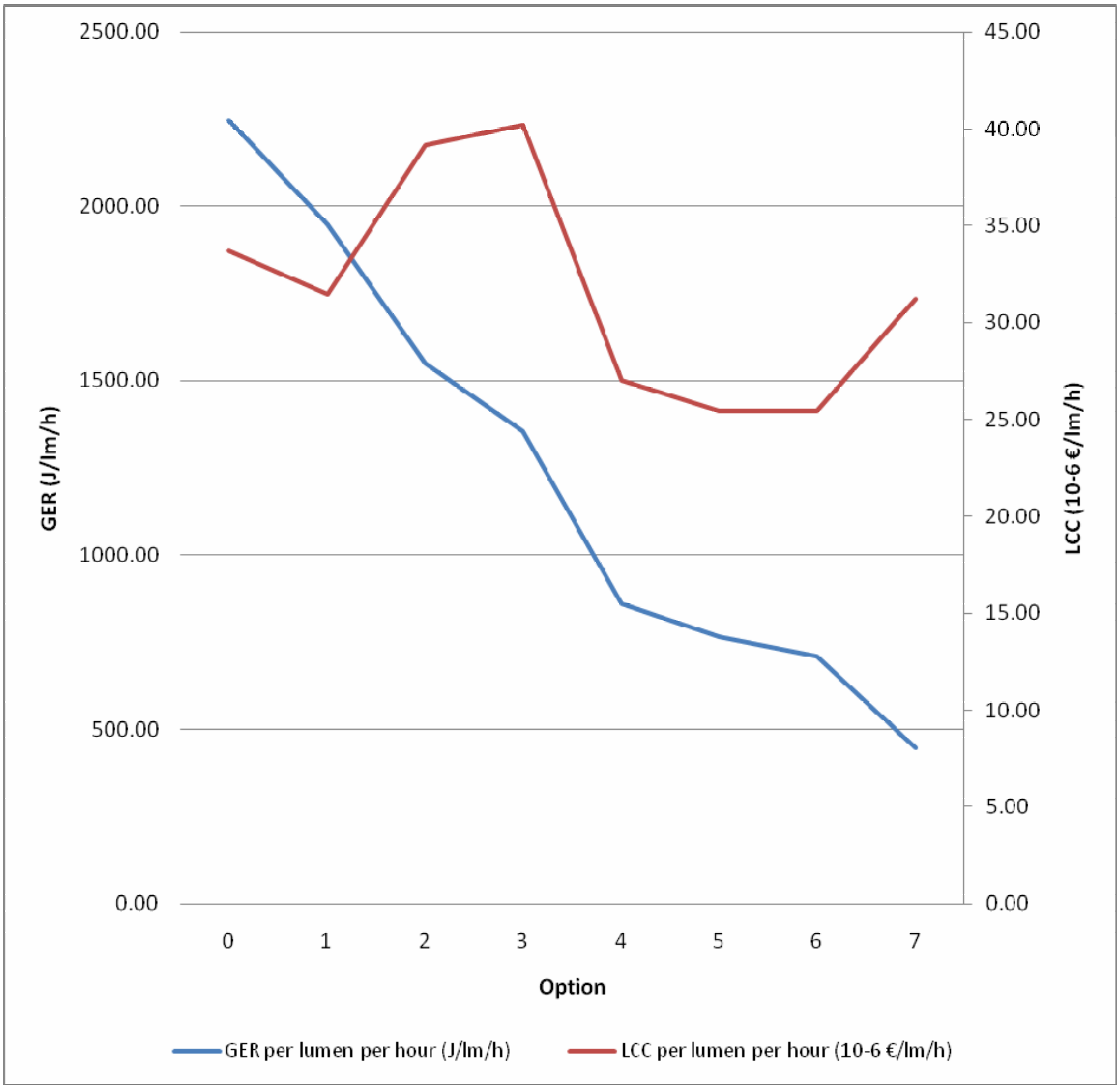

Figure 7.1: LCC curve – environmental performance expressed in total energy consumption (GER) for the improvement options for the base-case GLS-R

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 emissions. 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.

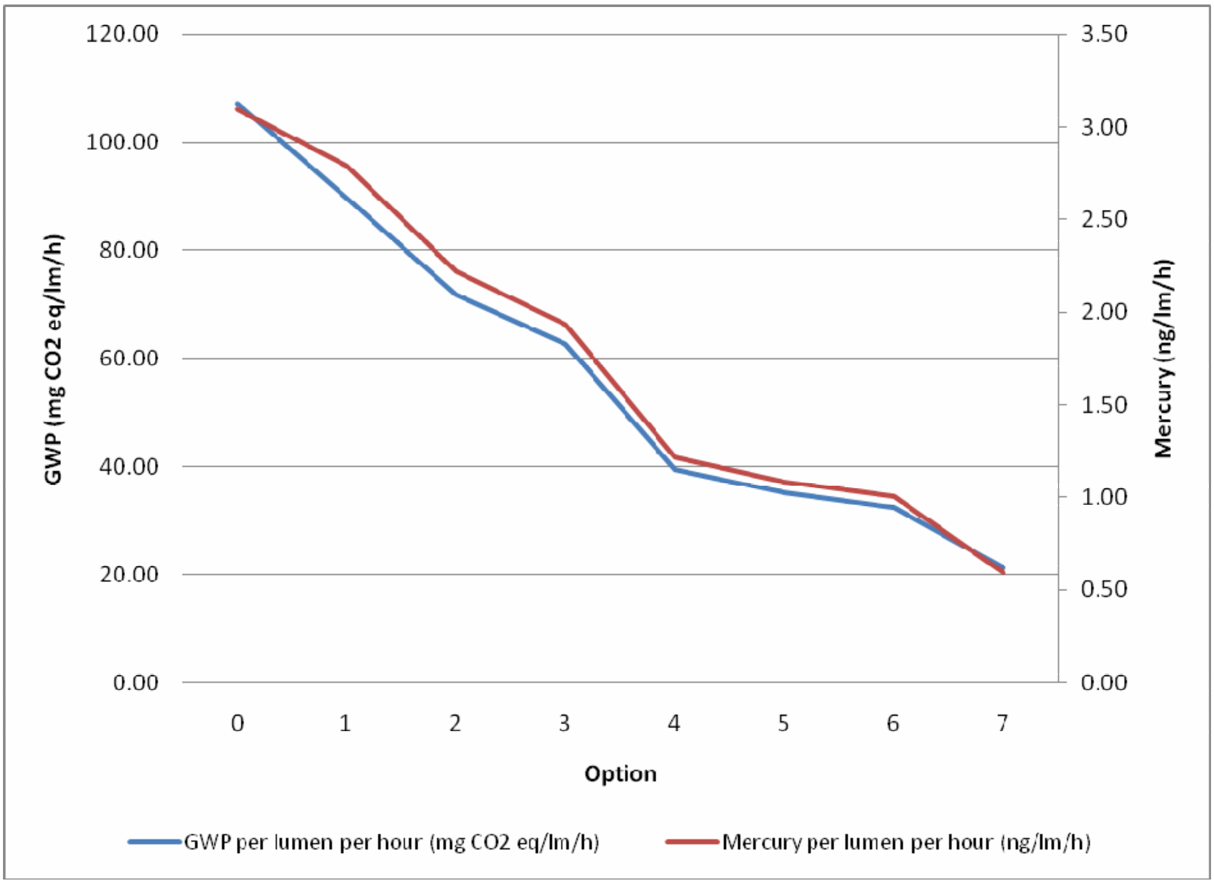

Figure 7.2: Environmental performance expressed in GWP and in mercury emissions for the improvement options for the base-case GLS-R

As already discussed in chapter 5, mercury emissions are created during the use phase as a direct result of power generation from coal. It is 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 mercury emissions of the replacement options, like global warming potential, have a direct correlation to the energy used and thus Option 7 presents the greatest reduction of 81%.

