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Preparatory Studies for Eco-design Requirements of EuPs

Lot 19: Domestic lighting
Part 1 - Non-Directional Light Sources

Draft final task reports
Task 7: Improvement Potential

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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

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7 IMPROVEMENT POTENTIAL

<u>Important remark</u>*: This chapter 7 only discusses part 1 of the study and does not yet discuss directional light sources such as reflector lamps. Those products are being analysed in the second part 2 of the lot 19 study.*

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.

As discussed in chapter 5, the hazardous character of mercury – contained in fluorescent lamps and emitted from coal-based power generation – implies the necessity to limit its emissions. The lower the electricity consumption (i.e. the higher the lamp efficacy) is, the lower the mercury emissions will be during the use phase. In the case of CFLi, another way to decrease this environmental impact is by reducing the mercury content of the CFLi lamp itself and by recycling the mercury. Unfortunately it seems like only 20 % of the mercury content is recycled because EU-27 countries are far from fullfil the EU regulation about recycling of mercury.

The EcoReport tool considers only the air emissions of the mercury during the end-of-life treatment of compact fluorescent lamps. The environmental impacts of mercury emissions to water and soil are not modelled separately and consequently not discussed in this study. However, it can be expected that mercury in CFLi going into landfills will not be released only to air but also to soil and water. Since already on the basis of the emissions to air data, mercury is considered as significant environmental impact in domestic lighting, the emphasis is put on the improvement options aiming at lowering mercury content in CFLi.

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 7.3 for determining the LLCC and BAT options.

7.1.1 Base-case GLS-C

After a detailed analysis of available technologies in task 6, the improvement options to decrease environmental impacts of a clear incandescent lamp aim at reducing the electricity consumption during the use phase. Each improvement option applicable to the base-case GLS-C 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-C (clear incandescent lamp).

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

	Wattage	Average LLMF[1]	Lamp efficacy (lm/W)	Lumen output (lm)	LWFt[2]	Electricity consumption (Wh/h)	Lamp life time (hours)	Yearly burning hours (hours/year)	Lamp lifespan (years)
Base-case GLS-C	54	0.965	11.0	594.0	1	54	1000	400	2.50
Option1: Xenon HL-MV-LW	42	0.975	14.6	614.3	1	42	2000	400	5.00
Option2: HL-MV-LW with infrared coating and electronic transformer	30	0.975	20.5	614.3	1	30	4000	400	10.00
Option3: CFLi	13	0.925	43.0	559.0	1.05	13.65	6000	400	15.00

[1] Lamp Lumen Maintenance Factor
[2] Total Lamp Wattage Factor

7.1.1.1 Option 1: Replacing the GLS-C with a Xenon HL-MV-LW

As already demonstrated in chapter 5, a typical HL-MV-LW (40 W – 480 lumen) has lower environmental impacts per lumen and per hour compared to a GLS-C (54 W – 594 lumen) due to the higher lamp efficacy of the HL-MV-LW base-case (12 lm/W compared to 11 lm/W). Chapter 6 describes the HL-MV-LW technology improved by using Xenon as filling gas. Thus, replacing GLS-C by a 42 W Xenon HL-MV-LW can be considered as an improvement option as discussed in chapter 6, section 6.1.10.

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-LW (40 W) (see chapter 5).

This option is clearly more efficient since it has at the same time a higher lamp efficacy (+ 33 %), a higher lamp lifetime (+ 100 %) and a lower electricity consumption (- 22 %). Nevertheless, these benefits imply an increase of the product cost by 500 % (3.6 € compared to 0.6 €). This high cost augmentation could be a barrier for the end-user without any "life cycle thinking".

7.1.1.2 Option 2: Replacing the base-case GLS-C with a HL-MV-LW with infrared coating technology and integrated electronic transformer

In chapter 6 (see section 6.1.12), a new technology for halogen lamps (mains voltage) was presented. Use of infrared coating technology, together with an integrated electronic transformer, allows enhancing the lamp efficacy as well as extending the lifetime.

Compared to the base-case GLS-C (54 W), the lamp efficacy is 84 % higher, the lamp lifespan 400 % longer, and the electricity consumption about 44 % lower. However, a consumer purchasing such an improved HL-MV-LW will have to spend 9 € (cost increase of 1400%), which could be a barrier.

7.1.1.3 Option 3: Replacing the base-case GLS-C with a CFL with integrated ballast (CFLi)

The third improvement option of the base-case GLS-C is to replace it with a 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.

The base-case CFLi, with a power output of 13 W, was chosen because this is the average wattage value for CFLi in use in EU-27 (see chapter 2). From a lumen output point of view it would have been right to replace the base-case 54W GLS-C by a CFLi of 14W. Anyway, this does not have a significant impact in the later calculations which are normalized per lumen and per hour.

The lamp efficacy for the CFLi is 43 lm/W which is 291 % better than the lamp efficacy of the base-case GLS-C. Another significant benefit of this type of lamp is its lifetime of 6000 hours which is 6 times longer than the base-case. The BOM and the packaged volume of the base-case CFLi defined in chapter 5 were used for this option.

As for the previous improvement options, the high product price of a CFLi 13 W (4.6 €, i.e. an increase of 667% compared to the price of the base-case) could be a barrier if the consumer's focus is on the purchase price. Furthermore, a CFLi is not always a satisfactory alternative for a GLS-C, e.g. in a chandelier or where a bright light source is required (e.g. for colour rendering or brilliance effects).

7.1.2 Base-case GLS-F

Two of the three improvement options in the base-case GLS-C are also improvement options for the base-case GLS-F: Xenon HL-MV-LW (42 W) and CFLi (13W) (see the describtion in respectively section 7.1.1.1 and section 7.1.1.3). The GLS-C improvement option HL-MV-LW with infrared coating technology and integrated electronic transformer cannot be used since this lamp type does not exist with frosted glass.
The two improvement options mentioned above are compared to the base-case GLS-F in Table 7.2.

Table 7.2: Summary of the main characteristics of the improvement options for the base-case GLS-F

	Wattage	Average LLMF	Lamp efficacy (lm/W)	Lumen output (lm)	LWFt	Electricity consumption (Wh/h)	Lamp life time (hours)	Yearly burning hours (hours/year)	Lamp lifespan (years)
Base-case GLS-F	54	0.965	10.6	572.4	1	54	1000	400	2.50
Option1: Xenon HL-MV-LW	42	0.975	14.6	614.3	1	42	2000	400	5.00
Option2: CFLi	13	0.925	43.0	559.0	1.05	13.65	6000	400	15.00

Option 1 presents the advantage of having a higher lamp efficacy (+ 38 %) and a higher lamp lifetime (+ 100 %) while for a lower power output (- 22 %). Option 2 is even more advantageous as the lamp efficacy is increased by 306 % compared to the base-case GLS-F, while its lifetime and its power output are respectively + 600 % and - 75 % lower.
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-MV-LW

The only improvement option investigated for the base-case HL-MV-LW is the replacement with a Xenon HL-MV-LW (33 W). The characteristics of this substitution lamp are presented in chapter 6, section 6.1.10, 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-MV-LW

	Wattage	Average LLMF	Lamp efficacy (lm/W)	Lumen output (lm)	LWFt	Electricity consumption (Wh/h)	Lamp life time (hours)	Yearly burning hours (hours/year)	Lamp lifespan (years)
Base-case HL-MV-LW	40	0.975	12.0	480.0	1	40	1500	450	3.33
Option1: Xenon HL-MV-LW	33	0.975	13.6	447.2	1	33	2000	450	4.44

The advantages of using Xenon HL-MV-LW are 13 % higher lamp efficacy reducing, 18 % less power consumption and increasing the lamp lifetime by 33 %. The product price of this improvement option is 8.9 €, i.e. 3.4 € more than the base-case which might be a barrier.

Replacement with the BAT HL-MV-LW with infrared coating technology and integrated electronic transformer is not considered as an improvement option because the socket type of the base-case is G9 and the BAT is only available for the socket types E27/B22D and E14/B15d.

7.1.4 Base-case HL-MV-HW

As for the base-case HL-MV-LW (300 W), the base-case HL-MV-HW can be improved with the use of Xenon of filling gas (230 W). The replacement lamp is assumed to have the same BOM and packaged volume as its base-case. The advantages are higher lamp efficacy (+ 24 %), lower electricity consumption (- 23 %) and longer lamp lifetime (+ 33 %), as highlighted in Table 7.4. The product price is 27% higher (3.8 € compared to 3 €).

Table 7.4: Summary of the main characteristics of the improvement option for the base-case HL-MV-HW

	Wattage	Average LLMF	Lamp efficacy (lm/W)	Lumen output (lm)	LWFt	Electricity consumption (Wh/h)	Lamp life time (hours)	Yearly burning hours (hours/year)	Lamp lifespan (years)
Base-case HL-MV-HW	300	0.975	17.3	5177.3	1	300	1500	450	3.33
Option1: Xenon HL-MV-HW	230	0.975	21.5	4933.5	1	230	2000	450	4.44

7.1.5 Base-case HL-LV

The improvement option identified for the base-case HL-LV (30 W) is the use of the infrared coating technology. It was assumed that the BOM and the volume of the improved product remain the same as for the base-case.

