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Preparatory Studies for Eco-design Requirements of EuPs

Final report

Lot 19: Domestic lighting

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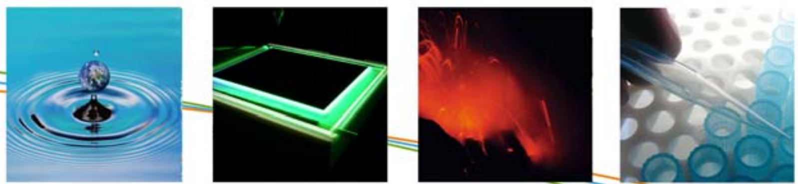

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Important note:
This report contains the updated draft results of research by the authors and is not to be perceived as the opinion of the European Commission.
This is an updated draft document intended for stakeholder communication.

SUMMARY

The aim of this preparatory study is to provide information on whether and which eco-design requirements could be set for domestic lighting products in order to improve their environmental performance, within the framework of Directive 2005/32/EC on eco-design requirements for energy-using products. The structure of this study is according to the MEEUP methodology and accordingly contains the typical 8 chapters. In a multi-stakeholder consultation, a number of groups and experts provided comments on a preliminary draft of this report. The report was then revised, benefiting from stakeholder perspectives and input. The views expressed in the report remain those of the authors, and do not necessarily reflect the views of the European Commission or the individuals and organisations that participated in the consultation. A list of stakeholders that participated in this consultation and further information on project meetings and comments can be found in a project report that is published complementary to this report.

The information provided herein serves to prepare for subsequent phases, including conducting an impact assessment on policy options, to prepare a paper for the Consultation Forum and finally draft regulation for the Regulatory Committee. Those phases are to be carried out by the European Commission. It should be mentioned that this preparatory study on domestic lighting products evolved into a more complicated study than originally planned. After the announcement of the Australian government to ban the incandescent bulbs, the European decision makers wanted to speed up the study in relation to the use of incandescent bulbs. Therefore the preparatory study was split up into two parts: part 1 on non-directional household lamps and part 2 on directional lamps plus household luminaires. In October 2008, part 1 was finalized and this resulted in Commission Regulation 244/2009. It must be noted that definitions in this part 2 must be as consistent as possible with the definitions incuded in Commission Regulation 244/2009.

The approach used throughout this study is the Methodology for Eco-design of EuP (MEEuP), which prescribes the way the life cycle oriented environmental assessment is conducted. The analysis comprises of the assessment of the current situation including the definition of the product category, a market analysis, user behaviour aspects, a systems analysis and an environmental assessment of the current products. Based on the above description of the current situation, the improvement potential is analysed considering life cycle costs and particularly the point of least life cycle costs for the consumer. Finally, technical feasible and available options are defined to improve the environmental performance.

The MEEUP methodology report structure includes 8 product specific chapters:

1. Product Definition;
2. Market and economic analysis;
3. Consumer Behaviour & Local Infrastructure;
4. Technical Analysis Existing Products;
5. Definition of Base Case(s);
6. Technical Analysis of Best Available Technology(BAT) and BNAT;
7. Improvement Potential;
8. Scenario, Policy, Impact and Sensitivity Analyses.

A project report is published together with this study, providing more background on how the preparatory study was conceived and the process to arrive at the results. Complementary to this study, calculation spreadsheets are published that include the MEEUP EcoReports, input data and scenarios.

The first step of the study includes the categorisation and definition of products within the scope as well as identification of key parameters for the selection of relevant products for the assessment analysis during the next steps of the study. A 'domestic lighting' product system is defined according to standard EN 12665, which defines a “lamp” as a “source made in order to produce an optical radiation, usually visible” and a ”luminaire” as an “apparatus which distributes, filters or transforms the light transmitted from one or more lamps”. Coloured lamps typically used for decorative purposes are excluded. Many so-called 'domestic lighting' products are also used in other areas (e.g. hotels, shops, offices) and thus are included in the study.

The focus in part 1 has been on Non Directional Lighting Sources (NDLS) that are most commonly used in the domestic market covering: incandescent lamps, halogen lamps, CFLs (Compact Fluorescent Lamps) with integrated ballast and white LED (Light Emitting Diode) lamps with integrated power supply. Linear Fluorescent Lamps (LFL) are also used in the domestic sector but were not considered because they were already addressed in the finished EuP preparatory studies (lots 8 and 9 on Office and Street Lighting). The focus in part 2 has been on Directional Lighting Sources and domestic luminaires, e.g. the halogen reflector lamps.

The main general lamp and luminaire performance specification parameters or so-called ‘functional unit’ included is the luminous flux Φ (lumen) during 1 hour of operation and for part 2 the direction of the light within a functional solid angle or cone. This is different from the studies on tertiary lighting (street and office lighting), where the chosen functional unit was the ‘provided illuminance or luminance during 1 hour operation’. This matched well with the practice of professional lighting design found in those sectors.

Important barriers not to be forgotten are discussed in chapter 3, e.g. the ‘Luminaire socket and space lock-in efffect’, the ‘Electrical wiring and control system lock-in effect’, the ‘Alleged negative health effects’ and ‘lighting quality’.

This study points out that the largest environmental impact comes from the use of electricity according to the MEEUP methodology applied to all quantified parameters (see chapter 5).

Different policy scenarios 2007-2020 are drawn up to illustrate quantitatively the improvements that can be achieved through the replacement of the base-cases with lamps with higher energy efficiency at EU level by 2020 versus a business-as-usual scenario (reference scenario). It should be mentioned that not all calculated scenarios in part 1 offer the same quality of lighting. For part 1 the EC adopted regulation 244/2009 is equivalent to scenario ‘option 2 Clear B Fast’, the estimated energy savings was 39 TWh or -29% compared to the BAU in 2020. For part 2, four scenarios have been analysed in order to provide an assessment of various alternative policy options related to lamp efficacy. This shows that the estimated BAU 2020 electricity consumption is about 51.1 TWh and could be further reduced to about 28.5 TWh in the BAT scenario with lock-in effects and 24.5 TWh without lock-in effects. The scenario “Luminaire improvement options introduced on top of scenarios BAT", that includes the lamp stock for both part 1&2, shows that on top of lamp efficacy improvement about 20% more energy savings are possible.

The Eco-design requirements for part 1 are already included in the adopted Commission Regulation 244/2009.

For part 2 lamps and all part 1&2 luminaires, a similar series of ecodesign options are formulated for further consultation (see chapter 8) by the EC on the implementation of Directive 2005/32/EC:

- Generic ecodesign requirements on the supply of information;
- Specific ecodesign requirement for increasing lamp efficacy and decreasing system-power demand;
- Specific ecodesign requirements for minimum lamp performance;
- Specific ecodesign requirements for domestic luminaires;
- Generic ecodesign requirements for domestic luminaires.

Finally, there are several additional recommendations in chapter 8 concerning the appropriate putting into service of domestic lighting and their luminaires, these include the introduction of an energy efficiency label for directional light sources.

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Part 1 - Non-Directional Light

Part 2 - Directional lamps and household luminaires

Part 1

Non-Directional Light

1 PRODUCT DEFINITION

Scope: This task should define the product category and define the system boundaries of the 'playing field' for eco-design. It is important for a realistic definition of design options and improvement potential and it is also relevant in the context of technically defining any implementing legislation or voluntary measures (if any).

The objective of this task is to discuss definition and scope issues related to the EuP preparatory study for the lot 19. It consists of categorisation of products, description of product definitions, scope definition as well as identification of key parameters for the selection of relevant products to perform detailed analysis and assessment during the next steps of the study.

Further, the harmonised test standards and additional sector-specific procedures for product-testing are identified and discussed, covering the test protocols for:

- Primary and secondary functional performance parameters;
- Resource use (energy, etc.) during product-life;
- Safety (electricity, EMC, stability of the product, etc.);
- Other product specific test procedures.

Finally, it aims to identify existing legislations, voluntary agreements and labelling initiatives at the EU level, in the Member States and outside Europe.

1.1 Product category and performance assessment

1.1.1 System boundary and technical product definition

<u>Proposed product definition, scope and system boundary:</u>

The proposal is to use a product definition derived from existing European standards and the Prodcom classification.

A 'domestic lighting' product system can more generally be considered as 'lighting equipment' as defined in standard EN 12665 (Light and lighting - Basic terms and criteria for specifying lighting requirements) for domestic application, containing:

1. A "*lamp" as "source made in order to produce an optical radiation, usually visible*";
2. A *"luminaire*" as *"apparatus which distributes, filters or transforms the light transmitted from one or more lamps and which includes, except the lamps themselves, all parts necessary for fixing and protecting the lamps and, where necessary, circuit auxiliaries together with the means for connecting the lamps to the electric supply".*

Furthermore it is proposed to exclude coloured lamps that are typically used for decorative purposes, therefore a definition of a white light source is included in Annex 9.1.1

It is important to note that the definition of domestic lighting in this eco-design study covers products with similar characteristics. Moreover, many so-called 'domestic lighting' products are also used in other areas (e.g. hotels, shops, offices). According to the MEEuP Methodology Report, these product groups that are functionally similar have to be envisaged. As a consequence all that products that are based on the same technology will be included in this study.

The 'domestic lighting' is not a lighting specifiers market, this means that the technical lighting requirements (e.g. illuminance levels) are not specified by the consumer before installation according to technical standards. Therefore the approach is different from the previous EuP studies for office and street lighting. In this study, a lamp technology based approach is proposed. This means a focus on the lighting technology that is most commonly used in the domestic market. The advantage of this approach is that the Prodcom classification according to lamp technology can directly be adopted and possible implementing measures can easily be followed up.

For luminaires it is proposed to exclude decorative elements because their functionality can not be quantified and moreover there are too many different versions on the market. The approach for luminaires will be elaborated in a second phase of the project. It is proposed to consider the minimum elements (e.g. sockets) and functional elements (e.g. dimming control, presence detector, control elements, ..). Also functional properties will be considered that enable energy efficient light sources or light use (lamp compartment properties, ..). For the found system-related improvement options (if any) environmental impact assessment and LCC impact assessment will be made in task 8 at product level.

1.1.2 Classification of domestic lamps and luminaires

Please note that in Eurostat's product-specific statistics for trade and production (the so-called Europroms[1]-Prodcom[2] statistics) domestic lighting can be reported in two manners:

1. According to lamp technology.
2. According to function of the luminaire.

Prodcom is a valuable source of information in total number of sales and average price. This level of aggregation is rather raw. For the purpose of the eco-design analysis extra sub-categories will be therefore added.

1.1.2.1 Lamps applicable in domestic lighting

The PRODCOM segmentation for lamps related to domestic lighting is displayed in Table 1-1.

[1] Europroms is the name given to published Prodcom data. It differs from Prodcom in that it combines production data from Prodcom with import and export data from the Foreign Trade database.
[2] Prodcom originates from the French "PRODuction COMmunautaire"

Table 1-1: Prodcom segmentation for lamps related to domestic lighting

31.50.12.93	*Tungsten halogen filament lamps, for a voltage > 100V* *Excluding:* *- ultraviolet and infra-red lamps* *- for motorcycles and motor vehicles*
31.50.12.95	*Tungsten halogen filament lamps for a voltage ≤ 100V* *Excluding:* *- ultraviolet and infrared lamps* *- for motorcycles and motor vehicles*
31.50.13.00	*Filament lamps of a power ≤ 200W and for a voltage > 100V* *Including:* *- reflector lamps* *Excluding:* *- ultraviolet and infrared lamps* *- tungsten halogen filament lamps* *- sealed beam lamp units*
31.50.15.10	*Fluorescent hot cathode discharge lamps, with double ended cap* *Excluding:* *- ultraviolet lamps*
31.50.15.30	*Fluorescent hot cathode discharge lamps* *Excluding:* *- ultraviolet lamps* *- lamps with double ended cap*

31.50.15.53 Mercury vapour discharge lamps

Excluding:

- ultraviolet lamps

- dual lamps

(Including : metal halide lamps)

As mentioned before, for the purpose of the eco-design analysis, extra sub- categories will be added; the complete list of lamp types is included in Table 1-2.

In this study directional light sources (DLS) or directional lamps (e.g. reflector lamps) and non-directional light sources (NDLS) or non-directional lamps will be discriminated, because the performance data provided by manufacturers are different for both lamp types and it allows to execute the study in two phases. Within directional light sources, further discrimination can be made according to light distribution or beam angle.

The base line proposal for defining these directional and non-directional light sources is based on the light distribution per solid angle. The unit for a solid angle is the steradian [sr]; a complete solid angle can e.g. be visualized as a sphere and counts 4π sr (see Figure 1-1).

Figure 1-1: Visualization of a complete solid angle.

Discrimination of directional light sources will be made in the following categories:

- 'Non-Directional Light Source' or NDLS shall mean a light source having less than 80 % light output in a solid angle of π sr (corresponding with a cone with angle of 120°).

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- "Directional Light Source" or DLS shall mean a light source having at least 80% light output within a solid angle of π sr (corresponding to a cone with angle of 120°). A DLS uses a reflector or an optical component (e.g. lens for LED) to align the luminous flux. All 'reflector lamps' are considered as DLS

Table 1-2: Overview of lamp types to be discussed in this study

PRODCOM Code	**Definition Prodcom**	**Voltage [V]**	**Wattage [W]**	**Low luminance Frosted** / **High luminance**	**Directional / Non-Directional Light Source**	**Socket type**	**Application**	**Other names**	**Acronym in this study**
31.50.13.00  	*Filament lamps of a power ≤ 200W and for a voltage > 100V Including:* *-reflector lamps Excluding:* *-ultraviolet and infrared lamps* *-tungsten halogen filament lamps*	*220-240*	*≤200*	*Low* *Frosted / silicated / coated*	*NDLS*	*E14* *E27* *B15d* *B22d* *E10* *BA..* *etc.*	*Domestic* *In general, not used for domestic lighting*	*Incandescent lamp or General Lighting Service lamp* *Incandescent lamp or General Lighting Service lamp*	*GLS-F*
31.50.13.00 	*-sealed beam lamp units* *.*			*High* *Clear*	*NDLS*	*E14* *E27* *B22d* *B15d*	*Domestic*	*Incandescent lamp or General Lighting Service lamp*	*GLS-C*

PRODCOM Code	Definition Prodcom	Voltage [V]	Wattage [W]	Low luminance Frosted	High luminance	Directional / Non-Directional Llight Source	Socket type	Application	Other names	Acronym in this study
							E10 BA.. etc	In general, not used for domestic lighting	Incandescent lamp or General Lighting Service lamp	
31.50.13.00			5 - 60	High / Low		NDLS	E14 E27	Decorative effects	Special decorative lamps	GLS-deco
				Clear / Frosted			B22d B15d			
31.50.13.00		230 - 240		High / Low		NDLS	S14d S14s	Furniture lighting	Linear filament lamp	GLS-lin
				Clear / Frosted			S19			

PRODCOM Code	Definition Prodcom	Voltage [V]	Wattage [W]	Low luminance Frosted	High luminance	Directional / Non-Directional Llight Source	Socket type	Application	Other names	Acronym in this study
31.50.13.00 			15 - 60			NDLS	E14 E27 B15d B22d etc	Amenity lighting, demarcation lighting, etc. In general, not used for domestic lighting	Coloured lamp	GLS-colour
31.50.13.00 			15-60	High and Low Clear and Frosted		NDLS	E14 E27 B15d B22d	Oven Refrigerator Sewing machines Cooker hood	Oven lamp Refrigerator lamp Sewing machines lamp Cooker hood lamp	GLS-special
31.50.13.00 			60 - 150	High Clear		NDLS	E27 B22 etc	Traffic lights Portable lamps. In general, not used for domestic lighting	Traffic sign lamp Reinforced filament lamp	GLS-signal

PRODCOM Code	Definition Prodcom	Voltage [V]	Wattage [W]	Low luminance Frosted	High luminance	Directional / Non-Directional Llight Source	Socket type	Application	Other names	Acronym in this study
31.50.14.93 	Filament lamps for a voltage > 100V Excluding: -ultraviolet and infrared lamps -tungsten halogen filament lamps -those of a power ≤ 200W -for motorcycles and motor vehicles -sealed beam lamp units	230-240	>200	High Clear		NDLS	E27 E40	In general, not used for domestic lighting (large surfaces)	Incandescent lamp or General Lighting Service lamp High Wattage	GLS-C-HW

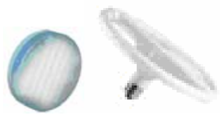
PRODCOM Code	Definition Prodcom	Voltage [V]	Wattage [W]	Low luminance Frosted High luminance	Directional / Non-Directional Llight Source	Socket type	Application	Other names	Acronym in this study
31.50.14.95 	*Filament lamps for a voltage ≤ 100V Excluding:* *-ultraviolet and infrared lamps* *-tungsten halogen filament lamps* *-for motorcycles and motor vehicles* *-sealed beam lamp units*	*≤100*	*15 - 100*	*High and Low* *Clear and Frosted*	*NDLS*	*E27* *B22d* *etc.*	*Emergency lighting* *etc.* *In general, not used for domestic lighting*	*Incandescent lamp or General Lighting Service lamp Low Voltage*	*GLS-LV*
31.50.13.00  	*Filament lamps of a power ≤ 200W and for a voltage > 100V Including:* *-reflector lamps Excluding:* *-ultraviolet and infrared lamps* *-tungsten halogen filament lamps*	*230 - 240*	*≤200*		*DLS*	*E14* *E27* *B15d* *B22d*		*Incandescent reflector lamp or General Lighting Service reflector lamp*	*GLS-R*

PRODCOM Code	Definition Prodcom	Voltage [V]	Wattage [W]	Low luminance Frosted	High luminance	Directional / Non-Directional Llight Source	Socket type	Application	Other names	Acronym in this study
31.50.13.00 	-sealed beam lamp units .					DLS	E27 B22d	Amenity lighting, (disco bar, etc.) In general, not used for domestic lighting	Coloured incandescent reflector lamp	GLS-R-colour
31.50.14.93 	Filament lamps for a voltage > 100V Excluding: -ultraviolet and infrared lamps	230 - 240	>200			DLS	E40	Floodlighting In general, not used for domestic lighting	Incandescent reflector lamp or General Lighting Service reflector lamp High Wattage	GLS-R-HW
31.50.14.93  	-tungsten halogen filament lamps -those of a power ≤ 200W -for motorcycles and motor vehicles -sealed beam lamp units		300			DLS	MP GX16d	Traffic signalling flash lamp In general, not used for domestic lighting		GLS-R-special

PRODCOM Code	Definition Prodcom	Voltage [V]	Wattage	Low luminance Frosted	High luminance	Directional / Non-Directional Llight Source	Socket type	Application	Other names	Acronym in this study
31.50.12.95 	Tungsten halogen filament lamps for a voltage ≤100V Excluding: -ultraviolet and infrared lamps	12	5 - 100	High Clear		NDLS	G4 G8,5 GY6,35		Halogen lamp	HL-LV
31.50.12.95 	-for motorcycles and motor vehicles		15 - 100			DLS	GU4 GU5,3		Halogen reflector lamp	HL-R-LV
							G53 B15 Ba15d	In general, not used for domestic lighting	Halogen reflector lamp	

PRODCOM Code	Definition Prodcom	Voltage [V]	Wattage [W]	Low luminance Frosted	High luminance	Directional / Non-Directional Llight Source	Socket type	Application	Other names	Acronym in this study
31.50.12.93	Tungsten halogen filament lamps, for a voltage > 100V Excluding:	230	25 - 2000	High		NDLS	E14	General lighting		HL-MV
				(Low)			E27	Projector lamp		
							B15d	etc.		
	- ultraviolet and infra-red lamps			Clear			B22d			
	- for motorcycles and motor vehicles			(Frosted)			G9			
							R7s			
							Fa4			
							E40	In general, not used for domestic lighting		
							B35			
										
										

PRODCOM Code	Definition Prodcom	Voltage [V]	Wattage [W]	Low luminance Frosted	High luminance	Directional / Non-Directional Llight Source	Socket type	Application	Other names	Acronym in this study
31.50.12.93  	Tungsten halogen filament lamps, for a voltage > 100V Excluding: - ultraviolet and infra-red lamps - for motorcycles and motor vehicles	230	20 - 100			DLS	GU10 GZ10 E14 E27		Halogen reflector lamp	HL-R-MV
31.50.12.93 			20 - 100			DLS	GU10 GZ10 E14 E27	Amenity lighting, (disco bar, etc.) In general, not used for domestic lighting	Coloured Halogen Reflector lamp	HL-R-MV-colour
31.50.14.60 31.50.15.70	Automotive-, Bycicle- and Torch lamps Infrared lamps UV lamps			High Clear				Not used for domestic lighting		

PRODCOM Code	Definition Prodcom	Voltage [V]	Wattage [W	Low luminance Frosted	High luminance	Directional / Non-Directional Llight Source	Socket type	Application	Other names	Acronym in this study
31.50.15.10 	Fluorescent hot cathode discharge lamps, with double ended cap Excluding: ultraviolet lamps	-----	15 - 58	Low Frosted		NDLS		General (domestic) lighting	Linear Fluorescent Lamp	LFL
31.50.15.30  	Fluorescent hot cathode discharge lamps Excluding: -ultraviolet lamps -with double ended cap	230	3 - 30	Low Frosted		NDLS	E27 E14 B22d GX53	Domestic, retrofit for incandescent lamp	Compact Fluorescent Lamp with integrated ballast or 'energy saving lamp'	CFLi

PRODCOM Code	Definition Prodcom	Voltage [V]	Wattage [W]	Low luminance Frosted	High luminance	Directional / Non-Directional Llight Source	Socket type	Application	Other names	Acronym in this study
31.50.15.30   	Fluorescent hot cathode discharge lamps Excluding: -ultraviolet lamps -with double ended cap	------	5 - 120	Low Frosted		NDLS	G10q G23 GX24d -1-3 GX24q -1-6 GR8 GR10 q 2G7 2G8-1 2G10 2G11 2GX13	Professional, Shop, Office, Industry, Hotel, Domestic	Compact Fluorescent lamp Compact Fluorescent lamp non integrated ballast Circular fluorescent lamp	CFLni

PRODCOM Code	Definition Prodcom	Voltage [V]	Wattage [W]	Low luminance Frosted	High luminance	Directional / Non-Directional Llight Source	Socket type	Application	Other names	Acronym in this study
31.50.15.30  	*Fluorescent hot cathode discharge lamps* *Excluding:* *-ultraviolet lamps* *-with double ended cap*	*230*	*9* *11* *15* *20*			*DLS*	*E14* *E27* *GU10*	*Domestic, Hotel, etc., retrofit for incandescent or halogen reflector lamp*	*Compact Fluorescent Reflector Lamp with integrated ballast*	*CFLi-R*
(31.50.15.59 ?) 	*Discharge lamps Excluding:* *-fluorescent hot cathode lamps* *-dual lamps* *-mercury or sodium vapour lamps* *-ultraviolet lamps*	*230*	*20*			*NDLS*	*E27* *B22d*	*Domestic (etc.) retrofit for incandescent and halogen lamp*	*Electrodeless induction lamp*	*CFLi-ind*
(31.50.15.59 ?) 			*23*			*DLS*	*E27* *B22d*	*Domestic (etc.) retrofit for incandescent and halogen reflector lamp*	*Electrodeless induction reflector lamp*	*CFLi-R-ind*

PRODCOM Code	Definition Prodcom	Voltage [V]	Wattage [W]	Low luminance Frosted	High luminance	Directional / Non-Directional Llight Source	Socket type	Application	Other names	Acronym in this study
(31.50.15.59 ?) 	(Fluorescent, electrodeless induction lamp)	-----	55 - 165			NDLS	------	Industry halls, tunnels, hardly accessible places	Induction lamp (Lifetime 60000h)	CFLni-ind
31.50.15.53  	Mercury vapour discharge lamps Excluding: -ultraviolet lamps -dual lamps (Including: metalhalide lamps)	-------	20 - 150	High Clear		NDLS	G12 G8,5 PGJ5 RX7s		Metalhalide lamp	MH

PRODCOM Code	Definition Prodcom	Voltage [V]	Wattage [W]	Low luminance Frosted	High luminance	Directional / Non-Directional Llight Source	Socket type	Application	Other names	Acronym in this study
31.50.15.53  			*20* *35* *70*			*DLS*	*GU10* *E27* *B22d*		*Metalhalide reflector lamp*	*MH-R*
	*White Light Emitting Diode lamp* *White Light Emitting lamp with multicolour LED's*	*230*	*>0,5*	*Low*		*NDLS*	*E27* *B22d* *E15* *B15d*		*WLED Lamp* *White Light Solid State Lamp*	*WLED*

PRODCOM Code	Definition Prodcom	Voltage [V]	Wattage [W]	Low luminance Frosted	High luminance	Directional / Non-Directional Llight Source	Socket type	Application	Other names	Acronym in this study
No specific code (to be confirmed)	White, Light Emitting Diode Reflector lamp	230	>0,5			DLS	GU10		WLED Reflector Lamp White Light Solid State Reflector Lamp	WLED-R

Remarks:

- External halogen transformers (power supplies) and lamp ballasts, non integrated in the lamp, will not be addressed in this study. They were already addressed in the finished EuP preparatory studies (lot 7 on External Power Supplies and lots 17 and 18 on Office and Street Lighting); the authors of this study are well informed. Although at system level, recommendations for halogen transformers will be given in chapter 8.
- The following lamps were also part of the previous EuP studies on Office and Street Lighting:
  - linear fluorescent lamps
  - CFLni (compact fluorescent lamps with non integrated ballast
  - HID lamps.

  Although they are not again part of all tasks in this study, they will be considered as BAT in task 6.
- HID lamps with high colour rendering index, especially MH-lamps, will be included in this study (task 6) because they form an energy efficient alternative for halogen lamps. MH-lamps are nowadays rarely or not used in domestic lighting (to be confirmed in task 2); they are mainly used in professional lighting applications (shops, sport fields, etc.). However they will be considered as BNAT or BAT (task 6) because of their potential to replace halogen lamps. Please also note that the Prodcom code 31.50.15.53 covers the complete group of mercury vapour discharge lamps. The Prodcom data are therefore not relevant for this study.
- Normal HPM lamps, included in the same Prodcom code 31.50.15.53 are not used in domestic lighting applications and phasing out was already proposed in the EuP preparatory study on street lighting.

1.1.2.2 Luminaires applicable in domestic lighting

Prodcom segmentation for domestic luminaires is represented in Table 1-3.

Table 1-3: Prodcom segmentation for domestic luminaires.

31.50.22.00	*Electric table, desk, bedside or floor-standing lamps*
31.50.25.30	*Chandeliers and other electric ceiling or wall lighting fittings Excluding:* *- those used for lighting public open spaces or thoroughfares*

Please consult also the related section in part 2 of this study.

1.1.3 General lamp and luminaire performance specification parameters

1.1.3.1 General lamp performance specification parameters

Each lamp has its own specific characteristics; the important performance assessment parameters are (EN 12665(2002))[3]:

- Rated luminous flux Φ [lm]: quantity value of the initial luminous flux of the lamp, for specified operating conditions. The value and conditions are specified in the relevant standard, corresponding unit: lumen [lm];
- Nominal luminous flux Φ [lm]: a suitable approximate quantity value of the initial luminous flux of the lamp, corresponding unit: lumen [lm];
- Rated lamp power (Plamp [W]): quantity value of the power consumed by the lamp for specified operating conditions. The value and conditions are specified in the relevant standard, corresponding unit: Watt [W];
- Nominal lamp power (Plamp [W]): a suitable approximate quantity value of the power consumed by the lamp, corresponding unit: Watt [W];
- Lamp Survival Factor (LSF): fraction of the total number of lamps which continue to operate at a given time under defined conditions and switching frequency;
- Operational lifetime
- Lamp Lumen Maintenance Factor (LLMF): ratio of the luminous flux emitted by the lamp at a given time in its life to the initial luminous flux;
- Luminous efficacy of a lamp (ηlamp): quotient luminous flux emitted by the power consumed by the source, unit lumen per Watt [lm/W];
- Colour Rendering: the effect of an illuminant on the colour appearance of objects by conscious or subconscious comparison with their colour appearance under a reference illuminant.
- CIE general colour rendering index CRI [R_a]: mean of the CIE special colour rendering indices for a specific set of eight (a = 8) test colour samples. (If the colour rendering index is based on more colour samples, ‘a’ must be specified, e.g. R_{14} or R_{20}.) For a source like a low-pressure sodium vapour lamp, which is monochromatic, the R_a is nearly zero, but for a source like an incandescent light bulb, which emits essentially black body radiation, R_a is assumed to be one hundred. (see also CIE 13.3).
- Chromaticity coordinates (x, y): these are coordinates which characterise a colour stimulus (e.g. a lamp) by a ratio of each set of tristimulus values to their sum. Tristimulus values means the amounts of the three reference colour stimuli required to match the colour of the stimulus considered (e.g. a lamp). As the sum of three chromaticity coordinates equals 1, two of them are sufficient to define a chromaticity. The CIE defined different colour spaces with its own coordinates, for light sources the most common system is 'CIE xy' also known as 'CIE 1931 colour space'. The gamut of all visible chromaticities on the CIE plot is tongue-shaped or horseshoe-shaped shown in colour in Figure 1-2. In more general terms, a distance on the xy chromaticity diagram does not correspond to the 'degree' of 'perceived' difference between two colours. Other colour spaces (CIELuv and CIELab in particular) have been designed

[3] The definitions of ‘nominal’ and ‘rated’ value are not mentioned in this standard but in several other standards such as EN 60081 and EN 50294.

to reduce this problem but there is currently no single solution. Light with a flat energy spectrum (white) corresponds to the point (x,y) = (0.33 ,0.33).

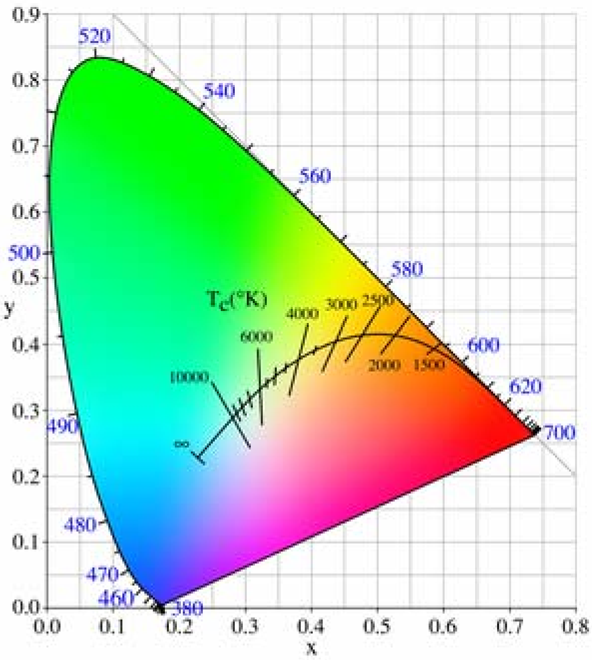


Figure 1-2 The CIE 1931 x,y chromaticity space, also showing the chromaticities of black-body light sources of various colour temperatures (Tc), and lines of constant correlated colour temperature (Tcp).

- Colour temperature Tc: temperature of a Planckian radiator whose radiation has the same chromaticity as that of a given stimulus, unit [K].
- Correlated colour temperature (Tcp [K]): temperature of a Planckian (black body) radiator whose perceived colour most closely resembles that of a given stimulus at the same brightness and under specified viewing conditions. The recommended method for calculation is included in CIE publication 15[4]. Please note that a black body absorbs all electromagnetic radiation that falls onto it and the amount and wavelength (colour) of electromagnetic radiation they emit is directly related to their temperature (see also Figure 1-2). Incandescent lamps (non coloured) are Planckian (black body) radiators and are located exactly on the black body locus (see Figure 1-2). Other light sources can have coordinates that are not exactly located on the black body locus, therefore they have a 'correlated' colour temperature. Please note also that the chromaticity of these light sources (e.g. CFL) is therefore not identified by a single parameter such as correlated colour temperature, this means that for example CFL lamps can appear with different colour but have the same correlated colour temperature[5].
- MacAdam Ellipses: MacAdam ellipse is the region on a chromaticity diagram which contains all colours which are indistinguishable, to the average human eye, from the colour at the centre of the ellipse. MacAdam ellipses are described as having 'steps' which really means 'standard deviations'. If a large sample of the population were used and if a trained observer could reliably repeat his observations, then the steps would

[4] CIE 15: 2004 Colorimetry, 3rd ed.

[5] Rensselaer (2003), 'Increasing market acceptance of compact fluorescent lamps (CFLs)',Mariana Figueiro et al., Project Report of Lighting Research Center, Rensselaer Polytechnic Institute, September 30, 2003.

translate to probabilities for the general population as follows:1 sd = 68.26 % of the general, colour-normal population 2 sd = 95.44 % “3 sd = 99.44 %. Any point on the boundary of a '1-step' ellipse, drawn around a target, represents 1 standard deviation from the target. For a '3-step'ellipse, the boundary represents 3 standard deviations from the target, and so on. These MacAdam Ellipses are included in the standards for fluorescent lamps for describing acceptable colour deviation (EN 60901, EN 60081). Please note that LED lamps don't use these MacAdam Ellipses but defined zones of product groups in the CIE 1931 x,y chromaticity diagram. LEDs are binned for chromaticity in the manufacturing process. These bins, when superimposed on the CIE 1931 Chromaticity Diagram, take the form of quadrangles, as opposed to ellipses (standardisation work is under progress[6]).

Other performance parameters addressed in this study:

- dimmability;
- starting time: time needed for the lamp to start fully and remain alight, after the supply voltage is switched on;
- warm-up time: time needed for the lamp to reach 80% of its full luminous flux, after the supply voltage is switched on (in the ongoing revision of standard EN 60969 a change to limit the warm-up time to 60% is proposed);
- hot restrike capabilities (i.e. start-up after a short switch off time);
- power quality (power factor and harmonic currents e.g. third harmonic line current (%), fifth harmonic line current, current crest factor).
- unit purchase cost;
- a bright point source is defined as a light source that has only clear glass covers see Annex 9.1.1.
  (This is a clear GLS, clear halogen, clear HID lamp, not including frosted or silicated GLS, frosted or silicated halogen lamp, frosted or fluorescent HID, LPS, HPM, LFL, CFLi or CFLni lamps or other light sources with luminance above 25000 cd/m² for lamps below 2000 lm and above 100000 cd/m² for lamps with more lumen output.)
- a second lamp envelope: an additional lamp envelope that is not required for the normal functioning of the lamp (see second lamp envelope criterion in Annex 9.2.3).
- UV radiation content (% UV-A, % UV-B, % UV-C)
- the lamp dimensions and sockets, especially for more energy efficient lamp retrofit solutions.
- Please consult also the related section in part 2 of this study.