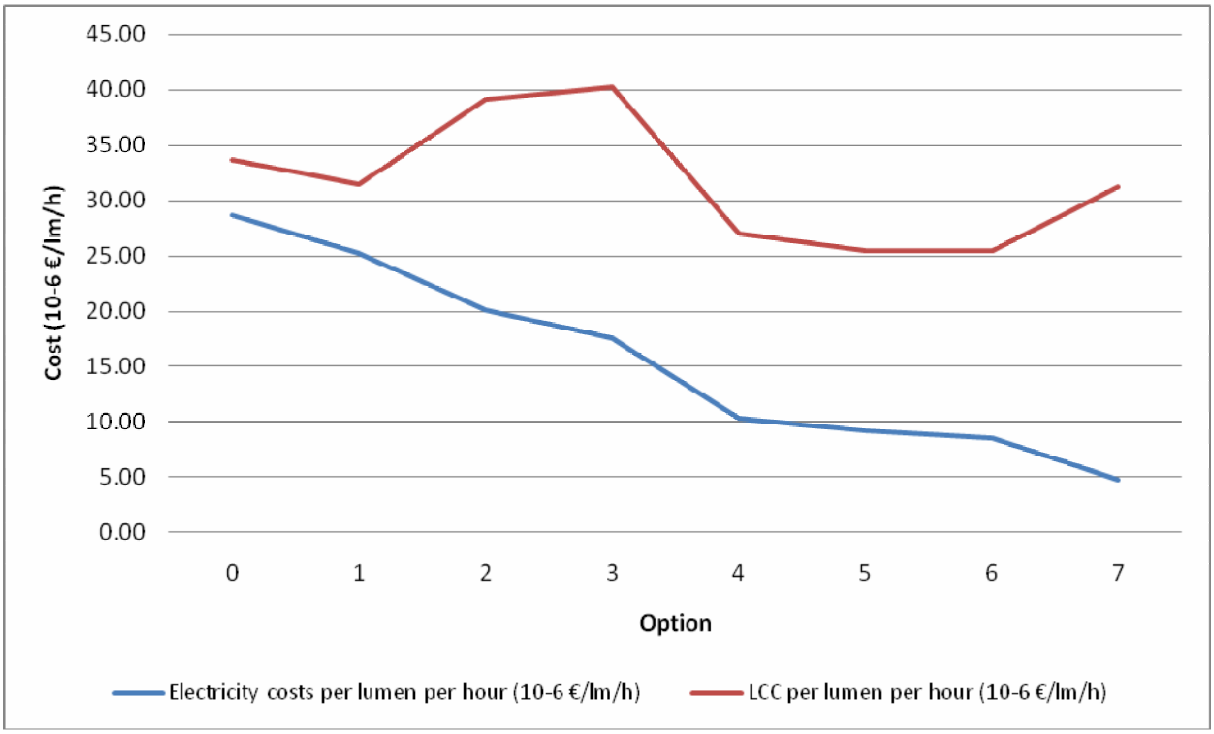

Figure 7.3: LCC curve – environmental performance expressed in total electricity costs for the improvement options for the base-case GLS-R

Electricity costs, reflecting the electricity consumption, as well as 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 Options 2 and 3 are higher than that of the base-case. Also, the very high product price of Option 7 is clear.

The complete results of the EcoReport including the different options are presented per lumen and per hour in Table 7.6 in order to allow a straightforward comparison.

Table 7.6: Comparison of GLS-R options for each environmental indicator

		Base-case GLS-R	***Option 1***	***Option 2***	***Option 3***	***Option 4***	***Option 5***	***Option 6***	***Option 7***
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**	**value per lumen per hour**	**value per lumen per hour**	**value per lumen per hour**
Total Energy (GER)	J	2247.06	1946.02	1551.11	1354.36	859.74	766.10	709.87	445.69
	variation with the base-case	0.00%	-13.40%	-30.97%	-39.73%	-61.74%	-65.91%	-68.41%	-80.17%
of which, electricity	J	2035.59	1832.22	1456.14	1271.44	807.53	719.58	666.77	393.49
	variation with the base-case	0.00%	-9.99%	-28.47%	-37.54%	-60.33%	-64.65%	-67.24%	-80.67%
Water (process)	µltr	136.63	122.72	97.56	85.18	65.36	58.24	53.97	29.26
	variation with the base-case	0.00%	-10.18%	-28.60%	-37.65%	-52.16%	-57.37%	-60.50%	-78.58%
Water (cooling)	µltr	5423.50	4883.23	3880.82	3388.56	2131.38	1899.25	1759.85	1038.09
	variation with the base-case	0.00%	-9.96%	-28.44%	-37.52%	-60.70%	-64.98%	-67.55%	-80.86%
Waste, non-haz./ landfill	µg	2726.00	2352.29	1878.53	1640.25	1118.39	996.59	923.44	783.49
	variation with the base-case	0.00%	-13.71%	-31.09%	-39.83%	-58.97%	-63.44%	-66.12%	-71.26%
Waste, hazardous/ incinerated	µg	51.31	44.35	35.33	30.85	156.53	139.48	129.25	51.78
	variation with the base-case	0.00%	-13.57%	-31.14%	-39.88%	205.09%	171.86%	151.91%	0.91%
Emissions (Air)									
Greenhouse Gases in GWP100	mg CO2 eq.	107.20	89.85	71.80	62.69	39.42	35.13	32.55	21.40
	variation with the base-case	0.00%	-16.19%	-33.02%	-41.52%	-63.23%	-67.23%	-69.64%	-80.04%
Acidifying agents (AP)	µg SO2 eq.	572.67	497.87	396.72	346.40	222.97	198.69	184.11	114.77
	variation with the base-case	0.00%	-13.06%	-30.73%	-39.51%	-61.06%	-65.30%	-67.85%	-79.96%

Volatile Org. Compounds (VOC)	ng	1035.22	834.78	669.18	584.30	450.29	401.25	371.80	254.25
	variation with the base-case	0.00%	-19.36%	-35.36%	-43.56%	-56.50%	-61.24%	-64.08%	-75.44%
Persistent Org. Pollutants (POP)	10^{-3} pg i-Teq	15.49	13.31	10.63	9.28	6.05	5.39	5.00	7.01
	variation with the base-case	0.00%	-14.09%	-31.39%	-40.09%	-60.95%	-65.21%	-67.76%	-54.75%
Heavy Metals (HM)	ng Ni eq.	47.49	38.57	30.94	27.01	17.97	16.01	14.84	11.90
	variation with the base-case	0.00%	-18.78%	-34.86%	-43.12%	-62.16%	-66.28%	-68.76%	-74.95%
PAHs	ng Ni eq.	14.79	9.10	7.45	6.50	3.67	3.27	3.03	4.32
	variation with the base-case	0.00%	-38.49%	-49.64%	-56.03%	-75.19%	-77.90%	-79.52%	-70.81%
Particulate Matter (PM, dust)	µg	28.13	20.38	16.61	14.50	12.13	10.81	10.02	15.85
	variation with the base-case	0.00%	-27.55%	-40.96%	-48.45%	-56.88%	-61.57%	-64.39%	-43.65%
Emissions (Water)									
Heavy Metals (HM)	ng Hg/20	14.27	12.54	9.99	8.73	15.15	13.50	12.51	6.32
	variation with the base-case	0.00%	-12.12%	-29.95%	-38.84%	6.20%	-5.37%	-12.31%	-55.67%
Eutrophication (EP)	ng PO4	106.76	84.66	68.40	59.73	149.18	132.93	123.18	97.71
	variation with the base-case	0.00%	-20.70%	-35.93%	-44.05%	39.73%	24.52%	15.38%	-8.48%