Table 7.5: Summary of the main characteristics of the improvement option for the base-case HL-LV

	Wattage	Average LLMF	Lamp efficacy (lm/W)	Lumen output (lm)	LWFt	Electricity consumption (Wh/h)	Lamp life time (hours)	Yearly burning hours (hours/year)	Lamp lifespan (years)
Base-case HL-LV	30	0.975	14.5	435.0	1.11	33.3	3000	500	6.00
Option1: HL-LV with infrared coating technology	20	0.975	18.4	368.6	1.11	22.2	4000	500	8.00

The improvement option is characterised by a 27 % higher lamp efficacy and a 33 % extended lamp lifetime, while the product price is much higher (7 € compared to 3 €). Furthermore, the use of the infrared coating technology in a HL-LV lamp provides an extension of the lamp lifetime (4000 hours compared to 3000 hour for the base-case HL-LV).
As for the base-cases HL-MV (both HL-MV-LW and HL-MV-HW), a CFLi cannot substitute the base-case HL-LV as the socket/cap of these two lamp types are different (2 pins for a typical HL-LV and a screw socket for a typical CFLi). Therefore, the luminaire also needs to be changed. Since luminaires will be examined in part 2 of this preparatory study, this improvement option will be discussed during the second phase.

7.1.6 Base-case CFLi

Based on the Best Available Technologies (BATs) related to compact fluorescent lamps with integrated ballast presented in chapter 6, four improvement options were identified. Option 1 aims at reducing direct environmental impacts with less mercury contained in the lamp, and Options 2 to 4 allow reducing the environmental impacts (per lumen and per hour) by an increased lamp efficacy and/or by longer lifetime. The comparison per lumen and per hour will be further discussed in section 7.2.5.

Table 7.6 presents the main technical characteristics of the base-case CFLi and its improvement options. All lamps have the same power input (13 W).

Table 7.6: Summary of the main characteristics of the improvement options for the base-case CFLi

	Wattage	Average LLMF	Lamp efficacy (lm/W)	Lumen output (lm)	LWFt	Electricity consumption (Wh/h)	Lamp life time (hours)	Yearly burning hours (hours/year)	Lamp lifespan (years)
Base-case CFLi	13	0.925	43.0	559.0	1.05	13.65	6000	800	7.50
Option1: CFLi with less mercury (2 mg)	13	0.925	39.8	559.0	1.05	13.65	6000	800	7.50
Option2: CFLi with enhanced lamp efficacy	13	0.925	48.2	626.3	1.05	13.65	6000	800	7.50
Option3: CFLi with enhanced lamp efficacy and long life time	13	0.925	48.2	626.3	1.05	13.65	10000	800	12.50
Option4: CFLi with enhanced lamp efficacy and very long life time	13	0.925	48.2	626.3	1.05	13.65	15000	800	18.75

7.1.6.1 Option 1: Replacing the base-case CFLi with a CFLi with less mercury

The fluorescent lamp technology includes use of mercury. As mercury is a hazardous substance, reduction in use of mercury is an environmental improvement. There are CFLi available on the market with less mercury content (2 mg) than the base-case (4 mg) and use of these CFLi is assessed as Option 1. Apart from the different mercury content, the BOM of Option 1 is assumed to be equal to the BOM of the base-case. The product price for these CFLi is a little higher (5 € compared to 4.6 €).

7.1.6.2 Option 2: Replacing the base-case CFLi with a CFLi with enhanced lamp efficacy

As mentioned in chapter 6 (section 6.1.1), the integration of an electronic control circuit inside a CFLi allows enhancing its lamp efficacy. Therefore, compared to the base-case CFLi, for the same wattage, the lumen output increases by 12 % for a 8 % higher product price.

Since the production phase is negligible for the environmental impacts over the whole life cycle, the BOM of Option 2 is assumed to be equal to the BOM of the base-case.

7.1.6.3 Option 3: Replacing the base-case CFLi with a CFLi with enhanced lamp efficacy and long lifetime (10000 h)

In case the quality of the electronic control circuitry is high, both the lamp efficacy and the lamp lifetime are increased. For a product price nearly the double price of the base-case (9 € compared to 4.6 €), the lamp efficacy is improved as in Option 2 while the lifetime is extended (10000 hours compared to 6000 hours for the base-case).

As for Option 2, technical data (BOM and packaged volume) of this improvement option were assumed to be the same as the base-case.

7.1.6.4 Option 4: Replacing the base-case CFLi with a CFLi with enhanced lamp efficacy and very long lifetime (15000 h)

With electronic control circuit of even higher quality than in Option 3, a CFLi can provide a "very long" lifetime (15000 hours) while the lamp efficacy is the same as in Options 2 and 3. The product price is very high compared to the base-case (11 € compared to 4.6 €).

The bill of materials and the package volume is also the same as for the base-case.

7.1.6.5 Option5: Option 1 + Option 3

According to the MEEuP methodology, the assessment of the cumulative improvement and cost effect due to the implementation of various options simultaneously should be carried out.
Contrary to the other base-cases, a combination of several improvement options exists for the base-case CFLi, by combining Option 1 (CFLi with less mercury) and Option 3 (CFLi with enhanced lamp efficacy and long lifetime, 10000 hours).
The product price of this combination (Option 5) is 10 €.

Combination of options will be compared to the base-case in section 7.2.6.

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.

7.2.1 Base-case GLS-C

Based on the inputs of the improvement options presented in section 7.1.1, Table 7.7 highlights the main results in terms of environmental impacts (GER and GWP) as well as in monetary terms (Life Cycle Cost).

Table 7.7: Key results of the improvement options analysis for the base-case GLS-C

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} €)*
0	***Base Case GLS-C***	1000	594.0	621	**1045**	29	**49.54**	8.60	**14.47**
1	***Replacement with Xenon HL-MV***	2000	614.3	934	**760**	43	**35.04**	15.77	**12.84**
2	***Replacement with HL-MV with infrared coating and electronic transformer***	4000	614.3	1344	**547**	61	**24.91**	25.64	**10.44**
3	***Replacement with CFLi***	6000	559.0	925	**276**	43	**12.74**	15.51	**4.62**

Figure 7.1 shows that Option 3 leads clearly to the least life cycle cost (per lumen and per hour) and requires much 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 68 % and about 74 % in terms of total energy consumption.

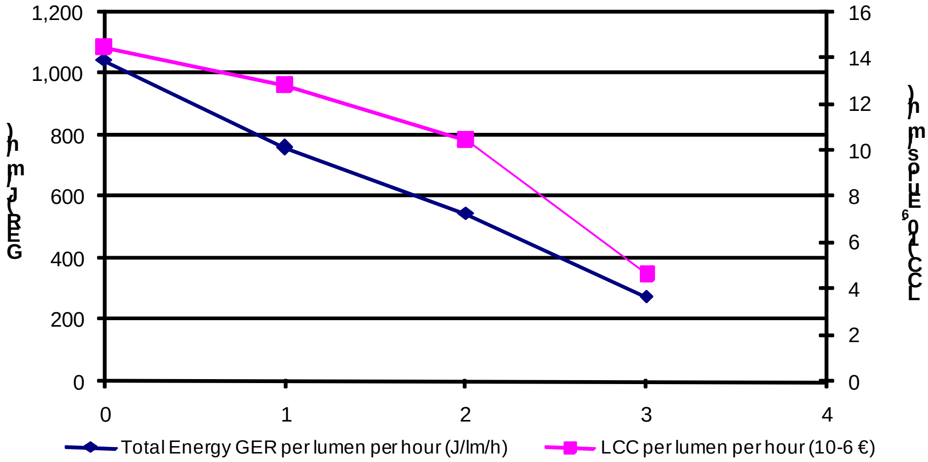

Figure 7.1: LCC curve – environmental performance expressed in total energy consumption (GER) for the improvement options for the base-case GLS-C

Figure 7.2 presents the same trend when the focus is on the global warming potential. 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 (assumed equal to 80 %). Therefore, for a typical CFLi containing 4 mg of mercury, 3.2 mg is assumed to be emitted to air at the end-of-life due to it seems like only 20 % of the mercury content is recycled at present although EU regulation requires recycling.

Due to the lack of recycling, Option 3 does not give the lowest overall mercury emissions although the electricity consumption per lumen and per hour is much lower for this option. Option 2 (replacement with HL-MV-LW with infrared coating and electronic transformer) provides a reduction of 46.3 % of mercury emissions whereas Option 3 (replacement with CFLi) implies 'only' a reduction of 7.5 %. This statement is clearly highlighted in Figure 7.2.