Additional light distribution parameters for 'reflector lamps':

- Please consult the related section in part 2 of this study.

1.1.3.2 Definition of a “white light source”:

A white light source contains all colours of the visible light spectrum and gives a natural appearance to all different colours. Visible light is the electromagnetic radiation with a wavelength between 380 nm (upper limit of UV) and 780 nm (lower limit of infrared) and all combinations of these wavelengths).

[6] Energystar (2007), 'ENERGY STAR® Program Requirements for Solid State Lighting Luminaires Eligibility Criteria – Version 1.0 DRAFT' April 9, 2007.

Currently there is no scientific definition nor for a white, neither for a coloured light source. Therefore a definition of a ‘white light source’ was developed for this study. This definition can be found in Annex 9.1.1.

It must be noted that this white light definition is only used in this study to limit the scope of the lamps that will be considered because coloured lamps are excluded. It can never be used as a quality parameter for lamps.

1.1.3.3 General luminaire performance specification parameters:

Please consult also the related section in part 2 of this study.

1.1.4 Functional unit for domestic lighting

Knowing the functional product used in this study we now further explain what is called the “functional unit” for domestic lighting. In standard 14040 on life cycle assessment (LCA) the functional unit is defined as “the quantified performance of a product system for use as a reference unit in life cycle assessment study”. The primary purpose of the functional unit in this study is to provide a calculation reference to which environmental impacts (such as energy use), costs, etc. can be related and to allow for comparison between functionally equal domestic lighting products with and without options for improvement. Please note that further product segmentations will be introduced in this study in order to allow appropriate equal comparison.

The proposed functional parameter (FP) for domestic lighting in this study is:

“1 lumen provided by a light source during 1 hour of operation”.

(As defined in many standards, the measurement of the lumen output shall be performed after the lamp has burned for 100 hours.)

It is assumed that the performance of a domestic 'luminaire' is difficult to quantify.

1.2 Lighting test standards or guidelines

This paragraph identifies and shortly describes the 'test standards or guidelines' that are related to the functional unit, resource use (energy, materials, ..), safety and other lighting product specific standards.
A “test standard or guideline” is defined in the context of this study as a standard or guideline that sets out a test method, but that does not indicate what result is required when performing that test. Therefore, strictly speaking, a test standard can be different from a “technical standard”. Especially 'technical standards' that are a specification against which all others may be measured are not discussed hereafter(e.g. the measurement of power, luminous flux, ..). In addition to “official” test standards, there are other sector specific procedures for product testing that are compiled by industry associations or other stakeholders for specific purposes

included in this section. Also ongoing work for the development of new standards or guidelines is discussed together with recommendations for new ones.

The following references are made to:

- EN, European standard ratified by either CEN (European Committee for Standardization) or CENELEC (European Committee for Electro-technical Standardization),
- IEC, International Electro-technical Commission,
- CIE, International Commission on Illumination.

1.2.1 Standards and guidelines related to the functional unit for NDLS lamps

- *EN 60064:* '*Tungsten filament lamps for domestic and similar general lighting purposes - Performance requirements*'.

  Scope:

    This standard applies to tungsten filament incandescent lamps for general lighting services (GLS) which comply with the safety requirements in EN 60432-1.

- *EN 60357:* '*Tungsten halogen lamps (non-vehicle) - Performance specifications*'.

  Scope:

    This standard specifies the performance requirements for single-capped and double-capped tungsten halogen lamps, having rated voltages of up to 250 V, used for the following applications:
    - projection (including cinematograph and still projection)
    - photographic (including studio)
    - floodlighting
    - special purpose
    - general purpose
    - stage lighting.

    This third edition cancels and replaces the second edition published in 1982 and amendments.

- *EN 60969 : 'Self-ballasted lamps for general lighting services - Performance requirements'.*

  Scope:

    This Standard specifies the performance requirements, together with the test methods and conditions, required to show compliance of tubular fluorescent and other gas-discharge lamps with integral means for controlling starting and stable operation (self-ballasted lamps) intended for domestic and similar general lighting purposes.

- *EN 60081 : 'Double-capped fluorescent lamps - Performance specifications'.*

  Scope:

    This International Standard specifies the performance requirements for double-capped fluorescent lamps for general lighting service.

The requirements of this standard relate only to type testing. Conditions of compliance, including methods of statistical assessment, are under consideration.

The following lamp types and modes of operation are included:
a) lamps having preheated cathodes, designed for operation on a.c. mains frequencies with the use of a starter, and additionally operating on high frequency;
b) lamps having preheated high-resistance cathodes, designed for operation on a.c. mains frequencies without the use of a starter (starter less), and additionally operating on high frequency;
c) lamps having preheated low-resistance cathodes, designed for operation on a.c. mains frequencies without the use of a starter (starter less), and additionally operating on high frequency;
d) lamps having preheated cathodes, designed for operation on high frequency;
e) lamps having non-preheated cathodes, designed for operation on a.c. mains frequencies;
f) lamps having non-preheated cathodes, designed for operation on high frequency.

For some of the requirements given in this standard, reference is made to "the relevant lamp data sheet". For some lamps these data sheets are contained in this standard. For other lamps, falling under the scope of this standard, the relevant data are supplied by the lamp manufacturer or responsible vendor.

- *EN 60901:* '*Single-capped fluorescent lamps – Performance specifications*'.

Scope:

This International Standard specifies the performance requirements for single-capped fluorescent lamps for general lighting service.
The requirements of this standard relate only to type testing. Conditions of compliance, including methods of statistical assessment, are under consideration.

The following lamp types and modes of operation with external ballasts are included:
a) lamps operated with an internal means of starting, having preheated cathodes, for operation on a.c. mains frequencies;
b) lamps operated with an external means of starting, having preheated cathodes, for operation on a.c. mains frequencies with the use of a starter, and additionally operating on high frequency;
c) lamps operated with an external means of starting, having preheated cathodes, for operation on a.c. mains frequencies without the use of a starter (starter less), and additionally operating on high frequency;
d) lamps operated with an external means of starting, having preheated cathodes, for operation on high frequency;
e) lamps operated with an external means of starting, having non-preheated cathodes, for operation on high frequency.

- *EN 50285: 'Energy efficiency of electric lamps for household use – Measurement methods'.*

Scope:

Specifies the test conditions and method of measurement of luminous flux, lamp wattage and lamp life as given on a label on the lamp packaging, together with a procedure for verification of the declared values. Only those parameters that are specific to Directive 92/75/EEC are included in this standard, all other parameters are defined in the relevant lamp performance standards.

- *EN 60921:* '*Ballasts for tubular fluorescent lamps – Performance requirements*'.

Scope:

This standard specifies performance requirements for ballasts, excluding resistance types, for use on a.c. supplies up to 1 000 V at 50 Hz or 60 Hz, associated with tubular fluorescent lamps with pre-heated cathodes operated with or without a starter or starting device and having rated wattages, dimensions and characteristics as specified in IEC 60081 and 60901. It applies to complete ballasts and their component parts such as resistors, transformers and capacitors. (It only applies to ferromagnetic ballasts; electronic ballasts are covered under IEC60929.)

- *EN 60929 :* '*AC-supplied electronic ballasts for tubular fluorescent lamps – Performance requirements*'.

Scope :

This International Standard specifies performance requirements for electronic ballasts for use on a.c. supplies up to 1 000 V at 50 Hz or 60 Hz with operating frequencies deviating from the supply frequency, associated with tubular fluorescent lamps as specified in IEC 60081 and IEC 60901 and other tubular fluorescent lamps for high frequency operation. (It only applies to electronic ballasts; ferromagnetic ballasts are covered under IEC60921.)

1.2.2 Other test standards and guidelines not related to the functional unit

- *EN 12665 (2002): 'Light and lighting - Basic terms and criteria for specifying lighting requirements'*

Scope:

This standard defines basic terms for use in all lighting applications; specialist terms with limited applications are given in individual standards. This standard also sets out a framework for the specification of lighting requirements, giving details of aspects which shall be considered when setting those requirements.

- *EN 60968 : ‘Self-ballasted lamps for general lighting services - Safety requirements’.*

  Scope:

  This Standard specifies the safety and interchangeability requirements, together with the test methods and conditions, required to show compliance of tubular fluorescent and other gas-discharge lamps with integrated means for controlling starting and stable operation (self-ballasted lamps), intended for domestic and similar general lighting purposes, having: -a rated wattage up to 60 W; -a rated voltage of 100 V to 250 V; -Edison screw or bayonet caps.

- *EN 60630 : ‘Maximum lamp outlines for incandescent lamps’.*

  Scope:

  This Standard specifies the maximum outlines for GLS-lamps in different shapes, with different caps etc.

- *EN 60669-2-1 : 'Electronic switches for households and similar use'.*

  Scope :

  Applies to electronic switches and to associated electronic extension units for household and similar fixed electrial installations either indoors or outdoors.

- *EN 61047 : 'D.C. or A.C. supplied electronic step-down converters for filament lamps. Performance requirements'.*

  Scope :

  Specifies performance requirements for electronic step-down convertors for use on d.c. supplies up to 250 V and a.c. supplies up to 1000 V at 50 Hz or 60 Hz with operating frequencies deviating from the supply frequency, associated with tungsten halogen lamps as specified in IEC 60357 and other filament lamps.

- *EN 50294 : ‘Measurement Method of Total Input Power of Ballast-Lamp Circuits’.*

  Scope:

  This Standard gives the measurement method of the total input power for ballast-lamp circuits when operating with their associated fluorescent lamp(s). This standard applies to electrical ballast-lamp circuits comprised solely of the ballast and of the lamp(s). NOTE: Requirements for testing individual ballasts during production are not included. It specifies the measurement method for the total input power for all ballasts sold for domestic and normal commercial purposes operating with the following fluorescent lamps: linear lamps with power equal to or greater than 15 W; single ended (compact) lamps with power equal to or greater than 18 W; other general purpose lamps. This standard does not apply to: ballasts which form an integral part of the lamp; ballast-lamp circuits with capacitors connected in series; controllable wire-wound magnetic ballasts; luminaires which rely on additional optical performance aspects.

The standard mandates that a ballast lumen factor be declared by the manufacturer - this has to be in the range 0.925 to 1.0 for magnetic ballasts and between 0.925 and 1.075 for electronic ballasts.

The test method for ferromagnetic and electronic ballasts is quite different and each is described below:
For magnetic ballasts, the test ballast is operated with a reference lamp. In addition the reference lamp is operated with a reference ballast. The total input power and the lamp power are measured for each circuit in parallel. Finally, the total input power for the test ballast/lamp circuit is corrected for the ballast lumen factor (BLF), this correction is done by measurement of the lamp power compared to the reference lamp. Please note that for the reference ballast a normalized ballast lumen factor of 0.95 has been chosen (this suggests that manufacturers tend to under-run lamps on average on magnetic ballasts). A similar method exists for electronic ballasts, in this case a reference ballast lumen factor of 1 is chosen. The total input power for the test ballast/lamp circuit is corrected for the ballast lumen factor (BLF), this correction is done by measurement of the lamp luminous flux compared to the reference lamp. Please note that for T5 fluorescent lamps no magnetic reference ballast exists, therefore an electronic reference ballast with known BLF needs to be obtained (Klinger (2006)), e.g. from a lamp manufacturer.
It is important to realize that in this approach the losses of the lamp filament preheating are accounted as ballast losses, because magnetic ballasts have switch-off lamp filament preheating enforced by the principle and also the most advanced T5 ballasts that are used as reference ballast do so.

- *EN 60927: 'Specification for auxiliaries for lamps. Starting devices (other than glow starters). Performance requirements'.*

Scope:

Specifies performance requirements for starting devices (starters and igniters) for tubular fluorescent and other discharge lamps for use on a.c. supplies up to 1 000 V at 50 Hz or 60 Hz which produce starting pulses not greater than 5 kV. Should be read in conjunction with IEC 60926.

- *EN 61048 : 'Auxiliaries for Lamps - Capacitors for Use in Tubular Fluorescent and Other Discharge Lamp Circuits - General and Safety Requirements'.*

Scope :

This International Standard states the requirements for both self-healing and non-self-healing continuously rated a.c. capacitors of up to and including 2,5 kVAr, and not less than 0,1 µF, having a rated voltage not exceeding 1 000 V, which are intended for use in discharge lamp circuits operating at 50 Hz or 60 Hz and at altitudes up to 3000m.

- *EN 61049 : 'Capacitors for Use in Tubular Fluorescent and Other Discharge Lamp Circuits Performance Requirements'.*

Scope :

Specifies the requirements for both self-healing and non-self-healing continuously rated a.c. capacitors of up to and including 2,5 kVAr, and not less than 0,1 F, having a rated voltage not exceeding 1 000 V, which are intended for use in discharge lamp circuits operating at 50 Hz or 60 Hz and at altitudes up to 3 000 m. Does not cover radio-interference suppressor capacitors, the requirements for which are given in IEC 60384-14. This publication supersedes IEC 60566.

- *CIE 089 (1989) : 'Measurement of luminous flux' (technical report)*

Scope :

This technical report defines the terminology required for luminous flux measurements. It then deals with the principles of luminous flux measurements and describes methods for the evaluation of the illuminance distribution, the measurement of luminous flux by means of an integrating sphere photometer and the determination of luminous flux via luminance, luminous intensity and luminance measurements.

- *IEC/TS 61231 : 'International lamp coding system (ILCOS)'.*

Scope :

This technical specification gives the rules for the international lamp coding system and covers all lamp categories, excluding vehicle lamps. Coding for the main lamp types is specified and, for the others, will follow by amendments to this technical specification as appropriate.

The object of the international lamp coding system is:

- to improve communication about the different types of lamps;
- to help in discussions concerning interchangeability and compatibility of products;
- to create a closer relationship between international standards and manufacturers' literature (for example the code could be given in future in the relevant parts of a standard);
- to enable correct replacements of lamps;
- to be used as a complementary marking on the luminaire;
- to replace national and regional coding systems.

- *IEC 62471 (CIE S 009:2002): 'Photobiological safety of lamps and lamp systems'.*

Scope :

This international Standard gives guidance for evaluating the photobiological safety of lamps and lamp systems including luminaires. Specifically it specifies the exposure limits, reference measurement technique and classification scheme for the evaluation and control of photobiological hazards from all electrically powered incoherent broadband sources of optical radiation, including LED's but excluding lasers, in the wavelength range from 200 nm through 3000 nm.

1.3 Existing legislation

Please consult also the related section in part 2 of this study for more updated information.

1.3.1 Legislation and Agreements at European Community level

1.3.1.1 Environmental Directives (RoHS, WEEE)

- *Directive 2002/95/EC on Restriction of the use of certain Hazardous Substances in electrical and electronic equipment (RoHS)*

Scope:

The RoHS Directive stands for "the restriction of the use of certain hazardous substances in electrical and electronic equipment". This Directive bans the placing on the EU market, from 1 July 2006, of new electrical and electronic equipment containing lead, cadmium, mercury, hexavalent chromium, polybrominated biphenyl (PBB) and polybrominated diphenyl ether (PBDE) flame retardants.

Exemptions:

In annex, the exemptions from this requirements (a.o. for lamps) are listed:

- mercury in compact fluorescent lamps not exceeding 5mg per lamp
- mercury in straight fluorescent lamps for general purposes not exceeding

halophosphate	10mg
triphosphate with normal lifetime	5mg
triphosphate with long lifetime	8mg

- mercury in straight fluorescent lamps for special purposes
- mercury in other lamps not specifically mentioned in this annex
- lead in glass of fluorescent tubes.

There are no exemptions for luminaires and ballasts.

- *Directive 2002/96/EC on waste electrical and electronic equipment (WEEE)*

Scope:

The WEEE Directive aims to:

- reduce waste arising from electrical and electronic equipment (EEE);
- make producers of EEE responsible for the environmental impact of their products, especially when they become waste.
- encourage separate collection and subsequent treatment, reuse, recovery, recycling and sound environmental disposal of EEE .
- improve the environmental performance of all those involved during the lifecycle of EEE.

Exemptions:

In annex I A, all general categories of electric and electronic equipment concerned are mentioned; in annex I B, the subcategories with the exemptions are listed. In the subcategory of luminaires for fluorescent lamps, an exception is made for luminaires in households. Also filament bulbs (incandescent and halogen lamps) are exempted from this directive.

1.3.1.2 *Efficiency Directives*

- *Directive 2000/55/EC on energy efficiency requirements for ballasts for fluorescent lighting*

Scope:

The purpose of this Directive is to improve the efficiency of the systems by limiting the ballast losses. For this purpose, CELMA developed a classification system that takes both parts of the system into account, the lamp and the ballast and that is compliant with the directive. It constitutes an implementing measure within the meaning of article 15 of Directive 2005/32/EC.

- *Directive 98/11/EC of 27 January 1998 implementing Council Directive 92/75/EEC with regard to energy labelling of household lamps*

Scope:

This Directive, which was published on 10th March 1998, applies the energy labelling requirements for household electric lamps supplied directly from the mains (filament and integral compact fluorescent lamps) and to household fluorescent lamps (including linear and non-integral compact fluorescent lamps), even when marketed for non-household use.

In Annex I of the Directive, the design and content of the label is setted out, as well as the colours that may be used.
The label must include the following information:
• the energy efficiency class of the lamp;
• the luminous flux of the lamp in lumens;
• the input power (wattage) of the lamp;
• the average rated life of the lamp in hours.
The label shall be chosen from the following illustrations in Figure 1-3. Where the label is not printed on the packaging but a separate label is placed on or attached to the packaging, the colour version shall be used. If the ‘black on white’version of the label is used, the printing and background may be in any colours that preserve the legibility of the label.

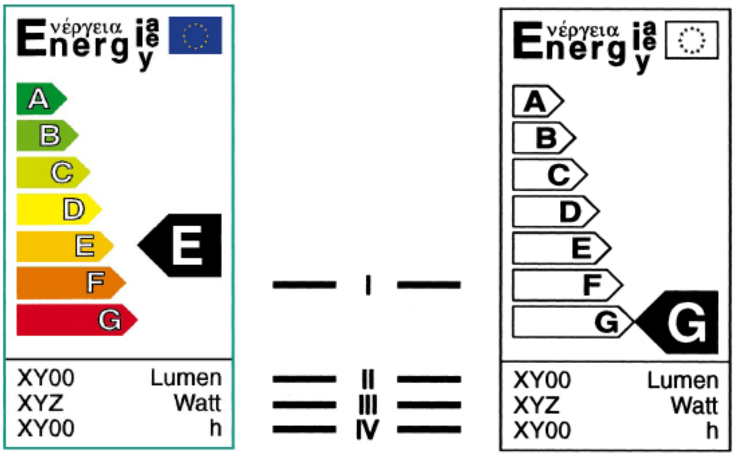


Figure 1-3: Energy efficiency label

The following notes define the information to be included:

I. The energy efficiency class of the lamp, determined in accordance with Annex IV. This indicator letter shall be placed at the same level as the relevant arrow.

II. The luminous flux of the lamp in lumens, measured in accordance with the test procedures of the harmonised standards referred to in Article 1(4).

III. The input power (wattage) of the lamp, measured in accordance with the test procedures of the harmonised standards.

IV. The average rated life of the lamp in hours, measured in accordance with the test procedures of the harmonised standards. Where no other information on the life of the lamp is included on the packaging, this may be omitted.

Where the information specified in II, III and, where applicable, IV is included elsewhereon the packaging of the lamp, it may omitted from from the label, as may the box that contains it.

Annex IV of the Directive specifies the calculation to determine the energy efficiency class of a lamp.

Identified gaps:

- The mention of the average rated life of the lamp is not strictly imposed.
- The origin of the formulas in Annex IV is not clear.
- Some much used lamps are excluded from the labelling e.g. reflector lamps (DLS) and lamps with an inut power of less than 4W (e.g. LED's).
- Also all lamps that are not directly supplied from the mains, e.g. the widespread low voltage halogen lamps (HL-LV) are not included in this Directive.

- *Commission Decision of 9 September 2002 establishing revised ecological criteria for the award of the Community eco-label to light bulbs and amending Decision 1999/568/EC*

Scope:

This Decision amends the Decision 1999/568/EC for the award of the Community eco-label. It sets specific criteria for light bulbs that aim in particular at promoting:

- the reduction of environmental damage or risks related to the use of energy (global warming, acidification, depletion of non-renewable resources) by reducing energy consumption,
- the reduction of environmental damage or risks related to the use of resources in both the manufacture and treatment/disposal of a light bulb by increasing its average lifetime,
- the reduction of environmental damage or risks related to the use of mercury by reducing the total emissions of mercury during the lifetime of a light bulb. to become this Community eco-label.

In annex also the test method is described to measure the mercury content.

- *There is a ' European Compact Fluorescent Lamps QUALITY CHARTER' see ' http://re.jrc.cec.eu.int/energyefficiency/CFL/ '*

Scope:

This charter, that is in revision at this moment, is an initiative promoted by the European Commission in co-operation with the following organisations: EURELECTRIC, ELC, ADEME (France), NOVEM (The Netherlands), THE DANISH ELECTRICITY SAVING TRUST (Denmark) and THE UK ENERGY SAVING TRUST (UK).

The aim of the European CFL Quality Charter is to offer a high quality standard to be used by utilities and other bodies in their promotion and procurement campaigns. The ultimate goal of the European Quality Charter for CFL is to increase consumer confidence in this environmentally friendly technology, which save money and the environment. To achieve this, the charter promotes the manufacturing, marketing and sales of high quality CFLs in the European Union in order to offer residential customers a satisfying product from an energy, comfort and economic point of view.

The requirements that are imposed by this charter are related to safety, performance, information, guarantee and information:

- Safety: standards EN 60968, EN 61199 and EN 60598 and comply with CE-marking legislation;
- Performance: luminous efficacy following energy label A (with a derating factor for lamps with an external casing 'bulb form') see Figure 1-4, lumen maintenance, running up time, number of ignitions (> lifetime in hr) and colour rendering (Ra≥80), with a written conformity certificate from an approved 'Notified Body[7]';

[7] Notified bodies as defined in the Annex to 93/465/EEC: Council Decision of 22 July 1993 concerning the modules for the various phases of the conformity assessment procedures and the rules for the affixing and use of the CE conformity marking, which are intended to be used in the technical harmonization directives.

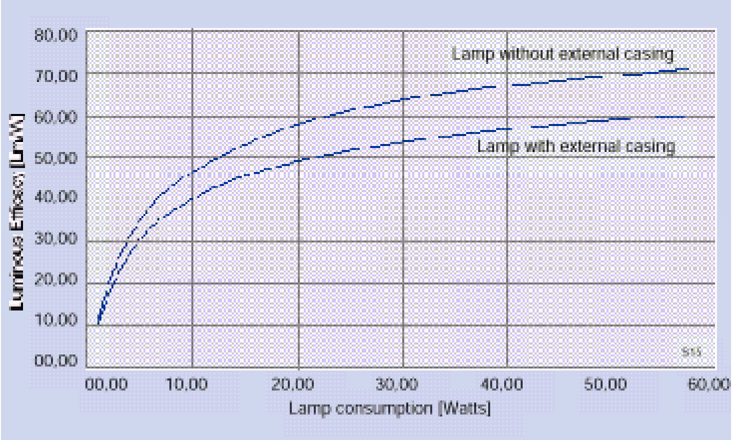


Figure 1-4: Luminous Efficacy limits for Integral Compact Fluorescent lamps

- Lifetime: minimum 6000hr and for 'Long Life' lamps minimum 1200hr;
- Information: lifetime and energy label A must be shown on the individual package of each lamp, mentioned equivalence with GLS filament lamp must comply with defined lumen output;
- Guarantee: 2 years on lamp failure;
- Quality of production: manufactured under a Quality Assurance System EN ISO 9002 or equivalent.

It is important to note that the charter is a voluntary set of criteria established by the European Commission in collaboration with the organisations mentioned above.

1.3.1.3 Other product related directives

- *Electromagnetic Compatibility (EMC) Directive 2004/108/EEC*

Scope:

The Council Directive *2004/108/EEC* of 15 December 2004 on the approximation of the laws of the Member States relating to electromagnetic compatibility (EMC Directive) governs on the one hand the electromagnetic emissions of this equipment in order to ensure that, in its intended use, such equipment does not disturb radio and telecommunication as well as other equipment. In the other the Directive also governs the immunity of such equipment to interference and seeks to ensure that this equipment is not disturbed by radio emissions normally present used as intended.

- *Low Voltage Directive (LVD) 73/23/EEC*

Scope:

The Low Voltage Directive (LVD) 73/23/EEC seeks to ensure that electrical equipment within certain voltage limits both provides a high level of protection for European citizens and enjoys a Single Market in the European Union. The Directive covers electrical equipment designed for use with a voltage rating of between 50 and 1000 V for alternating current and between 75 and 1500 V for direct current. It should be noted that these voltage ratings refer to the voltage of the electrical input or output, not to voltages that may appear inside the equipment. For most electrical equipment, the health aspects of emissions of Electromagnetic Fields are also under the domain of the Low Voltage Directive.

1.3.1.4 Voluntary agreements from industry on EU-level

The European Lamp Companies federation (ELC) has elaborated eco-design levels for certain lamp types the so-called ELC Eco-Profiles.
The following ecoprofiles can be found on their website
http://www.elcfed.org/2_resource_publications.html :

- *Eco-Profile for Self-ballasted Fluorescent Lamps*
- *Eco-Profile for Fluorescent Lamps*
- *Eco-Profile for Compact Fluorescent Lamps non-integrated*
- *Eco-Profile for HID Lamps.*

1.3.2 Legislation and Agreements at Member State level

Please note that this section is updated in part 2.
There are member states (a.o. in the UK by the Energy Saving Trust, in Sweden by the Swedish Energy Agency) that are preparing minimum performance specifications for (domestic) lamps. The specifications aim to enhance energy efficiency but also envisage colour rendering, colour temperature, lifetime, lumen maintenance, starting time, warm-up time, number of ignitions and guarantee period.

1.3.3 Third Country Legislation and Agreements

This section again deals with the subjects as above, but now for legislation and measures in Third Countries (extra-EU); some of them were indicated by stakeholders (NGO's, industry, consumers) as being relevant for the product group.
There are various minimum standards and labelling programs applied worldwide for compact fluorescent lamps (CFL) but only 4 countries have MEPS programmes that prohibit the sale of low efficiency CFL's[8]:

- China
- Mexico
- South Korea
- Japan.

The US have federal legislation with MEPS for Fluorescent Lamps (not for CFL's), for Incandescent Reflector Lamps and for Under-Cabinet Luminaires[9].
California has the 'Energy Star Label' (a voluntary agreement) for CFL's and for Residential Light Fixtures (Luminaires)[10].
Australia and New Zealand are working on MEPS for compact fluorescent lamps[11].

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[8] Source : Report No :2005/12 from the (Australian) National Appliance and Equipment Energy Efficiency Program : Minimum Energy Performance Standards - Compact Fluorescent Lamps.
[9] Source : Appliance – Efficiency Regulations, December 2006, CEC-400-2006-002-REV2, California
[10] Source : Energy Star Program Requirements for Residential Light Fixtures, Eligibility Criteria – Version 4.0 and Energy Star Program Requirements for CFL's – Partner Commitments Final Version

Japan has a 'Top Runner Programme' for the efficiency of Energy using Products. For lighting, this programme imposes burdens for fluorescent lighting (see: http://www.eccj.or.jp/top_runner/).

On the website www.apec-esis.org existing MEPS and labelling programmes worldwide at the moment of this study can be found. Due to accelerated efforts of several governments, the accuracy of this source can not be guaranteed.

In Annex 9.4, some current MEPS and quality parameters for CFLi's worldwide can be found.

[11] http://www.energyrating.gov.au/library/details200718-phaseout-incandescent-lamps.html.

2 ECONOMIC AND MARKET ANALYSIS

The aims of the economic and market analysis are:

- to place the product group "domestic lighting" within the total of EU industry and trade policy (see 2.1),
- to provide market and cost inputs for the assessment of EU-27 environmental impact of the product group (see 2.2),
- to provide insight in the latest market trends so as to indicate the place of possible eco-design measures in the context of the market-structures and ongoing trends in product design (see 2.3), and
- to provide a practical data set of prices and rates to be used in the Life Cycle Cost calculation (LCC) (see 2.4).

2.1 Generic economic data

2.1.1 Definition of 'Generic economic data' and data sourcing

"Generic economic data" gives an overview of production and trade data as reported in the official EU statistics. It places domestic lighting products within the total of EU industry and trade and also enables to check whether the product complies with the eligibility criterion of Art. 15., par. 2, sub a, of the EuP Directive:

> "*the EuP [to be covered by an implementing measure] shall represent a significant volume of sales and trade, indicatively more than 200,000 units a year within the Community according to more recently available figures.*"

To investigate the volume of sales and trade of a product group, it makes sense to rely on Eurostat's product-specific statistics. For trade and production figures, these are the so-called Europroms[12]-Prodcom statistics.

Although the aim is to take into account the specific attributes of the Member States' national lighting markets, much of the analysis could only be performed at the level of the EU total lighting market or regions of EU, as data were only available for few years and only in an aggregated form. The comparisons of imports, exports, production and apparent consumption[13] give an impression of the relative scales within the total lighting market but for

[12] Europroms is the name given to published Prodcom data. It differs from Prodcom in that it combines production data from Prodcom with import and export data from the Foreign Trade database.

[13] "Apparent consumption" is the estimation of the yearly consumption for each product based on the amount produced plus the amount imported minus the amount exported. This is the rationale for combining Prodcom and Foreign Trade data in Europroms (Eurostat Data Shop Handbook, part 6.4.2 Europroms-Prodcom data, version 29/08/2003).

numerous reasons[14] the comparisons must be considered only as approximations. The required data for all lamps (in both physical volume and in money units) is expressed by:

Apparent EU-27 consumption = Production + Imports – Exports

2.1.2 Generic economic data on lamp sales

At present, the main relevant domestic lamp types[15] are: GLS lamps, halogen lamps, linear fluorescent and compact fluorescent lamps. New lamp types like LED (Light Emitting Diode) and metalhalide are relevant as new technologies. Table 2-1 shows the relevant lamp categories in Eurostat.

Table 2-1: Domestic Lighting categories in Eurostat

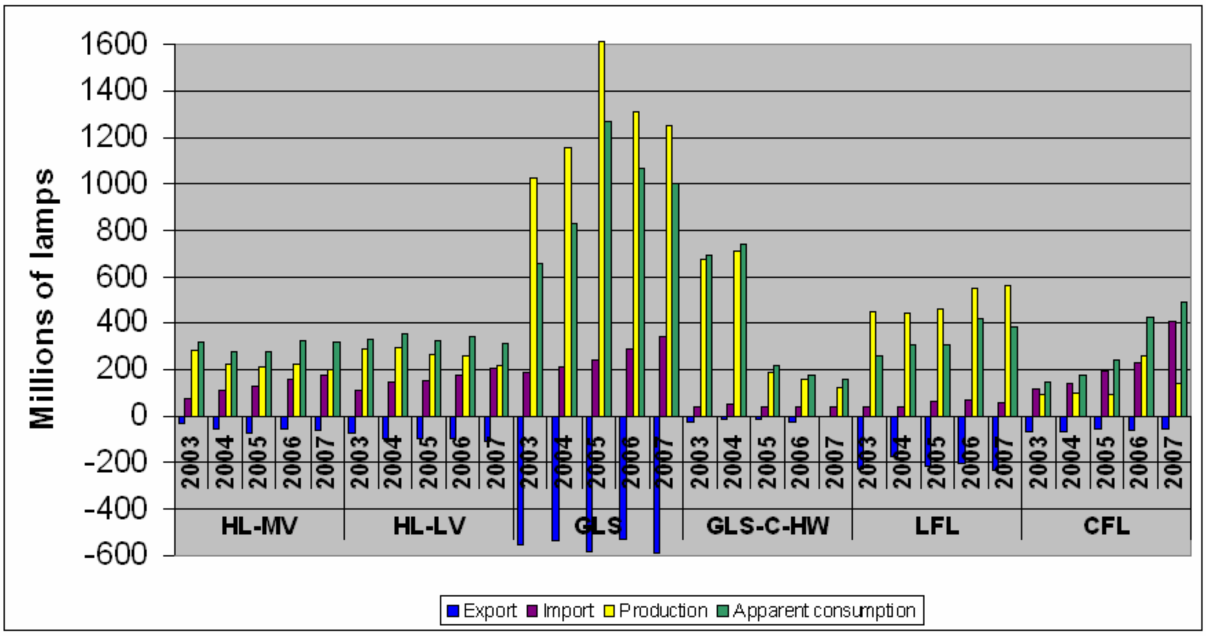
PRODCOM Code	DESCRIPTION
3150 1293	Halogen lamps : HL-MV, HL-R-MV
3150 1295	Halogen lamps : HL-LV, HL-R-LV
3150 1300	GLS lamps : GLS-F, GLS-C, GLS-R
3150 1493	GLS lamps : GLS-C-HW
3150 1510	Linear fluorescent lamps: LFL
3150 1530	Compact fluorescent lamps: CFLi + CFL-R-I and nearly not domestic used CFLni + CFL-R-ni

The market data in physical volume and monetary units was retrieved for these product categories from the Eurostat[16] for EU-27 trade[17] and production for the years 2003-2007. Results including the calculated apparent consumption are presented in Figure 2-1 and Figure 2-2.

Figure 2-1 shows that for EU-27:

- In the last two years, the apparent consumption of GLS lamps has decreased with 21% from 1271 million in 2005 to around 1001 million in 2007.
- Apparent consumption of GLS-C-HW has over the last three years decreased from 214 to 158 million (the high numbers in 2003 and 2004 seem to be wrong as they don’t match with information received from the manufacturers).
- Apparent consumption of HL-MV and HL-LV was both around 300 million/year. A substantial part of these lamps are sold in the commercial sector. Table 2.3 shows a large increase in ELC sales from 2004-2006 with respectively 14% for HL-LV and 18% for HL-MV. Several countries report their domestic stock of HL has considerably increased during the last years, e.g. Denmark where the halogen part of the stock increased from 15% in 2000 to 29% in 2006. For 2006, the contribution of halogen lamps has increased to 31% of the stock in Germany and 24% for EU-27 (see table 2.11). Eurostat data do not seem to include all halogen sales maybe because sales of 6- and 8-packs are counted as 1 lamp and lamp sales along with luminaires are missing.