Table 7.6 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 70 - 80% for nearly all the environmental impacts, except for hazardous waste (+0.91%), particulate matter (-43.65%), heavy metals (-55.67%) and eutrophication (-8.48%). However, it is very important to see that improvements options 4, 5 and 6 actually increase certain environmental indicators, most notably hazardous waste (+205%, +172% and +152%, respectively over the base-case). This is due to the electronic components in the transformer of these improvement options.

The analysis of the improvement options of the base-case GLS-R shows that the dimmable 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-HW

The main outcomes of the environmental assessment of the base-case HL-MV-R-HW and its improvement option as well as their life cycle cost are presented in Table 7.7. Values are given per lumen and per hour allowing a comparison between the lamp types.

Table 7.7: Key results of the improvement option analysis for the base-case HL-MV-R-HW

Option	*Option description*	*Product lifetime (hours)*	*Average 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-HW*	2000	1054	2185.4	**1036.74**	98.5	**46.73**	42.62	**20.22**
1	*Option1: HID retrofit reflector lamp. PAR38. E27 (average of all presented in Chapter 6)*	8100	846	2334.9	**340.54**	105.1	**15.33**	67.54	**9.85**
2	*Option2: Compact fluorescent reflector lamp. PAR38(R120). E27*	8100	658	2121.8	**398.29**	95.1	**17.86**	52.34	**9.82**

The environmental indicators GER, GWP and mercury emissions are plotted in Figure 7.4 and Figure 7.5. Replacing a typical HL-MV-R-HW (100 W) with Option 1 results in the decrease of the total energy required during the entire life cycle by 67 %. The reduction is the same for the global warming potential. Both Option 1 and Option 2 present almost the same LCC with a 51% reduction over the base-case. The monetary savings come from the dramatic reduction of electricity use.

Despite 2.5 mg of embedded mercury in Option 1, this improvement option has 45% less mercury emissions because of lower energy use. It is assumed that 80% of embedded mercury is emitted to the air because only 20% of lamps are estimated to be recycled, despite EU regulation requiring it.

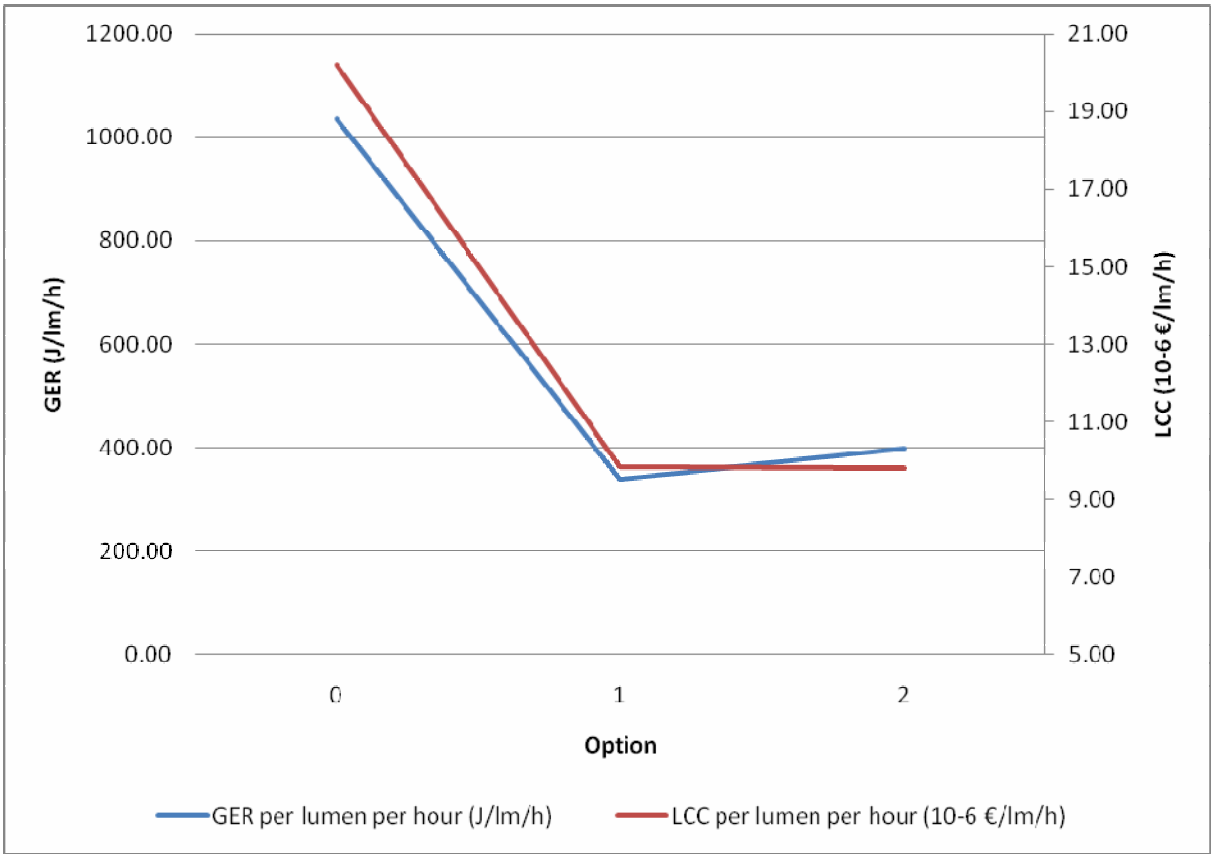

Figure 7.4: LCC curve – environmental performance expressed in total energy consumption (GER) for the improvement options for the base-case HL-MV-R-HW