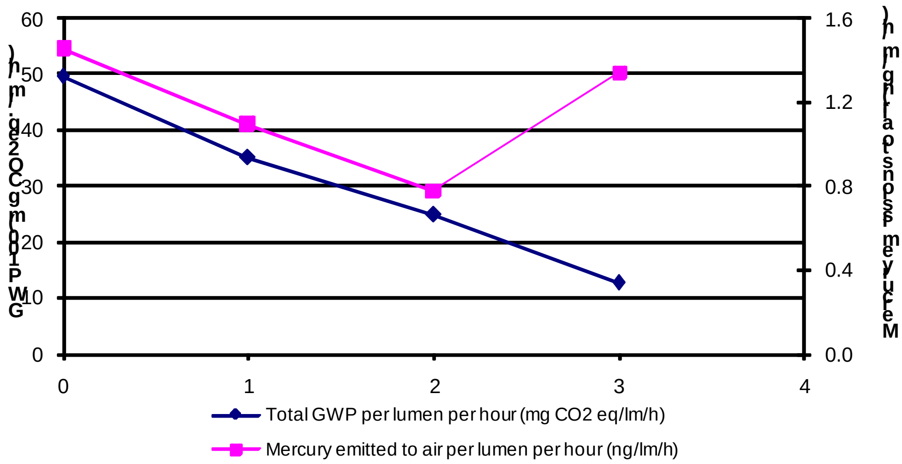

Figure 7.2: Environmental performance expressed in GWP and in mercury emissions for the improvement options for the base-case GLS-C

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.

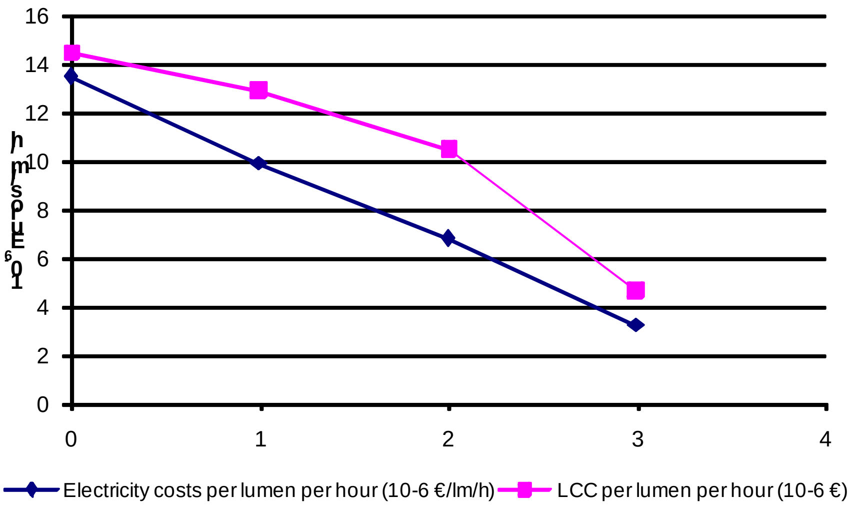

Figure 7.3: LCC curve – environmental performance expressed in total electricity costs for the improvement options for the base-case GLS-C

The complete results of the EcoReport are presented per lumen and per hour in Table 7.8. Variations with the base-case GLS-C are also given in order to allow a straightforward comparison.

Table 7.8: Comparison of GLS-C options for each environmental indicator

		Base-case GLS-C	*Option 1*	*Option 2*	*Option 3*
main environmental indicators	**unit**	**value per lumen per hour**	**value per lumen per hour**	**value per lumen per hour**	**value per lumen per hour**
Total Energy (GER)	J	**1045.2**	**760.3**	**546.8**	**275.8**
	variation with the base-case	*0.0%*	*-27.3%*	*-47.7%*	*-73.6%*
of which, electricity	J	**955.0**	**718.0**	**518.0**	**258.2**
	variation with the base-case	*0.0%*	*-24.8%*	*-45.8%*	*-73.0%*
Water (process)	µltr	**63.9**	**47.9**	**40.7**	**19.3**
	variation with the base-case	*0.0%*	*-25.1%*	*-36.4%*	*-69.8%*
Water (cooling)	µltr	**2545.5**	**1914.5**	**1369.7**	**684.5**
	variation with the base-case	*0.0%*	*-24.8%*	*-46.2%*	*-73.1%*
Waste, non-haz./ landfill	µg	**1245.8**	**876.4**	**701.7**	**328.7**
	variation with the base-case	*0.0%*	*-29.7%*	*-43.7%*	*-73.6%*
Waste, hazardous/ incinerated	µg	**23.7**	**17.4**	**85.8**	**30.8**
	variation with the base-case	*0.0%*	*-26.8%*	*261.7%*	*29.9%*
Emissions (Air)					
Greenhouse Gases in GWP100	mg CO2 eq.	**49.5**	**35.0**	**24.9**	**12.7**
	variation with the base-case	*0.0%*	*-29.3%*	*-49.7%*	*-74.3%*
Acidifying agents (AP)	µg SO2 eq.	**266.7**	**194.7**	**141.7**	**71.2**
	variation with the base-case	*0.0%*	*-27.0%*	*-46.9%*	*-73.3%*
Volatile Org. Compounds (VOC)	ng	**463.7**	**317.1**	**279.6**	**134.7**
	variation with the base-case	*0.0%*	*-31.6%*	*-39.7%*	*-71.0%*
Persistent Org. Pollutants (POP)	10^{-3} pg i-Teq	**7.06**	**4.96**	**3.82**	**1.80**
	variation with the base-case	*0.0%*	*-29.8%*	*-45.9%*	*-74.6%*
Heavy Metals (HM)	ng Ni eq.	**21.5**	**14.5**	**11.1**	**5.4**
	variation with the base-case	*0.0%*	*-32.7%*	*-48.3%*	*-74.8%*
PAHs	ng Ni eq.	**6.51**	**3.56**	**2.29**	**1.35**
	variation with the base-case	*0.0%*	*-45.4%*	*-64.8%*	*-79.3%*
Particulate Matter (PM, dust)	µg	**10.2**	**5.1**	**6.8**	**2.0**
	variation with the base-case	*0.0%*	*-50.1%*	*-33.7%*	*-80.6%*
Emissions (Water)					
Heavy Metals (HM)	ng Hg/20	**6.57**	**4.70**	**8.71**	**3.41**
	variation with the base-case	*0.0%*	*-28.4%*	*32.6%*	*-48.1%*
Eutrophication (EP)	ng PO4	**43.2**	**23.7**	**83.0**	**27.3**
	variation with the base-case	*0.0%*	*-45.0%*	*92.3%*	*-36.6%*

Table 7.8 shows that the replacement of a GLS-C 54 W by a typical CFLi 13 W is the best option for all environmental indicators, with a decrease of about 75 % for all the environmental impact indicators, except for the eutrophication and emissions of heavy metals to water, as well as for the weight of waste incinerated where only Option 1 presents a

reduction compared to the base-case. This is explained by the fact that Option 1 only contains glass and aluminium in its BOM, whereas Option 2 and Option 3 also contain electronics (printed wire board) due to the transformer (for Option 2) or to the ballast (for Option 3).
These electronic parts also explain the more modest reduction for the two indicators related to the emissions to water (heavy metals and eutrophication) for Option 3 compared to the other environmental impacts.

The analysis of the improvement options of the base-case GLS-C shows that the CFLi 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 GLS-F

The main outcomes of the environmental assessment of the base-case GLS-F and of its improvement options as well as their life cycle cost are presented in Table 7.9. Values are given per lumen and per hour allowing a comparison between the lamp types.

Environmental impacts and LCC of the improvement options are the same as Option 1 and Option 3 of the base-case GLS-C since these two options have the same characteristics.

Table 7.9: Key results of the improvement option analysis for the base-case GLS-F

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} €)*
0	***Base-Case GLS-F***	1000	572.4	621	**1085**	29	**51.41**	8.60	**15.02**
1	***Replacement with Xenon HL-MV-LW***	2000	614.3	934	**760**	43	**35.04**	15.77	**12.84**
2	***Replacement with CFLi***	6000	559	925	**276**	43	**12.74**	15.51	**4.62**

The environmental indicators GER, GWP and mercury emissions are plotted in Figure 7.4 and Figure 7.5. Replacing a typical frosted incandescent lamp (54 W) with a typical CFLi (13 W) results in the decrease of the total energy required during the entire life cycle by 75 %. The reduction is the same for the global warming potential.
Regarding mercury emissions over the whole life cycle, as for the base-case GLS-C, the improvement option allowing the greater reduction is Option 1 (1.09 ng/lm/h compared to 1.51 ng/lm/h for the base-case GLS-F and 1.34 ng/lm/h for Option 2), as Option 2 contained mercury (4 mg) and 80 % is emitted ad end-of-life due to only 20 % of the CFLi seems to be recycled.

The percentage decrease in environmental impacts compared to the base-case is greater than for the base-case GLS-C, as the lumen output of the latter is higher than for the base-case GLS-F (11 lm/W compared to 10.6 lm/W). Regarding the impacts of Option 1 and Option 2 in monetary terms, Figure 7.4 and Figure 7.6 show a reduction of about respectively 15 % and 69 % compared to the base-case GLS-F.