[14] The general advantages, flaws and limitations of these official EU statistics are extensively discussed in i) the MEEUP Methodology Report and ii) the Eurostat data shop Handbook (part 6.4.2.) Europroms-Prodcom data, version 29/08/2003.
[15] See in chapter 1 for an overview of lamp types, names and codes.
[16] http://epp.eurostat.ec.europa.eu (Theme “Industry, trade and services”, last consulted 06/08/2008)
[17] In this study the interest is trade leaving and entering the EU27 - Eurostat also includes data per EU country.



Production of GLS in 2007 is an estimated value as the statistical value is not available now

Figure 2-1: Volume of production, trade and sales of lamps for EU-27

- Apparent consumption of LFL has increased from 250 to 400 million. Most of these lamps are used in the commercial sector.
- There has been a 340% increase in the apparent consumption of CFL (CFLi+CFLni) from 145 million in 2003, 177 million in 2004, 241 million in 2005, a dramatic increase to 426 million in 2006 and finally 493 million in 2007 – or even 628 million which seems to be the apparent consumption in the Eurostat update taking place in October 2008. A considerable part of these lamps are CFLi used in the domestic sector (see details in the end of 2.2.2).
- EU-27 is a net-exporter of GLS and LFL and net-importer of HL, GLS-C-HW and CFL (CFLi+CFLni).

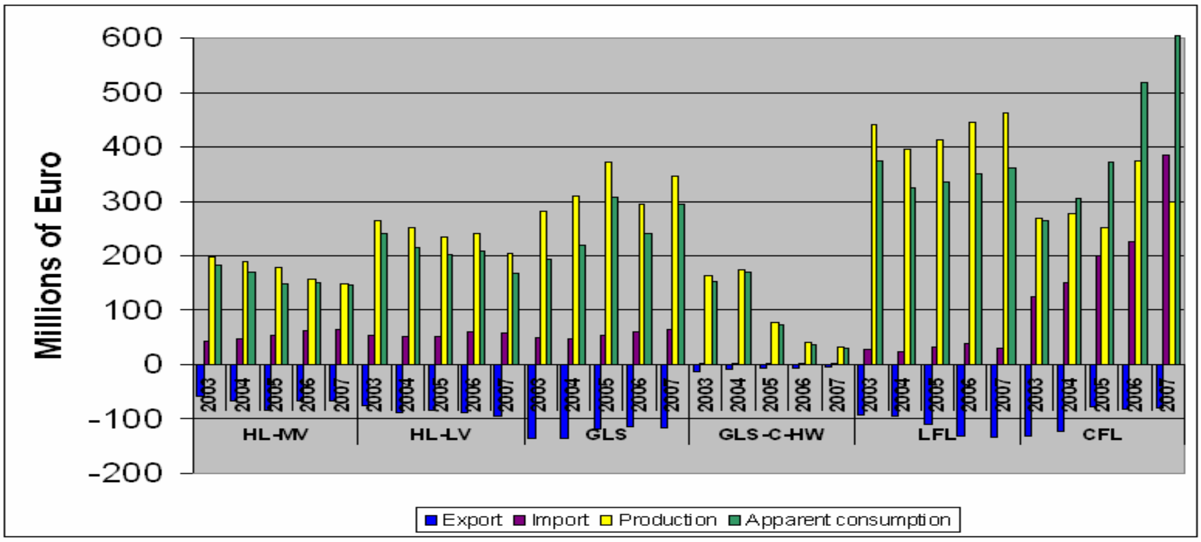


Figure 2-2: Value of production, trade and sales of lamps for EU-27

Comparison of the export value to the production value in Figure 2-2 shows:

- an increase from 29% in 2003 to 46% in 2007 for both HL-MV and HL-LV,
- a decrease from 49% in 2003 to 34% in 2007 for GLS,
- an increase from 7% in 2003 to 18% in 2007 for GLS-C-HW but this is not very important since the use of this lamp type is reduced to a very small amount in the period,
- an increase from 21% in 2003 to 29% in 2007 for LFL,
- a decrease from 49% in 2003 to 27% in 2007 for CFL (CFli+CFLni) so a growing share of the produced CFLs are used in EU-27.

Comparison of the value of import to the value of apparent consumption in Figure 2-2 shows:

- an increase from 23% to 45% for HL-MV in the period 2003-2007 – so there is a growing and rather large import of this lamp type,
- an increase from 22% to 35% for HL-LV in the period 2003-2006,
- a decrease from 25% to 22% for GLS in the period 2003-2007 – so the import is rather small for this lamp type,
- an increase from 1% to 4% for GLS-C-HW in the period 2003-2006,
- an increase from 7% to 9% for LFL in the period 2003-2006 – so the import is very small,
- an increase from 48% to 64% for CFL (CFLi+CFLni) in the period 2003-2007 – the main and very large increase happens in 2007; the import is thus very high for this lamp type and the monetary value of the import is high.

One must bear in mind that these results hold for all lamps in all sectors (the whole society and not only domestic lighting application). In section 2.2, the use of different lamps in lighting is studied in more detail. Please note that some lamps are sold in multipacks that could have been introduced as 'one' unit in Eurostat data and that many luminaires sold for domestic lighting are sold with lamps, hence for some lamp categories these figures might be higher. This could especially affect new trendy lamps, e.g. HL-MV with G9, GU10 or R7s caps.

2.1.3 Generic economic data on luminaire sales

Please consult the related section in part 2 of this study.

2.2 Market and stock data

The purpose of this sub-task is to provide market data for the identification of the most representative products in the European market and for the EU-wide environmental impact assessment of the product group 'domestic lighting' (chapters 5 and 8) as defined in section 1.1 and to provide market inputs for scenario analysis up to 2020 (chapter 8).

Market and stock data are required for the following time periods:

- 1990 (Kyoto reference);
- 2003-2006 (most recent real data);
- 2010-2012 (forecast, end of Kyoto phase 1) in a Business as Usual scenario;
- 2020-2025 (forecast, year in which all – or at least a substantial share of - new ecodesigns of today will be absorbed by the market) in a Business as Usual scenario.

Please note that it is not the purpose of chapter 2 to forecast the effect of future policy options related to domestic lighting, however we should keep in mind that market data of the past are influenced by promotional campaigns for energy efficient lighting. Future policy options and their estimated impacts are discussed in chapter 8.

In order to assess the environmental impact, according to the MEEuP methodology, 'primary MEEuP market parameters' that will be used for impact modelling in chapters 5, 7 and 8 are identified (see Table 2-2). These parameters should reflect:

- Installed lamps (stock) in domestic lighting according to the product categories defined in section 1.1 most recently (2003-2007) and in the past (1990 estimation) per EU-27 country;
- Annual lamp sales according to the product categories defined in section 1.1 per EU-27 country;
- Lamp sales growth (% or physical units) according to the product categories defined in section 1.1 to forecasting the impact in Business as Usual for 2011 and 2020 for a BAU scenario;
- Average Product Life (in years);

From the above data, the following dedicated MEEuP parameters will be derived:

- Total sales according to the product categories defined in section 1.1 versus generic data, (also in €, when available);
- Total sales estimated when purchasing a new luminaire versus replacement lamp sales for existing luminaires (derived, if available);

In this section will be defined 'additional MEEuP model parameters' because the 'Primary MEEuP market parameters' are not always available.

As average product data in years are not directly available for domestic lighting, the product life in years can be deducted, based on the average operational hours and the operational lifetime in hours. Operational lifetime data are included in chapter 4.

Some country market data are available from R&D along a number of households per country. Some data are available per region and some regional differences can be observed and used.

Table 2-2 gives an overview of the market parameters that are chosen to be included in the MEEuP model for EU-27. Regarding the parameters, it is important to note that:

- 1, 2, 3, 6, 8: available data per EU-27 Member State are used, which are then accumulated to generate total EU-27 data.
- 1, 2, 5, 6, 7, and 8: data change over the concerned time frame 1990-2020 (forecast trends), but these data do not vary between different scenarios.
- 3 and 4 data change over the concerned time frame 1990-2020 (forecast trends), and these data also vary depending on the scenario that is applied: business as usual, least life cycle cost, best available technology etc.

Table 2-2: Input data included in the MEEuP Model totals for EU27

Ref.	**Table. inputs for EU-27 Totals**	**Unit**	**Primary MEEuP market paramenter**	**Additional MEEuP market parameter**
1	Number of households per country and total	Households		x
2	Increase in number of households (per 5 years)	%		x
3	Number of different types of lamps per household	Lamps		x
4	Per lamp types % division on NDLS and DLS lamps	%	x	
5	Forecast of increase in number of lamps (per 5 years)	%	x	
6	Weighted average Wattage per lamp type	W	x	
7	Lamp life time per lamp type	Hours		x
8	Average operational hours per lamp type	Hours/year	x	

Ballasts for LFL and CFL in the domestic sector are included in the luminaire that customers buy. As a consequence, they are not handled as a separate parameter in this study on domestic lighting. For details on ballasts, please refer to the preparatory study on Office lighting (Lot 8).

Luminaires for the domestic sector include a huge amount of different products with a very large price range. They are sold by thousands of luminaire manufacturers organised in CELMA[18]. It is very difficult for CELMA to provide statistics for the luminaire market due to this large number of companies from many countries with different statistical reporting systems. Since no reliable EU-27 luminaire market data exist, it is chosen to handle the luminaires as a part of the system.

[18] Federation of National Manufacturers Association for Luminaires and Electronical Components for Luminaires in the European Union,. CELMA represents 16 national associations.

Nevertheless, an analysis of the system and its impacts will be included in part 2 of the study.

For part 1 of the study, section 2.2.6 summarizes the market and stock data that will be used in the other chapters.

2.2.1 Data retrieval

The following 4 approaches for retrieving market data (complementary to Eurostat data in section 2.1) were explored:

1. **Literature research and EU R&D project data:** various studies have been conducted on the energy use of domestic lighting for EU R&D programmes and several Member States have delivered useful data on the number of installed lamps and their related energy consumption. The most recent overview of the global trade in lamps and lighting products and the global market value and trends can be found in the recently published IEA Light's Labour's Lost (IEA, 2006).

2. **Consultation of ELC[19], major retailers, Chinese Chamber of Commerce and CELMA:** a request for lamp and luminaire sales data and any other relevant information was launched at the first stakeholder meeting (19/07/2007). The following data are largely based on the answers from ELC: sales of lamps divided by types and wattages and estimation of lamp sales over the different EU regions. Based on sales data and average lamp lifetimes, stocks can be estimated.

3. **Expert-inquiry**: DG JRC (Joint Research Centre) of the European Commission sent in spring 2007 a 10-question-survey to experts in different Member States and to other lighting related organisations. Experts from nearly all EU-27 filled in the questionnaire and the responses provided useful data on number of lamps per household and numbers and use of energy efficient lamps for the different Member States. These data are used along with new and more detailed information collected in the EU R&D project REMODECE[20] including 12 countries plus some national research projects in other EU countries. Data for the remaining countries are estimated based on the above data.

4. **Calculated estimations based on the number of households in EU-27 and stock data from EU R&D projects:** Data on the number of houeholds per Member State can be found in Eurostat. The EU-27 total installed base of domestic lamps can be derived by combining this with the lamps-per-household data available for a number of EU countries and the average measured and estimated lifetime of different lamp types. Forecast on population, number of households, number of luminaires and lamps can be used to make projections regarding the future installed base and annual sales of domestic lighting products (up to 2020).

[19] European Lamp Companies federation including 8 members
[20] Residential Monitoring to Decrease Energy Use and Carbon Emissions in Europe

2.2.2 Annual lamp sales

The objective of this section is to determine the actual sales as reliably as possible for the domestic lighting lamp types as defined in section 1.1 for the latest full year for which data are available. A questionnaire for sales data and other relevant market information was addressed directly to ELC, 2 major European lamp retailers, and The China Chamber of Commerce. All other stakeholders were also invited to contribute; the questionnaire can be downloaded by registered stakeholders on the project website (www.eup4light.net).

In December 2007, ELC has been answering the questionnaire as far as possible for the period 2004-2006. ELC has kindly provided data for 4 regions of EU: Central&Eastern, Middle, Norther and Southern. The available data include sales in all sectors in the society and unfortunately no data are available on the division of these sales between different sectors.

The sales figures for application in domestic lighting can only be estimated using information from research, lamp industry experts and assumptions. At present, the most used lamps in the domestic sector are GLS and halogen lamps, a small amount of linear fluorescent lamps (LFL's) and an increasing amount of CFL's with integrated ballast.

Table 2-3 presents the annual sales for the different types of lighting sources and shows that:

- more changes in the sales from 2004 to 2005 than from 2005 to 2006,
- sales of GLS are decreasing but still in 2006 they represent around half of the total sales volume,
- HL-MV is the fastest growing category within HL lamps,
- CFLi has the fastest growth but in 2006 it represents only around 5% of total sales volume,
- LFL's are primarily used in the non-domestic sectors (see more in section 2.2.3)

Table 2-3: Volume of ELC sales in EU-27, 2004-2006

	2004	2005	2006	% Change 2004-2006
GLS-F, GLS-C	**1.230.600.887**	**1.121.433.531**	**1.096.187.033**	-11%
GLS-R	**163.822.491**	**144.513.034**	**138.360.572**	-16%
HL-LV	**53.121.906**	**58.318.203**	**60.348.996**	14%
HL-MV	**37.225.445**	**39.554.523**	**43.765.438**	18%
HL-R-LV	**66.915.971**	**71.422.261**	**73.181.823**	9%
HL-R-MV,HL-R-MV colour	**28.753.170**	**29.758.531**	**31.705.477**	10%
LFL	**377.650.078**	**394.780.333**	**385.637.398**	2%
CFLi	**73.073.235**	**92.593.327**	**97.412.114**	33%
Others **)	**49.806.285**	**43.484.686**	**44.167.210**	-11%
TOTAL	**2.080.969.470**	**1.995.858.428**	**1.970.766.061**	-5%

**) including <=25W of GLS-colour, -deco, -lin, -signal, -special plus HL-R-LV 15W

Concerning GLS and HL sales, the annual percentage distribution of the sales on wattages and regions is not changing much in the period 2004-2006, so to get a picture of the distribution it is enough to look at the last year with available data (2006).

Table 2-4 shows that:

- one third of the sold GLS lamps are 60W and nearly another third are 40W,
- sales of 100W lamps are substantial with 12,2% of the GLS sales (equal to around 134 million/year) and these sales are spread over all regions of EU-27,
- sales of lamps with wattage above 100W account for only 0,6% (around 7 million/year) and thus relatively speaking very limited.

Table 2-4: GLS-F + GLS-C % distribution of ELC sales in EU-27, 2006

% ELC sales 2006	***EU Region***				
GLS Wattage	*Central & Eastern*	*Middle*	*Northern*	*Southern*	***Total***
<=25W	3,2	7,3	2,9	3,4	**16,8**
40W	5,1	16,6	3,1	6,7	**31,6**
60W	7,1	16,8	1,9	7,2	**33,0**
75W	2,4	2,4	0,2	0,9	**5,8**
100W	4,2	4,9	0,2	2,9	**12,2**
150W	0,2	0,1	0,0	0,1	**0,4**
>=200W	0,05	0,05	0,0	0,1	**0,2**
Total	**22,2**	**48,2**	**8,4**	**21,3**	**100**

Table 2-5 shows that:

- 55% of the GLS-R lamps sales are 40W and more than half of the rest are 60W,
- 6,5% (around 9.000.000/year) of the GLS-R sales are wattages of 100W or higher.

Table 2-5: GLS-R % distribution of ELC sales in EU-27, 2006

% ELC sales 2006	***EU Region***				
GLS Wattage	*Central & Eastern*	*Middle*	*Northern*	*Southern*	***Total***
<=25W	2,0	5,0	1,4	0,6	**9,0**
40W	10,1	37,7	2,4	4,9	**55,2**
60W	5,0	18,1	0,4	3,4	**26,9**
75W	0,2	1,6	0,0	0,6	**2,4**
100W	0,2	2,4	0,0	0,8	**3,5**
150-200W	0,3	2,3	0,0	0,4	**3,0**
Total	**17,7**	**67,1**	**4,3**	**10,8**	**100**

Table 2-6 shows that:

- HL-LV are rather equal spread on 10W, 20W and >20W,
- HL-R-LV is one third 20W and two third >20W.
- The largest sales increase is seen for HL-R-LV 20W.

Table 2-6: HL-LV EU-27 % distribution of ELC sales in 2006 and 2004-6 sales increase

% ELC sales 2006	***EU Region***				
Wattage	*Central & Eastern*	*Middle*	*Northern*	*Southern*	***Total***
HL-LV 10W	2,2	16,4	3,3	7,2	**29,0**
HL-LV 20W	3,0	23,1	3,5	8,9	**38,4**
HL-LV >20W	1,4	23,4	1,9	5,9	**32,6**
HL-LV total	**6,5**	**62,9**	**8,6**	**22,0**	**100**
HL-R-LV 20W	2,2	20,1	2,0	9,8	**34,2**
HL-R-LV >20W	3,8	37,3	2,7	21,9	**65,8**
HL-R-LV total	**6,0**	**57,4**	**4,8**	**31,7**	**100**
Wattage	**2004**	**2005**	**2006**	**Increase in sales (%)**	
HL-LV 10W	15.148.171	16.422.461	17.495.671	**15%**	
HL-LV 20W	20.580.911	22.783.516	23.163.963	**13%**	
HL-LV >20W	17.392.824	19.112.226	19.689.362	**13%**	
HL-R-LV 20W	19.466.508	24.142.385	25.010.136	**28%**	
HL-R-LV >20W	47.449.463	47.279.876	48.171.687	**2%**	

HL-R-LV 15W is included by ELC in the general category (see Table 2-3) because of lack of answers

Table 2-7 summarizes sales of very different products, among others R7s double-ended lamps and lamps with E/B sockets. The results are:

- In 2006, HL-MV sales are distributed as follows: 39% ≥ 200W, 32% 75-100W, 21% 26-50W and 7% 25W.
- Sales of HL-MV 25W is increasing with 152% but 2004 sales volume is very low.
- Sales of HL-MV 26-50W are increasing with 30% but sales volume is not the highest.
- Sales of HL-R-MV sales are distributed as follows: 42% >60W, 35% 60W and 23% ≤ 40W. Sales of HL-R-MV ≤ 40W are anyway increasing fast with 44%.

Table 2-7: HL-MV EU-27 % distribution of ELC sales in 2006 and 2004-2006 sales increase

% ELC sales 2006	***EU Region***				
Wattage	*Central & Eastern*	*Middle*	*Northern*	*Southern*	***Total***
HL-MV 25W	2,7	2,9	0,3	1,3	**7,2**
HL-MV 26-50W	1,4	13,2	0,8	5,8	**21,2**
HL-MV 75-100W	2,5	16,5	3,3	10,1	**32,3**
HL-MV >=200W	4,7	21,0	1,8	11,8	**39,3**
HL-MV total	**11,1**	**53,6**	**6,3**	**29,0**	**100**
HL-R-MV <=40W	2,3	15,8	2,0	3,2	**23,2**
HL-R-MV 60W	1,8	23,3	3,4	6,7	**35,2**
HL-R-MV >60W	1,5	30,0	3,1	7,0	**41,6**
HL-R-MV total	**5,6**	**69,0**	**8,6**	**16,8**	**100**

Wattage	2004	2005	2006	Increase in sales (%)
HL-MV 25W	1.245.917	1.650.277	3.137.223	**152%**
HL-MV 26-50W	7.115.644	7.886.819	9.284.155	**30%**
HL-MV 75-100W	12.513.781	13.529.781	14.154.779	**13%**
HL-MV >= 200W	16.350.103	16.487.646	17.189.281	**5%**
HL-R-MV <=40W	5.103.999	5.863.506	7.369.583	**44%**
HL-R-MV 60W	10.176.305	10.513.726	11.151.501	**10%**
HL-R-MV >60W	13.472.866	13.381.299	13.184.393	**-2%**

Table 2-8: CFLi volume and % distribution of ELC sales in EU-27, 2004-2006

CFLi Wattage	EU Region	2004	2005	2006	2006 %
<=7W	Central & Eastern	345.283	402.129	482.736	0,5
	Middle	1.351.001	1.823.951	2.152.422	2,2
	Northern	114.777	131.455	195.650	0,2
	Southern	341.878	371.730	547.833	0,6
	EU Total	***2.152.938***	***2.729.264***	***3.378.641***	**3,5**
8-10W	Central & Eastern	1.197.376	1.221.123	1.379.275	1,4
	Middle	6.128.107	8.790.830	10.370.058	10,6
	Northern	505.317	508.097	615.116	0,6
	Southern	2.363.315	2.750.290	3.314.585	3,4
	EU Total	***10.194.114***	***13.270.340***	***15.679.034***	**16,1**
11-14W	Central & Eastern	2.428.500	2.426.132	2.638.215	2,7
	Middle	12.176.283	21.576.425	22.270.544	22,9
	Northern	944.198	1.017.624	1.588.646	1,6
	Southern	4.592.422	5.759.366	6.378.072	6,5
	EU Total	***20.141.404***	***30.779.546***	***32.875.477***	**33,7**
15W	Central & Eastern	797.590	892.987	1.071.267	1,1
	Middle	6.818.021	6.875.306	5.446.916	5,6
	Northern	459.673	532.971	640.151	0,7
	Southern	3.612.455	4.563.609	6.922.551	7,1
	EU Total	***11.687.740***	***12.864.872***	***14.080.885***	**14,5**
>15W	Central & Eastern	3.282.179	3.440.097	3.899.581	4,0
	Middle	16.705.927	19.263.858	12.432.857	12,8
	Northern	365.726	363.359	396.482	0,4
	Southern	8.543.207	9.881.989	14.669.156	15,1
	EU Total	***28.897.039***	***32.949.303***	***31.398.077***	**32,2**
CFLi Total		**73.073.235**	**92.593.327**	**97.412.114**	**-**

Table 2-8 shows that:

- One third of the CFLi sales are 11-14W where Middle EU is growing fast in 2005.
- Another third of the CFLi sales are >15W where Southern EU is growing fast and Middle EU is decreasing in 2006.
- CFLi sales in Central and Eastern EU are small compared to the number of homes.

Table 2-9 summarizes sales data for the year 2006:

- The total for GLS is adjusted to 1350 million (from 1067 million in Eurostat, see Figure 2-1) as Eurostat data are lower than the sum of the sales data from the manufacturers – maybe because some sales of packages of two bulbs sometimes go into statistics as sales of one bulb. Reasons for significant differences between sales data and apparent consumption from official statistics are extensively discussed in the MEEuP report (VHK, 2005).

- ELC data are summarized data from Table 2-3.
- 2 major European lamp retailers have kindly informed the rough size of their yearly 2006/2007 sales.
- Other sales are including the residual sales from other manufactures.
- ELC provided their 2006 CFLni sales, i.e. 170 million.
- The data about EU regulation n° 1205/2007 of 15. Oct. 2007 imposing anti-dumping duties on imports of CFLi result in an EU-27 CFLi consumption of 144 million in 2004, 198 million in 2005 and 214 million in the period 1/7 2005 – 30/6 2006. The MEEuP Model calculation of a consumption of 244 million CFLi (see Table 2-25) is verily fine in line with the above data found in the regulation analysis.

Table 2-9: Volume of EU-27 sales (millions/year) for all sectors in 2006

Lamp type	Total (Euro-stat)	ELC Sales	2 major European lamp retailers Sales	Other Sales (residual)	Non Direct and Direct Lamp Sources %
GLS	1.350	1.096	62	44	NDLS 89%
GLS-R		138	10		DLS 11%
HL-LV	300	60	26	120	NDLS 45%
HL-R-LV		73	21		DLS 55%
HL-MV-LW	330	20[21]	10	193	NDLS 58%
HL-MV-HW		24	1		
HL-R-MV-LW		25	46		DLS 42%
HL-R-MV-HW		7	4		
LFL	390	386	0	4	NDLS 100%
CFLi	426	97	60 (3% DLS)	159	NDLS 99%
CFLni		90 ¤	0	20	-

¤ Value estimated from EuP lot 8 information and informal data about ELC CFLni sales in 2007

Table 2-9 shows 2006 data for all sectors and that ELC is covering nearly all GLS and LFL sales but less than half of the HL and CFL sales. 2 major European lamp retailers covered 25% of the CFLi sales in 2006. The NDLS/DLS distribution for halogen lamps is derived from new data received in 2008 and the distribution is a bit different from MEEuP model in Table 2-25 developed earlier in the study. Instead of updating the MEEuP model and all calculations in chapter 5, 7 and 8, a sensitivity analysis was executed in chapter 8 to see the influence of using the new NDLS/DLS distributions. The results show a small difference of about 2-3% in energy savings and no influence on the outcome of comparison and ranking of the scenarios.

Table 2-10 shows the CFL sales during the last 5 years. It shows that CFLi sales has been growing very much during 2006 and 2007.

[21] ELC HL-MV sales 44 million and HL-R-MV sales 32 million is divided on LW (≥75W) and HW (>75W) by own judgement

Table 2-10: EU-27 sales (millions/year) of CFL for all sectors 2003-2007

	2003	2004	2005	2006	2007
Eurostat sales	145	177	241	426	493 (628) ¤
CFLni [22]	51	56	88	110	140
CFLi [23]	94	121	153	316	353

¤ Eurostat is about to update CFLi production for 2007 and it seems the apparent consumption will then be 628 million

2.2.3 Stock of different lamp types per household

The current stock data in Table 2-11 are kindly provided by an end-user survey in the ongoing EU R&D project REMODECE including 500 consumers/country for 11 countries. Besides this, Sweden and UK have provided data from large national surveys performed in 2007. It includes data from a JRC questionnaire to national experts [Bertoldi and Atanasiu, 2007]. and it was estimated that the mentioned 13 countries use 76% of the total EU-27 stock. The detailed data for the 13 countries was finally rescaled to four EU regions.

Table 2-11 shows big differences in numbers of different types of lamps used per country:

- the EU-27 average is 24,3 lighting points/household (variation: 10-40 points/country),
- the average share of GLS lamps is 13,1 GLS/households equal to 54% of the lamps,
- the average share of HL-LV is 4,46 equal to 18% of the lamps,
- the average share of HL-MV is 1,32 equal to 5% of the lamps,
- the average share of LFL is 1,83 equal to 8% of the lamps,
- the average share of CFLi is 3,58 equal to 15% of the lamps.

Table 2-12 shows an estimation of the stock of lamps for 1995 for EU-27 although the EU did not include that many countries at that time:

- the EU-27 average is 21,3 lighting points/household (variation: 6-36 points/country),
- the average share of GLS lamps is 18,0 GLS/households equal to 85% of the lamps,
- the average share of HL-LV is 0,9 equal to 4% of the lamps,
- the average share of LFL is 1,4 equal to 6% of the lamps,
- the average share of CFLi is 1,0 equal to 5% of the lamps.

[22] 2003-2004 comes from EuP lot 8 (Office Lighting) table 133, CFL retrofit. 2007 is ELC sales 99 million plus estimates 41 million sales by others. 2005 and 2006 is found by interpolation.
[23] Found as difference between Eurostat and CFLni sales.

Table 2-11: Stock of lamps used in EU-27 in 2007

			REMODECE survey						JRC questionnaire		
EU region	Coun-try	Number of house holds	GLS	Halogen LV	Halogen MV	LFL	CFLi	Lamp per HH	Lighting points	% of HH with CFLi's	CFLs/HH incl. HH without CFLi
		millions	no/HH	no/HH	no/HH	no/HH	no/HH	No/HH	no/HH	%	no/HH
Central and Eastern	BG	3,7	9,10	4,11	0,24	0,55	1,73	15,7	10,0	7	0,20
	CZ	4,40	8,85	3,50	0,38	1,60	4,80	19,1	10,0	70	2,90
	CY	0,32							16,0	79	2,00
	EE	0,60							6,0	20	0,25
	HU	4,10	8,30	1,40	0,00	0,30	3,20	13,2	18,0	60	1,00
	LV	0,97							20,0	19	0,42
	LT	1,30							6,0	20	0,25
	MT	0,13							15,0	50	1,00
	PL	13,3							20,0	50	0,50
	RO	8,13	8,37	0,80	0,27	0,75	1,05	11,2	10,0	20	0,20
	SK	2,1							15,0	60	1,00
	SI	0,69							19,0	50	1,00
Middle	AT	3,3							26,0	70	4,00
	BE1	4,3	9,3	10,0	1,10	3,0	7,2	30,7	26,0	71	2,50
	FR	32,2	12,80	2,10	0,80	1,50	3,20	20,4	18,9	52	2,26
	DE	39,1	12,50	7,10	0,70	1,90	3,10	25,3	32,0	70	6,50
	EI	1,44							18,0	38	1,50
	LU	0,20							20,0	70	2,00
	NL	7,0							40,0	60	4,00
	UK	26,20	15,6	2	3,80	1	2,3	25,0	20,0	50	2,00
Northern	DK	2,5	14,10	9,10	1,70	2,40	5,40	32,7	25,4	65	4,90
	FIN	2,5							23,5	50	1,00
	SE	4,5	21,0	4,0	1,0	4,8	4,0	34,8	22,0	55	2,20
Southern	GR	3,7	11,3	2,6	0,5	1,4	3,0	18,8	7,0	50	1,00
	IT	22,5	15,4	7,0	2,0	3,2	5,8	33,4	18,0	60	0,80
	PT	4,2	11,84	3,51	0,79	1,80	3,39	21,3	11,4	54	1,70
	ES	17,2							25,0	15	2,00

EU region	House-holds	GLS	Halogen LV	Halogen MV	LFL	CFLi	Lamps in survey	Lighting points by Remodece +JRC (rest)	Percentage of HH with CFLi's (JRC)	CFLs/HH incl. HH without CFLi, JRC
	millions	millions	millions	millions	mio.	mio.	mio.	millions	%	No/HH
Central+Eastern	39,73	386	95	10	36	109	288	636	42	0,8
Middle	113,74	1569	525	183	185	367	2433	2829	59	3,8
Northern	9,50	162	51	11	34	39	238	297	56	2,6
Southern	47,60	653	269	73	130	239	934	1364	42	1,3
EU-27	210,57	2770	939	277	385	753	3893	5125	52	2,6
	No/hh	13,15	4,46	1,32	1,83	3,58		**24,34**		

1 In the Podo project (2005-2006) Socio Technical factors influencing residential energy consumption, a survey in 40 older (> 20 years) homes there could apply for renovation (might explain that the number of halogen LV was low) the numbers were GLS 10.28, HL-LV 1.0, HL-MV 0.73, LFL 2.03 and CFL 2.23 in total 16.25 lamps.

Table 2-12: Estimation of the stock of lamps used in EU-27 in 1995

			Data from DELIGHT, CFLi DISSEMINATION and JRC						
EU region	Country	Number of house holds 1995	GLS	Halogen LV	Halogen MV	LFL	CFL	Total number of lamps	Lighting points
		millions	no/HH	no/HH	no/HH	no/HH	no/HH	no/HH	no/HH
Central and Eastern EU	BG	3,1	10,25	1,00	0,00	0,55	0,00	11,8	11,8
	CZ	3,7							10,0
	CY	0,3	15,40				0,6	16,0	16,0
	EE	0,5							6,0
	HU	3,5	13,00	0,00	0,00	0,30	0,70	14,0	14,0
	LV	0,8							18,0
	LT	1,1							6,0
	MT	0,1							14,0
	PL	11,3	14,50				0,5	15,0	15,0
	RO	6,9	8,25	0,00	0,00	0,75	0,00	9,0	9,0
	SK	1,8							14,0
	SI	0,6							17,0
Middle EU	AT	3,3	25,20				0,8	26,0	26,0
	BE	4,1	24,70	2	0,00	3	1,0	30,7	30,7
	FR	24,8	15,50	1,00	0,00	1,50	0,50	18,5	18,5
	DE	36,9	23,00	2,00	0,00	1,90	2,10	29,0	29,0
	EI	1,2	24,10				0,9	25,0	25,0
	LU	0,1	17,60				0,4	20,0	18,0
	NL	6,4	33,60				2,4	36,0	36,0
	UK	21,5	18,40		0,00	1	0,7	20,0	20,0
Northern EU	DK	2,3	19,60	2,00	0,00	2,40	2,00	26,0	26,0
	FIN	2,1	21,00		0,00		1,0	22,0	22,0
	SE	3,9	28,80	1,0	0,0	4,8	0,4	35,0	35,0
Southern EU	GR	3,6	12,50	0,00	0,00	1,40	0,10	14,0	14,0
	IT	22,3	13,70	2,00	0,00	3,20	1,10	20,0	20,0
	PT	3,6							11,0
	ES	15,1	19,40				0,6	20,0	20,0

EU region	Number of households 1995	GLS	Halogen LV	Halogen MV	LFL	CFL	Lamps surveyed	Lighting points
	millions	millions	millions	millions	millions	millions	millions	millions
Central+Eastern EU	33,76	395	4	0	10	11	322	420
Middle EU	98,36	2060	107	0	139	128	2434	2434
Northern EU	8,30	202	9	0	24	8	243	243
Southern EU	44,60	675	47	0	80	36	798	838
EU 27	185,02	3332	166	0	254	183	3797	3935
	no/hh	18,01	0,90	0,00	1,37	0,99		21,27

1995 lighting points and CFLi data based on a mix of data from two EU SAVE project DELIGHT and Dissemination of CFLi.

1995 LFL s assumed to be similar in 1995 as in 2006.

In 1995, there is assumed to be no HL-MV lamps in use and only a fraction of the HL-LV used in 2006.

No of households from European Environment Agency for EU-15 - for other countries assumed 15% increase from 1995 to 2007.