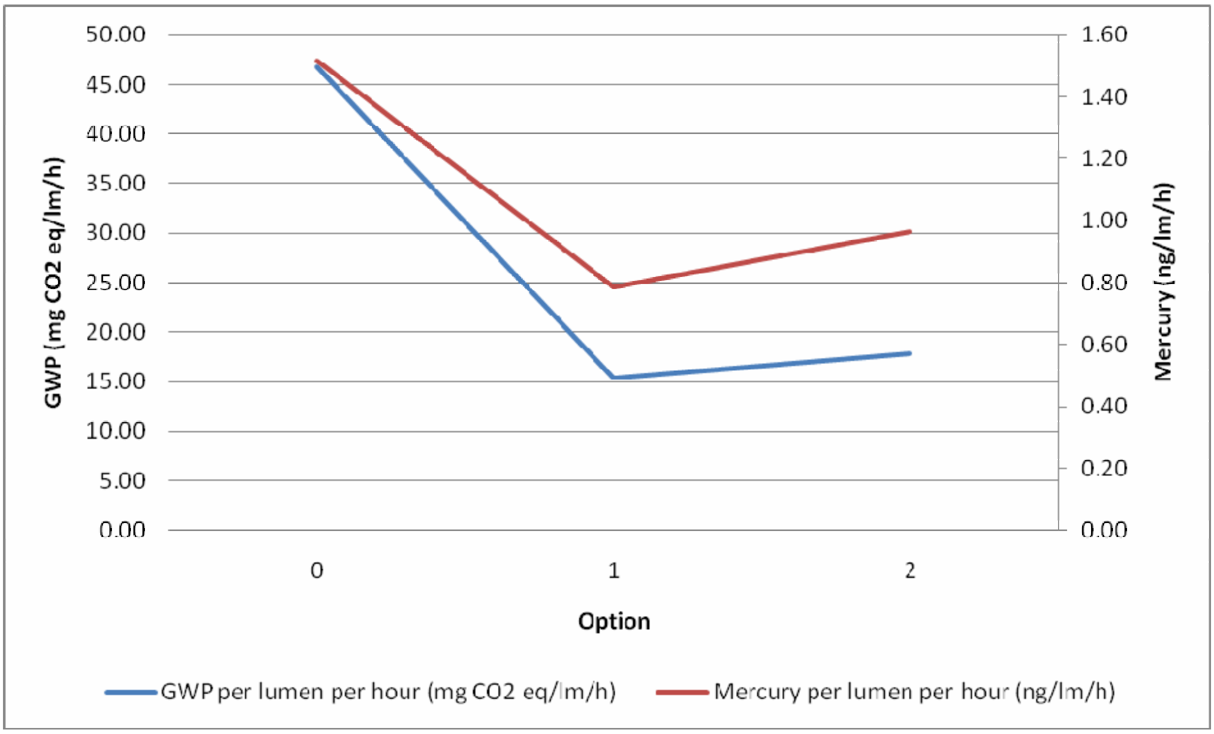

Figure 7.5: Environmental performance expressed in GWP and in mercury emissions for the improvement options for the base-case HL-MV-R-HW

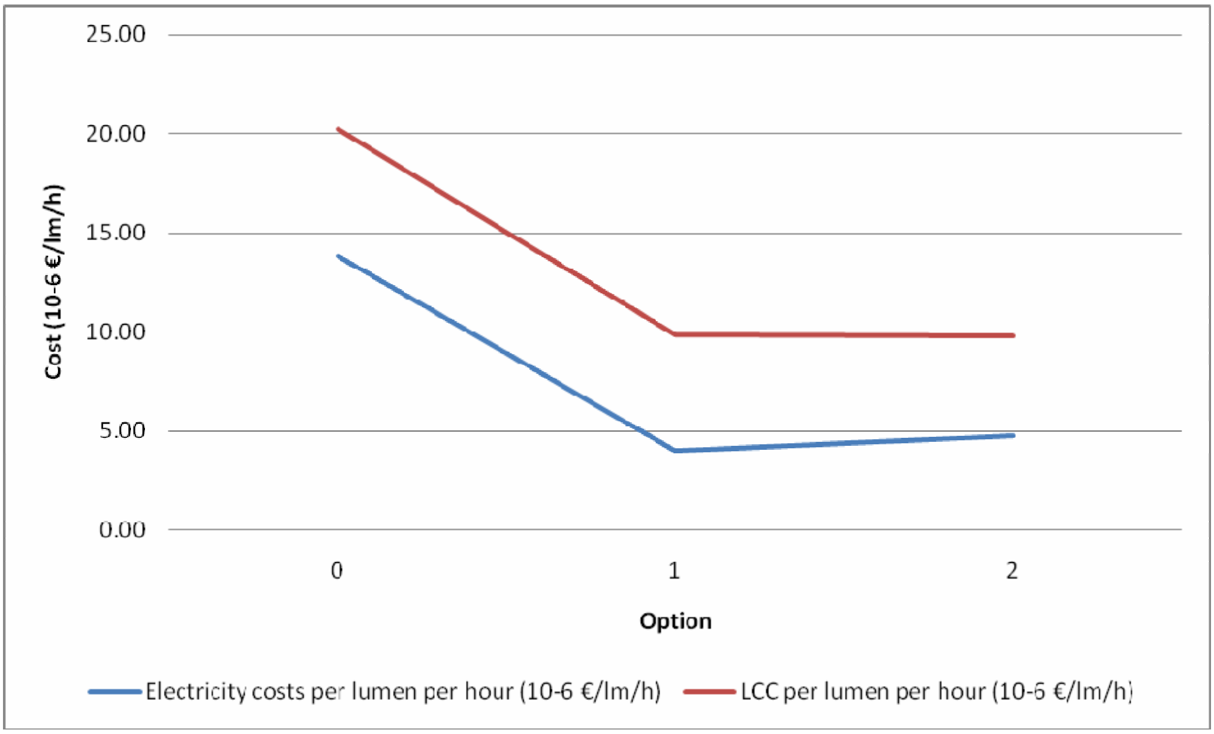

Figure 7.6: LCC curve – environmental performance expressed in total electricity costs for the improvement options for the base-case HL-MV-R-HW

Table 7.8 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 7.8: Comparison of HL-MV-R-HW options for each environmental indicator

		Base-case HL-MV-R-HW	***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	1036.74	340.54	398.29
	variation with the base-case	0.00%	-67.15%	-61.58%
of which, electricity	J	998.54	327.48	385.94
	variation with the base-case	0.00%	-67.20%	-61.35%
Water (process)	µltr	67.92	23.61	25.85
	variation with the base-case	0.00%	-65.24%	-61.94%
Water (cooling)	µltr	2656.61	868.83	1029.63
	variation with the base-case	0.00%	-67.30%	-61.24%
Waste, non-haz./ landfill	µg	1410.56	470.16	480.76
	variation with the base-case	0.00%	-66.67%	-65.92%
Waste, hazardous/ incinerated	µg	23.55	24.17	16.62
	variation with the base-case	0.00%	2.62%	-29.44%
Emissions (Air)				
Greenhouse Gases in GWP100	mg CO2 eq.	46.73	15.33	17.86
	variation with the base-case	0.00%	-67.19%	-61.79%
Acidifying agents (AP)	µg SO2 eq.	264.83	87.36	102.11
	variation with the base-case	0.00%	-67.01%	-61.44%
Volatile Org. Compounds (VOC)	ng	466.88	162.64	167.08
	variation with the base-case	0.00%	-65.16%	-64.21%
Persistent Org. Pollutants (POP)	10^{-3} pg i-Teq	8.18	2.69	2.72
	variation with the base-case	0.00%	-67.13%	-66.69%
Heavy Metals (HM)	ng Ni eq.	21.96	7.30	7.59
	variation with the base-case	0.00%	-66.74%	-65.42%
PAHs	ng Ni eq.	3.25	1.05	1.33
	variation with the base-case	0.00%	-67.76%	-59.19%
Particulate Matter (PM, dust)	µg	23.95	8.01	5.42
	variation with the base-case	0.00%	-66.55%	-77.39%
Emissions (Water)				
Heavy Metals (HM)	ng Hg/20	7.52	3.61	2.67
	variation with the base-case	0.00%	-52.01%	-64.53%
Eutrophication (EP)	ng PO4	88.42	41.73	25.27
	variation with the base-case	0.00%	-52.81%	-71.42%

The improvement options 1 and 2 are quite similar, with Option 1 providing slightly higher environmental performance in general. There is an increase in hazardous waste due to the electronic parts in Option 1.