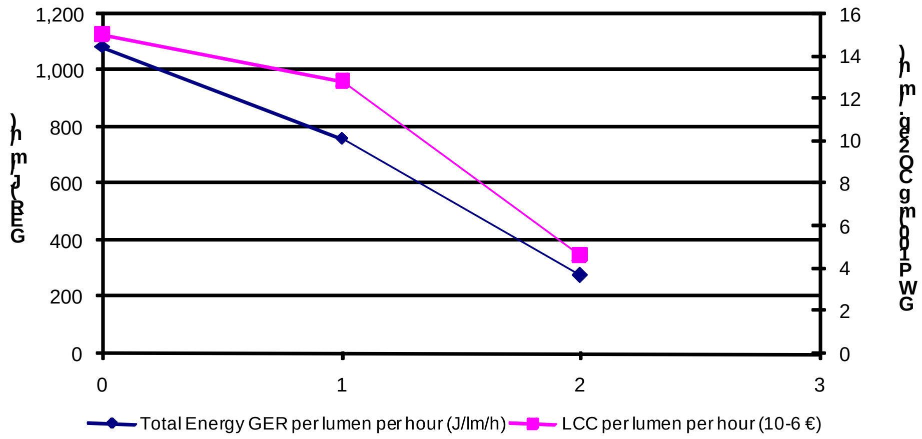

Figure 7.4: LCC curve – environmental performance expressed in total energy consumption (GER) for the improvement options for the base-case GLS-F

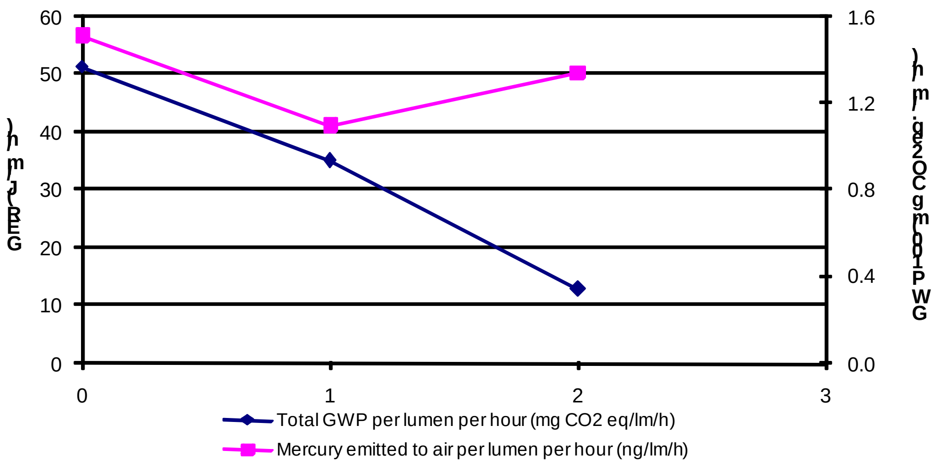

Figure 7.5: Environmental performance expressed in GWP and in mercury emissions for the improvement options for the base-case GLS-F

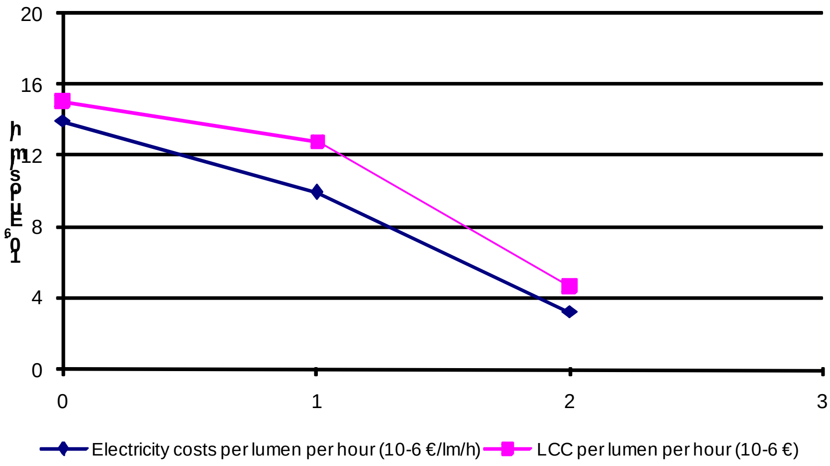

Figure 7.6: LCC curve – environmental performance expressed in total electricity costs for the improvement options for the base-case GLS-F

Table 7.10 presents the EcoReport outcomes per lumen and per hour as well as the difference of Option 1 and Option 2 results compared to those of the base-case.

Table 7.10: Comparison of GLS-F option for each environmental indicator

main environmental indicators	unit	***Base-case GLS-F*** value per lumen per hour	***Option 1*** value per lumen per hour	***Option 2*** value per lumen per hour
Total Energy (GER)	J	**1084.6**	**760.3**	**275.8**
	variation with the base-case	*0.0%*	*-29.9%*	*-74.6%*
of which, electricity	J	**991.0**	**718.0**	**258.2**
	variation with the base-case	*0.0%*	*-27.6%*	*-73.9%*
Water (process)	µltr	**66.3**	**47.9**	**19.3**
	variation with the base-case	*0.0%*	*-27.8%*	*-70.9%*
Water (cooling)	µltr	**2641.5**	**1914.5**	**684.5**
	variation with the base-case	*0.0%*	*-27.5%*	*-74.1%*
Waste, non-haz./ landfill	µg	**1292.8**	**876.4**	**328.7**
	variation with the base-case	*0.0%*	*-32.2%*	*-74.6%*
Waste, hazardous/ incinerated	µg	**24.6**	**17.4**	**30.8**
	variation with the base-case	*0.0%*	*-29.4%*	*25.1%*
Emissions (Air)				
Greenhouse Gases in GWP100	mg CO2 eq.	**51.4**	**35.0**	**12.7**
	variation with the base-case	*0.0%*	*-31.8%*	*-75.2%*
Acidifying agents (AP)	µg SO2 eq.	**276.8**	**194.7**	**71.2**
	variation with the base-case	*0.0%*	*-29.6%*	*-74.3%*
Volatile Org. Compounds (VOC)	ng	**481.2**	**317.1**	**134.7**
	variation with the base-case	*0.0%*	*-34.1%*	*-72.0%*
Persistent Org. Pollutants (POP)	10^{-3} pg i-Teq	**7.33**	**4.96**	**1.80**
	variation with the base-case	*0.0%*	*-32.4%*	*-75.5%*
Heavy Metals (HM)	ng Ni eq.	**22.3**	**14.5**	**5.4**
	variation with the base-case	*0.0%*	*-35.1%*	*-75.7%*
PAHs	ng Ni eq.	**6.76**	**3.56**	**1.35**
	variation with the base-case	*0.0%*	*-47.4%*	*-80.1%*
Particulate Matter (PM, dust)	µg	**10.6**	**5.1**	**2.0**
	variation with the base-case	*0.0%*	*-52.0%*	*-81.3%*
Emissions (Water)				
Heavy Metals (HM)	ng Hg/20	**6.81**	**4.70**	**3.41**
	variation with the base-case	*0.0%*	*-31.0%*	*-50.0%*
Eutrophication (EP)	ng PO4	**44.8**	**23.7**	**27.3**
	variation with the base-case	*0.0%*	*-47.0%*	*-38.9%*

Option 2 (replacement with a CFLi) results in a reduction of impacts by about 75 % compared to the base-case GLS-F for most of the environmental indicators, except for “waste, hazardous/incinerated” (+ 25.1 %), “emissions of heavy metals to water” (- 50.0 %) and

“eutrophication” (- 38.9 %). For the two later environmental impacts, Option 1 (replacement with a Xenon HL-MV-LW) allows the highest reduction.
As for the base-case GLS-C, the higher impacts for hazardous waste and the more modest reductions in the emissions to water are explained by the bill of materials of the CFLi. Indeed, electronic components used for the integrated ballast have a significant contribution to those impacts.

7.2.3 Base-case HL-MV-LW

The improvement option of the base-case HL-MV-LW (40 W) uses Xenon as filling gas. Besides increasing the lamp efficacy by 13 %, this improvement option also has an extended lifetime (2000 hours compared to 1500 hours for the base-case). Table 7.11 presents key environmental and monetary results from the EcoReport tool.

Table 7.11: Key results of the improvement option analysis for the base-case HL-MV-LW

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} €)*
0	Base-Case HL-MV-LW	1500	480.0	682	**946.86**	32	**44.49**	14.32	**19.89**
1	Replacement with Xenon HL-MV-LW	2000	447.2	745	**832.61**	35	**38.89**	18.51	**20.69**

When replacing the base-case HL-MV-LW with a Xenon HL-MV-LW, all environmental impacts are reduced, such as the total energy consumption (GER) and the global warming potential (GWP) as shown in Figure 7.7. Trends are similar for both indicators and the reduction compared to the base-case is about 12 %.