2.2.4 Average lamp wattages for different lamp types

Table 2-4 to Table 2-8 contain usefull information about ELC yearly sales of different wattages but this is not the same as the wattages stock distribution per household. Table 2-13 to Table 2-17 contain information about the stock of lighting sources divided by wattages origining from:

- EU R&D project EURECO (1999-2000) provided for Denmark, Greece, Italy and Portugal
- “Eclairage 100" (1999) for France
- UK lighting market transformation survey (2007)
- Belgium Podo project (2005-2006)

Table 2-13: Use of GLS divided by wattages

Wattages	*Belgium*	*Denmark*	*France*	*Greece*	*Italy*	*Portugal*	*UK*	*EU-27 estimate*	*ELC sales*
15-20W	-	3%	1%	0%	1%	2%	2%	1%	17%
25-30W	6%	23%	10%	3%	1%	12%	4%	9%	
35-40W	35%	45%	40%	17%	22%	43%	42%	40%	32%
50W	-	0%	0%	2%	5%	1%	-	1%	-
60W	49%	22%	31%	33%	34%	32%	43%	35%	33%
70-80W	5%	2%	10%	18%	16%	6%	-	6%	6%
100W	5%	1%	8%	24%	19%	7%	7%	7%	12%
120-150	-	0%	0%	1%	1%	1%	2%	1%	0,6%
Weighted average	***53 W***	***40 W***	***52 W***	***67 W***	***64 W***	***53 W***	***51 W***		

Table 2-14: Use of halogen lamps divided by wattages

<table>
<tr><th></th><th colspan="2">Belgium</th><th rowspan="2">Denmark</th><th colspan="2">France</th><th rowspan="2">Greece</th><th rowspan="2">Italy</th><th rowspan="2">Portu gal</th><th colspan="2">UK</th></tr>
<tr><th>Wattages</th><th>LV</th><th>MV</th><th>LV</th><th>MV</th><th>LV</th><th>MV</th></tr>
<tr><td>10W</td><td>-</td><td>-</td><td>2%</td><td rowspan="2">13%</td><td rowspan="3">0%</td><td>0%</td><td rowspan="7">0%</td><td rowspan="2">0%</td><td>1%</td><td>2%</td></tr>
<tr><td>15W</td><td>-</td><td>-</td><td>2%</td><td>0%</td><td>1%</td><td>3%</td></tr>
<tr><td>16-20W</td><td>-</td><td>-</td><td>7%</td><td rowspan="3">43%</td><td>3%</td><td>18%</td><td>18%</td><td>12%</td></tr>
<tr><td>22W</td><td>-</td><td>-</td><td>50%</td><td rowspan="2">12%</td><td>0%</td><td rowspan="2">0%</td><td>-</td><td>-</td></tr>
<tr><td>25W</td><td>-</td><td>-</td><td>6%</td><td>6%</td><td>14%</td><td>10%</td></tr>
<tr><td>30-39W</td><td>35% (35W)</td><td>-</td><td>12%</td><td>10%</td><td rowspan="2">39%</td><td>3%</td><td>14%</td><td>-</td><td>-</td></tr>
<tr><td>40-60W</td><td>65% (50W)</td><td>-</td><td>4%</td><td>33%</td><td>39%</td><td>37%</td><td>66% (40W)</td><td>46%</td></tr>
<tr><td>100-250W</td><td>-</td><td>31%</td><td>5%</td><td rowspan="3">0%</td><td rowspan="2">16%</td><td>13%</td><td>29%</td><td>32%</td><td>0%</td><td>2%</td></tr>
<tr><td>300W</td><td>-</td><td>55%</td><td>1%</td><td>19%</td><td>59%</td><td rowspan="2">0%</td><td>0%</td><td rowspan="2">25% (Other)</td></tr>
<tr><td>500W</td><td>-</td><td>14%</td><td>0%</td><td>33%</td><td>16%</td><td>12%</td><td>0%</td></tr>
<tr><td>Weighted average</td><td>45 W</td><td>284</td><td>32 W</td><td>29 W</td><td>209 W</td><td>182 W</td><td>288 W</td><td>83 W</td><td>33 W</td><td>39 W</td></tr>
</table>

For Belgium there was no MV data for wattages below 100W (data from Podo project)

Since 1999 (Table 2-14 originates from this year), the use of halogens and especially HL-MV-LW 40-60W has increased considerably. Table 2-14 shows also that HL-MV-HW 300W is an appropriate base case wattage. Below is made an estimate of the distribution related to the yearly sales data from ELC (Table 2-6 and Table 2-7):

EU-27 HL-MV estimate

- 10-20W 5% ELC ≤25W 7%
- 20-30W 10%
- 30-40W 15% ELC 26-49W 21%
- 40-60W 25% ELC 50-100W 32%
- 100-150W 25%
- 200-250W 15% ELC ≥200W 39%
- 300-500W 5%

EU-27 HL-LV estimate

10W 20% ELC 10W 29%
15W 6%
16-20W 40% ELC 20W 38%
21-30W 15% ELC >20W 33%
31-40W 15%
41-60W 4%

Table 2-15: Use of LFL lamps divided on wattages

Wattages	Belgium	Denmark	France	Greece	Italy	Portugal	UK
8W	-	0%	15%	2%	0%	0%	1%
11-13W	7%	2%		2%	2%	2%	1%
15W	-	2%		2%	2%	0%	-
16-18W	15%	5%	25%	8%	5%	39%	-
20-25W	15%	35%		4%	27%	0%	5%
26-30W	-	4%	1%	4%	10%	4%	-
31-39W	36%	16%	44%	45%	40%	39%	-
40-45W	15% (40W)	23%		20%	8%	0%	17% (40 W)
50-60W	12%	7%	2%	4%	8%	16%	32%
70-72W	-	1%	13%	10%	0%	0%	17% (100W)
Weighted average	***33 W***	***31 W***	***31 W***	***38 W***	***32 W***	***30 W***	***57 W***

Table 2-16: Use of CFLi lamps divided on wattages

Wattages	Belgium	Denmark	France	Greece	Italy	Portugal	UK	ELC sales
5-7W	10%	23%	4%	4%	0%	0%	-	4%
8-10W	19%	15%	6%	0%	3%	7%	5%	16%
11-12W	38%	37%	19%	20%	8%	38%	-	34%
13-15W	9%	14%	42%	15%	20%	21%	26%	15W 15%
16-18W	-	6%	O%	4%	9%	6%	-	32%
19-20W	15%	1%	29%	33%	22%	9%	35%	
22-26W	9%	1%	0%	24%	39%	19%	17%	
40W	-	-	-	-	-	-	*17%*	
Weighted average	***13 W***	***10 W***	***15 W***	***18 W***	***19 W***	***15 W***	***21 W***	

Table 2-17 summarizes the finding in Table 2-13 to Table 2-16, and makes an upscaling of the average wattages found per country to EU-27. Central & Eastern Europe (with no data available) are assumed to be rather similar to data for Middle EU.

Table 2-17: Calculation of weighted average wattage per lamp types for EU-27

EU region	Country	Number of households	Lamps per HH	GLS	Halogen LV	Halogen MV	LFL	CFLi	HH survey
		millions	no/HH	W	W	W	W	W	millions
Central and Eastern EU	BG	3,7	10,0						
	CZ	4,40	10,0						
	CY	0,32	16,0						
	EE	0,60	6,0						
	HU	4,10	18,0						
	LV	0,97	20,0						
	LT	1,30	6,0						
	MT	0,13	15,0						
	PL	13,3	20,0	50	35	150	32	15	13,3
	RO	8,13	10,0						
	SK	2,1	15,0						
	SI	0,69	19,0						
Middle EU	AT	3,3	26,0						
	BE	4,3	26,0	53	45	284	33	13	4,3
	FR	32,2	18,9	52	29	209	31	15	32,2
	DE	39,1	32,0						
	EI	1,44	18,0						
	LU	0,20	20,0						
	NL	7,0	40,0						
	UK	26,20	20,0	51	33	100	57	21	26,2
Northern EU	DK	2,5	25,4	40	22	100	31	10	2,5
	FIN	2,5	23,5						
	SE	4,5	22,0						
Southern EU	GR	3,7	7,0	67	26	200	38	18	3,7
	IT	22,5	18,0	64	27	288	32	19	22,5
	PT	4,2	11,4	53	28	100	30	15	4,2
	ES	17,2	25,0						

EU region	Number of households	Lamps	GLS	Halogen LV	Halogen MV	LFL	CFLi	HH surveyed
	millions	millions	W	W	W	W	W	millions
Central+Eastern EU	39,73	584	50	35	150	32	15	13,3
Middle EU	113,74	2891	52	32	160	44	18	62,7
Northern EU	9,50	221	40	22	100	31	10	2,5
Southern EU	47,60	909	63	27	251	32	18	30,4
EU-27	210,57	4606	54	31	178	38	17	108,9

Since there is no devision on Halogen LV and halogen MV in the EURECO project, this division has been estimated.
Data for PL are assumptions based on results from Middle EU as the calculation method requires data for at least one county per region.

2.2.5 Average operational hours per lamp type

The average operational hours per lamp type is an important parameter necessary for estimating the total stock of lamps along with the technical lamp lifetime and lamp sales.

The average operational hours for lamps depend on the user behaviour and on the environment; these topics are discussed in chapter 3 and also include presence of household members, activities, lighting control e.g. by clock, burglar protection, outdoor lighting level and/or presence detection. This chapter only focuses on measured market data for operational hours.

Spring 2007, JRC [Bertoldi and Atanasiu, 2007] asked national experts for their estimate of average operational hours for the **three most used lamps** in the household. The results variated from 700 – 2200 hours/year. The weighted average for EU-27 was calculated to be 1150 hours.

In the EU EURECO project, burning hours were monitored in different room types during one year (1999-2000) as shown in Table 2-18 to Table 2-23. For "All lighting sources", "n°1" is the average burning hours for the most used lamp per home without looking at the type of lamp – that means that all 100 households are included when calculating this average. The burning hours for specific lamp types (e.g. CFLi) only households using CFLi's were evaluated. This explains that "n°1" can be higher for CFLi than for "All lighting sources".

Table 2-18: Average operational hours for lamps in the kitchen

		Kitchen				
Lighting source	**Luminaires**	**Denmark hours/year**	**France hours/year**	**Greece hours/year**	**Italy hours/year**	**Portugal hours/year**
All lighting Sources	**n°1**	1144	736	1044	1150	1022
	n°2	610	301	349	488	-
	n°3	410		-	-	-
	n°4	-		-	-	-
GLS	**n°1**	865	571	795	894	668
	n°2	562	294	-	537	-
	n°3	363		-	-	-
	n°4	-		-	-	-
Halogen	**n°1**	869	536	381	-	-
	n°2	563	244	-	-	-
	n°3	-		-	-	-
LFL	**n°1**	804	525	951	1416	1118
	n°2	295		-	-	-
CFLi	**n°1**	1280	839	1277	1084	816
	n°2	449		-	-	-

Table 2-19: Average operational hours for lamps in the dining/living room

		Dining room/living room				
Lighting source	**Luminaires**	**Denmark hours/year**	**France hours/year**	**Greece hours/year**	**Italy hours/year**	**Portugal hours/year**
All lighting sources	**n°1**	1427	757	801	683	1122
	n°2	866	352	470	316	553
	n°3	533	250	-	189	-
	n°4	421		-	-	-
GLS	**n°1**	822	561	670	574	878
	n°2	551	284	345	373	614
	n°3	223	209	333	183	-
	n°4	139		-	-	-
Halogen	**n°1**	497	486	817	504	1360
	n°2	233		-	-	-
	n°3	-		-	-	-
LFL	**n°1**	-	-	-	-	-
	n°2	-	-	-	-	-
CFLi	**n°1**	1066	793	1826	1150	1216
	n°2	480	493	-	-	

Table 2-20: Average operational hours for lamps in the sleeping room

		Sleeping room				
Sources lumineuses	**Luminaires**	**Denmark hours/year**	**France hours/year**	**Greece hours/year**	**Italy hours/year**	**Portugal hours/year**
All lighting Sources	**n°1**	711	432	608	414	452
	n°2	320	226	323	148	368
	n°3	194	162	-	-	-
	n°4	161		-	-	-
GLS	**n°1**	711	355	675	451	469
	n°2	448	174	420	189	316
	n°3	242	119	345	-	-
	n°4	-		-	-	-
Halogen	**n°1**	542	311	-	289	582
	n°2	-	110	-	-	-
	n°3	-		-	-	-
LFL	**n°1**	-	-	918	335	-
	n°2	-	-	-	-	-
CFLi	**n°1**	723	542	567	498	780
	n°2	357	410	-	123	-

Table 2-21: Average operational hours for lamps in the bathroom

		Bathroom				
Sources lumineuses	**Luminaires**	**Denmark hours/year**	**France hours/year**	**Greece hours/year**	**Italy hours/year**	**Portugal hours/year**
All lighting Sources	**n°1**	681	334	765	458	594
	n°2	236	185	246	231	-
	n°3	-	88	-	-	-
	n°4	-		-	-	-
GLS	**n°1**	641	317	757	440	570
	n°2	411	202	-	233	282
	n°3	257	101	-	-	-
	n°4	161		-	-	-
Halogen	**n°1**	548	299	-	-	346
	n°2	-	213	-	-	-
	n°3	-		-	-	-
LFL	**n°1**	430	209	838	404	594
	n°2	-		-	-	-
CFLi	**n°1**	704	364	-	518	960
	n°2	-		-	-	-

Table 2-22: Average operational hours for lamps in the office at home

		Office			
Sources lumineuses	**Luminaires**	**Denmark hours/year**	**Greece hours/year**	**Italy hours/year**	**Portugal hours/year**
All lighting Sources	**n°1**	603	589	-	-
	n°2	348	-	-	-
	n°3	-	-	-	-
	n°4	-	-	-	-
GLS	**n°1**	692	380	-	-
	n°2	562	-	-	-
	n°3	283	-	-	-
	n°4	201	-	-	-
Halogen	**n°1**	415	-	-	-
	n°2	-	-	-	-
	n°3	-	-	-	-
LFL	**n°1**	472	-	-	-
	n°2	-	-	-	-
CFLi	**n°1**	649	916	-	-
	n°2	140	-	-	-

Table 2-23: Average operational hours for lamps in the entrance/hall

		Entrance/Hall				
Sources lumineuses	**Luminaires**	**Denmark hours/year**	**France hours/year**	**Greece hours/year**	**Italy hours/year**	**Portugal hours/year**
All lighting Sources	**n°1**	878	389	800	337	773
	n°2	364	162	346	-	-
	n°3	-	145	-	-	-
	n°4	-		-	-	-
GLS	**n°1**	973	288	530	343	1112
	n°2	588	111	212	152	-
	n°3	384		-	-	-
	n°4	242		-	-	-
Halogen	**n°1**	448	323	-	-	-
	n°2	-		-	-	-
	n°3	-		-	-	-
LFL	**n°1**	-	-	-	-	-
	n°2	-	-	-	-	-
CFLi	**n°1**	1340	667	2800	665	501
	n°2	-	418	-	-	-

In 2007/2008 the Remodece project measured the operating time in 100 homes/country **for the around 7 most used lamps per home during 2 weeks except for France that included nearly all lamps in the home.** Table 2-24 shows results for 6 countries plus UK (large survey performed in the UK lighting market transformation project (2007) that estimated the average operational hours for all lamps in the household.

Table 2-24: Average operational hours for different types of lamps (only including the most used lamps except for France that included all lamps)

Country	Number of households	GLS	Halogen LV	Halogen MV	LFL	CFLi
	Millions	Hours/year	Hours/year	Hours/year	Hours/year	Hours/year
BG	3,7	864	1049	1048	1706	946
CZ	4,4	576	868	689	1080	1058
DE	39,1	536	739	491	607	928
FR	32,2	280	358	238	383	674
GR	3,7	585	877	1032	802	996
PT	4,2	394	351	417	714	564
UK	26,2	450	780		925	750
Weighted average		452	646	527	681	809
Lamps/hh measured		4,7	0,5	0,2	0,4	0,9

Table 2-24 shows that the operating hours for France (including all lamps) are remarkable lower than for the other countries (only including the most used lamps). For France must be considered that 10% of the total number of dwellings are second homes which is equal to 3,2 million homes and these homes will lower the average.

Except for LFL and CFLi, the calculated weighed averages of operating hours are evaluated to be too high since only the most used lamps are included except for France. Based on all the tables in this section is assumed the following average EU-27 operational hours for the domestic sector:

- GLS-F and GLS-C 400 hours
- HL-MV 450 hours
- HL-LV 500 hours
- LFL 700 hours
- CFLi 800 hours

It has to be mentioned here that the impact assessment calculations use **lumen / hour** as the functional unit. As a consequence, differences in burning hours will have a low impact on the calculations in chapter 7 (improvement options) and 8 (scenarios).

2.2.6 Summary of MEEuP market parameters

Table 2-25 summarizes the data to be used in the EcoReport calculations in the next chapters of the study. Comments to this table are:

- 2006 stock of lamps/household are from Table 2-11 (R&D surveys). These data are to be considered as bottom line data because a luminaire with two lamps might have counted as one and some sockets might have been forgotten.
- %NDLS and %DLS are based on sales data in Table 2.9.
- Forecast of changes in NDLS and DLS for 2011 and 2020 are estimates. Alternatively, was considered to perform a trend analysis based on the UNECE database[24] but this was refused since the large changes between lighting sources have happen witin the last few years.
- Based on impressions from contacts and visits is assumed 70% GLS-F and 30% GLS-C.
- Weighted wattages are based on values calculated in Table 2-17.
- Lamp lifetimes are presented in chapter 4 by studying the manufacturers catalogues.
- Average operational hours are based on Table 2-18 to Table 2-24.
- Any yearly forecast of the stock = Yearly replacement sales + Yearly change in stock.
- Yearly replacement sales = Stock in 2006 * lamp lifetime/ operational hours per year.
- Yearly change in sales is calculated from an forecast of the stock of different lamps as explained in part 2.27 and 2.3.
- Number of homes is not available in Eurostat so these data is collected from a comparative study of UNECE House statistics (old data from 2002), House Statistics

[24] The database model of the Statistical Division (UNECE/STAT) maintained by the Environment and Human Settlements Division, contains data with specific reference to data on housing and building. Data are collected for the ECE Bulletin of Housing and Building Statistics and through the Country Profiles on the Housing Sector from a number of both national and international sources.

in EU (2004), data used in other studies and national statistics. The actual number of homes (dwellings) in EU-27 is found to be 210 million homes.

- It is a trend that more and more people live alone and naturally this results in an increase in number of homes whereas the population size seems to be rather stable in most EU countries.
- The growth rates are related to trends and are explained in section 2.3.1. Amongst others it explains the relative high assumed HL-MV-HW stock increase between 2006 and 2011.

Table 2-25: MEEuP lighting model with Business as Usual (BAU) forecast

Scenario: BAU — **MEEuP Lighting Model**

Capita	477.000.000
Homes	210.000.000
capita/home	2,27
Input data	(green)
Calculated	(orange)

EU27 — Domestic sector

EU27	GLS-F	GLS-C	HL-MV LW	HL-MV HW	HL-LV	LFL	CFLi	Total
Stock of lamps (NDLS+DLS) per home 2006	9,2	3,95	0,61	0,71	4,46	1,83	3,58	24,3
% NDLS	99	66	55	55	49	100	99	
% DLS	1	34	45	45	51	0	1	
Stock of lamps	1.932.000.000	829.500.000	128.100.000	149.100.000	936.600.000	384.300.000	751.800.000	5.111.400.000
Stock of NDLS lamps	1.912.680.000	547.470.000	70.455.000	82.005.000	458.934.000	384.300.000	744.282.000	4.200.126.000
Stock of DLS lamps	19.320.000	282.030.000	57.645.000	67.095.000	477.666.000	0	7.518.000	911.274.000
Lamp life time (hours)	1000	1000	1500	1500	3000	12000	6000	
Average operational hours (hours/year)	400	400	450	450	500	700	800	
Replacement Sales per year	772.800.000	331.800.000	38.430.000	44.730.000	156.100.000	22.417.500	100.240.000	1.466.517.500
Forecast of stock (NDLS+DLS) in 2011	4,9	2,5	3,0	2,0	5,1	2,0	8,1	27,6
Stock of lamps	1.022.700.000	525.000.000	630.000.000	420.000.000	1.071.000.000	420.000.000	1.701.000.000	5.789.700.000
Stock of NDLS lamps	1.012.473.000	346.500.000	346.500.000	231.000.000	524.790.000	420.000.000	1.683.990.000	4.565.253.000
Stock of DLS lamps	10.227.000	178.500.000	283.500.000	189.000.000	546.210.000	0	17.010.000	1.224.447.000
Forecasted change in sales in 2007	-181.860.000	-60.900.000	100.380.000	54.180.000	26.880.000	7.140.000	252.760.000	198.580.000
Total sales 2007	590.940.000	270.900.000	138.810.000	98.910.000	182.980.000	29.557.500	353.000.000	1.665.097.500
NDLS sales 2007	585.030.600	178.794.000	76.345.500	54.400.500	89.660.200	29.557.500	349.470.000	1.363.258.300
DLS sales 2007	5.909.400	92.106.000	62.464.500	44.509.500	93.319.800	0	3.530.000	301.839.200
Forecast of stock (NDLS+DLS) 2020	3,5	2,3	4,7	2,5	5,9	2,0	10,1	31,0
Wattage weighted average (W)	54	54	40	300	30	38	13	
Lamp Wattage Factor	1	1	1	1	1,11	1,05	1,05	
Electricity consumption in 2006, TWh (total)	41,73	17,92	2,31	20,13	15,59	10,73	8,21	
Electricity consumption in 2006, TWh (NDLS)	41,31	11,83	1,27	11,07	7,64	10,73	8,13	
Electricity consumption, %	35,78%	15,36%	1,98%	17,26%	13,37%	9,20%	7,04%	

Data control for 2007 — **Eurostat includes both domestic and commercial customers.**

	GLS-F	GLS-C	HL-MV LW	HL-MV HW	HL-LV	LFL	CFLi+CFLni
Eurostat Apparant consumption for EU27 in 2007	811.626.000	347.000.000	318.000.000		310.460.000	388.072.000	493.000.000
Domestic 2007 Sales/Apparant consumption 2007	0,7	0,8	0,4	0,3	0,6	0,08	0,7

Apparent EU27 consumption = Production in EU27 + Imports – Exports

Non-domestic sector

	GLS-F	GLS-C	HL-MV LW	HL-MV HW	HL-LV	LFL	CFLi+CFLni
2007 sales in the non-domestic sector (calculated as the residual)	220.686.000	76.100.000	80.280.000		127.480.000	358.514.500	140.000.000

In Table 2-25, data control by relation to Eurostat apparent consumption in 2007 gives reasonable results related to our expectations and Table 2-10 concerning CFLi.

Table 2-26 summarizes the domestic MEEuP data that are used in section 2.2.7 to develop MEEuP data for all sectors. These MEEuP data are used in other chapters.

Table 2-26: Lamp data and domestic stock used in section 2.2.7 and next parts of the study

Lamp type	Stock of Domestic lamps	DLS	Lamp life	Average operation per year	Base case wattages
	millions	%	Hours	Hours	Watt
GLS-F	1932	1	1000	400	54
GLS-C	830	34	1000	400	54
HL-MV LW	128	45	1500	450	40
HL-MV HW	149	45	1500	450	300
HL-LV	937	51	3000	500	30
LFL	384	0	12000	700	38
CFLi	752	1	6000	800	13

2.2.7 Stock and sales MEEuP data for all sectors

The lamp types identified as base-cases (part 1 concerning NDLS) in chapter 5 are used in order to investigate environmental and economic results for the domestic sector as well as "other sectors" with the assumption that lamp life, the average wattage, the lamp price and the shares of NDLS lamps are the same as in the domestic sector. Regarding CFLi, it is assumed that sales in the non-domestic sectors are negligible.

The shares of replacement sales (see definition in section 2.2.6) for the non-domestic sector are assumed to be the same as found for the domestic sector: 131 % for GLS-F, 125 % for GLS-C, 28 % for HL-MV-LW, 45 % for HL-MV-HW, and 85 % for HL-LV.

Finally is assumed that all base-cases in the non-domestic sector operated 1800 hours per year (250 working days/year with around 7 operating hours per day). The annual burning hours for all sectors are calculated in Table 2-27 based on a weighted average:

$$\textit{Operation hours}_{All} = (\textit{Operation hours}_{Dom} \times \textit{Sales}_{Dom} + \textit{Operation hours}_{Other} \times \textit{Sales}_{Other}) / \textit{Sales}_{All}$$

Table 2-27: Calculation of average operation hours per year for all sectors

	CLS-F	GLS-C	HL-MV-LW	HL-MV-HW	HL-LV	CFLi
Domestic sector	400	400	450	450	500	800
Non-Domestic	1800	1800	1800	1800	1800	-
All sectors	505	551	538	536	705	800

The stock of lamps for non-domestic sctors are calculated as:

$$\textit{Total Stock} = (\textit{Lamp life} / \textit{Operation hours}) \times \textit{Share of Replacement Sales} \times \textit{Total Sales}$$

Based on the market trends described in section 2.3, a Business as Usual (BAU) forecast has been made on the stock and sales data, see Table 2.28. This BAU forecasts will be used in chapter 8 scenarios.

Table 2-28: BAU (Business as Usual) forecast of NDLS stock and sales for all sectors

	GLS-F		GLS-C		HL-MV-LW		HL-MV-HW		HL-LV		CFLi	
	Stock	Sales	Stock	Sales	Stock	Sales	Stock	Sales	Stock	Sales	Stock	Sales
1995	2.131.000.000	1.098.000.000	673.000.000	347.000.000	0	0	34.000.000	21.250.000	52.000.000	60.000.000	180.000.000	100.000.000
2007	1.800.065.189	767.385.600	568.509.931	297.000.000	134.417.807	97.379.464	119.442.239	84.120.536	558.259.592	147.000.000	1.010.100.000	353.000.000
2008	1.580.042.277	687.946.619	523.464.062	273.114.493	193.472.689	115.167.651	151.277.051	89.792.317	571.458.374	149.258.129	1.228.500.000	353.080.000
2009	1.399.919.366	624.935.727	478.418.193	249.228.986	252.527.572	132.955.838	183.111.863	95.464.097	584.657.156	151.516.259	1.407.000.000	342.300.000
2010	1.251.296.455	573.674.336	433.372.325	225.343.479	311.582.454	150.744.025	214.946.675	101.135.878	597.855.938	153.774.388	1.554.000.000	334.600.000
2011	1.123.673.543	527.820.444	388.326.456	201.457.972	370.637.336	168.532.212	246.781.486	106.807.659	611.054.720	156.032.517	1.680.000.000	333.200.000
2012	1.038.294.179	444.839.604	384.972.443	200.832.573	394.348.142	174.770.885	253.511.891	107.623.879	622.189.495	158.214.017	1.778.700.000	322.700.000
2013	992.814.814	446.277.547	381.618.430	200.207.173	418.058.948	181.009.559	260.242.295	108.440.099	633.324.270	160.395.516	1.837.500.000	295.960.000
2014	953.635.450	434.264.989	378.264.418	199.581.774	441.769.754	187.248.232	266.972.699	109.256.319	644.459.044	162.577.015	1.890.000.000	297.500.000
2015	927.056.085	431.733.931	374.910.405	198.956.374	465.480.560	193.486.905	273.703.103	110.072.538	655.593.819	164.758.515	1.929.900.000	291.900.000
2016	900.476.721	422.965.873	371.556.392	198.330.975	489.191.366	199.725.578	280.433.507	110.888.758	666.728.594	166.940.014	1.969.800.000	297.220.000
2017	878.097.356	418.397.816	368.202.379	197.705.575	512.902.172	205.964.251	287.163.911	111.704.978	677.863.369	169.121.513	2.005.500.000	298.340.000
2018	859.917.992	415.950.758	364.848.367	197.080.175	536.612.978	212.202.924	293.894.316	112.521.198	688.998.144	171.303.012	2.037.000.000	298.900.000
2019	841.738.627	411.424.700	361.494.354	196.454.776	560.323.784	218.441.597	300.624.720	113.337.418	700.132.919	173.484.512	2.068.500.000	303.100.000
2020	823.559.263	406.898.642	358.140.341	195.829.376	584.034.590	224.680.270	307.355.124	114.153.637	711.267.694	175.666.011	2.100.000.000	307.300.000
020 distribution of stoc	17%		7%		12%		6%		15%		43%	
995 distribution of stoc	69%		22%		0%		0%		4%		5%	

The data in table 2.28 refer to NDLS in all base cases (see chapter 5). The stock in 2007 is calculated based on survey data from 2006 in Table 2-25 and on Eurostat Sales data from 2007. As mentioned in section 2.1.2 CFLi sales in 2007 might even be underestimated.The data for 1995 is calculated based on data in Table 2-12 and Prodcom data (EU-15 data are upscaled to EU-27) – it has to be underlined these data are best estimates.

Figure 2-3 shows the forecasted yearly sales for GLS, halogen and CFLi. GLS sales is decreasing rapidly until 2012 and hereafter the decrease is slow. Use of HL increases constanly during the period (see section 2.3 for further explanation). CFLi sales is expected to peak in 2007-2008 and hereafter to decrease to a constant level around 2013 – this is a conservative forecast as the manufactures are actually inventive in order to keep the actual level of CFLi sales as described in section 2.3. Due to the gradually saturation in use of CFLi, the replacement sales goes from being 35% of the yearly CFLi sales in 2007 to 90% in 2020.

Figure 2-4 shows the forecasted distribution of the stock of GLS, halogen and CFLi. Use of GLS is decreasing rapidly in the first part of the period as both the stock of HL and CFLi is increasing fast. After 2011, the stock of CFLi is increasing slowly, but the stock of HL is still increasing and the stock of GLS is continuing to decrease.

The growth rates are related to trends and are explained in section 2.3.1. Amongst others it explains the relative high assumed HL-MV-HW stock increase between 2006 and 2011.

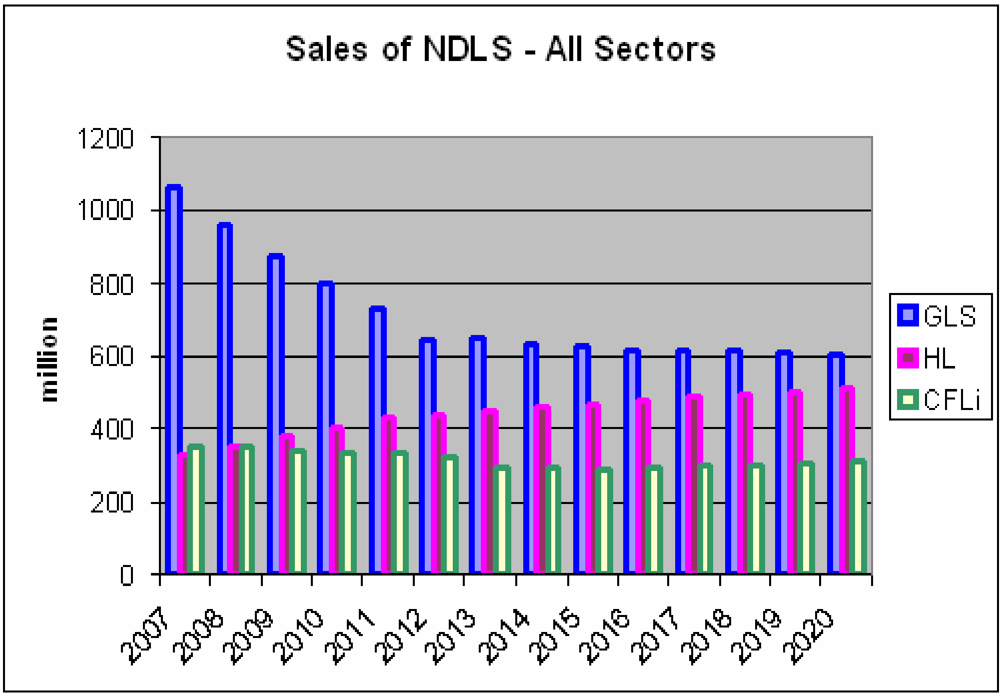


Figure 2-3: BAU (Business as Usual) forecast of NDLS sales in all sectors

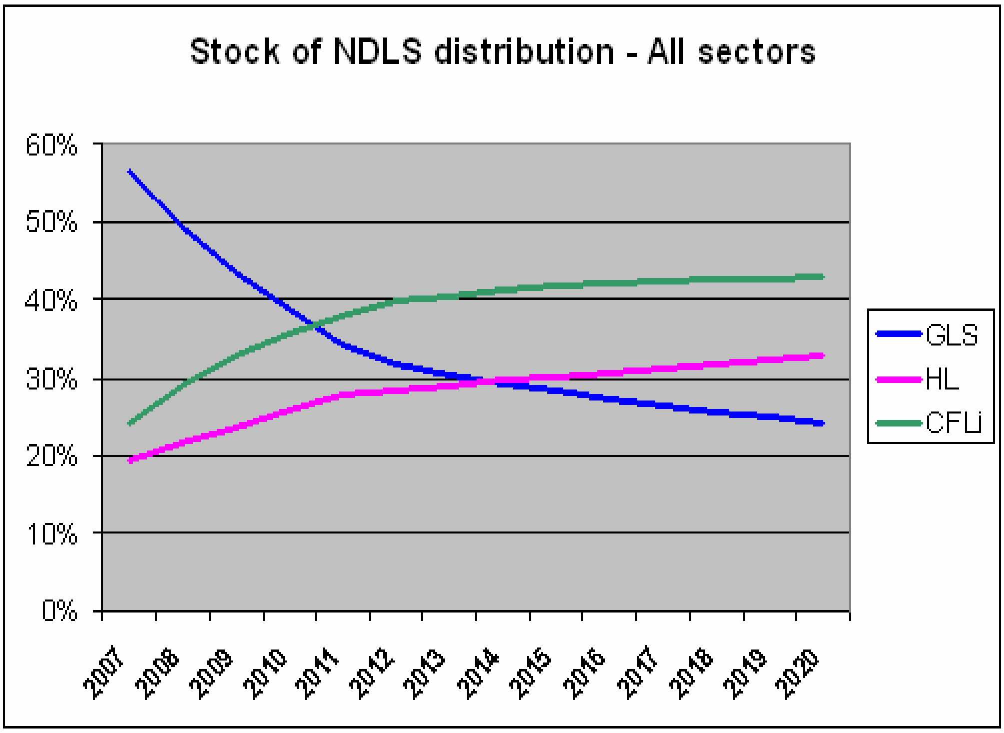


Figure 2-4: Business as Usual (BAU) forecast of the NDLS stock in all sectors

2.3 Market trends

2.3.1 General product design trends and features from marketing point of view

Lamps

Lamps are currently considered as replacement parts for luminaires because lamp lifetime is typically shorter than the luminaire lifetime. LED's could change this by making lamps that last as long as the luminaire. The LED technology will be considered in chapter 6.

Domestic customers are typically doing maintenance/shift of lamps themselves.

The following paragraphs give an overview of the market and production structure and identify the major players of the sector.

Domestic lighting purchase process

The current domestic lighting purchase process mainly takes place in the retail market. The customer buys luminaires and lighting sources in lighting shops, furniture stores, do-it-yourself shops and supermarkets. Those products are installed by the user (frequently), a home decorator or qualified electrician.