7.2.3 Base-case HL-MV-R-LW

The key results of the EcoReport comparison for base-case HL-MV-R-LW are shown in Table 7.9.

Table 7.9: Key results of the improvement option analysis for the base-case HL-MV-R-LW

Option	Option description	Product lifetime (hours)	Average 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-MV-R-LW***	1500	315	842.8	**1786.54**	39.1	**82.99**	14.63	**31.01**
1	***Option1: Halogen reflector lamp, MR16, GU10, xenon***	2000	278	937.3	**1686.55**	43.3	**77.87**	19.23	**34.60**
2	***Option2: Halogen reflector lamp, MR16, GU10, xenon + optimized filament wire design***	2000	339	895.3	**1319.33**	41.4	**61.07**	19.23	**28.34**
3	***Option3: Halogen reflector lamp, MR16, GU10, xenon + optimized filament wire design + silver***	2000	367	895.3	**1221.08**	41.4	**56.52**	19.23	**26.23**
4	***Option4: Halogen reflector lamp, MR16, GU10, xenon + optimized filament wire design + silver + Anti-Reflect***	2000	388	895.3	**1153.59**	41.4	**53.40**	19.23	**24.78**

Figure 7.7 shows the total energy use and life-cycle costs per lumen per hour for the various improvement options. Option 1 actually presents an increase in life cycle costs of 12% due to increased product price of 94%. Option 4 has both the best environmental performance and least life cycle cost, giving reductions of 35% and 20%, respectively.

Figure 7.8 presents GWP and mercury emissions. For all lamps considered, there is no embedded mercury. Thus, all GWP and mercury emissions are directly correlated to energy use, and follow the same trend.

Figure 7.9 presents the comparison of life cycle costs and initial product prices. The space between the two lines is the cost of electricity.

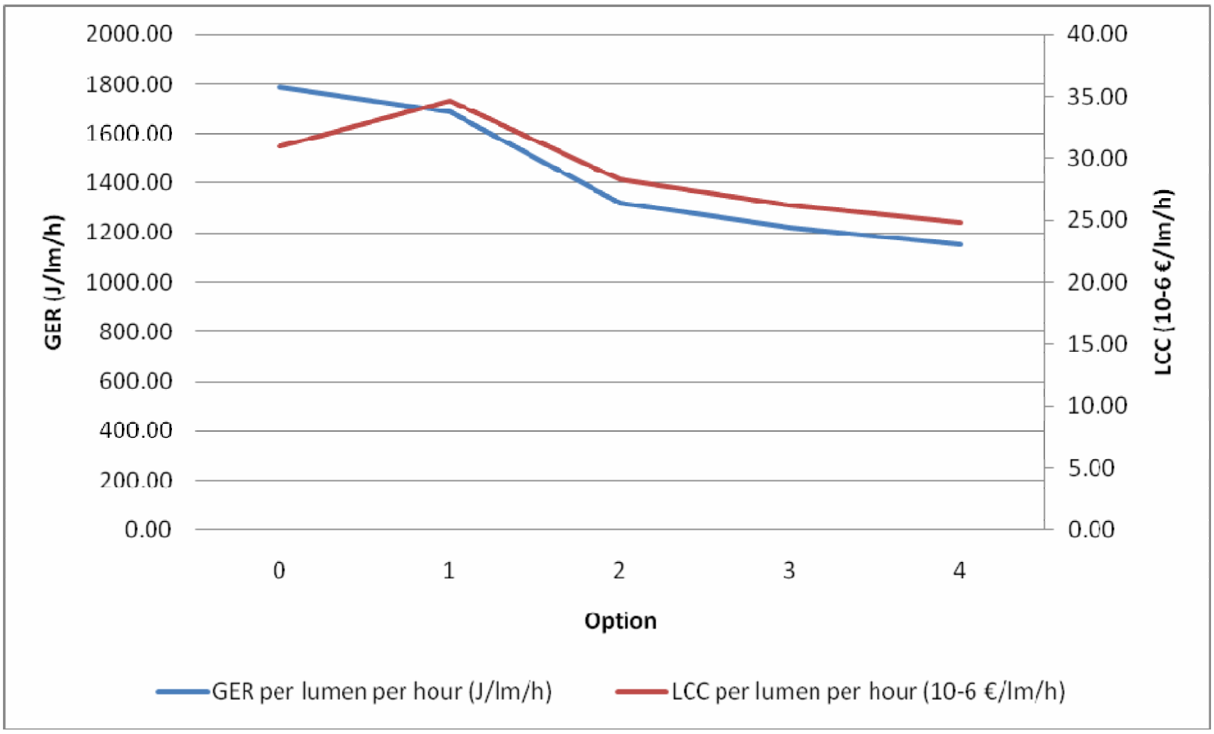

Figure 7.7: LCC curve – environmental performance expressed in total energy consumption (GER) for the improvement options for the base-case HL-MV-R-LW

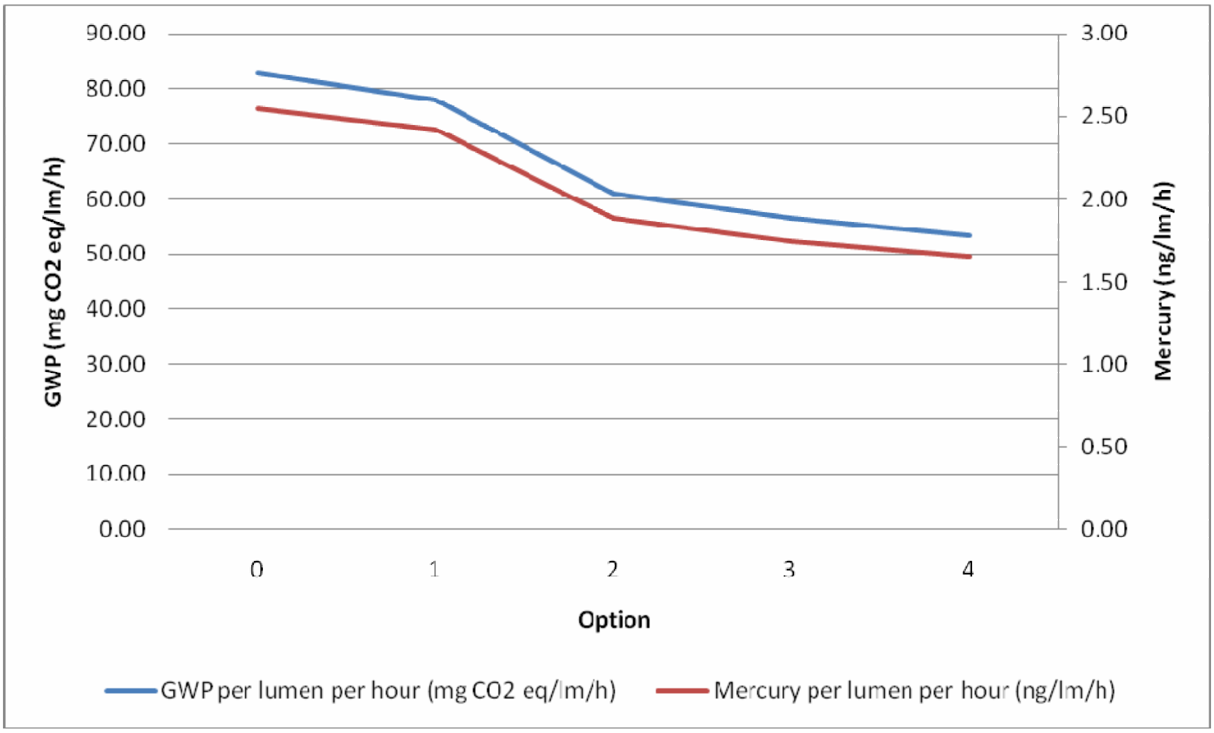

Figure 7.8: Environmental performance expressed in GWP and in mercury emissions for the improvement options for the base-case HL-MV-R-LW