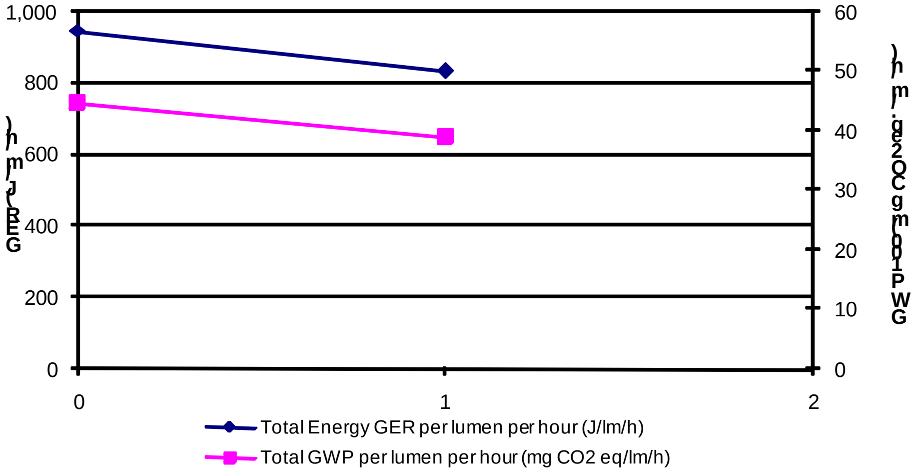

Figure 7.7: Environmental performances expressed in GER and in GWP for the improvement option for the base-case HL-MV-LW

Figure 7.8, electricity costs, representing the electricity consumption during the use phase, present the same trend as GER or GWP. Indeed, the reduction with Option 1 is about 12 % compared to the base-case HL-MV-LW.
Even if electricity costs (per lumen and per hour) are lower for Option 1, the LCC (per lumen and per hour) of this improvement option is not reduced compared to the base-case, and the increase is of 4 %. The explanation is that this improvement is quite recent. However, it can be expected that the product price (which is the gap between the pink and blue curves in Figure 7.10) of the Xenon HL-MV-LW will decrease in few years and therefore this lamp will be more efficient both in environmental and monetary terms.

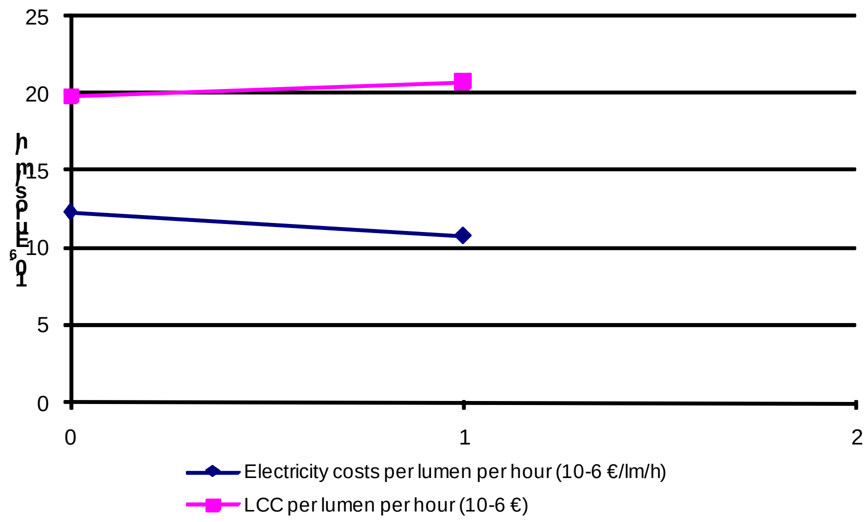

Figure 7.8: LCC curve – environmental performance expressed in total electricity costs for the improvement option for the base-case HL-MV-LW

Outcomes of the LCA carried out with the EcoReport tool for both the base-case HL-MV-LW and its improvement option are provided in Table 7.12. Reductions of environmental impacts are between 11.5 % and 13 % except for the emissions of PAH to air.

Moreover, when looking at mercury emissions, for halogen lamps, only the use phase contributes to this environmental damage as this lamp type does not contain mercury in its BOM (contrary to CFLi). Therefore, Option 1 allows the same decrease as for the electricity consumption, i.e. 11.5 %.

Table 7.12: Comparison of HL-MV-LW option for each environmental indicator

		Base-case HL-MV-LW	*Option 1*
main environmental indicators	**unit**	**value per lumen per hour**	**value per lumen per hour**
Total Energy (GER)	J	**946.9**	**832.6**
	variation with the base-case	*0.0%*	*-12.1%*
of which, electricity	J	**875.0**	**774.8**
	variation with the base-case	*0.0%*	*-11.5%*
Water (process)	µltr	**58.4**	**51.7**
	variation with the base-case	*0.0%*	*-11.5%*
Water (cooling)	µltr	**2333.3**	**2066.0**
	variation with the base-case	*0.0%*	*-11.5%*
Waste, non-haz./ landfill	µg	**1089.3**	**958.5**
	variation with the base-case	*0.0%*	*-12.0%*
Waste, hazardous/ incinerated	µg	**21.6**	**19.0**
	variation with the base-case	*0.0%*	*-12.0%*
Emissions (Air)			
Greenhouse Gases in GWP100	mg CO2 eq.	**44.5**	**38.9**
	variation with the base-case	*0.0%*	*-12.6%*
Acidifying agents (AP)	µg SO2 eq.	**242.0**	**213.0**
	variation with the base-case	*0.0%*	*-12.0%*
Volatile Org. Compounds (VOC)	ng	**402.4**	**350.4**
	variation with the base-case	*0.0%*	*-12.9%*
Persistent Org. Pollutants (POP)	10^{-3} pg i-Teq	**6.16**	**5.42**
	variation with the base-case	*0.0%*	*-12.0%*
Heavy Metals (HM)	ng Ni eq.	**18.7**	**16.3**
	variation with the base-case	*0.0%*	*-13.0%*
PAHs	ng Ni eq.	**5.36**	**4.46**
	variation with the base-case	*0.0%*	*-16.9%*
Particulate Matter (PM, dust)	µg	**5.65**	**4.94**
	variation with the base-case	*0.0%*	*-12.7%*
Emissions (Water)			
Heavy Metals (HM)	ng Hg/20	**5.77**	**5.10**
	variation with the base-case	*0.0%*	*-11.6%*
Eutrophication (EP)	ng PO4	**29.7**	**26.1**
	variation with the base-case	*0.0%*	*-12.2%*

Using a Xenon HL-MV-LW instead of a typical HL-MV-LV is clearly more advantageous in terms of environmental impacts. However, due to the novelty of this improvement option on the market, its high product price increases the LCC per lumen and per hour compared to the base-case.

7.2.4 Base-case HL-MV-HW

The improvement option identified for the base-case HL-MV-HW (Xenon HL-MV-HW) aims at increasing the lamp efficacy as well as the lamp lifetime without implying other changes. The main impacts of Option 1 compared to the base-case Hl-MV-HW are presented in Table 7.13.

Table 7.13: Key results of the improvement option analysis for the base-case HL-MV-HW

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} €)*
0	***Base-Case HL-MV-HW***	1500	5177.3	4777	**615.19**	211	**27.14**	69.16	**8.91**
1	***Replacement with Xenon HL-MV-HW***	2000	4933.5	4882	**494.83**	215	**21.83**	70.77	**7.17**

Reductions of GER and GWP between Option 1 and the base-case being equal, the trend of the two curves in Figure 7.9 is the same. The reduction for both environmental impacts is about 19.6 %.

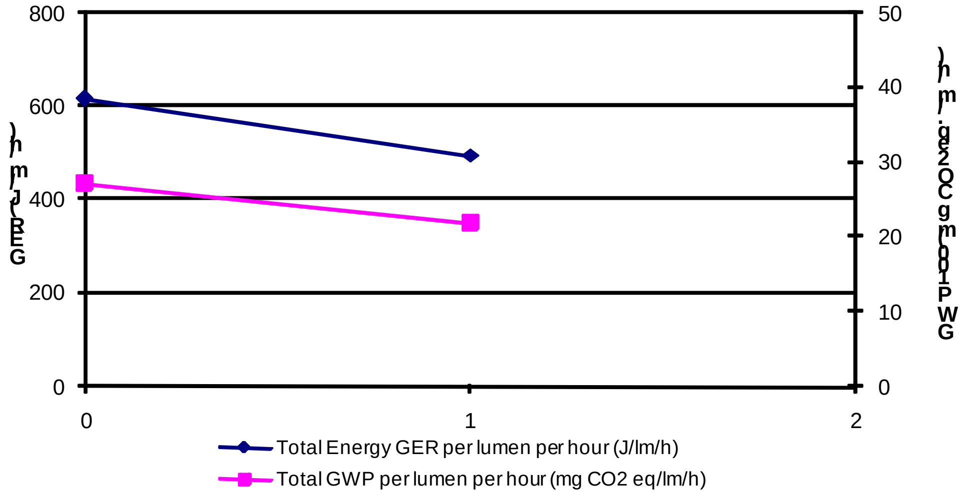

Figure 7.9: Environmental performances expressed in GER and in GWP for the improvement option for the base-case HL-MV-HW

Even with a higher product price (3.8 € compared to 3 € for the base-case), the use of a Xenon HL-MV-HW is economically advantageous as the Life Cycle Cost is also about 19.5 % lower. This variation is similar to those of the environmental impacts since electricity costs represent around 95 % of the LCC and since the variation of electricity consumption between Option 1 and the base-case is 19.6 %.