With the growing welfare, many people are installing new kitchens, bathrooms or are adding verandas. In this process, the designers and installers have a large influence by including lighting solutions. Some of those furniture and appliance manufacturers are including lighting in their products, and this market seems to be dominated by halogen down lighting (e.g. reflector lamps). This causes a shift from GLS to a multitude of halogen lamps from 1995 until 2007 as can be seen from Table 2-11 and Table 2-12. Halogen down lighting typically includes several light points. This is a first driver for more light points at home. A second driver is the growing welfare in general. This also results in an increased use of ligth points as can be concluded from Table 2-11 and Table 2-12, probably because the living space per capita increased (e.g. by a growing number of people living alone) or simply because more light sources were installed. One could fear that there is no natural limitation on this growth rate because the eye is able to adapt to a broad luminance range and daylight levels are by far not yet reached in domestic lighting. However, in some new installations complains about glare and overheating of the room did already slow down this growth rate. The latter was sometimes already experienced in shop lighting or new glossy kitchens with reflector lamps. Therefore some market saturation could occur on the long run.

There is thus a clear BAU trend to replace GLS by halogen lighting. There is also a trend of market shift from HL-LV (12 volt) to HL-MV (230 V), mainly because the installation work is easier without a transformer. This is documented by ELC sales in Table 2.6 and Table 2.7 showing a larger much increase in low wattage HL-MV sales. Therefore, increases in halogen lamp sales of 9.3%/year for HL-MV-LW, 2.5%/year for HL-MV-HW and 1.4%/year for HL-LV are assumed, for the period 2007-2020.

A fast stock increase of HL-MV-HW from 2006 until 2011 for all sectors was assumed. Combination of data in Table 2-11 and Table 2-29 shows that domestic customers in Belgium, Italy and UK are already at the high 2020 HL-MV-HW stock level. Table 2-30 shows an increase a yearly increase 6.5%/year for HL-MV 75-100W and 2.5%/year for HL-MV >= 200W. With this in mind along with the number of households is suppose to increase from 2007 to 2020 and that Central & Eastern EU might expand their use of lighting to a level similar to the rest of EU. In the domestic sector, HL-MV-HW's are used in up-lighters (floor and wall), spots in the hall/staircase/entrance, outdoor lighting and in do-it-your-self working lamps (typically 500W lamps in floodlights). Floor standing up-lighters can easily be installed. One should be aware that those lamps are also sold with luminaires at low cost and hence 'lamp' sales data lags behind. Hence, the stock estimates for other countries in previous sections might be far to low and this is compensated.

The other strong trend is to replace GLS by CFLi due to the public awareness of the climate change problems and the rising energy prices. In 2006, CFLi sales increased very fast by 77% and the growth continued in 2007, see Figure 2-1 and this might even be underestimated (see 2.1.2). A visit to the Light&building 2008 fair in Frankfurt showed that both European and Asian manufacturers are inventive and could be expected to maintain their high 2006-2007 CFLi sales, e.g. they could use the following techniques:

- Selling more shapes of CFLi.
- Promoting different colour temperatures for use in different seasons and applications.
- Selling decorative CFLi.
- Increasing the CFLi functionality (e.g. dimmable, incorporated sensors (light, presence, ..), remote control, ..).
- Reduction of product price through selling multi-packs.
- Price discounts.

Anyhow, as shown in Figure 2-3 the sales of CFLi is expected to decrease gradually after 2008 until -18% in 2015 and hereafter sales will start to increase slowly again. The explanation for this development is the large increase in use of halogen lamps (replacing GLS), the long lifetime for CFLi and the fact that some customers have a few light points left where they prefer to keep the GLS due to barriers for CFLi as explained in chapter 3 (e.g. requirements to color rendering, sparkling effect etc.) or because of the lamp has little usage such as in cellars, staircases or storage rooms and where full lighting is also needed immediately.

Table 2.24 shows that the EU-27 average number of light points per household was 24.3 in 2006 (survey data) and that the BAU (Business as Usual) stock is forecasted to increase up to 27.5 in 2011 and 31 in 2020.

Global lighting production market

The global lighting-product manufacturing industry is made up of many enterprises ranging from large multinational private companies that manufacture a broad range of lighting products to small single-product firms publicly or privately owned. (IEA, 2006).

When viewed as a region, the European Union is the world's largest producer of lighting equipment in terms of value, although China is about to surpass in terms of volume (IEA, 2006). The European lighting manufacturing industry has annual revenues of about EUR 13 billion, of which EUR 5 billion (USD 6.2 billion) is from lamp manufacturers (ELC, 2005 in IEA, 2006) and EUR 8 billion from luminaires, ballasts and associated electro technical equipments (CELMA, 2005 in IEA, 2006).

Lamp manufacturers are represented by the European Lamp Companies Federation (ELC), which includes among its members[25] Philips Lighting, OSRAM, GE Lighting, Aura Lighting Group, BLV, Leuci, Narva and Sylvania Lighting International (SLI). The European activity of these companies employs roughly 50,000 people and produces an annual revenue of EUR 5 billion[26] (IEA, 2006). ELC claims to represent 95% of the total European lamp production but their part of the sales are much lower as a consirable part e.g. of the CFLi sales is covered by retailers that import directly from China.

Manufacturers of luminaires and electro-technical parts for luminaires are represented by CELMA. The 16 national member associations of CELMA represent some 1,200 companies in 11 European countries. These producers, which include many SMEs, directly employ some 100,000 people and generate EUR 8 billion annually. CELMA claims to supply more than 90% of luminaires and associated electro-technical parts for the EU market (IEA, 2006).

Market shares and competition

Lamps are a globally traded commodity and there is a high degree of standardisation between international lighting markets. The lamp market is highly concentrated, with a limited amount of players and thus financial power in the marketplace, whereas the luminaire market is very fragmented.

For several decades four major multinational lamp manufacturers have dominated the international lamp market:

- Philips, based in the Netherlands
- OSRAM, based in Germany (also present in the United States as Sylvania)
- General Electric, based in the United States.
- Sylvania, based in Europe, recently renamed as Havells Sylvania.

While these companies have a strong presence in almost all global markets their strength varies in the different sectors and regions appreciably (IEA, 2006).

Shift to a higher degree of use of CFLi's will result in a large import of lighting products from China.

The forecast in Table 2-25 shows that even without any legislation, the market share and the stock of GLS-F and GLS-C are decreasing as they are increasingly replaced by halogen lamps and CFLi (see section 2.2.7 for more details about the forecast).

2.3.2 Duration of redesign cycle and market lifetime of the EuP

For these aspects, domestic lighting products are discussed as consisting of two essential parts:

- the light source, in some cases including its control gear,
- the luminaire as a holder for lamp and control gear.

[25] ELC, Make the switch: The ELC roadmap for deploying energy efficient lighting technology across Europe http://www.elcfed.org/uploads/documents/-3-01elc_a5report_6_05.pdf
[26] http://www.elcfed.org/index.php?mode=0

Both parts have different redesign cycles and different market lifetimes.

2.3.2.1 Redesign cycle for a light source

The duration of a redesign for a light source depends mainly on technology and it can last from several months to more than 50 years from first idea to functioning technology and working prototype. The redesign cycle will always include the long term reliability testing.

If it is only a question of amelioration of known, patent free technology, the main factor is lifetime testing: maximum number of possible burning hours per year is about 8.000. A conversion of the production lines with possible investment decisions can extend this period. Manufacturers are continuously working on ameliorating their products in that way that the new product can replace the old one, without changing luminaire or control gear.

For example the low voltage, pin based halogen lamp was introduced in the seventies of the previous century and pleased the designers and customers by its bright, small appearance. Infrared reflecting coating in lamp production was already applied in low pressure sodium lamps in the beginning of the years 1980. It took about a decade to introduce this technology in the low voltage halogen lamps production; the results in energy savings are significant (for more information see chapter 6).

A similar example is the compact fluorescent lamp with integrated ballast that was globally introduced in the early years 1980 and is still continuously ameliorated to replace a (frosted) incandescent lamp. The first lamp was fairly large and heavy with magnetic ballast and low R_a. New lamps are smaller, have lightweight electronic control gear, a colour rendering $80<R_a<90$ and finger, spiral or GLS look-alike forms (see chapter 6).

The LED is an example of an important technology change. The light emitting diode was invented in 1924 but the first application only appeared on the market in 1948 as a small indicator lamp. Only in the years 1990, after the invention of the blue LED, LED’s became available for different purposes (colour signalling, colour displays etc.). At last the introduction as a ‘general’ light source was made a few years ago.

2.3.2.2 Redesign cycle for a luminaire

A luminaire for domestic lighting is mostly intended to hold the light source and its possible control gear and to embellish the ‘home environment’. The redesign cycle depends on the technological changes of light sources, fashion, the creativity of the designer and the production cycle. Changing production lines, finish up available stocks of spare parts and new purchase contracts are the most influencing parameters. This cycle can be short e.g. some months after a decision or after the introduction of a new light source.

2.3.2.3 Market lifetime of a light source

It is not always obvious to determine the market lifetime of a light source and its possible control gear.

A clear example of a long market lifetime is the incandescent lamp, that was invented in 1879.

After its introduction on the market (almost 140 years ago), only a few small improvements were performed: the carbon wire was replaced by a tungsten wire, the vacuous bulb was first filled with an inert gas as nitrogen and later in some cases with argon or krypton.

Also the halogen lamp is a special type of incandescent lamp where the filling gas contains halogen or xenon. The first halogen lamps came on the market in the years 1960 in the known form with R7s-cap. It was introduced for its increased lifetime and efficacy.

The smaller size low voltage halogen lamp that was introduced in the years 1970 stays on the market although a better technology, the infra-red coating, is available on the market. The end of the product life of the non-IRC halogen lamps will mainly depend on retail price and sufficient availability on the market; the fact that these new IRC-lamps are more energy-efficient doesn't seem to influence the consumers so much when the price stays high.

For CFLi's, the market lifetime is dependent on the meaning of 'product'. The first generation of compact fluorescent lamps can be considered a different product from the current CFLi's and thus the lifetime was 10-20 years. These first generation lamps have even completely disappeared from the European market due to the better quality, shape and price of the new generation. At this time, the new generation lamps are being continuously ameliorated but basically the product is not changed. It is very difficult to determine a product's market lifetime as the 'product' itself is not clearly determined.

2.3.2.4 Market lifetime of a luminaire

For the market lifetime of a luminaire, a subdivision has to be made between:

- classic or traditional luminaires like crystal luminaires, bronze luminaires etc.
- design luminaires.

For the first small category, the market lifetime does not expire; manufacturers will only change details, but the basic model almost lasts for 'eternity'. The second and largest category, that is fashion dependent, has rarely more than a maximum market lifetime of 3 years as lighting designers like to renew their products as frequent as possible to be trendy.

For some special applications such as Christmas lights, the market lifetime can even be only one season, especially nowadays that LED's are entering the market for this purpose.

As a consequence, a uniform lifetime for domestic luminaires can hardly be given. A weighted average for both categories of 3 years can be assumed.

2.4 Consumer expenditure data

Please consult also the related section in part 2 of this study for more updated data.

2.4.1 Product prices

Eurostat data are not suitable for estimating product prices (luminaires, lamps, ballasts, other replacement parts). For product prices, we therefore used manufacturers' catalogues. Taking into account that the prices displayed in these catalogues are for retail trade, realistic assumptions for the prices of different lighting parts were made based on the experience of the market, e.g. consultation of small and large retailers, advertising brochures etc.

Chapter 4 (Table 4.6) gives specific retail lamp prices for products (except LFL). Examples of typical retail prices for domestically used lamps are given in Table 2-31:

Please note that product prices on CFLi can include an anti-dumping tax in EU-27. By Council Regulation (EC) 1470/2001, the EC imposed anti-dumping duties ranging from 0% to 66.1% on imports of CFLi's originating from China. By Council Regulation (EC) 866/2005 these duties were extended to the Socialist Republic of Vietnam, the Islamic Republic of Pakistan and the Republic of the Philippines. In October 2007, the Council adopted a regulation for a one year extension (Council Regulation (EC) 13040/1/07).

Table 2-31: Typical EU-27 retail prices for lamps for domestic use

Lamp price	Typical in €
HL-MV G9	5,5
HL-LV GY6,35	3
GLS-C 60W	0.5
GLS-F 60W	0.5
GLS-C 40W	0.7
GLS-F 40W	0.7
GLS-C-HW	2
LFL T8 18W	4,5
LFL T5 14W	8
CFLi 15W	5
CFLi 10W	4
CFLi 20W dimmable	20

Product prices can also include taxes or recycling contributions that can differ from country to country, some examples are included hereafter.

Denmark has a taxation on lighting sources added to the sales price:

- CFLi no tax
- GLS 3.75 DKK (= 0.5 Euro)
- Fluorescent tube 7.5 DKK (= 1 Euro)
- Halogen low voltage 0.75 DKK (0.1 Euro)
- Halogen 230V 3.75 DKK (= 0.5 Euro)
- Metalhalogen 7.5 DKK (= 1 Euro)
- Emission lamp 7.5 DKK (= 1 Euro)

The Danish taxation is basically a tax to collect state income but also an energy efficiency effort since there is no tax on CFLi's - nevertheless there is a tax for fluorescent tubes and metalhalide lamps although these lamps are very energy efficient.

According to a decree-law of April 12, 2007 *Portugal* has such an added cost or 'tax' for low energy efficiency lamps to compensate for environmental influence from this type of lighting. The tax is calculated based on the following parameters: electric power and life cycle of the lamp compared to energy efficient lamps and the average value of CO_2 emission factor and cost for Portugal. The tax income will feed the Portuguese Fund for Carbon (80%) and the Energy Efficiency Fund (20%).

Several countries have an added 'disposal/recycling' contribution that is included in the sales price. For example *Belgium* has a WEEE directive specifying that a cost is added to the sales price for recycling. It is not a tax since it is not raised by the government but a contribution to take care of the recycling. The cost per lamp is at present € 0,30 and is added for CFL, LFL and other discharge lamps while there is no cost for GLS and HL. For more information on recycling schemes and costs in other EU-27 countries please consult www.weee-forum.org.

2.4.2 Electricity rates

Electricity costs account for an important part in the domestic lighting costs: according to IEA[27] lighting amounts up to 79% of the total cost. Electricity rates (euro/kWh) are subject to fluctuations due to recent market liberalisation.

Eurostat regularly reports on electricity prices for domestic household consumers are shown in the table below.

[27] Source: IEA, 2006

Table 2-32: Electricity prices for domestic customers [28]

EU region	Country	Number of households millions	Electricity price for hh customers using 3500 kWh/year €/kWh by 1/1 2007
Central and Eastern EU	Bulgaria (BL)	3,7	0,0658
	Czech Republic (CZ)	4,40	0,1067
	Cyprus (CY)	0,32	0,0796
	Estonia (EE)	0,60	0,075
	Hungary (HU)	4,10	0,1222
	Latvia (LV)	0,97	0,0686
	Lithuania (LT)	1,30	0,0777
	Malta (MT)	0,13	0,0895
	Poland (PL)	13,30	0,1184
	Rumania (RO)	8,13	0,1018
	Slovenia (SK)	2,10	0,1537
	Slovakia (SI)	0,69	0,1064
Middle EU	Austria (AT)	3,30	0,1545
	Belgium (BE)	4,30	0,1581
	France (FR)	32,20	0,1211
	Germany (DE)	39,10	0,1949
	Ireland (IE)	1,44	0,1662
	Luxembourg (LU)	0,20	0,1684
	The Netherlands (NL)	7,00	0,218
	United Kingdom (UK)	26,20	0,1323
Northern EU	Denmark (DK)	2,50	0,258
	Finland (FI)	2,50	0,116
	Sweden (SE)	4,50	0,1714
Southern EU	Greece (EL)	3,70	0,072
	Italy (IT)	22,50	0,2329
	Portugal (PT)	4,20	0,15
	Spain (ES)	17,20	0,1225
EU27 average (weighted by hh)		210,6	**0,1529**

2.4.3 Repair, maintenance and installation costs

Replacement and installation of lamps is practically always done by the domestic user and hence no labour cost will be taken into account.

For domestic luminaires, maintenance and installation are typically also done by the domestic user. For some ceiling and outdoor luminaires installed during construction, the replacement might be so difficult that the customer needs to hire a professional to do this; in that case the cost might be very high and is thus unpredictable.

In part 1 of this study, no installation or maintenance costs are taken into consideration. Please consult the related section in part 2 of this study.

[28] Eurostat collects regularly data for 5 categories of domestic consumption, ranging between annual consumption 600 kWh to 20,000 kWh. Here is used "medium size household" (3,500 kWh/year) .

Interest and inflation rate EU-27 averages for interest rate and inflation rate are published by ECB and Eurostat:

- Interest rate = 3,9 % (source ECB[29]).
- The Inflation rate was 2,1 % (source Eurostat[30]) when this study started. Lately the inflation rate has raised to around 4 % and many economical experts forecast that the inflation will be at a higher level during the next 5 years.

Please note that these values can vary on a monthly basis and are related to currency (Euro-zone and outside Euro-zone member states).

[29] ECB long-term interest rate; 10-year government bond yields, secondary market. Annual average (%), 2005

[30] EU27 Annual Inflation (%) in Dec 2005 Eurostat "Euro-Indicators", 7/2006 - 19 January 2006.

3 CONSUMER BEHAVIOUR AND LOCAL INFRASTRUCTURE

Consumer behaviour can -in part- be influenced by product-design but overall it is a very relevant input for the assessment of the environmental impact and the Life Cycle Cost of a product. The scope of this chapter is to identify barriers and restrictions to possible eco-design measures, due to social, cultural or infra-structural factors. A second aim is to quantify relevant user-parameters that influence the environmental impact during product-life and that are different from the Standard test conditions as described in section 1.2.

3.1 Definition of 'consumer'

For domestic lighting it is important to discriminate two main types of consumer:

1. The responsible person for the putting into service of a new house/flat or renovation of parts of the home, e.g. property developers, kitchen and bathroom designers and installers, hereafter called the *'service providers'*. Please note also that more and more appliances are including lighting, e.g. extractor fans in the kitchen, so here is also a service provider involved.
2. The consumer who lives in the home and makes use of the lighting equipment, hereafter called the *' user'*.

In the domestic lighting market the 'service provider' and 'user' can be the same, especially when Do-It-Yourself (DIY) equipment is bought and put into service by a DIY consumer.

Anyhow, 'service providers' are having a growing influence on energy used in the domestic homes because for some domestic rooms (e.g. kitchen or bath room) lighting is an integral subcomponent of the design and installation process – the customer buys "the whole package" including lighting. In this case both service providers and the consumer take decisions that affect the quality, cost and efficiency of lighting in the home.

3.2 Real Life Efficiency and quantification of relevant parameters

3.2.1 Design criteria

The concept of energy-efficient lighting is meaningless unless the lighting system provides the conditions necessary to perform the task. The goal in designing a lighting system is to provide a suitable visual environment that provides “right light at the right time at the right place”.

The main objectives for installing electric lighting systems are:

- Facilitating the performance of visual tasks
- Promoting safety and security
- Attractively revealing the environment – create atmosphere
- Participate in the interior design of the household by attractive design of lamp or luminaire.

The priority of the above objectives in the design process depends on the specific situation and the preference of the user. Moreover, if the object is three-dimensional or coloured, the direction of the incident light or its colour-rendering properties become important determinants of visibility. In the domestic sector all the design is up to the consumer in contrast to the commercial sector using lighting codes and standards for satisfactory visual performance.

3.2.2 Lamp efficacy and sensitivity of the human eye

It is important in the context of lighting that the standard performance parameter on lamp 'efficacy' is defined taking into account the sensitivity of the human eye. The visual performance of the eye varies with people and eyes deteriorate with age. As we get older we need a higher quantity of light and in addition, more care has to be taken to avoid glare.

The colour perception is essential for visual performance. Some colours are more visible than others. Figure 3-2 shows that the visual response is at maximum in the yellow-green region of the spectrum (at luminance above 10 cd/m^2), but also contrast between colours is important. Blue contrasts strongly with yellow, as these colours are «complementary», but not as strongly with green as these colours are close in the spectrum.

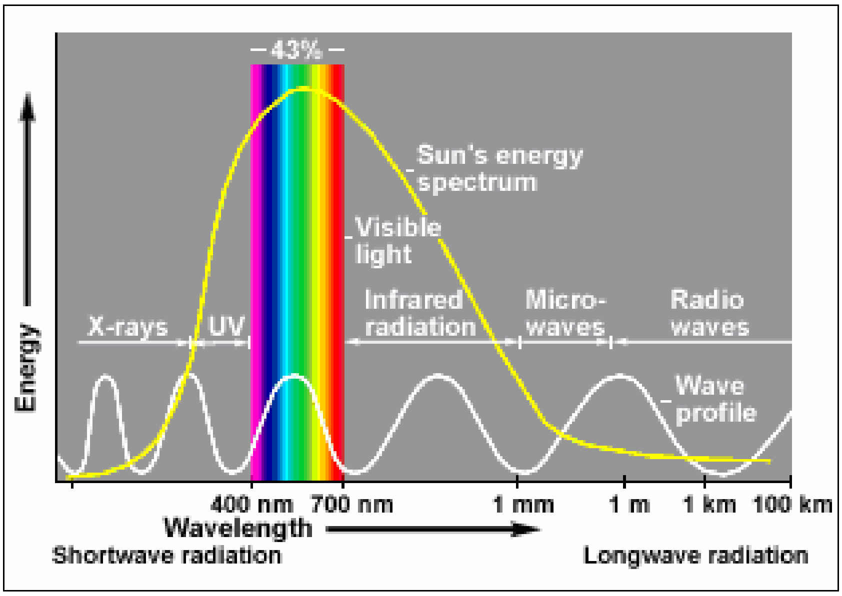


Figure 3-1: Radiation from the sun.

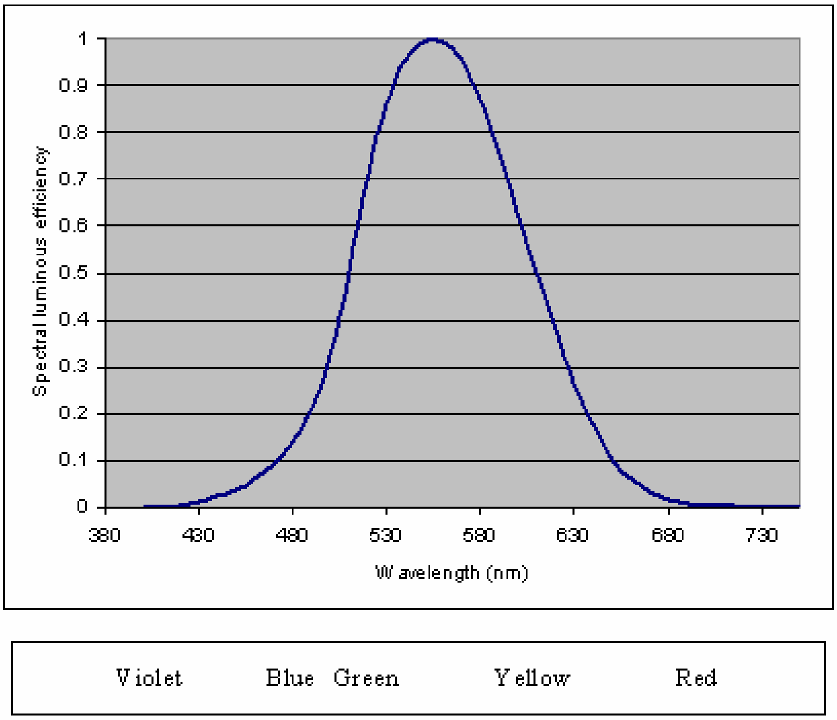


Figure 3-2: Relative spectral sensitivity of the human eye.

Lamps with a colour spectrum that match the normalised eye sensitivity will therefore have an improved lamp 'efficacy'.

To provide an indication of the **colour-rendering** properties of a light source, the general colour-rendering index Ra was introduced. The maximum value of Ra is 100. This Ra decreases with decreasing colour-rendering quality. According to standard EN 12464 for commercial working condition, lamps with a colour-rendering index lower than 80 should not be used in interiors where people stay for longer periods.

The "colour appearance" of a lamp refers to the apparent colour (chromaticity) of the light emitted. It is quantified by its correlated colour temperature (CCT). The choice of an appropriate colour appearance of a light source should largely be determined by the function of the room to be lit but it also involves psychological aspects as warmness, relaxation and clarity. The Commission Internationale de l'Eclairage specifies three different correlated colour temperature groups as shown in Table 3-1.

Table 3-1: Colour appearance groups.

Colour appearance group	Colour appearance	Correlated colour temperature
1	Warm - Could be used for relaxation spaces lit to less than 300 lux	Below 3300 K
2	Intermediate – good for blending with daylight	3300-5300 K
3	Cool – for working interiors with high lighting levels	Above 5300 K

"Good lighting conditions" is more than the quantity of lighting. The visual perception also deals with the **contours of surfaces and contrasts** between surfaces (brightness), the **direction** of light and the general lighting of the environment. Normally, the eye adapts to whatever it is viewing, but if the object or background is too bright or the contrast is too great, vision suffers either by the situation becoming visually uncomfortable (**discomfort glare**) or by the object becoming too difficult to see (**disability glare**). Disability glare refers to reduced visibility of a target due to the presence of a light source elsewhere in the field[31]. It occurs when light from a glare source is scattered by the ocular media. This scattered light forms a veil of luminance which reduces the contrast and thus the visibility of the target.

Disablity glare can be a cause for increased lighting consumption at home because an increase in the background luminance contributes to an increase in veiling luminance and as a consequence a higher luminance for the object to be perceived could be needed. For example, incorporating more decorative lighting in furniture could increase the lighting demand for general room illumination.

3.2.3 User influence on switching schemes (annual operating time)

User influence on final lighting energy consumption is primary related to presence of users in the home. It is also related to automatic systems (also domotica) that are introduced more and more:

- photocell control for outdoor lighting;
- time control lighting schemes pretending to possible burglars that there are people in the home;
- presence detection that switches lighting on with a switch-off e.g. 5 minutes after the last presence detection;
- dimming of some lighting sources.

[31] Narisada K. & D. Schreuder (2004), Light pollution handbook., Springer verlag 2004, ISBN 1-4020-2665-X

The yearly operating time per lighting source is different depending on the family members present in the home and the activities taking place. Quantitative data about operational hours are included in chapter 2.

3.2.4 Lamp dimming

It is quite common to install lamp dimmers for some lamps in the home – typically in the living room. Lamp dimming is probably mainly applied in domestic lighting for modifying the atmosphere by either lowering the light level, changing illumination contrast or modifying the colour temperature of the lamp. In principle lamp dimming can also be used to save energy in domestic lighting but it doesn't seem to be a real driver for installing lamp dimmers in domestic applications. Dimmed GLS or HL lamps change to a warmer colour temperature when they are dimmed (an example is shown in Figure 3-3).

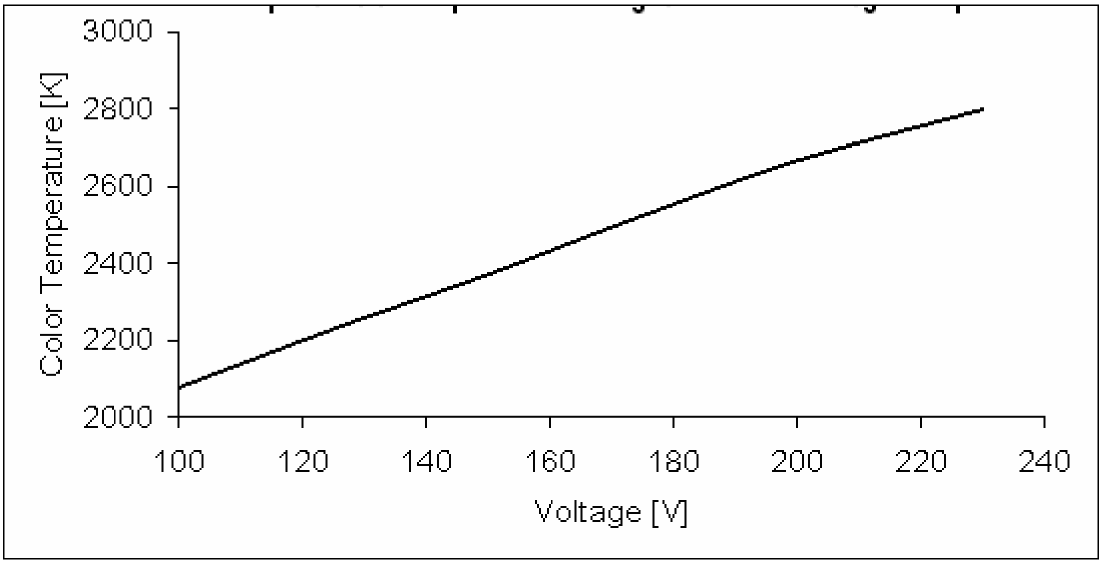


Figure 3-3: Colour temperature for dimmed halogen lamp in function of line voltage.

Dimming is also used to light a "path" dimly in the night (e.g. for elderly people or children) in new home automation solutions that are easy to build into existing homes without renovation work. The same objective can be obtained by installing small LED lights etc., but this usually requires work on the installation.

3.2.5 Influence of the power factor and harmonic currents of a light source

The power factor of an AC electric power system is defined as the ratio of the real power to the *apparent* power and is a number between 0 and 1. *Real* power is the capacity of the circuit for performing work in a particular time. Apparent power includes the *reactive* power that utilities need to distribute even when it accomplishes no useful work. Low-power-factor loads can increase losses in a power distribution system and result in increased energy costs (LRC

(1995)[32]). Most utilities for electricity distribution have penalties for large consumers when the total power factor is below 0.8.

There exists inductive, reactive power as well as capacitive, reactive power in the electrical grid and both can compensate each other. Motors (e.g. refrigerators, elevators, vacuum cleaners, pumps,..) or inductors (magnetic ballasts for fluorescent or HID lamps) are typically inductive loads while many electronic sources (CFLi, PCs, TVs, ..) are capacitive. In general the grid tends to be more inductive due to the high amount of motor loads and in industry power factor compensation capacitors are frequently installed. Incandescent lamps and electronic ballasts with power levels above 25 W however have power factor 1, electronic ballasts because an active power factor compensation (PFC) circuit is needed in order to satisfy the harmonic current limits of standard EN 61000-3-2 (Basu (2004)[33]); please note that there is no direct limitation on the power factor itself in the standard but it is a consequence of the harmonic current requirement and the technology used. In standard EN 61000-3-2 anno 2007 the strongest requirements are limited to lighting products above 25 W while other electronic equipment (PCs, TVs, ..) has much lower requirements, there is no public known rationale for this. Hence CFLi's that are capacitive are unlikely to create strong negative grid influences because they rather compensate inductive loads and are unlikely to dominate the total active power demand of the grid.

For CFLi's, the power factor can go down to 0,50[34]; the lower the power factor, the higher the electrical current that is needed to result in the same real power. VITO has recently measured power factors for 6 CFLi (9-17W) and the power factor was in all cases within the interval 0,62-0,66. and 0,95 for a HL-MV-IR (with integrated transformer). Neverthelesse, the lower power factor for CFLi could cause as mentioned above a higher current which again could cause around 5% more losses in the electrical grid not taking into account the existing inductive loads. Therefore a correction factor 'Lamp Wattage Factor LWFp' is introduced in order not to overestimate CFLi gains; for values see Table 3-2.

Table 3-2: LWFp correction factors for power quality used in this study

Lamp type	***LWFp***
GLS	*1*
HL types	*1*
CFLi	*1.05*

The formula for the real power and real annual energy consumption (E_{yreal}) per lamp becomes:

P_{real} [W] = Plamp x LWFp and E_{yreal} [kWh] = E_y [kWh] x LWFp.

[32] LRC (1995), Robert Wolsey, Lighting Answers: Power Quality, National Lighting Product Information Program, volume 2, number 2, February 1995.
[33] Basu (2004), Supratim Basu, T.M.Undeland, PFC Strategies in light of EN 61000-3-2, EPE-PEMC 2004 Conference in Riga, LATVIA, 1- 3 September 2004.
[34] IAEEL newsletter 3-4/95, 'Power Quality for Beginners'

3.2.6 Influence of voltage change

The primary cause of voltage fluctuations[35] in the medium and high voltage grid (>1000 VAC) is the time variability of the reactive power component of fluctuating loads; in the low voltage grid (e.g. 230/400VAC) it is the fluctuating load of active and reactive power. Also variations in the DER (Distributed Energy Resources) generation capacity can have an effect and because the number of such installations will increase in the future, it can be expected that voltage fluctuations will increase accordingly.

For lamps, the flicker that is generated significantly impairs vision and causes general discomfort and fatigue[36]. The permissible magnitude of light flicker is regulated by International Standards [37] [38] and was based on perception criteria related to incandescent lamps or so-called General Lighting Service (GLS) lamps. The light flicker requirements had an impact on standard EN 50160 (2007): 'Voltage characteristics of electricity supplied by public distribution networks'. For these GLS-lamps the permissible supply voltage variation (+/- 10 %) causes an incandescent lamp to deliver as little as 70% or as much as 140% of its nominal luminous flux respectively[39]. The same is trough for other filament lamps that are directly operated by the mains (e.g. mains voltage halogen lamps). Fluorescent lamps are less sensitive and will vary only +/- 20 % and even less when they are operated by inverters with power factor controllers, e.g. all electronic ballasts above 25W (see lot 8).

An increase of the voltage will also influence the lifetime of the lamps.
A major manufacturer[40] reports that an incandescent CLAS A 230V 100W lamp supplied with 240V will provide 17.5% more luminous flux, have 50% less life time and 6,6% more power consumed with the burning risk through overheating of the cap in the socket. On the contrary, an incandescent CLAS A 240V 100W lamp supplied with 230V will provide 15% less luminous flux, will convert from energy class E to F but the life time will be 80% longer.

The influence described above might explain why some customers complain about to short life time of their lamps.

3.2.7 Decrease in lamp efficacy in real life operation compared to standard conditions

The lamp efficacy that is announced by manufacturers is measured after an ageing period of a number of hours burning in standard conditions as defined in the specific European standard on performance requirements for the lamptype (see section 1.1.3.1). Due to normal ageing

[35] Power Quality Application Guide: Voltage Disturbances-Flicker, Leonardo Power Quality Initiative (LPQI), available from www.lpqi.org.
[36] Power Quality Application Guide: Voltage Disturbances-Flicker, Leonardo Power Quality Initiative (LPQI), available from www.lpqi.org.
[37] IEC 61000-3-3:1995, Electromagnetic compatibility (EMC) – Part 3: Limits – Section 3: Limitation of Voltage Fluctuations and Flicker in Low-voltage Supply Systems for Equipment with Rated Current ≤16A.
[38] IEC 60868: 1986, Flickermeter, Functional and Design Specifications
[39] Power Quality Application Guide: Voltage Dips - Introduction, Leonardo Power Quality Initiative (LPQI), available from www.lpqi.org
[40] GLS Product Training, OSRAM, Munich Sep. 22nd 2008

and deviation of the installed lamp from standard conditions in the use fase, this efficacy can be influenced.