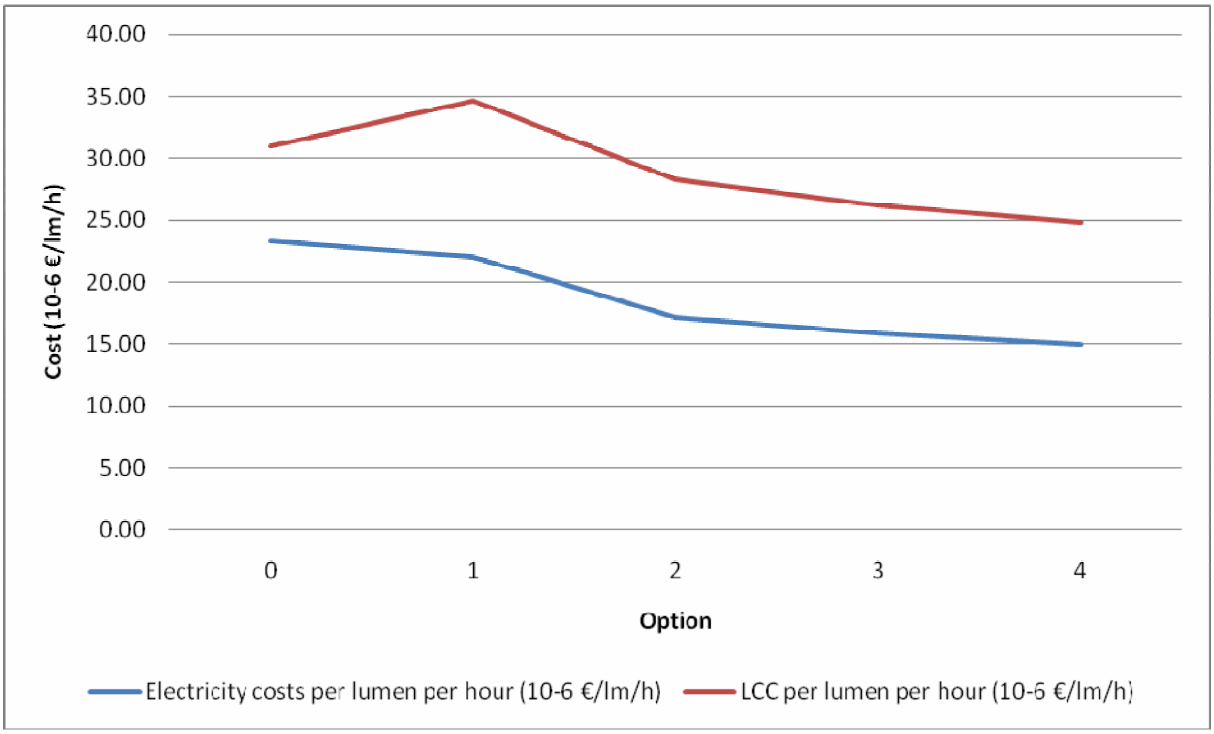

Figure 7.9: LCC curve – environmental performance expressed in total electricity costs for the improvement options for the base-case HL-MV-R-LW

Table 7.10 presents a comparison of all environmental indicators for each improvement option. As expected, option 4 reduces the environmental impacts the most of all considered improvement options. The reduction of about 35-37% is fairly uniform across all environmental factors because the BOM is the same for the base-case and improvement options.

Table 7.10: Comparison of HL-MV-R-LW options for each environmental indicator

		Base-case HL-MV-R-LW	***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	1786.54	1686.55	1319.33	1221.08	1153.59
	variation with the base-case	0.00%	-5.60%	-26.15%	-31.65%	-35.43%
of which, electricity	J	1670.35	1587.92	1238.56	1146.33	1082.96
	variation with the base-case	0.00%	-4.93%	-25.85%	-31.37%	-35.17%
Water (process)	μltr	111.94	106.36	82.98	76.80	72.56
	variation with the base-case	0.00%	-4.99%	-25.87%	-31.39%	-35.19%
Water (cooling)	μltr	4451.52	4232.13	3300.92	3055.11	2886.23
	variation with the base-case	0.00%	-4.93%	-25.85%	-31.37%	-35.16%
Waste, non-haz./ landfill	μg	2169.40	2038.66	1597.83	1478.84	1397.10
	variation with the base-case	0.00%	-6.03%	-26.35%	-31.83%	-35.60%
Waste, hazardous/ incinerated	μg	40.66	38.43	30.05	27.81	26.27
	variation with the base-case	0.00%	-5.48%	-26.10%	-31.60%	-35.38%
Emissions (Air)						
Greenhouse Gases in GWP100	mg CO2 eq.	82.99	77.87	61.07	56.52	53.40
	variation with the base-case	0.00%	-6.17%	-26.41%	-31.89%	-35.66%
Acidifying agents (AP)	μg SO2 eq.	456.74	431.49	337.44	312.31	295.05
	variation with the base-case	0.00%	-5.53%	-26.12%	-31.62%	-35.40%
Volatile Org. Compounds (VOC)	ng	776.85	723.48	569.19	526.81	497.69
	variation with the base-case	0.00%	-6.87%	-26.73%	-32.19%	-35.94%
Persistent Org. Pollutants (POP)	10^{-3} pg i-Teq	12.28	11.54	9.04	8.37	7.91
	variation with the base-case	0.00%	-6.04%	-26.35%	-31.84%	-35.60%
Heavy Metals (HM)	ng Ni eq.	35.94	33.43	26.31	24.35	23.01
	variation with the base-case	0.00%	-7.00%	-26.79%	-32.24%	-35.99%
PAHs	ng Ni eq.	8.89	7.88	6.33	5.86	5.54
	variation with the base-case	0.00%	-11.35%	-28.77%	-34.07%	-37.72%
Particulate Matter (PM, dust)	μg	19.71	17.66	14.13	13.07	12.35
	variation with the base-case	0.00%	-10.37%	-28.32%	-33.66%	-37.33%
Emissions (Water)						
Heavy Metals (HM)	ng Hg/20	11.51	10.87	8.50	7.87	7.43
	variation with the base-case	0.00%	-5.59%	-26.15%	-31.65%	-35.43%
Eutrophication (EP)	ng PO4	80.27	73.37	58.18	53.85	50.87
	variation with the base-case	0.00%	-8.60%	-27.52%	-32.92%	-36.62%

7.2.4 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 7.11.