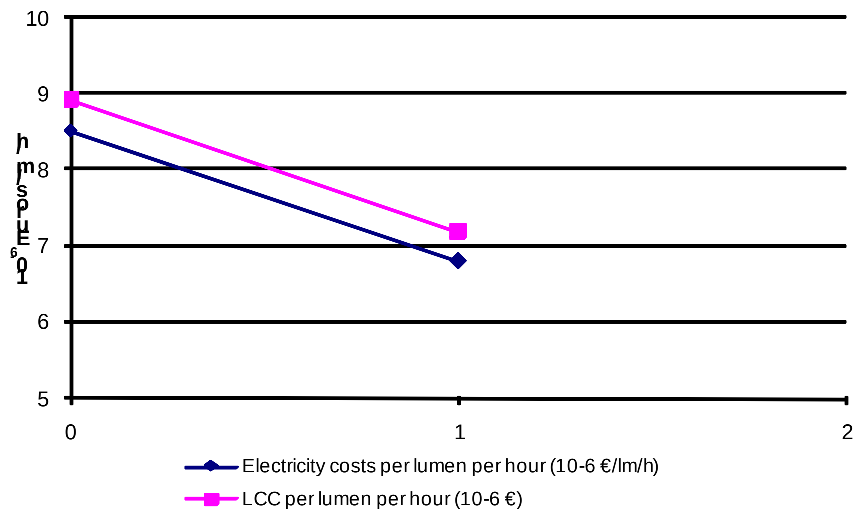

Figure 7.10: LCC curve – environmental performance expressed in total electricity costs for the improvement option for the base-case HL-MV-HW

Variation of environmental impacts between Option 1 and the base-case is between 19.5 % and 19.6 %, i.e. equal to the variation of the lamp efficacy of the two lamps (21.5 lm/W for Option 1 and 17.3 lm/W for the base-case), except for the indicator "emissions of PAHs to air" (-19.9 %).

Compared to other base-cases, one may observe that the variation is quite constant for all environmental indicators for the base-case HL-MV-HW. This can be explained by the fact that the use phase contributes for at least 94 % of the environmental impacts over the whole life cycle, except for the emissions of PAHs to air (78 %). Therefore, the contributions of the other stages are quite insignificant and variations of the environmental impacts are only visible for the use phase and so for the impacts due to the electricity consumption. Thus, the reduction due to the use of Option 1 is almost similar, and equal to the one of the indicator "electricity".
The exception is for the emission of PAHs as for this indicator the use phase is 'only' responsible of 78 % of the total over the life cycle.

Although not presented in the following table, the reduction of mercury emissions is also about 19.6 %.

Table 7.14: Comparison of HL-MV-HW option for each environmental indicator

		Base-case HL-MV-HW	***Option 1***
main environmental indicators	**unit**	**value per lumen per hour**	**value per lumen per hour**
Total Energy (GER)	J	**615.2**	**494.8**
	variation with the base-case	*0.0%*	*-19.6%*
of which, electricity	J	**608.4**	**489.5**
	variation with the base-case	*0.0%*	*-19.5%*
Water (process)	µltr	**40.6**	**32.6**
	variation with the base-case	*0.0%*	*-19.5%*
Water (cooling)	µltr	**1622.5**	**1305.4**
	variation with the base-case	*0.0%*	*-19.5%*
Waste, non-haz./ landfill	µg	**713.5**	**573.9**
	variation with the base-case	*0.0%*	*-19.6%*
Waste, hazardous/ incinerated	µg	**14.2**	**11.4**
	variation with the base-case	*0.0%*	*-19.6%*
Emissions (Air)			
Greenhouse Gases in GWP100	mg CO2 eq.	**27.1**	**21.8**
	variation with the base-case	*0.0%*	*-19.6%*
Acidifying agents (AP)	µg SO2 eq.	**158.2**	**127.3**
	variation with the base-case	*0.0%*	*-19.6%*
Volatile Org. Compounds (VOC)	ng	**236.4**	**190.1**
	variation with the base-case	*0.0%*	*-19.6%*
Persistent Org. Pollutants (POP)	10^{-3} pg i-Teq	**4.04**	**3.25**
	variation with the base-case	*0.0%*	*-19.6%*
Heavy Metals (HM)	ng Ni eq.	**10.8**	**8.7**
	variation with the base-case	*0.0%*	*-19.6%*
PAHs	ng Ni eq.	**1.54**	**1.23**
	variation with the base-case	*0.0%*	*-19.9%*
Particulate Matter (PM, dust)	µg	**3.55**	**2.85**
	variation with the base-case	*0.0%*	*-19.6%*
Emissions (Water)			
Heavy Metals (HM)	ng Hg/20	**3.94**	**3.17**
	variation with the base-case	*0.0%*	*-19.6%*
Eutrophication (EP)	ng PO4	**19.3**	**15.5**
	variation with the base-case	*0.0%*	*-19.6%*

As for the base-case HL-MV-LV, the use of Xenon as filling reduces all environmental impacts compared to the base-case. Further, this improvement option is also attractive in monetary terms.

7.2.5 Base-case HL-LV

The improvement option of the base-case HL-LV (30 W) employs the infrared coating technology. Besides increasing the lamp efficacy by 27 %, Option 1 also has an extended lifetime (4000 hours compared to 3000 hours for the base-case). Table 7.15 present key results from the EcoReport tool.

Table 7.15: Key results of the improvement option analysis for the base-case HL-LV

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} €)
0	***Base-Case HL-LV***	3000	435.0	1101	**844**	50	**38.56**	17.35	**13.29**
1	***Replacement with HL-LV with infrared coating***	4000	368.6	984	**668**	45	**30.69**	19.53	**13.25**

Option 1 leads to a reduction of the GER by 20.8 % compared to the base-case HL-LV, and the GWP by 20.4 % for the indicator GWP as shown in Figure 7.11.

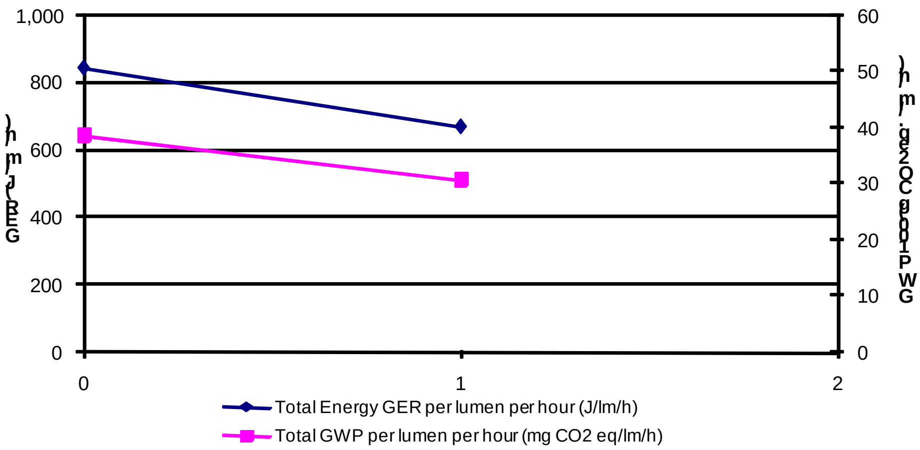

Figure 7.11: Environmental performances expressed in GER and in GWP for the improvement option for the base-case HL-LV

When looking at the life cycle cost and at electricity costs, it is clearly visible that Option 1 does not present a important advantageous in monetary terms, with only a reduction of 0.3 % when comparing per lumen and per hour (see Figure 7.12). This is due to the increase of the product cost.

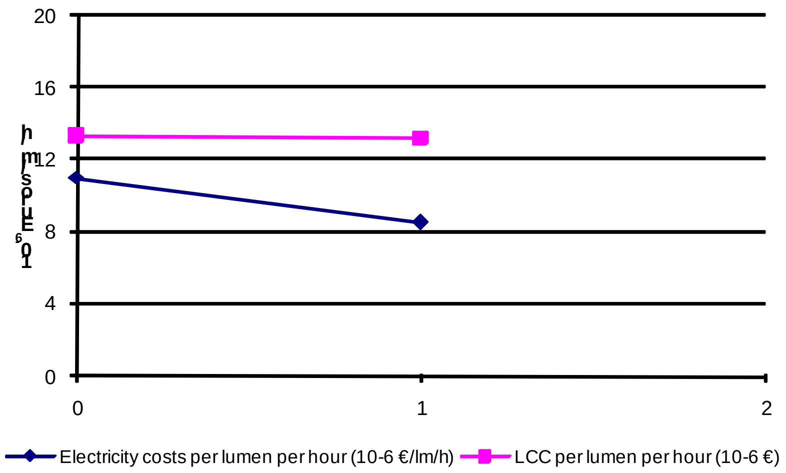

Figure 7.12: LCC curve – environmental performance expressed in total electricity costs for the improvement option for the base-case HL-LV

Except for the indicator “PAHs emissions to air”, the reduction of environmental impacts through the infrared coating technology is between 20 % and 22 % (see Table 7.16). The decrease is lower for the PAHs (- 15.8 %)

Besides environmental impacts listed in the table below, mercury emissions to air with Option 1 are 21.3 % lower than for the base-case HL-LV (0.96 ng/lm/hr compared to 1.22 ng/lm/hr). This reduction is equal to the decrease of the electricity use as halogen lamps do not contain mercury and the emissions to air are only generated indirectly in the use phase due to the power generation.