3.2.7.1 Due to lamp ageing

The lumen output of a lamp deteriorates during its lifetime. This decrease is not equal for all lamp types and is expressed by the Lamp Lumen Maintenance Factor (LLMF) (see section 1.1.3.1). Technical Report CIE 97: "Guide on the maintenance of indoor electric lighting systems", edited by the International Commission on Illumination, gives examples of the influence of aging, listed as shown in Table 3-3.

Table 3-3: Typical examples of the lamp lumen maintenance factor (LLMF) and the lamp survival factor (LSF) data (Source: CIE 97 – 2005).

			Burning hours in thousand hours											
		Differences	**0.1**	**0.5**	**1**	**2**	**4**	**6**	**8**	**10**	**12**	**15**	**20**	**30**
Incandescent	LLMF	Moderate	1.00	0.97	0.93									
	LSF	Big	1.00	0.98	0.50									
Halogen	LLMF	Big	1.00	0.99	0.97	0.95								
	LSF	Big	1.00	1,00	0.78	0.50								
Fluorescent Tri-phospor HF ballast	LLMF	Moderate	1.00	0.99	0.98	0.97	0.93	0.92	0.90	0.90	0.90	0.90	0.90	
	LSF	Moderate	1.00	1.00	1.00	1.00	1.00	0.99	0.98	0.98	0.97	0.94	0.50	
Flourescent Tri-phospor Magn. ballast	LLMF	Moderate	1.00	0.99	0.98	0.97	0.93	0.92	0.90	0.90	0.90	0.90		
	LSF	Moderate	1.00	1.00	1.00	1.00	1.00	0.99	0.98	0.98	0.92	0.50		
Flourescent halophospate Magn ballast	LLMF	Moderate	1.00	0.98	0.96	0.95	0.87	0.84	0.81	0.79	0.77	0.75		
	LSF	Moderate	1.00	1.00	1.00	1.00	1.00	0.99	0.98	0.98	0.92	0.50		
Compact fluorescent	LLMF	Big	1.00	0.98	0.97	0.94	0.91	0.89	0.87	0.85				
	LSF	Big	1.00	0.99	0.99	0.98	0.97	0.94	0.86	0.50				
HP Mercury	LLMF	Moderate	1.00	0.99	0.97	0.93	0.85	0.82	0,78	0,75	0,72	0,70	0,65	
	LSF	Moderate	1.00	1,00	0.99	0.98	0.97	0.94	0.90	0.86	0.79	0.69	0.50	
Metal halide (250-400W)	**LLMF**	Big	**1.00**	**0.98**	**0.95**	**0.90**	**0.87**	**0.83**	**0.79**	**0.65**	**0.63**	**0.58**	**0.50**	
	LSF	Big	**1.00**	**0.99**	**0.99**	**0.98**	**0.97**	**0.92**	**0.86**	**0.80**	**0.73**	**0.66**	**0.50**	
Ceramic metal halide (50-150W)	**LLMF**	Big	**1.00**	**0.95**	**0.87**	**0.75**	**0.72**	**0.68**	**0.64**	**0.60**	**0.56**			
	LSF	Big	**1.00**	**0.99**	**0.99**	**0.98**	**0.98**	**0.98**	**0.95**	**0.80**	**0.50**			
High pressure sodium	LLMF	Moderate	1.00	1.00	0.98	0.98	0.98	0.97	0.97	0.97	0.97	0.96	0.94	0.90
	LSF	Moderate	1.00	1.00	1.00	1.00	0.99	0.99	0.99	0.99	0.97	0.95	0.92	0.50
LED	LLMF	Big	Data are changing too rapidly											
	LSF	Big	Data are changing too rapidly											

Below the average LLMF over an assumed lifetime is calculated, based on the values in this Table 3-3:

- For incandescent lamps (GLS): 0,965 (life time assumption 1000 h);
- For halogen lamps (HL-types): 0,975 (life time assumtion 2000 h);
- For compact fluorescent lamps (CFLi): 0,925 (life time assumption 10000h).

Please note that in Table 3-3 moderate and big LSF and LLMF variations are reported for most lamp types. It indicates differences in LLMF and LSF among lamps, which belong to the same lamp type category. Few test data on halogen and incadescent lamps were found in literature while for CFLi some consumer test data are available. They are included hereafter and they confirm the strong variations, hence quality requirements can be beneficial.

Warentest 3/2008 tested 20 CFLi's for reduction in lighting output after 2000 respectively 10000 hours. The results are shown in Figure 3-4.

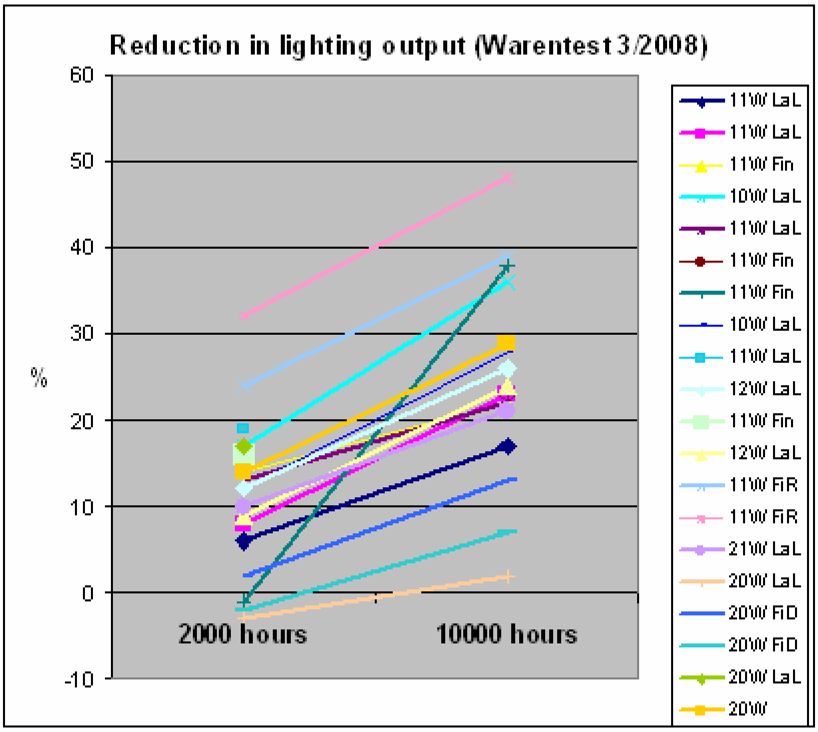


Figure 3-4: Reduction in lighting output found in test of 20 CFLi.

The average reduction after 2000 hours is already 9,6% for the 18 CFLi's excluding the very poor reflector lamps. The worst half includes both lamps from some of the large manufacturers as well as large retailers producing CFLi's. At the age of 10000 hours 3 of the 20 lamps had stopped working and the average reduction for the remaining 15 CFLi's (excluding the reflector lamps) was 21,9%. For these lamps the average LLMF is around 0,85 during the lifetime of 10000 hours.

3.2.7.2 Decrease in lumen output due to temperature or lamp position

Many CFLi's have light output claims that are only achieved at the optimum operating temperature and/or in some optimum burning position. As normal CFLi's for indoor applications have the optimal working conditions in the temperature interval 25-35 °C, lamp manufacturers are offering special CFLi's for outdoor applications.

By introducing amalgam technology (see chapter 6), manufacturers are trying to reduce as much as possible the influence of ambient temperature on light output of the lamps.
For many lamp types, the lumininous flux output is also different for base-up, horizontal and base-down position.

Because several adjustments[41] have already been developed to both the lamps and the fixtures to reduce the thermal efficiency problems and that lamp position is only dependent on

[41] Example: Fixing the Fixtures, Michael Siminovitch and Evan Mills, LBNL.

luminaire design, these effects will not be taken into account in the calculations in this part 1 of the study.

For luminaire design, Please consult the related section in part 2 of this study.

3.2.7.3 Interactive effects of the light source on heating or cooling needs

It should be noted that nearly all energy that is not converted by the light source into the defined functional unit 'light' is converted into heat. In some particular cases (e.g. winter season) this 'energy waste' is recovered as space heating and this could be considered as a useful interactive effect with the space heating needs.

This is a horizontal issue for all domestic energy using products that turn part of the electricity into heat while performing their defined function.

It should be noted that interactive effects are not the most effective way to provide indoor heating because: the installation is not optimized (e.g. the location on the ceiling can be inefficient), essential control functions are obsolete (e.g. the heating can be unnecessary in the summer period), adverse interactive effects could also occur (e.g. increased need for cooling), direct electrical heating is less effective compared to electrical heating using a heat pump (the typical Coefficient of Performance (COP) in indoor heating is 3 to 4), not all rooms need heating. Light sources installed in electrical ovens will only be discussed as exception in chapter 8. As a consequence, the wasted heat generated by lighting is considered as pure energy loss in the assessment of the performance of the lamps examined in this study.

3.2.7.4 Conclusion on correction factors used for real life lamp efficacy

In the study we have chosen to use average LLMF correction factors based on the Technical Report CIE 97: "Guide on the maintenance of indoor electric lighting systems", edited by the International Commission on Illumination (see Table 3-3). For CFLi we are using the factor for a CFLi with lifetime 10000 hours although for the base case (see chapter 5) we assume a CFLi with a lifetime of 6000 hours.

Table 3-4: Correction factors for lumen depreciation used in this study

lamp type	*LLMF (average)*
GLS	*0,965*
HL types	*0,975*
CFLi	*0,925*

The CIE values were used despite the fact that for CFLi some new test data were available that did show lower average performance but for an equal comparison the above data source was used because there was a lack of real test data especially for GLS and HL-types.

For GLS-lamps the CIE-data also seem to be optimistic as a decrease in lumen output to 80% of the initial output can be found in litterature[42] due to the evaporation of the tungsten wire (higher resistance, lower watts and lower light output) and the deposit of this tungsten particles on the bulb.

3.3 End of Life behaviour related to consumers

This section discusses only the information on user behaviour related to end of life of lamps. The technical aspects of recycling at end of life are dealt with in section 4.5.

Mercury is an essential component for producing fluorescent lighting. Therefore the RoHS-directive still allows the use of mercury in discharge lamps. Although the mercury content in CFLi's is restricted to 5mg and EU lamp manufacturers supply lamps down to 1 mg, mercury remains an hazardous substance and the release to the environment has to be avoided anywhere in the society.

Many lamps also contain a lot of electronics including hazardous substances too, or precious raw materials, which we have to recover in the near future (e.g.Tantalum).

For protection of the environment and the health of its citizens, the EU has also created the WEEE-directive. This directive obliges all manufacturers from electric and electronic equipment, including discharge lamps and luminaires, to take back used products so that they can be recycled. In this way the mercury is also taken out of circulation in the mean time.

Luminaires and ballasts contain high amounts of aluminium, steel and copper and prices offered for these materials are quite high, giving the incentive to collect them after use; even rag-and-bone men are eager for buying scrap metals.

This is different for CFLi's. Notwithstanding the fact that many components (glass, metal parts, phosphors and mercury) can be recycled, recycling doesn't seem to be very profitable. As a consequence, many people don't know what to do with their used lamps, moreover they don't even know that CFLi's are containing mercury.

A new study on the rate of recovery under the WEEE directive[43] has found that on average 27,9 % of the lamps covered (category 5B) are recycled. They do not disaggregate the figure by lamp types – CFLi used in the domestic sector are less likely to be recycled than LFLs or HIDs primarily used in the non-residential sectors.

[42] Illuminating Engineering Society of North America: Lighting Handbook 8th edition, p.187.

[43] http://ec.europa.eu/environment/waste/weee/studies_weee_en.htm
"2008 Review of Directive 2002/96/EC on waste electrical and electronic equipment (WEEE)"

A 2006 inquiry made by a large European retailer in Sweden found that only a small fraction of the customers did bring their used CFLi's to a recycling point and that another segment threw away their lamps in the domestic waste in spite of the marking on the packaging. Table 3.3 below shows that now 75% of the lamps in Sweden are recycled which as far as we know is much better than any other European country. The data in Table 3-5 are collected by co-operation with the partners in the EU R&D project ENERLIN and on knowledge of the consultants for this study.

Table 3-5: Recycling of mercury containing lamps

Country	Data from	Total recycling (%)	Domestic sector recycling (5)	Commercial sector recycling (%)	More information
Baltic States					ekogaisma.lv and ekogaisma.ee
Belgium					www.recupel.be
Bulgaria		0%			
Czech Republic					www.ekolamp.cz
Denmark	2007	>50%	-	-	www.lwf.nu
France	2007	36%	-	-	Recylum.com
Germany	2006	36%	10%	90%	LightCycle
Hungary					electro-coord.hu
Poland	2007	10%			
Portugal					erp-portugal.pt
Romania					www.recolamp.ro
Sweden	2007	75%	60%	90%	Data from STEM

In the Baltic countries, Philips, Osram, GE Hungary and BLV have founded the company Ekogaisma with main headquarter currently in Latvia. Currently they are executing a campaign called "Save, but don't pollute" to raise awareness that CFLi's have to be taken to the recycling points; at present it is unknown how often people follow this advice. Experts in the countries say it would be better if people could give the used CFLi back in the shops where they have bought them.

In Belgium, the company RECUPEL was founded in 2001 by all importers and distributers of electrical and electronic equipment. Since 2004 also all discharge lamps and lighting equipment are collected. The user, professional as well as non professional, pays a recycling contribution, not a tax, at purchasing. As a consequence he can dispose of the used products at end of life free of charge. Households can dispose of their equipment in the municipal deposit park; all municipalities have set up such a deposit park. Collection rates of CFLi's are not available yet.

Bulgaria has a legislation that requires the collection for recycling of different kinds of used lamps including CFLi. A Decree states that the manufacturers and importers are responsible for the collection and that it shall be done without payment by the households. The Decree requires that no less than 45% of the weight is collected in 2006, increasing to 60% in 2007 and 80% for 2008. Anyway, the manufacturers and importers have still only come to talk about starting a WEE association to take care of fulfilling the requirements, but in reality no activities are undertaken yet.

In Denmark, the manufacturers did form in 2005 a WEE association that is taking care of collection of used LFLs and CFLs by 110 commercial collection points and 127 municipal waste collection points. The manufacturers pay for the activity through a payment per lighting source. More than 50% of the lamps (in weight) is collected. The collection is working best for the non-residential sectors while the residential sector depends on the awareness of the consumer that seems low. The handling of the lamps at the recycling stations has to be improved as you can find CFLi's thrown into a container and broken.

Since March 2006, the German law requires the manufacturers of lamps to take back used discharge lamps in order to prevent hazardous material to be exposed to the environment. On behalf of the lamp manufacturers, Lightcycle Retourlogistik has the responsibility of taking back the lamps. More than 500 disposal points have been set up all over Germany. In 2006, 40 of 110 million discharge lamps were disposed properly, which equals a rate of 36% (all lamps included - most LFLs are supposed to be properly recycled). In 2007, a broad information campaign about proper disposal of discharge lamps was executed. Also a school competition was initiated. The goal is to increase the return rate drastically. Germany seems to be ahead of most other EU27 countries.

In France, also 36% was collected. The collection is done 55% by waste collectors, 23% by lamp distributors, 15% by installation companies and the remaining 7% by municipalities and directly by customers.

In Poland, the main act related to the recycling was implemented 21st October 2005 according to the EU Directive no. 2002/96/EC. In 2006, a new body Chief Environmental Inspector (CEI) was established as the main waste management regulatory authority that keeps the record of recycling. The following professional market actors have to report to the CEI:

- Producers, importers and distributors are obliged to inform, report (quantity and weight) organize and finance collecting and recycling.
- Retail and wholesale distributors are obliged to organize in the sales-point, cost-free waste receipt if the consumer buys a new similar piece and to report quarterly (weight).
- Consumers are obliged to return worn-out electric and electronic equipment to the points of selective waste collection.

District council is obliged to adapt regulations to the district waste management plan and district authorities are obliged to organize receipt of municipal waste from immovable owners who did not draw up a waste collection agreement.

CEI’s first annual report (April 2008) states that 8392 companies have registered: 2677 sales companies, 6413 collectors, 99 processing companies, 65 recycling/retrieving (other processes) companies and 5 retrievers of electronic equipment. Measured in weight, 8% of the waste is lighting equipment. In 2007, 10% of the lighting equipment was collected.

In Romania collection of used lamps started at the beginning of 2008. Recolamp association (<http://www.recolamp.ro>www.recolamp.ro) founded by Philips, Osram, Narva and General Electric is in charge of the collection. When buying a fluorescent lamp the customer pays for a green stamp tax e.g. aprox. 0.24 EUR/CFL. A national campaign has started in order to place around 1000 used-lamp-containers during 2008 at lamp retailers, at city disposal plants and companies that produce or distribute lamps.The containers are transported by local authorized operators to 4 regional points where the lamps are sorted by type and category, packed and then sent to a recycling company in Germany (several other Central-Eastern European countries are also exporting their disposed lamps as they don't have any recyling plant).

In Czech Republic, participants pay a treatment fee to Ekolamp proportional to their market share. The total collected "recycling fee" corresponds to the cost of recycling.

The general impression from contact with manufacturers and EU27 country representatives is that the recycling system for collection of mercury from lamps is in most countries not implemented properly, especially for the residential sector. A large part of the consumers don't even know that a CFLi contains mercury and that they should give back the disposed CFLi for recycling. An easy way to dispose CFLi's seems to be a requirement that it is mandatory to be able to return disposed CFLi's to the points of purchase.

3.4 Local infra-structure and facilities

3.4.1 Influence of the physical room infrastructure

As mentioned in section 3.2.2, "good lighting conditions" is more than just the quantity of lighting. The visual perception also deals with the contours of surfaces and with contrasts between surfaces (brightness).

Local infrastructure and room design can have an important influence on the efficiency of lighting installations. In one period, dark painted walls turn into fashion while another period white or bright colours come in again. Colour and reflection of walls, ceilings and floors are very important for the visual performance as shown in Table 3-6.

Table 3-6: Reflectance values used in the previous preparatory study on office lighting.

	very bright	typical (default)	very dark
Reflectance ceiling	0.8	0.7	0.3
Reflectance wall	0.5	0.5	0.3
Reflectance floor cavity	0.3	0.2	0.1

3.4.2 Lack of skilled and informed users

A very broad range of lamps for domestic application did become available on the market in the last decades (see chapter 1). A one to one comparison with the familiar GLS is not always straightforward and could create a user barrier as will be discussed in more detail in 3.5. The new lamp types often have very different selection parameters that, when applied correctly, could offer more comfort and user satisfaction. For example, a CFLi can be bought in a broader product range of colour temperatures, light distribution patterns or product life time compared to GLS. However this is often unknown and wrong product choices can lead to unsatisfied users. Users should therefore be clearly informed about correct lamp selection parameters (start up time, light colour, light distribution, light output, dimming method, life time, temperture sensivity, ..) It is also recommended that users are informed timely about the proper energy efficient retrofit solution in case certain products become obsolete.

3.4.3 Lack of skilled service providers

This is especially important for furniture-integrated luminaires (e.g. kitchens, bathrooms, ..) as sales people could have a strong indirect influence on the selection and amount of installed luminaires in modern houses. Also some energy retrofit solutions, e.g. replace a dimmable incandescent lamp by a CFL or efficient halogen solution, can benefit from professional advice in order to reduce trial and error by users resulting in negative consumer experiences.

3.4.4 Luminaire socket and space lock-in efffect

Some luminaires do not accept an energy efficient retrofit lamp due to the available space and/or socket types. Especially very compact luminaires with G9/R7s sockets will face difficulties to accept a more energy efficient lamp. In most cases a luminaire replacement should be recommended. Users of those luminaires should be informed in cases when replacement lamps will become obsolete in order to allow them to store sufficient replacements lamps in the cupboard. This cannot involve any problem because the cupboard store life time of these lamps is not limited.

It is also important to note that the introduction of amalgam technology (see chapter 6) in CFLi production enables the manufacturers to reduce the size of these lamps so that most problems with space lock-in effects has currently disappeared.

Some Edison socket luminaires (E14/E27) also reduce the real CFLi life time due to their poor thermal heat design. Nevertheless it is unsure whether users are sensitive to this reduced life time as they are already familiar with the low GLS lamp life time. In some cases a luminaire replacement should be recommended. Users should be informed about this potential occurrence.

3.4.5 Electrical wiring and control system lock-in effect

In domestic lighting two types of wiring are used:

- 'Two-wire installation' that contains only one wire between switch and lamp. In this system the switch/control product is connected in series with lamp/load and the neutral is not present in the switch (except in some countries). The advantage is the low amount of required copper wire and reduced short circuit risk during installation but the disadvantage is that no direct power supply is available for electronic control switches (e.g. dimmers). In Figure 3-5 an example of a (special) two wire installation with two three-way switches is shown. The neutral wire is directly going to the lamp, without intermediate switch.

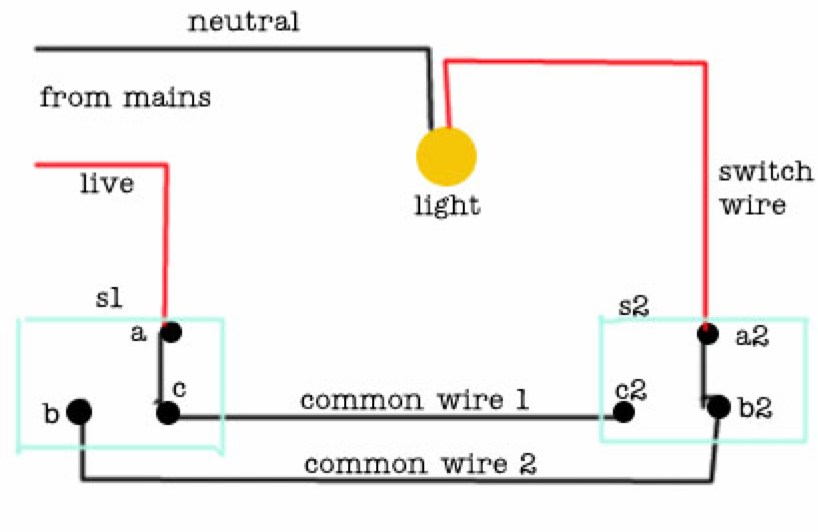


Figure 3-5: Example of a 'two wire installation'.

- 'Three wire installation' that contains both the neutral and phase wire between the switch and the lamp. The main advantage is that a power supply for the control switch can easily be obtained but it requires more copper wire for installation.

Two-wire installations with electronic control switches (e.g. dimmers, presence detectors, ..) do risk to create lock-in effect for high power incandescent lamps because they need to draw a small amount of current for their internal power supply (when no battery is used). Therefore a parasitic leakage current flows in the off state through the lamp. These systems were typically designed for incandescent lamps and require a minimum wattage. When more efficient lamps are installed below the minimum wattage they can face problems, typically:

- Although it looks alright to the user, the CFLi may draw excessive current which might cause overheating and reduce the lamp life significantly.
- The control product may not work correctly, if the supply current can't pass through the load (flashing, non-reaction or other erratic behaviour).
- The supply and the leakage current causes some CFLs to flash briefly at short intervals in off state.
- Some dimmers for two-wire installations are unable to reliably synchronise to the mains frequency when no minimum resistive load (incandescent lamp) load is connected. As a consequence they do not function properly and are unable to dim common CFLi.

Lamp manufacturers have developed lamps that do overcome this problem, they are implemented in the more expensive dimmable CFLi lamps or HL-MV lamps with integrated electronic ballast (see dimmable CFLi in chapter 6).

Standardisation is available, e.g. in "Electronic switches for households and similar use (EN 60669-2-1)" and EN 60969 for CFLi but there are currently no provisions for compatibility.

3.5 Potential barriers and restrictions to possible eco-design measures

This section, dealing with the lighting source, shall be seen as complementary to the earlier sections. Especially the CFLi is in the focus with regard to quality and questions e.g. to alleged negative health effects which have never been raised for other lamp types (GLS, HL-MV, HL-LV, LED). Anyhow, we recommend to pay more attention to quality tests of other lamp types like LED and halogen lamps e.g. the lumen maintenance for halogen lamps appears to be low in some cases but there is a lack of test data. Please also note that some of these barriers related to CFLi might become irrelevant supposing that certain types of lamps (e.g. efficient halogen lamp types, low power incandescent lamps and LED's) remain on the market.

3.5.1 CFLi quality and comparison with GLS

The quality of the CFLi's has been the focus of several eco-label or quality charter initiatives. This is also the fact for the correctly correlated lamp power of a GLS and a CFLi. Despite several initiatives for the sake of quality few up-to-date market surveillance data are known. Other lamp types, such as GLS, were paradoxally enough not in the focus of such quality initiatives.

The image of CFLi's is not as good as it could be[44]. This is mainly due to the experience with the first generation of CFLi's that came on the market twenty years ago with cold light colour, poor colour rendering, fairly heavy weight and large dimensions. In the mean time, most of these disadvantages are eliminated (see chapter 6). Anyway nowadays some people also have bad experiences with CFLi's of poor quality e.g. the light output is not enough, the lifetime is less than claimed etc. Although the quality of an incandescent lamps is often also not good enough, the bad experience of CFLi's can damage the image of higher quality products and can make people afraid of buying CFLi's again.

In 1999 EC and UNIPEDE/EURELECTRIC made a voluntary CFL Quality Charter including requirements concerning safety, performance, efficacy, lumen maintenance, time to stabilised light output, fast switching life evaluation, colour rendering, guarantee and information on the packaging.

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[44] LRC (2003), 'Increasing Market Acceptance of Compact Fluorescent Lamps', LRC Final project report, Rensselaer Polytechnic Institute.

In some EU countries, lists are produced with ‘good quality’ CFLi’s that fulfill the requirements of the European CFL Quality Charter[45]. These lists are based on information from the manufacturers as well as on independent testing.

More details about quality parameters are included in the subsequent sections.

Because few market data for CFLi are known and there is a complete lack of information about quality of other lamp types (e.g. incandescent lamps), there will be no correction factor introduced for quality. In chapter 8, some recommendations could be proposed for quality assurance.

3.5.1.1 The need for right comparison of light output from CFLi’s versus incandescent lamps

The user should know how to replace incandescent lamps by CFLi’s giving the same amount of light (lumen). Unfortunately, the manufacturers generally do not give correct information about this replacement. Most manufacturers admit this but have over the years continued to claim that it is not so important. The customers often say “CFLi’s don’t give good lighting” while they could mean that 'they do not give enough light'. For example, an 11W CFLi lamp with 550 lamp lumen can suggest on the package to be equivalent to a 60 Watt incandescent lamp (GLS) (Figure 3-6). As can be found in chapter 4, a 60 Watt GLS lamp has a lamp lumen output of 710 lumen, which is as a matter of fact about 30 % more. Comparing the initial lumen output (after 100 hours), mathematically a 60 W incandescent lamp should be replaced by a 13 W but this wattage is not commonly available on the market.

This has been and is still giving the CFLi’s a bad image and creates a barrier. Many people probably have stopped using the energy saving CFLi’s because of these negative experiences. Users have the need to be correctly informed on the packaging of the CFLi.

Figure 3-6: Example of misleading information on the product packaging of CFLi lamp.

Anyhow the equivalence must also take into account the decrease in lamp efficacy in real life operation by using the correction factors for lumen depreciation (see Table 3-4); as these correction factors were calculated as an average during the entire lifetime of the lamp, they already take into account that a GLS is “refreshed” by shifting to a new 6-12 times during the life of a CFLi.

[45] E.g. the Danish Electricity Saving Trust list at http://application.sparel.dk/asp/a-paere/query/paerewiz/liste.asp

The new version of the European Quality Charter (July 2008)[46] proposes that e.g. a 60W GLS (with initial lumen output 710 lumen) is replaced by a CFLi with 850 lumen (20% more). This is equal to an easily understandable "rule of thumb" for an equivalence of 4:1 where a 60W incandescent lamp will be replaced by a 15W CFLi. This requirement compensates for the lower real life performance of the CFLi compared to GLS due to lower LLMF (ageing factor, see section 3.2.7), temperature effects, potential influence from lamp position and a compensation for the low start performance due to warm-up time.

In the Northern part of EU, Energy Authorities and the utilities have for more than 15 years recommended the 4:1 equivalence as many lighting experts[47] in other parts of EU also have.

3.5.1.2 Warm-up time for CFLs

Energy Star defines warm-up time (also called run-up time) as the time needed for the lamp to reach 80% of its stable light output after being switched on. The new version of the European Quality Charter requires that the 80% level is reached within 60 seconds.

Figure 3-7, Figure 3-8 and Figure 3-9 show the results from three tests of warm-up for a total of 40 CFLi's. SAFE[48] did test 14 CFLi's (including both the finger type and the Look-a-Like type with external casing) and all of them had a warm-up time lower than 60 seconds.
VITO did test 7 CFLi's where 4 of them had longer warm-up times and that included CFli's distributed by large retailers as well as CFLi's produced by the 4 major manufacturers. Warentest did test 19 CFLi's where 5 of them had long warm-up times. All CFLi's coming from the 4 major manufactures had a sufficient warm-up time no matter the type of CFLi.

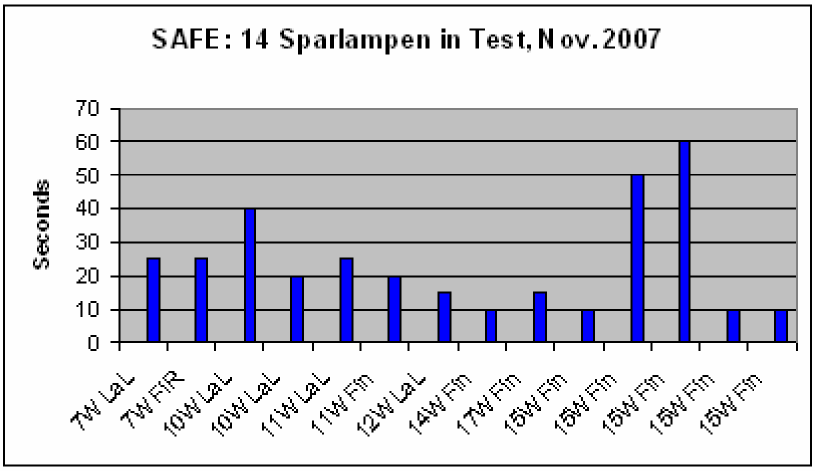

Figure 3-7: Warm-up time SAFE test.

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46 http://re.jrc.ec.europa.eu/energyefficiency/CFL/index.htm

47 http://lightinglab.fi/IEAAnnex45/publications/Technical_reports/On_the_substitution_of_incandescent_lamps.pdf

48 Schweizerische Agentur für Energieeffizienz: Sparlampen_07_Schlussbericht_191107

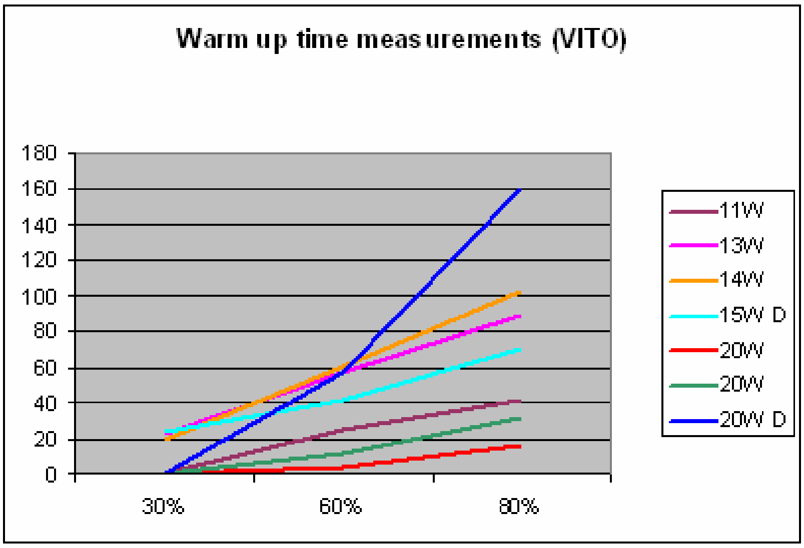

Figure 3-8: Warm-up time VITO test.

Fin=Finger, FiD=Finger Dimmable, FiR=Finger Reflector, LaL=Look-a-Like

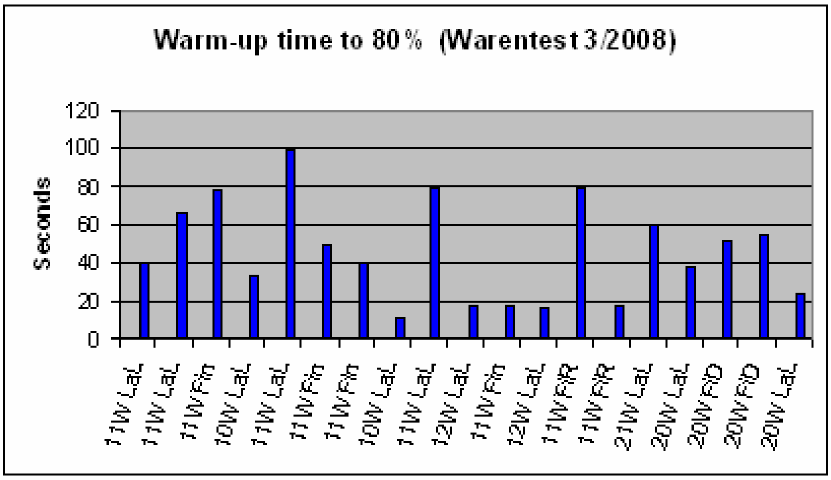

Figure 3-9: Warm-up time Warentest.

In total, 31 (77%) of the 40 CFLi's had an acceptable warm-up time and that includes all types of CFLi's: Fingertype, Look-a-Like, Finger reflector or Finger dimmable. For these 31 the warm-up time is on average 29 seconds so in the future the limit might be revised to less than 60 seconds. Anyway for the time being the EU Quality Charter requirement seems reasonable.

A barrier for reduction of the warm-up time is that manufacturers nowadays use amalgams in the CFLi's in order to reduce the influence of ambient temperature on the light output of a lamp during normal operation. This amalgam technology that is also necessary to produce the more compact types, increases the warm-up time. In chapter 6 the use and the advantage of amalgam is extensively discussed.