Table 7.11: Key results of the improvement option analysis for the base-case HL-LV-R

Option	Option description	Product lifetime (hours)	Average 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***	3000	392	1278.4	**1088.15**	58.1	**49.49**	19.14	**16.29**
1	***Option1: Halogen reflector lamp, MR16, 12V, GU5.3, xenon***	2000	358	611.1	**853.89**	29.0	**40.55**	14.55	**20.33**
2	***Option2: Halogen reflector lamp, MR16, 12V, GU5.3, IRC + xenon***	5000	358	1445.8	**808.13**	65.4	**36.58**	25.38	**14.18**
3	***Option3: Halogen reflector lamp, MR16, 36°, 12V, GU5.3, IRC + silver/dichroic***	5000	329	1167.6	**710.70**	53.3	**32.45**	22.20	**13.51**
4	***Option4: Halogen reflector lamp, MR16, 36°, 12V, GU5.3, IRC + silver/dichroic + Anti-Refl***	3500	350	833.7	**680.51**	38.7	**31.62**	18.56	**15.15**

Figure 7.10 presents a comparison of both GER and LCC for each option on a per lumen per hour basis. Option 1 actually presents an increase in LCC of 25% over the base-case. The best performer in terms of LCC is option 3, reducing costs by 17% compared to the base-case. Option 4 reduced total energy use by 37.5%.

As was the case with HL-MV-R-LW, there is no mercury embedded in any of the options presented for HL-LV-R. Thus, mercury emissions are directly correlated to energy during the use phase. Global warming potential follows roughly the same trend as GER. Thus, Option 4 provides the greatest reduction in both cases, as seen in Figure 7.11.

Figure 7.12 shows the LCC compared to life-cycle electricity costs, where the difference between the two curves is the product price. Despite Option 4 having the lowest electricity costs, Option 3 has the lowest cost reduction because of the high product price of Option 4 (233% higher than that of the base-case).

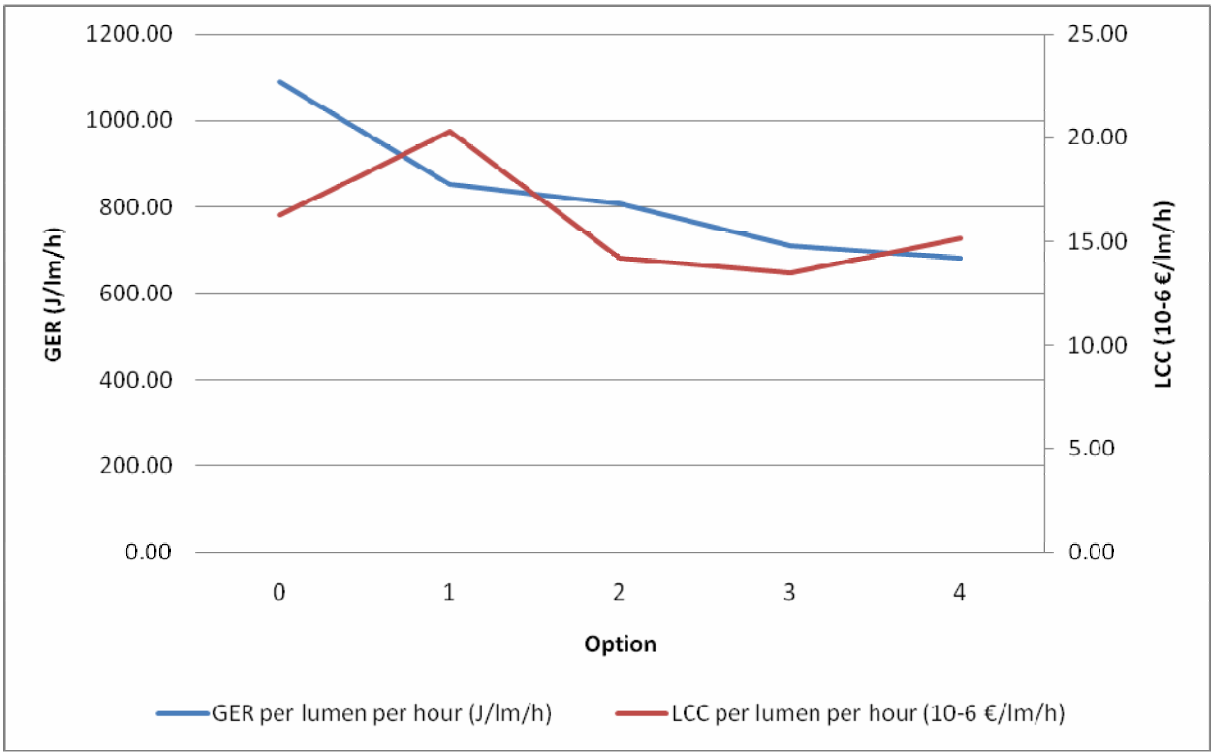

Figure 7.10: LCC curve – environmental performance expressed in total energy consumption (GER) for the improvement options for the base-case HL-LV-R

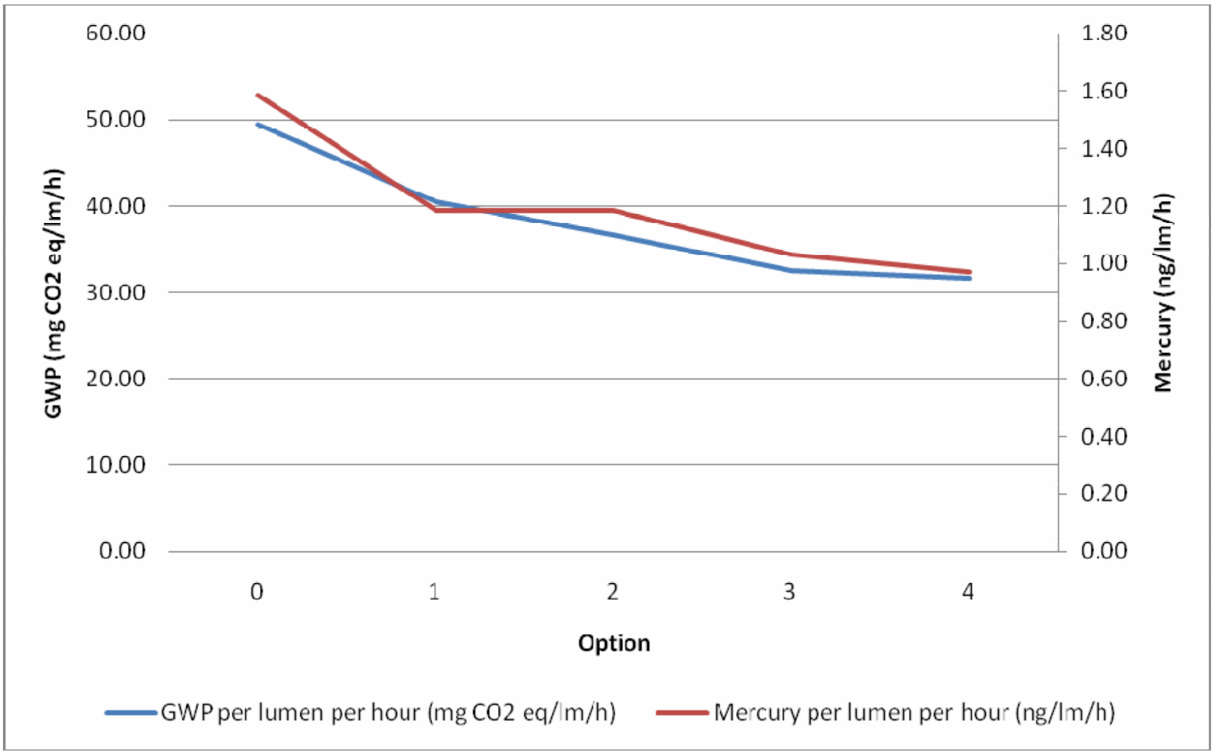

Figure 7.11: Environmental performance expressed in GWP and in mercury emissions for the improvement options for the base-case HL-LV-R