Table 7.16: Comparison of HL-LV option for each environmental indicator

		Base-case HL-LV	*Option 1*
main environmental indicators	**unit**	**value per lumen per hour**	**value per lumen per hour**
Total Energy (GER)	J	**843.5**	**667.7**
	variation with the base-case	*0.0%*	*-20.8%*
of which, electricity	J	**803.8**	**632.5**
	variation with the base-case	*0.0%*	*-21.3%*
Water (process)	µltr	**53.6**	**42.2**
	variation with the base-case	*0.0%*	*-21.3%*
Water (cooling)	µltr	**2143.4**	**1686.6**
	variation with the base-case	*0.0%*	*-21.3%*
Waste, non-haz./ landfill	µg	**973.3**	**769.9**
	variation with the base-case	*0.0%*	*-20.9%*
Waste, hazardous/ incinerated	µg	**19.3**	**15.3**
	variation with the base-case	*0.0%*	*-20.9%*
Emissions (Air)			
Greenhouse Gases in GWP100	mg CO2 eq.	**38.6**	**30.7**
	variation with the base-case	*0.0%*	*-20.4%*
Acidifying agents (AP)	µg SO2 eq.	**216.2**	**171.0**
	variation with the base-case	*0.0%*	*-20.9%*
Volatile Org. Compounds (VOC)	ng	**344.5**	**275.2**
	variation with the base-case	*0.0%*	*-20.1%*
Persistent Org. Pollutants (POP)	10^{-3} pg i-Teq	**5.50**	**4.35**
	variation with the base-case	*0.0%*	*-20.9%*
Heavy Metals (HM)	ng Ni eq.	**15.8**	**12.7**
	variation with the base-case	*0.0%*	*-20.0%*
PAHs	ng Ni eq.	**3.59**	**3.03**
	variation with the base-case	*0.0%*	*-15.8%*
Particulate Matter (PM, dust)	µg	**5.15**	**4.12**
	variation with the base-case	*0.0%*	*-19.9%*
Emissions (Water)			
Heavy Metals (HM)	ng Hg/20	**5.25**	**4.14**
	variation with the base-case	*0.0%*	*-21.2%*
Eutrophication (EP)	ng PO4	**26.3**	**20.8**
	variation with the base-case	*0.0%*	*-20.7%*

The energy efficiency of the base-case HL-LV can be enhanced by implementing the infrared coating technology. Besides, despite the product price increase of 133 %, the life cycle cost of the improved product is not higher than the one of the base-case (reduction of 0.3 %).

7.2.6 Base-case CFLi

As presented in section 7.1.6, four improvement options were identified for the base-case CFLi. Three of them aim at reducing indirect environmental impacts (electricity consumption) where as one (Option 1) allows for a decrease of direct environmental impacts (mercury emissions to air). Furthermore, a combination of Option 1 and Option 3 was investigated.
The key economic and environmental outcomes from the EcoReport tool are presented in Table 7.17.

Table 7.17: Key results of the improvement options analysis for the base-case CFLi

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} €)*
0	*Base Case CFL*	6000	559.0	925	**276**	43	**12.74**	16.23	**4.84**
1	*Less mercury*	6000	559.0	925	**276**	43	**12.74**	16.61	**5.35**
2	*High lamp efficacy*	6000	626.3	925	**246**	43	**11.37**	16.61	**4.42**
3	*Long lifetime*	10000	626.3	1498	**239**	68	**10.82**	27.53	**4.40**
4	*Very long lifetime*	15000	626.3	2215	**236**	99	**10.54**	37.35	**3.98**
5: 1+3	*Less mercury + Long lifetime*	10000	626.3	1498	**239**	68	**10.82**	28.53	**4.56**

Total energy consumption and global warming potential are equal for the base-case and Options 1 & 2, as the BOM, the packaged volume, the electricity consumption and the lamp lifespan are similar. Nevertheless, when calculating per lumen and per hour, Option 2 presents some variations due to its higher lamp efficacy, whereas Option 1 has the same results as the base-case since its lumen output is also identical to the one of the base-case.
As the product price of Option 1 (CFLi with less mercury) is higher than the one of the base-case, the LCC calculation shows an increase of 10.6 % over the whole life cycle (see Figure 7.13).

Option 4 (CFLi with very long lifetime and high lamp efficacy) leads to the highest decrease of the GER (about 15 %). Moreover, this improvement option also presents the least life cycle cost (3.98 10^{-6} € per lumen and per hour), 18 % lower than the base-case CFLi. These statements are underlined in Figure 7.13.
Option 5 (i.e. Option 1 + Option 3) presents the same environmental impacts (per lumen and per hour) than Option 3 when looking at GER, GWP or electricity costs. Indeed, reducing the mercury content in the combination has no effect on those environmental impacts as the lamp lifetime and the lamp efficacy are equal, but only on the environmental indicator “Emissions of heavy metals to air” since mercury emissions are taken into consideration. Nevertheless, the LCC (per lumen and per hour) of this combination is obviously higher than for Option 3 since the product cost presents a 1 € increase (10 € for Option 5 and 9 € for Option 3).

Slight differences are visible between Option 3 and Option 4 when looking at the total energy consumption and between Option 2 and Option 3 when looking at the LCC. Nevertheless, the product price of Option 2 is lower than Option 3 (5 € compared to 9 €). This variation is highlighted in Figure 7.14, the product price being the gap between the electricity costs and the life cycle cost.

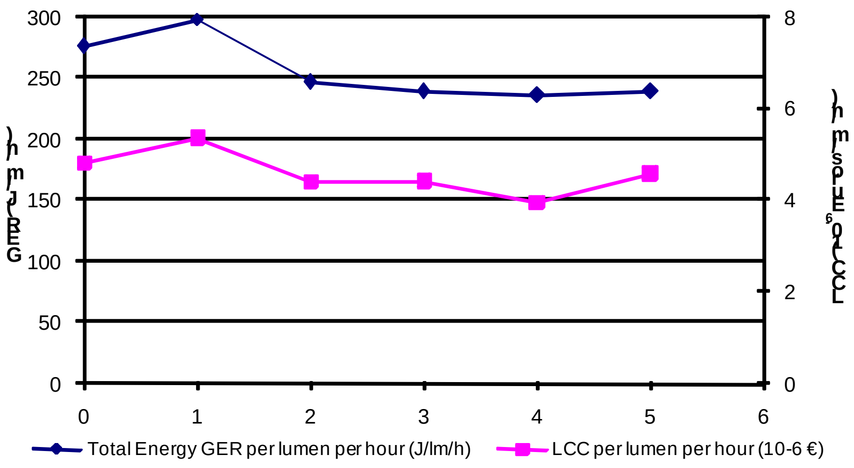

Figure 7.13: LCC curve – environmental performance expressed in total energy consumption (GER) for the improvement options for the base-case CFLi

If the focus is on the GWP, the trend of the curve is similar to the one of the GER (see Figure 7.15). The reduction implied by Option 4 for this indicator is about 17 % compared to the base-case.

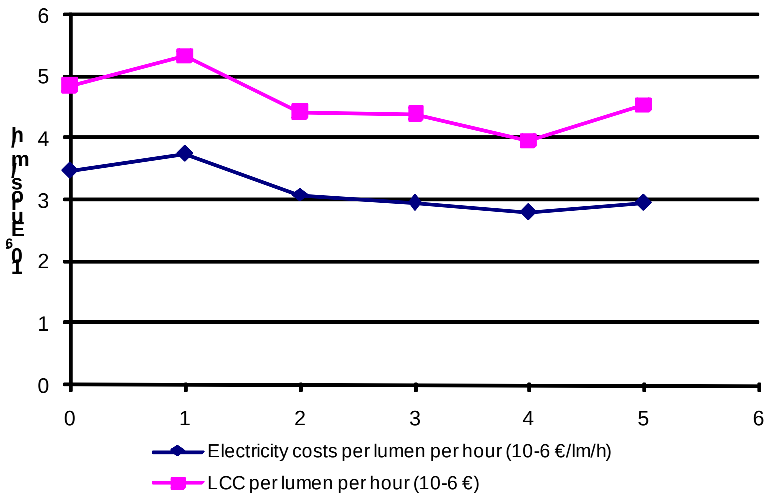

Figure 7.14: LCC curve – environmental performance expressed in total electricity costs for the improvement options for the base-case CFLi

The main direct environmental impact due to the use of fluorescent lamps is the emissions to air of the mercury at end-of-life. Indeed, as it seems that 80 % of compact fluorescent lamps are at present not treated in recycling facilities, mercury emissions occur. This percentage is the same for the all improvement options. However, for Option 1 and Option 5, the weight of the mercury contained in the lamp is twice lower (2 mg compared to 4 mg). Thereby, mercury emissions occurring during end-of-life for these improvement options are 1.6 mg.