3.5.1.3 Colour temperature and colour rendering

As described in part 3.2.2., the different lamp types have different intensities for the spectral distribution of the emitted light. The most important visual lamp characteristics are (see section 1.1.3.1):

- the colour appearance of the lamp, defined by the correlated colour temperature CCT in [K];.
- the colour rendition of objects or surfaces illuminated by the lamp, defined by the colour rendering index CRI.

The colour temperature of an incandescent lamp is situated between 2400K (for lower wattages or dimmed high wattages) and 2800K (for high wattages).
CFLI's are available with different colour temperatures. In the Southern part of the EU the tendency is that people prefer colder light i.e. a higher colour temperature (higher content of blue lighting) while people in the Northern part of the EU prefer warmer light i.e. a low colour temperature (higher content of yellow/red lighting).

Incandescent and halogen lamps have a CRI score close to 100 while this score is lower for other lamp types. For existing CFLi's, all using 3-band phosphor, the CRI is typically between 82 and 85. In the family of LFL's, 5-band phosphor types are available with CRI from 91 up to 98. This technique could also be used for CFLi's as an alternative for the lighting points where the user sets very high requirements for colour rendering. Special attention must be paid to the fact that in this case the lumen output decreases with about 30% and the product price will be higher due to the use of more expensive phosphorous powders. At the latest Quality Charter revision meeting in October 2007, the Danish Electricity Saving Trust and other participants recommended the manufacturers to start production and sales of CFLi's with higher CRI with CRI within the same area 91-98 as seen for LFL. In the Nordic countries ,some architects and designers are demanding such high quality CFLi lamps[49].

3.5.2 Visual appearance

The visual appearance of lamps is optimal when the luminaire is designed for the lamp type used in the luminaire. Most existing luminaires in the home are designed for incandescent lamps. Use of a CFLi in a luminaire dedicated to incandescent lamps might reduce the visual appearance (e.g. by losses in light output and/or glare). Currently this problem is mostly remedied by the introduction of look-a-like CFLi's for frosted or silicated incandescent lamps. It is important that luminaire manufacturers bring luminaires on the market that are dedicated to CFLi's so the customer is aware of combining luminaire and lamp in the best way. Please consult also the related section in part 2 of this study.

3.5.3 Luminaire socket and space lock-in efffect

For this item, see section 3.4.4.

[49] Dissemination in order to eliminate Barriers for use of Energy Saving Lamps in the Domestic Sector, SAVE project 4.1031/Z/97-030, December 2000, page 27 and 105.

3.5.4 Electrical wiring and control system lock-in effect

For this item, see section 3.4.5

3.5.5 Harmonic interference in the low voltage network

In many homes energy suppliers have observed network pollution by harmonic interference originating from appliances as TV and PC sets. CFLi's are also giving a little harmonic interference and some energy suppliers have discussed or claimed that the manufacturers should introduce an electronic compensation system in the CFLi's. According to the legal regulations in Europe (IEC 1000-3-2), reduction of harmonic emissions is not obligatory for appliances with an active input power less than 25 W. There is thus no regulation that requires compensation for CFLs.

A comprehensive field test study was carried out by The Community of the Austrian Electricity Suppliers including laboratory measurements and field measurements. The Austrian measurements showed that extensive use of CFLi's did not lead to negative effects on the voltage quality[50]. Computer simulations were carried out to estimate the effect of the increased use of CFLi's on the higher voltage levels. Considering the result of the calculation, the distortion factor will increase with less than 1%. Therefore it was concluded that remedial measures are not necessary.

This is in accordance with the result of an inquiry made by the German umbrella organisation ASEW including six local energy suppliers which showed that none of them had experienced any problems with harmonic interference caused by the use of CFLi's.

3.5.6 Alleged negative health effects due to optical and electromagnetic radiation from certain light sources

Safety requirements for electrical equipment (including lamps and luminaires) are laid down in annex I section 2 of the EU's Low Voltage Directive (LVD) 73/23/EEC (see also chapter 1). The directive requires that electrical equipment should be designed and manufactured to ensure protection against physical injury, harm or danger which may be caused by direct or indirect contact with the equipment, including radiation. All lamps and luminaires considered in this study have to comply with this directive. Any complaints related to physical injury, harm or danger caused by these products should thus be tackled under the Low Voltage Directive, and are not within the direct scope of the Ecodesign Directive and therefore of this study.

Some stakeholder groups (Lupus UK, Eclipse Support Group, Spectrum (UK) and Lupus DK)[51] have brought to the attention that some people who are light-sensitive are concerned that shifting to other lighting sources than low wattage incandescent lamps may affect their

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[50] Brauner G, Wimmer K., "Netzruckwirkungen durch konpaktleuchtsofflampen in Niederspannungsnetzen", Verband der Elektrizitätswerke Osterreich, 1995.
[51] SPECTRUM, www.spectrumalliance.org.uk, SLE/Lupus DK www.sle.dk, kirsten@lerstrom.dk

quality of life. Flickering and electromagnetic fields are also causing concern to some stakeholders.

To study these alleged effects, the European Commission (DG SANCO) has given the SCENIHR mandate; for more information see:
http://ec.europa.eu/health/ph_risk/committees/04_scenihr/docs/scenihr_q_016.pdf.

September 2008 SCENIHR has reported on light sensitivity health issues. The report is available at:
http://ec.europa.eu/health/ph_risk/committees/04_scenihr/docs/scenihr_o_019.pdf

Impact assessments on social, economic and environmental impacts of the planned measures will be done after the preparatory study and before the adoption of the measures.

4 TECHNICAL ANALYSIS EXISTING PRODUCTS

Important remark: This preliminary chapter 4 does only discuss part 1 of the study and does not yet discuss directional light sources such as reflector lamps. The discussion of those products will be done in part 2 of the study.

This chapter is a general technical analysis of current products on the EU-market and provides general inputs for the definition of the Base Case (chapter 5) as well as the identification of part of the improvement potential (chapter 7), i.e. the part that relates to better performing products on the market. Some Best Available Technologies will only be introduced in chapter 6.

4.1 Production phase

4.1.1 Introduction

The table below summarizes the types of lamps that are taken into account as most relevant for general domestic lighting. This list is based on the types of lamps that are currently installed in European domestic applications and the types that are expected to be installed in the near future. As mentioned before, Best Available Technology that is nowadays rarely used will only be introduced in chapter 6.

These representative lamps were selected after the analysis of the use phase. The catalogues contain a multitude of lamps for various, also non-domestic applications; for reasons of simplification only selected representative products that fulfil the requirements of the use phase are included in this study.

Selected omnidirectional lamps:

Table 4-1: Overview of selected lamps.

Lamp type / Acronym	Wattage [W]	Colour Temp [K]	Colour rendering Ra	Energy label	ILCOS-code
Incandescent lamp, clear, form A, E27/B22d **GLS-C**	200	2800	100	E	IAA/C-200-230-E27-80
Incandescent lamp, frosted, form A, E27/B22d **GLS-F**	60	2600	100	E	IAA/F-60-230-E27-55
Incandescent lamp, clear, form A, E27/B22d **GLS-C**	60	2600	100	E	IAA/C-60-230-E27-55
Incandescent lamp, frosted, form B, E14/B15d **GLS-F**	40	2600	100	E	IBB/F-40-230-E14-35
Incandescent lamp, clear, form B, E14/B15d **GLS-C**	40	2600	100	E	IBB/C-40-230-E14-35
Compact fluorescent lamp, bare, E27/B22d **CFLi**	15	2700	80≤Ra<90	A	FBT-15/27/1B-220/240-E27
Compact fluorescent lamp, enveloped form A, E27/B22d **CFLi**	15	2700	80≤Ra<90	A	FBA-15/27/1B-220/240-E27
Compact fluorescent lamp, bare, E14/B15d **CFLi**	10	2700	80≤Ra<90	A	FBT-10/27/1B-220/240-E14
Compact fluorescent lamp, enveloped form B, E14/B15d **CFLi**	10	2700	80≤Ra<90	A	FBB-10/27/1B-220/240-E14
Halogen lamp, clear, 230V, G9, **HL-MV**	40	2900	100	D	HSG/C/UB-40-230-G9-44

Halogen lamp, clear, 230V, linear, R7s	*300*	*4000*	*100*	*D*	*HDG-300-230-R7s-114,2*
HL-MV					
Halogen lamp, clear, 12V, GY6,35	*50*	*3000*	*100*	*C*[52]	*HSGST/UB-50-12-GY6,35*
HL-LV					
Halogen lamp, clear, 12V, GY6,35	*35*	*3000*	*100*	*C*[53]	*HSGST/UB-35-12-GY6,35*
HL-LV					

Linear fluorescent lamps and non-integrated compact fluorescent lamps are also used for domestic lighting. They were already discussed in the study on office lighting[54] and will not be discussed again in this study. Where needed, the data of that study shall be used in further chapters.

Selected reflector lamps** (part 2)**:

Table 4-2: Overview of selected reflector lamps

Lamp type	*Wattage* *W*	*Colour Temp* *K*	*Colour rend* *Ra*	*Energy label*	*ILCOS-code*

For these typical lamps, product data are collected as needed for the VHK model. The production phase is modelled according to the MEEuP methodology report. Detailed information on environmental impact is included in chapter 3 of this MEEuP methodology

[52] Until now, HL-LV lamps have neither a CE-marking nor an energy label. The mentioned C-label should be applied if our proposal in chapter 8 is followed.
[53] Until now, HL-LV lamps have neither a CE-marking nor an energy label. The mentioned C-label should be applied if our proposal in chapter 8 is followed.
[54] Preparatory Studies for Eco-design Requirements of EuPs, Lot 8: Office lighting, Final Report (April 2007).

report. The method focuses on seven environmental impact parameters (Total Gross Energy Requirement, Electricity, Feedstock energy (for plastics only), Process Water, Cooling Water, Hazardous Solid Waste, Non-Hazardous Waste). This method satisfies the requirement set out in article 15 paragraph 4 (a) of the eco-design directive (2005/32/EC): *'Considering the life cycle of the EuP and all its significant environmental aspects, inter alia energy efficiency, the depth of analysis of environmental aspects and of the feasibility of their improvement shall be proportionate to their significance. The adoption of eco-design requirements on the significant environmental aspects of an EuP shall not be unduly delayed by uncertainties to regarding the other aspects'.* In order to satisfy these requirements, the most relevant products were chosen and sometimes an available similar process or material (based on physical or chemical similarity) is used when it is not directly available in the MEEUP methodology. These requirements often allow to follow a simple and straightforward approach.

Mercury is an essential element for the operation of compact fluorescent lamps and is inserted during the production phase. In normal circumstances, mercury stays within the lamp enclosure during its entire lifetime and can be recycled at end-of-life (see chapter 3). It should be noted that, also during use phase, mercury is released to the atmosphere due to the electricity production (see MEEuP methodology table 29 parameter HM p. 88). In chapter 5, it will be evaluated if the use phase is the most significant stage of the life cycle**.** Total lamp mercury will be calculated separately in the related Eco-Reports.
In this study, types of lamps were put togheter within a certain range of weight of components and a range of power. Incandescent lamps in bulb form (form A) in the range from 15 to 100W have the same dimensions and thus an almost equal Bill of Material (BOM); the lamp of 60W can be taken as representative for this range. Moreover, in chapter 2 can be seen that this lamp is apparently the most used incandescent lamp in EU27. The incandescent lamp of 200W will be representative for the higher wattages. For incandescent lamps in candle form (form B), the 40W lamp is taken as the most representative. For CFLi's, 10W bare and enveloped are representative replacement lamps for 40W incandescent and the 15W for the 60W incandescent. This ranges will also allow the assessment of aberrations on the potential environmental impact of other lamps. But here again, one can expect a very low total environmental impact for lighting by the 'production phase' according to the previous studies on street and office lighting[55].
The results serve as input for the assessment of the base case, which is discussed in the next chapter.

If relevant and possible, data sets from different sources are checked on their consistency.
The BOM (Bill Of Materials) is used as input for modelling the production phase in the VHK-model. The input tables are included in the following sections. For the discussion of the end-of-life phase is referred to section 4.5.

4.1.2 Lamps production

Data on composition and weight of the lamps that are summarized in Table 4-4 are based on samples. Some data are also collected from producers' catalogues. Note that the substances in the same lamp family that have hazardous, environmental impact, are independent from the

[55] Preparatory Studies for Eco-design Requirements of EuPs, Lot 8 & 9: Office lighting & Street lighting

power [W] of the lamp but only dependent on technology, e.g. for CFL, mercury content is independent on lamp power but difference can be made between technologies e.g. amalgam (Hg-Pb) or not (only Hg).
For incandescent lamps, negligible differences can be found in the weight of glass, dependent on the bulb form, and in the weight of metal for the socket, dependent on the socket type E27/B22 versus E15/B15.
For CFLi's, also the weight of glass and the possible envelope, dependent on the power, and the weight of the socket can make a difference.

Some remarks about the environmental impacts related to this input table are:

- The environmental impacts of the residual rare earth metals is assumed negligible.
- The environmental impact of the noble filling gasses (argon or krypton) is assumed negligible. A noble gas is chemically inert and therefore not an hazardous gas. Carbondioxide emission due to production of 1 kg Argon is only 0.271 kg and for 1 kg Krypton only 102 kg[56]. This is far less than other lamp parts as can be checked after chapter 5.
- For the production of the lamp mercury (max. 0.005g) no detailed data are available on the environmental impact of mercury production itself, but we take the mercury itself as environmental impact (heavy metal) into account.
  VITO performed a control on the mercury content of a limited sample CFLi's, currently available on the market. The control was made by atomic fluorescence spectrometry, conform CMA 2/I/B.3. The results are shown in Table 4-3.
  It must be stated that sample #3 significantly exceeded the maximum allowed mercury content. This is probably caused by the cheap but inaccurate method of mercury filling (drip filling) that seems to be very common in most small far eastern production plants.

Table 4-3: Measured mercury content in CFLi's

Sample	***Mercury content in mg***
1	*1,8*
2	*1,1*
3	*6,4*
4	*3,5*
5	*0,28*

An acceptable average of 4 mg will be used in this study.

The potential effects of these assumptions in the environmental impact assessment will be further dicussed in chapter 8 in the sensitivity analysis.

The following tables present the input data using the terminology from, the VHK model for the environmental assessment (see Table 4-4).

[56] Swiss Centre for Life Cycle Inventories: Ecoinvent database

Table 4-4: Input data for the materials extraction and production of the lamps (expressed in g)

MATERIALS Extraction & Production	Incandescent lamp, clear, form A, E27/B22d - **200W**	Incandescent lamp, frosted, form A, E27/B22d - **60W**	Incandescent lamp, clear, form A, E27/B22d - **60W**	Incandescent lamp, frosted, form B, E14/B15d - **40W**	Incandescent lamp, clear, form B, E14/B15d - **40W**	Compact fluorescent lamp, bare, E27/B22d - **15W**	**Category**	**Material or Process MEEUP**
Description of component								
Glass	112	25,5	25,5	14	14	25	7-Misc.	**54-Glass for lamps**
Aluminium for caps		1,5	1,5	1	1	1,5	4-Non-ferro	**26-Al sheet/extrusion**
Copper for caps	3,2						4-Non-ferro	**30-CU tube/sheet**
Metal Mercury						0,004		
Plastic housing						25		**PBT**[57]
Lamp envelope								**54-Glass for lamps**
Printed circuit board, assembled						20		**53-PWB assembly**
Total weight								

[57] **PBT** PolyButyleneTerephtalate

MATERIALS Extraction & Production Description of component	Compact fluorescent lamp, enveloped form A , E27/B22d - **15W**	Compact fluorescent lamp, bare, E14/B15d - **10W**	Compact fluorescent lamp, enveloped form B, E14/B15d - **10W**	Halogen lamp, clear, 230V, G9 **40W**	Halogen lamp, clear, 230V, linear, R7s - **300W**	Halogen lamp, clear, 12V, GY6,35 - **50W**	Halogen lamp, clear, 12V, GY6,35 - **35W**	Category	Material or Process MEEUP
Glass	25	17,5	17,5	2	9	2	2	7-Misc.	**54-Glass for lamps**
Aluminium for caps	1,5	1	1					4-Non-ferro	**26-Al sheet/extrusion**
Copper for caps								4-Non-ferro	**30-CU tube/sheet**
Metal Mercury	0,004	0,004	0,004						
Plastic housing	23	22	11						**PBT**[58]
Lamp envelope	22		18						**54-Glass for lamps**
Printed circuit board, assembled	20	17	16						**53-PWB assembly**
Total weight									

More than 98% of the total weight is modelled; the remaining materials are expected to not have a major environmental impact. So only a minor underestimation of the total environmental impact of the lamp can be expected.

The inputs that refer to the production (manufacturing processes) of the lamps are directly deduced from the input data for the materials extraction and production . There is of course a significant difference in the production parameters per lamp family: incandescent, halogen or compact fluorescent.
Following the VHK case study, it is taken into account that for the production of 1 kg sheet metal for lamps, 1.25 kg sheet metal is needed as input material (20% sheet metal scrap).

4.1.3 Ballasts (control gear) and power supply production

Nor ballasts for LFL's and CFLni's, neither transformers and power supplies for low voltage halogen lamps will be discussed in this study. They were already discussed in the study on office lighting[59] or on external power supplies[60]. The BOMs of ballasts in CFLi's are included in the tables in section 4.1.2. Note that all currently available CFLi's use electronic ballasts.

[58] **PBT** PolyButyleneTerephtalate
[59] Preparatory Studies for Eco-design Requirements of EuPs, Lot 8: Office lighting, Final Report (April 2007).
[60] Preparatory Studies for Eco-design Requirements of EuPs, Lot 7: External power supplies and battery chargers (January 2007).

4.2 Distribution phase

The environmental impact of the distribution of the lamps is modelled according to the VHK-model. The input parameters for the lamps are shown in the table below. The main difference can be found in the volume of the packaged final product, which is based on the dimensions of the respective lamps.

Table 4-5: Input data for the environmental assessment of the distribution of the lamps (expressed in dm³)

MATERIALS Extraction & Production ***Description of component***	Incandescent lamp, clear, form A, E27/B22d - **200W**	Incandescent lamp, frosted, form A, E27/B22d - **60W**	Incandescent lamp, clear, form A, E27/B22d - **60W**	Incandescent lamp, frosted, form B, E14/B15d - **40W**	Incandescent lamp, clear, form B, E14/B15d - **40W**	Compact fluorescent lamp, bare, E27/B22d - **15W**	**Category**	**Material or Process MEEUP**
Volume per packaged retail product	1,25	0,35	0,35	0,13	0,13	0,40		**62-per dm³ retail product**

MATERIALS Extraction & Production ***Description of component***	Compact fluorescent lamp, enveloped form A , E27/B22d - **15W**	Compact fluorescent lamp, bare, E14/B15d - **10W**	Compact fluorescent lamp, enveloped form B, E14/B15d - **10W**	Halogen lamp, clear, 230V, G9 **40W**	Halogen lamp, clear, 230V, linear, R7s - **300W**	Halogen lamp, clear, 12V, GY6,35 - **50W**	Halogen lamp, clear, 12V, GY6,35 - **35W**	**Category**	**Material or Process MEEUP**
Volume per packaged retail product	1,1	0,30	0,27	0,05	0,15	0,15	0,15		**62-per dm³ retail product**

4.3 Use phase (product)

In this paragraph, an overview is included of the calculation of the annual resources consumption and the direct emissions related to the defined performance parameters in chapter 1 and 3 under standard and non-standard conditions. This paragraph also includes a representative overview of the performance parameters found for products on the market anno 2007. In chapter 6, dedicated to the Best Available Technology (BAT) and Best Not Yet Available Technology (BNAT), upcoming products are considered with more improved performance parameters but with a high actual price and/or a low actual trade volume or products that are only in the R&D phase.

4.3.1 Rated annual resources consumption (energy, lamps) during product life according to the test standards defined in chapter 1

4.3.1.1 Formulas that relate energy use to performance parameters

The annual energy consumption (E_y) of a lamp in standard conditions is straightforward related to the lamp power and burning hours per year:

$$E_y \text{ [kWh]} = P_{lamp} \text{ x } t_{operating}.$$

where,

- P_{lamp} = lamp power in Watt as defined in chapter 1,
- $t_{operating}$ = burning hours per year as defined in chapter 3.

4.3.1.2 Formulas related to consumption of lamps per lighting point

The annual consumption of lamps per lighting point in standard conditions is straightforward and related to the lamp lifetime in hours. It is assumed that in domestic lighting, lamps are used until end of life.

$$N_y = t_{operating} / t_{life}$$

where,

- t_{life} of the lamp is usually taken at LSF = 0,5 (LSF is the Lamp Survival Factor see chapter 1).

4.3.1.3 Assessment of relevant lamp types and product performance parameters

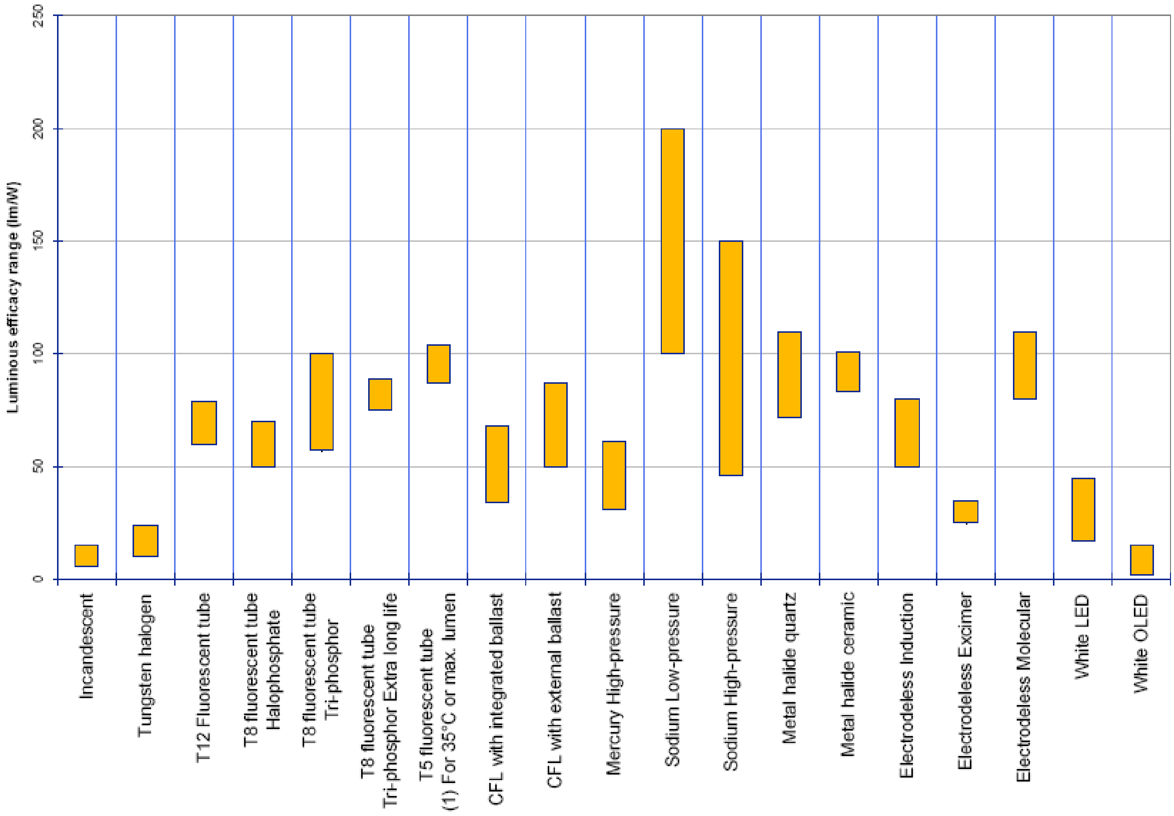

Figure 4-1: Luminous efficacy range of lamp technology (source: Laborelec)

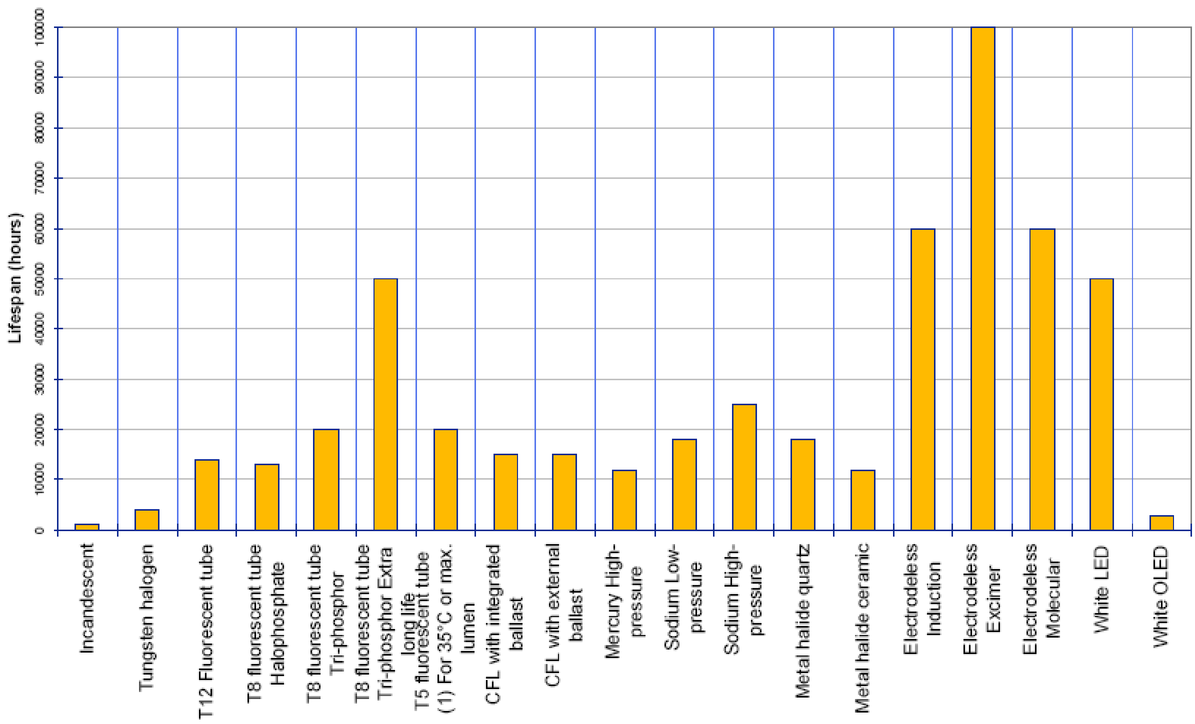

Figure 4-2: Typical life span range of lamp technology (source: Laborelec)

In Figure 4-1 typical luminous efficacy ranges are included per lamp technology and in Figure 4-2 typical lamp life span ranges are given.

For incandescent lamps, the typical declared operational lifetime t_{life} is 1000h and for halogen lamps, operational lifetimes from 2000 till 5000h are declared by manufacturers. For CFLi's, different declared operational lifetimes can be found on the market: e.g. 6000, 8000, 12000 and 15000h.

The colour rendering Ra of incandescent and halogen lamps is accepted to be 100.
For CFLi's, usually the colour rendering Ra is : $80 \leq Ra < 90$.

Colour temperature T_C for incandescent lamps is in the range from 2400K till 2900K and for halogen lamps T_C is about 3000K. Most currently used CFLi's have T_C = 2700K, but also lamps with a higher T_C are available on the market.

Table 4-6 includes the performance parameters for the selected lamp types that are used further in this study.
Lamp lifetime and ηlamp (luminous efficacy of the lamp) data were retrieved from the data supplied by manufacturers on their products and in their catalogues.

It is very important to notice that lamp efficacy, for lamps in the same category, also depends on lamp wattage: lamp efficacy rises with the wattage. This does of course not mean that one should simply replace lamps with lower wattage by lamps with higher wattage to save energy; preferably, one should replace a luminaire with many, low wattage lamps by a luminaire with less lamps but higher wattage.

Table 4-6: Selected lamp efficacy, cost data and life time

Lamp type Acronym	Wattage rated [W]	Colour Temp [K]	Colour rend Ra	LWFt[61]	ηlamp @25 °C [lm/W]	Operational Life time [h]	Unit price (for end user) [€]	ILCOS-code
Incandescent lamp, clear, form A, E27/B22d **GLS-C**	200	2800	100	1	15,2	1000	2	IAA/C-200-230-E27-80
Incandescent lamp, frosted, form A, E27/B22d **GLS-F**	60	2600	100	1	11,4	1000	0.5	IAA/F-60-230-E27-55
Incandescent lamp, clear, form A, E27/B22d **GLS-C**	60	2600	100	1	11,8	1000	0.5	IAA/C-60-230-E27-55
Incandescent lamp, frosted, form B, E14/B15d **GLS-F**	40	2600	100	1	9,9	1000	0.7	IBB/F-40-230-E14-35
Incandescent lamp, clear, form B, E14/B15d **GLS-C**	40	2600	100	1	10,4	1000	0.7	IBB/C-40-230-E14-35
Compact fluorescent lamp, bare, E27/B22d **CFLi**	15	2700	80≤Ra<90	1,05	50	6000	4	FBT-15/27/1B-220/240-E27
Compact fluorescent lamp, enveloped form A, E27/B22d **CFLi**	15	2700	80≤Ra<90	1,05	45	6000	6	FBA-15/27/1B-220/240-E27
Compact fluorescent lamp, bare, E14/B15d **CFLi**	10	2700	80≤Ra<90	1,05	50	6000	3.5	FBT-10/27/1B-220/240-E14
Compact fluorescent lamp, enveloped form B, E14/B15d **CFLi**	10	2700	80≤Ra<90	1,05	40	6000	5	FBB-10/27/1B-220/240-E14

[61] LWFt = Total Lamp Wattage Factor = LWFp x LWFe (see section 0).

Halogen lamp, clear, 230V, G9 **HL-MV**	40	2900	100	1	12,3	1500	5,5	HSG/C/UB-40-230-G9-44
Halogen lamp, clear, 230V, linear, R7s **HL-MV**	300	3000	100	1	17,7	1500	3	HDG-300-230-R7s
Halogen lamp, clear, 12V, GY6,35 **HL-LV**	50	2800	100	1,11	17,1	3000	3	HSGST/UB-50-12-GY6,35
Halogen lamp, clear, 12V, GY6,35 **HL-LV**	35	2800	100	1,11	15,4	3000	3	HSGST/UB-35-12-GY6,35

4.3.2 Assessment of energy consumption during product life, taking into account the system

4.3.2.1 Influence of the power factor

See for this item also section 3.2.5.
For lamps operating on a ballast or electronics such as CFLi's, this power factor can go down to 0,50[62]; the lower the power factor, the higher the electrical current that is needed to result in the same real power. This higher current causes 5% more losses in the electrical grid that feeds the lamp. Therefore a correction factor 'Lamp Wattage Factor LWFp' is introduced; for values see Table 4-7.

Table 4-7 LWFp correction factors for power quality used in this study

lamp type	LWFp
GLS	1
HL types	1
CFLi	1,05

The formula for the real power becomes:

P_{real} [W] = Plamp x LWFp.

The real annual energy consumption (E_{yreal}) per lamp is related to the standard energy consumption by:

[62] IAEEL newsletter 3-4/95, 'Power Quality for Beginners'

E_{yreal} [kWh] = E_y [kWh] x LWFp.

4.3.2.2 Influence of the external power supply or external ballast

The low voltage halogen lamps need an external power supply and CFLni's need an external ballast. Those transformers and ballasts are mostly incorporated in the luminaire. As discussed in other EuP studies[63], this also causes power losses in the system.

Table 4-8: Transformer efficiencies (source BIOIS)

Rated Lamp Load (P) (in watts)	Full load Efficiencies Assumption for EuP preparatory study	
	Magnetic transformers	Electronic transformers
$0 < P \leq 60$	80 %	92.5 %
$60 < P \leq 105$	84 %	
$105 < P \leq 210$	90 %	
$210 < P$	92 %	

To take into account those losses, a 'Lamp Wattage Factor LWFe' for low voltage halogen lamps is introduced. According to the values in Table 4-1, and a transformer distribution of 70% electronic vs. 30% magnetic, a value LWFe = 1,11 is taken into account; the same value is used for external ballasts on CFLni's.

Table 4-9: LWFe correction factors for the influence of the external power supply or external ballast

lamp type	***LWFe***
GLS	*1*
HL-MV types	*1*
HL-LV	*1,11*
CFLi	*1*
CFLni	*1,11*

The formulas for the real power and the real electricity consumption are the same as for the compensation of the power factor with LWFp replaced by LWFe.

[63] Preparatory Studies for Eco-design Requirements of EuPs, Lot 8 & 9: Office lighting & Street lighting and Lot 7: External power supplies and battery chargers.

4.4 Use phase (system)

This chapter is important to understand the limitations that are imposed to domestic light sources and also aspects related to the 'putting into service of domestic lighting equipment'. This section identifies and describes the functional system to which the product in question belongs and identifies and quantifies, to the extent possible, those product features that can reduce the environmental impact not only of the product but of the system as a whole. Please note that the scope of the system analysis is wider than the scope of the EuP Directive. The question that should be posed during the analysis is whether and how the system performance could be improved leading to environmental benefits with measures that are restricted only to issues that can be influenced by technical features or additional information of the product under investigation as defined in chapter 1. Furthermore, the system analysis serves as an addition to the more traditional product-specific analysis in paragraph 4.3, i.e. to design product specific legislation (if any) in such a way that it would not make system-oriented innovations impossible.

In domestic lighting, luminaires are assumed to constitute the most important part of the system environment of the lamp. Therefore, it is very important to understand the limitations that could be imposed by the luminaires.
This analysis will be elaborated in part 2 of the study.

Another important element of the system environment are dimming devices that are installed in the electrical grid. Not all CFLi lamps can be operated with a standard dimmer, more information will be included in chapter 6.

Also an external power supply or ballast[64] can be needed for low voltage lamps or CFLni's.

Finally, also the room itself belongs to the system. Improvement can be obtained by increasing use of day lighting, brighter and more reflective surfaces (floor, carpet, furniture, ..) and the positioning of the light source.

<u>Preliminary conclusions:</u>

1. The performance of domestic lighting sources could be improved through the luminaire design (detailed requirements to be elaborated in part 2 of this study).
2. The performance of domestic light sources can be improved if CFLi's with compatible dimmers are used (more technical info in chapter 6).
3. It should be noted that improvements can also be made at home design level (more daylight, ..) and interior design (brighter surfaces, orientation of the light source, location of the light source, ..).