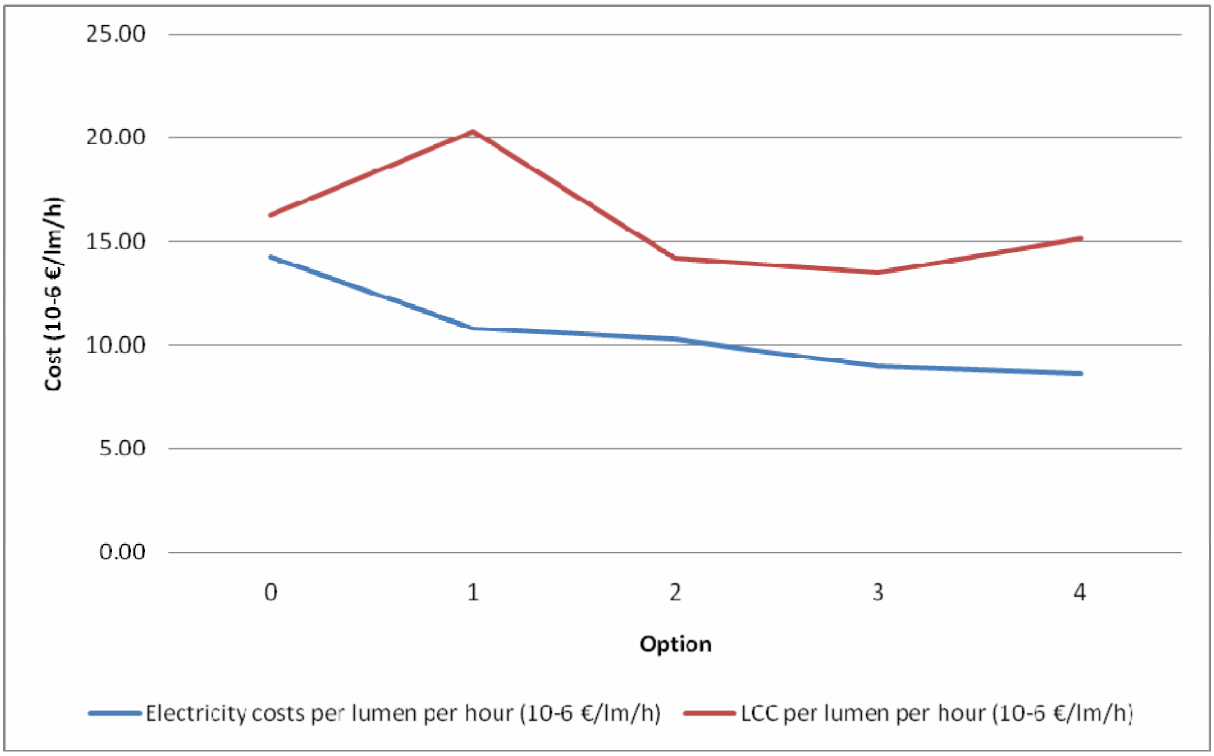

Figure 7.12: LCC curve – environmental performance expressed in total electricity costs for the improvement options for the base-case HL-LV-R

The outcomes of the LCA carried out with the EcoReport tool for both the base-case and its improvement options are provided in Table 7.12. Option 4 gives the biggest improvements on environmental indicators, reducing most categories by 20-40%. It is important to note that while improvement Option 1 decreases GER and GWP, some environmental indicators increase, particularly PAHs (+21%) and particulate matter (+10%). This is due to the shorter lifetime of Option 1 (-33%), which creates the need to replace lamps more often. These replaced lamps translate into greater environmental impacts from production and transportation.

Table 7.12: Comparison of HL-LV-R option for each environmental indicator

		Base-case HL-LV-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	1088.15	853.89	808.13	710.70	680.51
	variation with the base-case	0.00%	-21.53%	-25.73%	-34.69%	-37.46%
of which, electricity	J	1042.01	778.15	777.83	677.70	636.27
	variation with the base-case	0.00%	-25.32%	-25.35%	-34.96%	-38.94%
Water (process)	µltr	69.66	52.19	51.98	45.32	42.60
	variation with the base-case	0.00%	-25.08%	-25.38%	-34.94%	-38.84%
Water (cooling)	µltr	2777.84	2073.64	2073.64	1806.59	1695.88
	variation with the base-case	0.00%	-25.35%	-25.35%	-34.96%	-38.95%
Waste, non-haz./ landfill	µg	1285.45	1029.11	952.60	841.03	811.84
	variation with the base-case	0.00%	-19.94%	-25.89%	-34.57%	-36.84%
Waste, hazardous/ incinerated	µg	24.88	19.36	18.50	16.24	15.50
	variation with the base-case	0.00%	-22.19%	-25.67%	-34.74%	-37.72%
Emissions (Air)						
Greenhouse Gases in GWP100	mg CO2 eq.	49.49	40.55	36.58	32.45	31.62
	variation with the base-case	0.00%	-18.06%	-26.08%	-34.44%	-36.11%
Acidifying agents (AP)	µg SO2 eq.	278.88	217.71	207.23	182.06	173.97
	variation with the base-case	0.00%	-21.93%	-25.69%	-34.72%	-37.62%
Volatile Org. Compounds (VOC)	ng	449.97	387.49	330.72	296.37	294.79
	variation with the base-case	0.00%	-13.88%	-26.50%	-34.13%	-34.49%
Persistent Org. Pollutants (POP)	10^{-3} pg i-Teq	7.30	5.87	5.40	4.78	4.62
	variation with the base-case	0.00%	-19.60%	-25.93%	-34.55%	-36.71%
Heavy Metals (HM)	ng Ni eq.	20.64	17.88	15.16	13.60	13.56
	variation with the base-case	0.00%	-13.36%	-26.55%	-34.10%	-34.28%
PAHs	ng Ni eq.	4.30	5.22	3.01	2.94	3.41
	variation with the base-case	0.00%	21.41%	-30.05%	-31.58%	-20.75%
Particulate Matter (PM, dust)	µg	9.39	10.28	6.68	6.34	7.00
	variation with the base-case	0.00%	9.52%	-28.85%	-32.44%	-25.38%
Emissions (Water)						
Heavy Metals (HM)	ng Hg/20	6.94	5.38	5.16	4.53	4.32
	variation with the base-case	0.00%	-22.46%	-25.64%	-34.75%	-37.82%
Eutrophication (EP)	ng PO4	41.51	39.47	30.13	27.61	28.64
	variation with the base-case	0.00%	-4.91%	-27.40%	-33.49%	-30.99%

7.3 Conclusions

As presented in this chapter, the improvement potential of each of the 4 base-cases is significant. The Eco-Report analysis shows that most of the 17 environmental impact indicators, as well as mercury emissions to air, decrease by implementing an improvement option, mostly due to their electricity saving potential. However, the Least Life Cycle Cost (LLCC) option currently corresponds to the Best Available Technology (BAT) option only for base-case HL-MV-R-LW. For the other base-cases, the BAT does not provide great enough electricity cost savings to offset the high initial product price to become LLCC.

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, an 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.

8 SCENARIO- POLICY- IMPACT- AND SENSITIVITY ANALYSIS

For more info see website www.eup4light.net.