As discussed already, electricity production due to coal also generates mercury emissions (0.016 mg per kWh). Thus, the pink curve in Figure 7.15 indicates total mercury emissions to air over the entire life cycle per lumen and per hour. It shows that Option 5 allows a reduction of about 55 % compared to the base-case CFLi.
When looking at individual improvement options, Option 4 is clearly the one implying the highest reduction of mercury emissions (about 49 %). However, Option 5 is even lower with a 55 % reduction. Moreover, in opposition to other environmental impacts, Option 1 shows a significant decrease and mercury emissions to air for this option are even lower than for Option 2 due to less mercury contained in the CFLi.

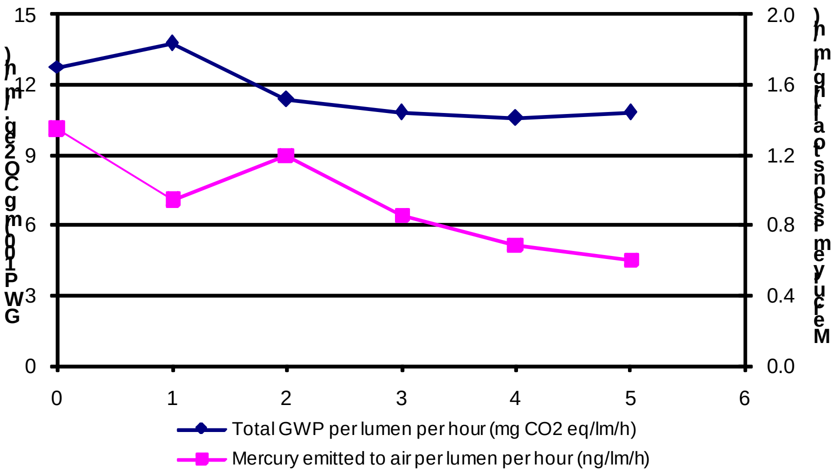

Figure 7.15: Environmental performance expressed in GWP and in mercury emissions for the improvement options for the base-case CFLi

All results of the "life cycle assessment" carried out with the EcoReport tool are presented in Table 7.18 per lumen and per hour for each improvement option as well as for the combination. Their variations with the base-case are also presented in order to make the comparison easier.

The interpretation of this table leads to several conclusions:

- Option 4 presents the highest reduction for all environmental impacts. The most important reductions are for environmental impacts where the use phase has the lowest contribution. Indeed, as the BOM and the packaged volume are similar for this option and for the base-case, when dividing per lumen and per hour impacts due to the distribution phase (e.g. PAHs) or to the production phase (e.g. waste, hazardous/incinerated) lead to a greater reduction in environmental impacts.
- Option 1 does not allow any benefit except for the indicator "emissions of heavy metals to air" (- 0.18 %). As mercury emissions have only a small impact for this indicator (0.35 % over the life cycle) for the base-case, and as the mercury weight is twice lower, the reduction of this impact due to Option 1 is 0.175 % (rounded 0.18 % in the following table).
- Option 2 allows a constant reduction for all indicators (- 10.7 %) as the lamp efficacy is the only technical characteristic which differs with the base-case.

- Option 3 and Option 5 present the same reductions for environmental impacts except for the "emissions of heavy metals to air" (-17.5 % for Option 3 and -17.6 % for Option 5) as the mercury content is the only difference between these two improved lamps (4 mg for Option 3 and 2 mg for Option 5) and as mercury emissions only have a significant impact for this indicator.

Table 7.18: Comparison of CFLi options for each environmental indicator

		Base-case CFLi	*Option 1*	*Option 2*	*Option 3*	*Option 4*	*Option 5 (=Options 1+3)*
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**
Total Energy (GER)	J	**275.8**	**275.8**	**246.2**	**239.3**	**235.8**	**239.3**
	variation with the base-case	*0.0%*	*0.0%*	*-10.7%*	*-13.3%*	*-14.5%*	*-13.3%*
of which, electricity	J	**258.2**	**258.2**	**230.5**	**229.8**	**229.5**	**229.8**
	variation with the base-case	*0.0%*	*0.0%*	*-10.7%*	*-11.0%*	*-11.1%*	*-11.0%*
Water (process)	µltr	**19.3**	**19.3**	**17.2**	**16.4**	**16.0**	**16.4**
	variation with the base-case	*0.0%*	*0.0%*	*-10.7%*	*-14.8%*	*-16.9%*	*-14.8%*
Water (cooling)	µltr	**684.5**	**684.5**	**610.9**	**610.7**	**610.6**	**610.7**
	variation with the base-case	*0.0%*	*0.0%*	*-10.7%*	*-10.8%*	*-10.8%*	*-10.8%*
Waste, non-haz./ landfill	µg	**328.7**	**328.7**	**293.4**	**282.2**	**276.6**	**282.2**
	variation with the base-case	*0.0%*	*0.0%*	*-10.7%*	*-14.2%*	*-15.9%*	*-14.2%*
Waste, hazardous/ incinerated	µg	**30.8**	**30.8**	**27.5**	**18.6**	**14.2**	**18.6**
	variation with the base-case	*0.0%*	*0.0%*	*-10.7%*	*-39.6%*	*-54.0%*	*-39.6%*
Emissions (Air)							
Greenhouse Gases in GWP100	mg CO2 eq.	**12.7**	**12.7**	**11.4**	**10.8**	**10.5**	**10.8**
	variation with the base-case	*0.0%*	*0.0%*	*-10.7%*	*-15.1%*	*-17.3%*	*-15.1%*
Acidifying agents (AP)	µg SO2 eq.	**71.2**	**71.2**	**63.5**	**61.7**	**60.8**	**61.7**
	variation with the base-case	*0.0%*	*0.0%*	*-10.7%*	*-13.3%*	*-14.6%*	*-13.3%*
Volatile Org. Compounds (VOC)	ng	**134.7**	**134.7**	**120.2**	**106.6**	**99.8**	**106.6**
	variation with the base-case	*0.0%*	*0.0%*	*-10.7%*	*-20.8%*	*-25.9%*	*-20.8%*
Persistent Org. Pollutants (POP)	10^{-3} pg i-Teq	**1.80**	**1.80**	**1.60**	**1.56**	**1.54**	**1.56**
	variation with the base-case	*0.0%*	*0.0%*	*-10.7%*	*-13.0%*	*-14.2%*	*-13.0%*
Heavy Metals (HM)	ng Ni eq.	**5.43**	**5.42**	**4.84**	**4.48**	**4.29**	**4.47**
	variation with the base-case	*0.0%*	*-0.18%*	*-10.7%*	*-17.5%*	*-20.9%*	*-17.6%*
PAHs	ng Ni eq.	**1.35**	**1.35**	**1.20**	**0.90**	**0.75**	**0.90**
	variation with the base-case	*0.0%*	*0.0%*	*-10.7%*	*-33.0%*	*-44.2%*	*-33.0%*
Particulate Matter (PM, dust)	µg	**1.99**	**1.99**	**1.77**	**1.57**	**1.46**	**1.57**
	variation with the base-case	*0.0%*	*0.0%*	*-10.7%*	*-21.1%*	*-26.3%*	*-21.1%*
Emissions (Water)							
Heavy Metals (HM)	ng Hg/20	**3.41**	**3.41**	**3.04**	**2.42**	**2.10**	**2.42**
	variation with the base-case	*0.0%*	*0.0%*	*-10.7%*	*-29.1%*	*-38.3%*	*-29.1%*
Eutrophication (EP)	ng PO4	**27.3**	**27.3**	**24.4**	**17.5**	**14.0**	**17.5**
	variation with the base-case	*0.0%*	*0.0%*	*-10.7%*	*-36.2%*	*-48.9%*	*-36.2%*

The analysis of the improvement potential of the base-case CFLi shows that an improvement of the electronic control leading to an extension of the lamp lifetime and to an increase of the lamp efficacy is the best option in monetary and in environmental terms.

7.3 System analysis

Scope:

- Discussion of long-term potential on the basis of changes of the total system to which the present archetype product belongs.

This analysis will be elaborated in part 2 of the study.

7.4 Conclusions

As presented in this chapter, the improvement potential of each of the 6 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 one (or several for the base-case CFLi) improvement option(s), due to their electricity saving potential.

Except for the base-case HL-MV-LW, the Least Life Cycle Cost option corresponds to the Best Available Technology option, as the use phase is both the highest contributor to the environmental impacts and the highest contributor to the LCC.

Nevertheless, the implementation of one or several options could be limited by the related increase in the cost for buying the lamp. Indeed, without any life cycle thinking the buyer would not necessarily purchase an improvement product instead of an average one (base-case) due to the higher product cost.

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 REFERENCES

9 ABBREVIATIONS AND ACRONYMS

10 ANNEXES