[64] Preparatory Studies for Eco-design Requirements of EuPs, Lot 8 & 9: Office lighting & Street lighting and Lot 7: External power supplies and battery chargers.

4.5 End-of-life phase

The environmental impact of the end-of-life phase is modelled according to the VHK-model. The parameters used as input for this environmental assessment are shown in the following table and are identical for all types of lamps. Most input data in the end-of-life phase are directly related to the input parameters for the production. An important factor that must be defined here is the percentage of mercury content that is not captured during the processing of the waste lamps.

Collected CFLi's at end of life are crushed in a closed installation and sieved. The mercury containing fraction is distilated at 600°C to separate the mercury. The pure, metallic mercury is used again by lamp industry.

There is a lack of reliable information about collecting rates of CFLi's used in households.

At this moment it will be assumed that 80% of the used CFLi's is not collected and as a consequence 80% of the mercury present in lamps is emitted during the end-of-life processing.

The assumption is based on the following information:

- an annual report from a German recycling organization[65] that states that only 20% of used CFLi's from households is collected;
- a report from UNU[66] in August 2007 that states that 27,9% of all lamps is collected at end of life;
- the results of an inquiry made by a large vendor[67];
- the assumptions made by ELC and presented at the EEB Conference on 'Mercury-containing Lamps under the Spotlights', held in Brussels on 27th June 2008.

Not any other public information on this average percentage of fugitive mercury in EU-25 was found.

The data of the first two mentioned sources seem identical and also the most reliable information at this moment. If the UNU-study reports a collection rate of 27,9% for all lamps and knowing that the rate for professional lamps is normally higher than for household lamps, an assumption of 20% collected CFLi's is completely in line with the German report and is also used in this study.

Because many initiatives in the EU were started up (see also chapter 3) and other initiatives are taken such as spots on TV in Germany and in The Netherlands, similar with the initiatives for collecting batteries, it can be assumed that the rate will grow significantly in the near future. In the sensitivity analysis in chapter 8, the influence of higher collection rates will be discussed.

[65] Lightcycle RetourlogistiK und Service GmbH : Jahresbericht 2006.

[66] United Nations University (August 2007): '2008 Review of Directive 2002/96 on Waste Electrical and Electronic Equipement (WEEE) Final Report'.

[67] Consumer inquiry made by IKEA in Sweden; this study was not published.

Table 4-10: Input data for the environmental assessment of the end-of-life processing of the lamps

DISPOSAL & RECYCLING	**Lamp Type**		**unit**
Description	**GLS / HL**	**CFLi**	
Substances released during Product Life and Landfill			
Refrigerant in the product (Click & select)	0	0	g
Percentage of fugitive & dumped refrigerant	0%	0%	
Mercury (Hg) in the product	0	≤ 0.005	g Hg
Percentage of fugitive & dumped mercury	0	80%	
Disposal: Environmental Costs per kg final product			
Landfill (fraction products not recovered) in g en %	100	5	%
Incineration (plastics & PWB not re-used/recycled)			g
Plastics: Re-use & Recycling ("cost"-side)			g
Re-use, Recycling Benefit		**in g**	**% of plastics fraction**
Plastics: Re-use, Closed Loop Recycling (please edit%)			1%
Plastics: Materials Recycling (please edit% only)			9%
Plastics: Thermal Recycling (please edit% only)			90%
Electronics: PWB Easy to Disassemble ? (Click&select)			**NO**
Metals & TV Glass & Misc. (95% Recycling)			

The parameters that are taken into account for the modelling of the environmental impact of the lamps are assumed to be identical. According to the VHK default values it is assumed that 5% of the materials go to landfill, 90% of the plastics is incinerated, 9% is recycled and 95% of the metals and glass is recycled.

5 DEFINITION OF THE BASE-CASE

Important remark: This chapter 5 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.

Chapter 5 comprises of an assessment of average EU products, the so called “base cases”.

A base-case is “a conscious abstraction of reality”. The description of the base-cases is the synthesis of the results of tasks 1 to 4. The environmental and life cycle cost analysis are built on these base-cases throughout the rest of the study and it serves as the point-of-reference for chapter 6 (technical analysis of BAT), chapter 7 (improvement potential), and chapter 8 (policy analysis).

According to the MEEuP methodology, the scope of a preparatory study should be covered by one or two base-cases in chapter 5. Nevertheless, as discussed in chapter 1, a wide range of lamps are available and chapter 2 highlighted that their sales amounts are significant. Therefore, it was decided to analyse a larger number of base-cases to portray the market reality in a comprehensive manner. Detailed analysis of several base-cases will also allow a more realistic assessment of improvement potentials in the subsequent tasks and EU-27 total environmental impact.

In this first part of the study, related to non-directional lighting sources, 6 base-cases were considered to be representative of the current European market:

- **Incandescent lamp, clear (GLS-C): 54 W**
- **Incandescent lamp, frosted (GLS-F): 54 W**
- **Halogen lamp, low voltage (HL-LV): 30 W**
- **Halogen lamp, mains voltage, low wattage (HL-MV-LW): 40 W**
- **Halogen lamp, mains voltage, high wattage (HL-MV-HW): 300 W**
- **Compact fluorescent lamp, with integrated ballast (CFLi): 13 W**

The average yearly use times are different for all base-cases and figures presented in chapter 2 (see section 2.2.5) are used in this chapter:

- Incandescent lamp, clear (GLS-C and GLS-F): 400 hours/year
- Halogen lamp, mains voltage (HL-MV): 450 hours/year
- Halogen lamp, low voltage (HL-LV): 500 hours/year
- Compact fluorescent lamp, with integrated ballast (CFLi): 800 hours/year

The choice of the wattage of the base-cases was based on the outcomes of the EU R&D project EURECO (see chapter 2, section 2.2.4) which provided information about the use of lighting sources by wattage groups for several European countries.

As already mentioned in chapter 4 (section 4.1.3), neither ballasts for LFL and CFLni, nor transformers and power supplies for low voltage halogen lamps will be discussed in detail in this study as they were already detailed in the study on office lighting[68] and on external power supplies[69].

The environmental impacts of the base-cases are evaluated with the EuP EcoReport tool as specified in the MEEuP methodology. This allows identifying the significance of the different phases of the life cycle in terms of environmental impacts.

Inputs used in this chapter were defined in previous chapters. Chapter 4 provides the required technical data, viz., Bill of Materials (BOM), packaging and packaged volume, energy consumption during the use phase and considerations regarding the end-of-life of materials for existing products. Economic data (sales and stocks in EU-27, as well as product price and electricity tariff) were established in chapter 2.

For each of the 6 base-cases, the electricity consumption used in chapter 5 is for real life conditions. Thereby, the correction lamp wattage factors, namely LWFp and LWFe, presented in section 4.3.2 have been taken into consideration. Further, the average lamp lumen maintenance factor (LLMF), as discussed in chapter 3, is used to calculate the lamp efficacy of the base-case.

5.1 Product-specific inputs

5.1.1 Base-case GLS (General Lighting Service)

Technical data for the two base-cases GLS-C and GLS-F are assumed to be the same as the wattages are equal. For the definition of the BOM and of the packaged volume of the base-cases, it was assumed that these parameters were equal to the ones defined for a GLS 50 W with an arithmetic mean of the product-cases GLS 40 W and GLS 60 W presented in chapter 4.

- **Bill of Material**

The BOM of these base-cases is derived from the products presented in chapter 4 (section 4.1.2) for the incandescent lamps 40 W and 60 W (see Table 5-1).

[68] Preparatory Studies for Eco-design Requirements of EuPs, Lot 8: Office lighting, Final Report (April 2007).
[69] Preparatory Studies for Eco-design Requirements of EuPs, Lot 7: External power supplies and battery chargers (January 2007).

For the base-case GLS-C, data related to the product case 200 W presented in chapter 4 were not taken into account. This assumption will be discussed in the conclusion of this chapter after the analysis of environmental impacts due to the production phase.

Table 5-1: EcoReport material input table for base-cases GLS-C & GLS-F

Nr	Product name		Date	Author
	Base-Case GLS-C			BIO

Pos nr	MATERIALS Extraction & Production Description of component	Weight in g	Category Click &select	Material or Process select Category first !
1	Glass	19.75	7-Misc.	54-Glass for lamps
2	Aluminium for caps	1.25	4-Non-ferro	26-Al sheet/extrusion
	TOTAL	21.00		

- **Primary scrap production during sheet metal manufacturing**

It was assumed that the production of 1 kg sheet metal for lamps required 1.25 kg sheet metal, which leads to 20 % of sheet metal scrap.
This assumption is valid for the 6 base-cases.

- **Volume and weight of the package volume**

The weight of the base-case is 21 g and it has a packaged volume of 0.24 dm^3.

- **Annual resource consumption and lamp efficacy**

The power rating of the two base-cases GLS-C and GLS-F is 54 W as the correction factors are equal to 1, with a lamp lifetime of 1000 hours. With a yearly use of 400 hours, the lifespan of a typical incandescent lamp (both clear and frosted) is 2.5 years.

Despite having the same power output, the two base-cases have different ‘functional’ lumen output. As discussed in chapter 4 (section 4.3.1.3), the luminous efficacy (ηlamp) of a clear incandescent lamp is higher than a frosted incandescent lamp for the same wattage: the luminous efficacy (at 100 hours) of a typical 54 W clear incandescent lamp is 11.4 lm/W, whereas it is 11 lm/W for a typical 54 W frosted incandescent lamp (figures defined considering that the luminous efficacy wattage relationship is linear between 40 W and 60 W). Further, in contrast to the interim report published in November 2007, lamp lumen maintenance factor (LLMF) needs to be taken into consideration in order to characterise the decrease in lamp efficacy with the lamp lifetime. This parameter is equal to 0.965 for GLS as presented in chapter 3, section 3.2.6.1.
Therefore, **the effective luminous efficacy of a typical 54 W GLS-C is 11.0 lm/W, whereas it is 10.6 lm/W for a typical 54 W GLS-F.**

- **Disposal and Recycling**

For incandescent lamps, 100 % of the product is assumed to be disposed in landfills.

5.1.2 Base-case HL-MV-LW (Halogen Lamp – Mains Voltage (230 V) – Low Wattage)

Chapter 4 presented one type of HL-MV-LW: a clear lamp with a G9 socket and a power of 40 W and the characteristics of this lamp are used to define the base-case HL-MV-LW.

- **Bill of Material**

The BOM of the base-case HL-MV-LW is presented in Table 5-2. As mentioned in chapter 4, about 98% of the weight of the lamp is modeled with the glass. The remaining 2% (i.e. about 0.04g) are negligible both in weight and in environmental impacts.

Table 5-2: EcoReport material input table for base-case HL-MV-LW

Nr	Product name		Date	Author
	Base-Case HL-MV-LW			BIO

Pos nr	MATERIALS Extraction & Production Description of component	Weight in g	Category Click &select	Material or Process select Category first !
1	Glass	2	7-Misc.	54-Glass for lamps
	TOTAL	2		

- **Volume and weight of the package volume**

The weight of the base-case HL-MV-LW is 2 g and it has a packaged volume of 0.05 dm^3.

- **Annual resource consumption and lamp efficacy**

The electricity consumption of the base-case HL-MV-LW is 40 Wh/h, as the total Lamp Wattage Factor (LWFt) is equal to 1 (see section 4.3.1.3). The lamp lifetime is 1500 hours with an average use of 450 hours per year resulting in a lifespan of 3.33 years.

Based on the luminous efficacy of the product-case presented in chapter 4 and an average LLMF of 0.975, it can be assumed that **the luminous efficacy of the base-case HL-MV-LW is about 12.0 lm/W.**

- **Disposal and Recycling**

Similar to incandescent lamps, 100 % of the halogen lamp is assumed to be placed in landfill.

5.1.3 Base-case HL-MV-HW (Halogen Lamp – Mains Voltage (230 V) – High Wattage)

Chapter 4 presented only one type of HL-MV-HW; a clear linear bulb with a power of 300 W and a R7s socket. The technical parameters presented in chapter 4 were used to define the base-case HL-MV-HW.

■ **Bill of Material**

The BOM of the base-case HL-MV-HW presented in the table below (Table 5-3) is based on the data presented in chapter 4. Only the glass is taken into consideration, as the weight of other components is negligible (maximum of 2% according to chapter 4, i.e. 0.18g). Further, when the neglected materials are measured in the environmental impact weighing system of the EcoReport (e.g. by assuming that the material neglected is aluminium for caps), differences are insignificant for all environmental indicators.

Table 5-3: EcoReport material input table for base-case HL-MV-HW

Nr	Product name		Date	Author
	Base-Case HL-MV-HW			**BIO**
Pos nr	**MATERIALS Extraction & Production Description of component**	**Weight in g**	**Category Click &select**	**Material or Process select Category first !**
1	Glass	9	7-Misc.	**54-Glass for lamps**
	TOTAL	9		

■ **Volume and weight of the package volume**

The weight of the base-case HL-MV-HW is 9 g and it has a packaged volume of 0.15 dm^3.

■ **Annual resource consumption and lamp efficacy**

The electricity consumption of the base-case HL-MV-HW is 300 Wh/h, as the total Lamp Wattage Factor (LWFt) is equal to 1 according to chapter 4 (section 4.3.1.3). The lamp lifetime is 1500 hours with an average use of 450 hours per year. Therefore, the lifespan of a typical HL-MV-HW is 3.33 years, as for the base-case HL-MV-LW.

Furthermore, it is assumed that **the luminous efficacy of the base-case HL-MV-HW is about 17.3 lm/W**, on the basis of an initial lamp efficacy of 17.7 lm/W and average LLMF of 0.975.

■ **Disposal and Recycling**

100 % of the HL-MV-High Wattage is assumed to be disposed in landfill.

5.1.4 Base-case HL-LV (Halogen Lamp – Low Voltage (12 V))

■ **Bill of Material**

The bill of material of the base-case HL-LV (see Table 5-4) derives from the BOMs of two product-cases presented in chapter 4 (35 W and 50 W) for which only the glass is taken into account, as it represents about 98% of the total weight of the lamp. Further, even if the neglected 2% were modelled with aluminium for the cap, it would not influence environmental impacts of the base-case over its whole life cycle.

Table 5-4: EcoReport material input table for base-case HL-LV

Nr	Product name		Date	Author
	Base-Case HL-LV			BIO

Pos nr	MATERIALS Extraction & Production Description of component	Weight in g	Category Click &select	Material or Process select Category first !
1	Glass	2	7-Misc.	**54-Glass for lamps**
	TOTAL	**2**		

- **Volume and weight of the package volume**

The weight of the base-case HL-LV is 2 g and it has a packaged volume of 0.15 dm^3.

- **Annual resource consumption and lamp efficacy**

The power of the base-case HL-LV is 30 W, and the total Lamp Wattage Factor (LWFt) is equal to 1.11 (see section 4.3.1.3) due to the electrical losses in the transformer required to connect this type of lamp to the domestic electric grid. Thus, the 'real' electricity consumption of this base-case is 33.3 Wh/h.

The lifetime of an HL-LV lamp is assumed to be 3000 hours with an average use of 500 hours per year. Therefore, the lifespan of a typical HL-LV is 6 years.

By considering that the luminous efficacy wattage relationship is linear between 30 W and 50 W and that the average LLMF of this lamp type is 0.975, **the luminous efficacy of the base-case HL-LV 30 W is 14.5 lm/W**.

- **Disposal and Recycling**

100 % of the halogen lamp is assumed to be placed in landfill.

5.1.5 Base-case CFLi (Compact Fluorescent Lamp with integrated ballast)

- **Bill of Material**

Chapter 4 presented technical data for 4 compact fluorescent lamps with integrated ballast. A simple arithmetic mean of these product-cases was taken as the bill of material of the base-case CFLi 13 W (see Table 5-5). Moreover, the plastic used for the housing (PBT: PolyButylene Terephtalate) cannot be modelled in the EcoReport, and only its weight was taken into account without specifying the plastic type. It is assumed not to impact the comparison of base-cases, as the environmental impacts during the production phase can be expected to be negligible compared to the use phase. This assumption will be further discussed in the sensitivity analysis of chapter 8, where the PBT will be modelled with LDPE, as PBT derives from polyethylene.

Table 5-5: EcoReport material input table for base-case CFLi

Nr	Product name		Date	Author
	Base-Case CFLi			**BIO**

Pos nr	MATERIALS Extraction & Production Description of component	Weight in g	Category Click &select	Material or Process select Category first !
1	Glass	**21.25**	7-Misc.	**54-Glass for lamps**
2	Aluminium for caps	**1.25**	4-Non-ferro	**26-Al sheet/extrusion**
3	Metal mercury	**0.004**		
4	Plastic housing (PBT)	**20.25**		
5	Lamp enveloppe	**10**	7-Misc.	**54-Glass for lamps**
6	Printed circuit board, assembled	**18.25**	6-Electronics	**51-PWB 6 lay 2 kg/m2**
	TOTAL	**71.004**		

- **Volume and weight of the package volume**

The weight of the base-case CFLi is about 71 g and it has a packaged volume of 0.5175 dm^3.

- **Annual resource consumption and lamp efficacy**

The power rating of the base-case CFLi is 13 W and the total Lamp Wattage Factor (LWFt) is equal to 1.05 (see section 4.3.1.3) due to electrical losses in the ballast. Thus, the 'real' electricity consumption of this base-case is assumed to be 13.65 Wh/h.

The lifespan of a typical CFL with integrated ballast is 7.5 years (i.e. life time of 6000 hours with an average use of 800 hours per year).

Two types of CFLi are investigated in chapter 4: bare CFLi and enveloped CFLi. They have different luminous efficacy for a same wattage due to the use of the envelope which reduces the luminous efficacy. In order to calculate the luminous efficacy of the base-case (13 W), it was first defined separately for a bare and enveloped CFLi 13 W (considering in both cases that the efficacy is linear between 10 W and 15 W). Then, an arithmetic mean of the two values was made (50 lm/W for a bare CFLi and 43 lm/W for an enveloped CFLi) and finally multiplied by the average LLMF of 0.925 for a CFLi (see section 3.2.6.1).
Thereby, **the luminous efficacy of a typical CFL 13 W with integrated ballast is assumed at 43.0 lm/W**.

- **Disposal and Recycling**

As CFL lamps should be collected separately, it was assumed that 5 % of the materials go to landfill and 95 % of the metals and glass is recycled. Furthermore, regarding the mercury contained in compact fluorescent lamp (0,004 g), it was assumed that 80 % (i.e. 3.2 mg) was emitted to air during the end-of-life processing, as mentioned in chapter 4. This value was obtained based on information related to recycling practices from different Member States, although according to the WEEE Directive, all CFLi have to be recycled.

5.2 Base-case Environmental Impact Assessment

5.2.1 Base-case GLS

Table 5-6 presents the results of the environmental impact assessment of both base-cases GLS-C and GLS-F.

It is clearly visible that for each of the 15 environmental impact indicators, the use phase is the most impacting stage over the whole product life cycle. The total energy consumption for the whole life cycle of the 54 W GLS base-case is 621 MJ of which about 91 % is consumed during the use phase.

Table 5-6: Environmental assessment results from EcoReport (base-case GLS)

Base-Case GLS						0 BIO				
Life Cycle phases -->		PRODUCTION			DISTRI-	USE	END-OF-LIFE*			TOTAL
Resources Use and Emissions		Material	Manuf.	Total	BUTION		Disposal	Recycl.	Total	
Materials	**unit**									
Bulk Plastics	g			**0**			0	0	**0**	**0**
TecPlastics	g			**0**			0	0	**0**	**0**
Ferro	g			**0**			0	0	**0**	**0**
Non-ferro	g			**1**			1	0	**1**	**0**
Coating	g			**0**			0	0	**0**	**0**
Electronics	g			**0**			0	0	**0**	**0**
Misc.	g			**20**			20	0	**20**	**0**
Total weight	g			**21**			21	0	**21**	**0**
								see note!		
Other Resources & Waste							debet	credit		
Total Energy (GER)	MJ	1	0	**1**	**52**	**567**	1	0	**1**	**621**
of which, electricity (in primary MJ)	MJ	0	0	**0**	**0**	**567**	0	0	**0**	**567**
Water (process)	ltr	0	0	**0**	**0**	**38**	0	0	**0**	**38**
Water (cooling)	ltr	0	0	**0**	**0**	**1512**	0	0	**0**	**1512**
Waste, non-haz./ landfill	g	5	0	**5**	**52**	**657**	26	0	**26**	**740**
Waste, hazardous/ incinerated	g	0	0	**0**	**1**	**13**	0	0	**0**	**14**
Emissions (Air)										
Greenhouse Gases in GWP100	kg CO2 eq.	0	0	**0**	**5**	**25**	0	0	**0**	**29**
Ozone Depletion, emissions	mg R-11 eq	negligible								
Acidification, emissions	g SO2 eq.	0	0	**0**	**12**	**146**	0	0	**0**	**158**
Volatile Organic Compounds (VOC)	g	0	0	**0**	**0**	**0**	0	0	**0**	**0**
Persistent Organic Pollutants (POP)	ng i-Teq	0	0	**0**	**0**	**4**	0	0	**0**	**4**
Heavy Metals	mg Ni eq.	0	0	**0**	**3**	**10**	0	0	**0**	**13**
PAHs	mg Ni eq.	0	0	**0**	**3**	**1**	0	0	**0**	**4**
Particulate Matter (PM, dust)	g	0	0	**0**	**1**	**3**	2	0	**2**	**6**
Emissions (Water)										
Heavy Metals	mg Hg/20	0	0	**0**	**0**	**4**	0	0	**0**	**4**
Eutrophication	g PO4	0	0	**0**	**0**	**0**	0	0	**0**	**0**
Persistent Organic Pollutants (POP)	ng i-Teq	negligible								

Figure 5-1 and Figure 5-2 show the contribution of each of life cycle phases to two main environmental indicators: gross energy requirement (GER) and global warming potential (GWP). As previously mentioned, the use phase is the highest contributor of these impacts. It represents about 91 % of the total energy consumption and about 84 % of the GWP over product's lifetime.

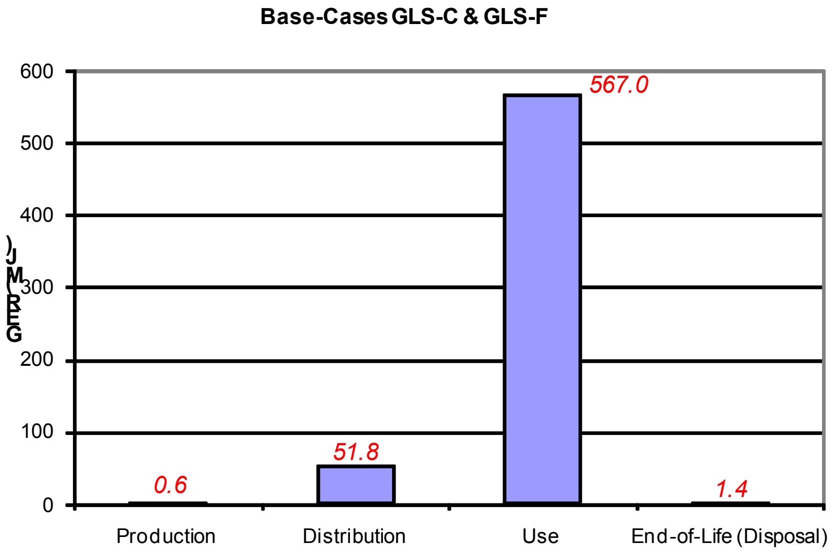

Figure 5-1: Total energy consumption during all life cycle phases

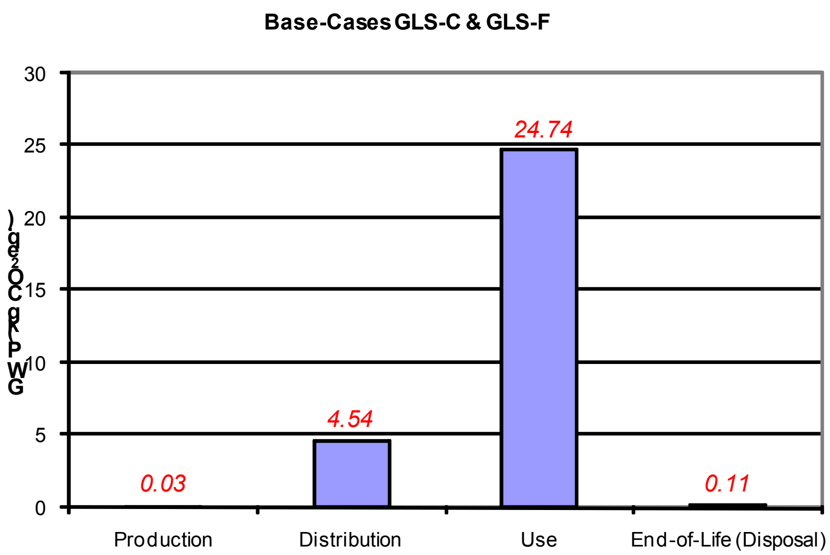

Figure 5-2: Total Global Warming Potential during all life cycle phases

Figure 5-3 presents the contribution of the life cycle phases for each of the 15 environmental impact indicators.

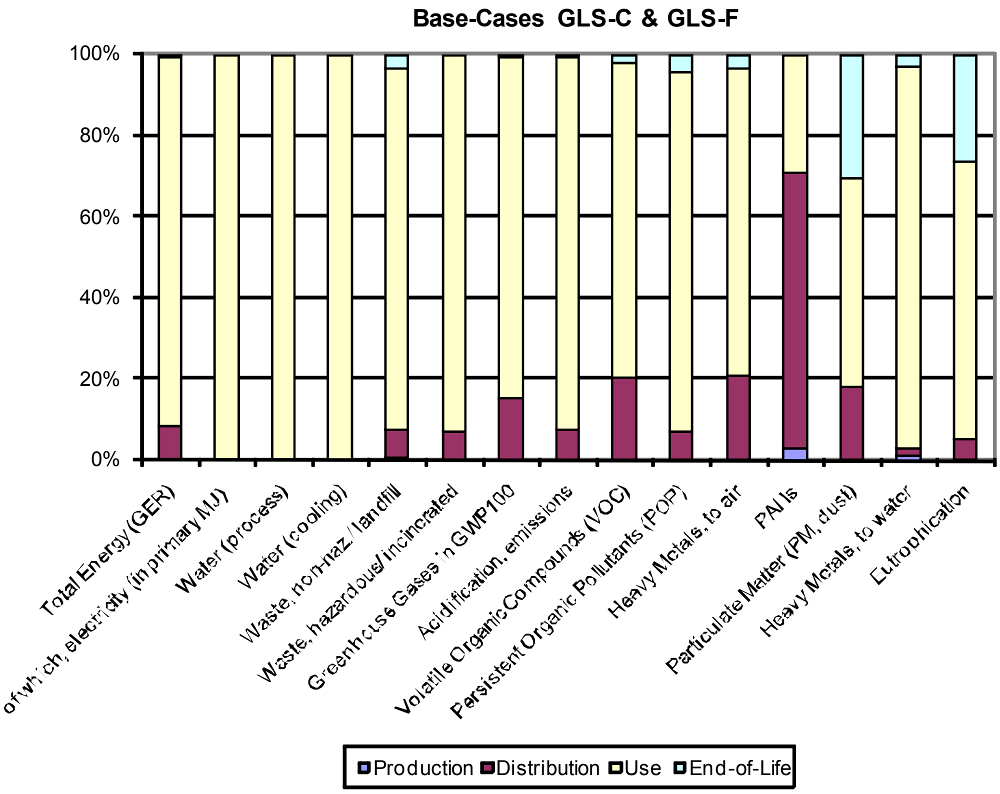

Figure 5-3: Distribution of environmental impacts per life cycle phase

Several observations can be made from this analysis:

- The production phase is negligible for all environmental impact indicators. Its highest contribution is 3 % to the emissions of Polycyclic Aromatic Hydrocarbons (PAHs) to air, due the use of aluminium for the caps of the lamps. Therefore, taking into consideration the BOM of the GLS-C 200 W when establishing the BOM of the base-case would have negligible effect on the present environmental assessment even if it contains copper which has more significant impacts than aluminium.
- The distribution phase contributes more than 5 % of the life cycle impacts for 11 of the 15 environmental impact indicators. Impacts of this phase are the highest for the emission of PAHs (69 %), heavy metals (22 %), volatile organic compounds (VOC) (21 %), and particulate matter to air. This can be explained by the assumption related to transport in trucks from the retailer's central warehouse to the shop. Nevertheless, although the distribution phase has a high contribution to these indicators, their total values over the life cycle remain low. The EcoReport tool does not allow specifying means of transport ant distances between the production place of the lamp and retailer's central warehouse; only the volume of the product is taken into consideration to assess environmental impacts of the transport. Nevertheless, according to the MEEuP methodology (section 5.3.6, page 96), a mix of means of transport (trucking, rail, sear freight and air freight) with assumptions on distances was used for all base-cases. This assumption could be considered as disadvantageous for lamps mainly produced in Europe (e.g. GLS-F and GLS-C) and advantageous for lamps produced in Asia (e.g. CFLi). However, as mentioned previously, the contribution of the

distribution phase to the environmental impacts is either low in relative terms compared to other life cycle phases (e.g. for energy consumption or GWP), or low in absolute terms as total values over the whole life cycle are not significant compared to other products (e.g. for PAHs or VOC).

- The contribution of the use phase to environmental impact varies between 29 % (for the emissions of PAHs to air) and 100 % (for the use of cooling water). For 10 environmental impact indicators, the use phase contributes to more than 80 %.
- For incandescent lamps, the whole product is disposed of into landfill and no benefit is possible with recycling. The end-of-life phase is significant for the emissions of particulate matter to air (32 %) due to the transport to the landfill, and for eutrophication (28 %). However, the eutrophication potential due to the life cycle of an incandescent lamp is very low (less than 0,03 g PO_4) compared to, for example a typical 32” LCD TV (about 15 g PO_4)[70].

One has to keep in mind that although the two base-cases have the same electricity consumption, their luminous efficacy differs. Therefore, with a reference of 594 functional lumen output (54 W x 11 lm/W for the base-case GLS-C) environmental impacts related to the use phase should be multiplied by a correctional factor for the base-case GLS-F. This correctional factor is approximately 1,038 (= 11/10,6). A comparison of these two base-cases is further detailed in section 5.5.

Power generation based on coal implies emissions of mercury to air. According to the DG Joint Research Centre, **the generation of 1 kWh emits 0.016 mg of mercury to air**, with a EU fuel mix of 31 % coal, 22 % gas and oil, and 47 % non-fossils fuels (of which 32% of nuclear)[71]. This assumption will be used for all base-cases.

Therefore, the total electricity consumption of both base-cases GLS-C and GLS-F during the use phase over the product lifetime being 54 kWh (54 Wh during 1000 hours), **0.86 mg of mercury is emitted to air over the whole life cycle** (mercury emissions in other phases than the use phase are assumed to be negligible for this lamp type).

5.2.2 Base-case HL-MV-LW

Table 5-7 presents the outcomes of the “life cycle assessment” of the base-case HL-MV-LW using the EcoReport tool.

[70] Source: EuP Preparatory Study on Television (Lot 5) http://www.ecotelevision.org/docs/Lot%205_T5_Final_Report_02-08-2007.pdf

[71] Source: http://lca.jrc.ec.europa.eu/lcainfohub/datasets/html/processes/Power_grid_mix_UCTE__83c1f02c-f2ef-4ac4-9a57-ac2172c38D15__01.00.001.html

Table 5-7: Environmental assessment results from EcoReport (base-case HL-MV-LW)

Life cycle Impact per product:	Date	Author
Base-Case HL-MV-LW	0	BIO

Life Cycle phases -->		PRODUCTION			DISTRI-	USE	END-OF-LIFE*			TOTAL
Resources Use and Emissions		Material	Manuf.	Total	BUTION		Disposal	Recycl.	Total	
Materials	**unit**									
Bulk Plastics	g			**0**			0	0	**0**	**0**
TecPlastics	g			**0**			0	0	**0**	**0**
Ferro	g			**0**			0	0	**0**	**0**
Non-ferro	g			**0**			0	0	**0**	**0**
Coating	g			**0**			0	0	**0**	**0**
Electronics	g			**0**			0	0	**0**	**0**
Misc.	g			**2**			2	0	**2**	**0**
Total weight	g			**2**			2	0	**2**	**0**
								see note!		
Other Resources & Waste							debet	credit		
Total Energy (GER)	MJ	0	0	**0**	**52**	**630**	0	0	**0**	**682**
of which, electricity (in primary MJ)	MJ	0	0	**0**	**0**	**630**	0	0	**0**	**630**
Water (process)	ltr	0	0	**0**	**0**	**42**	0	0	**0**	**42**
Water (cooling)	ltr	0	0	**0**	**0**	**1680**	0	0	**0**	**1680**
Waste, non-haz./ landfill	g	0	0	**0**	**51**	**730**	2	0	**2**	**784**
Waste, hazardous/ incinerated	g	0	0	**0**	**1**	**15**	0	0	**0**	**16**
Emissions (Air)										
Greenhouse Gases in GWP100	kg CO2 eq.	0	0	**0**	**5**	**27**	0	0	**0**	**32**
Ozone Depletion, emissions	mg R-11 eq					negligible				
Acidification, emissions	g SO2 eq.	0	0	**0**	**12**	**162**	0	0	**0**	**174**
Volatile Organic Compounds (VOC)	g	0	0	**0**	**0**	**0**	0	0	**0**	**0**
Persistent Organic Pollutants (POP)	ng i-Teq	0	0	**0**	**0**	**4**	0	0	**0**	**4**
Heavy Metals	mg Ni eq.	0	0	**0**	**3**	**11**	0	0	**0**	**13**
PAHs	mg Ni eq.	0	0	**0**	**3**	**1**	0	0	**0**	**4**
Particulate Matter (PM, dust)	g	0	0	**0**	**0**	**3**	0	0	**0**	**4**
Emissions (Water)										
Heavy Metals	mg Hg/20	0	0	**0**	**0**	**4**	0	0	**0**	**4**
Eutrophication	g PO4	0	0	**0**	**0**	**0**	0	0	**0**	**0**
Persistent Organic Pollutants (POP)	ng i-Teq					negligible				

Figure 5-4 and Figure 5-5 highlight the importance of the use phase for two main environmental impact indicators (total energy consumption and global warming potential). The production phase is negligible for all the indicators as shown in Figure 5-6 since the BOM of the base-case HL-MV-LW contains only 2 grams of glass. This also explains why the end-of-life phase is negligible.

Regarding the distribution phase, its contribution to the environmental impacts does not surpass 19 % except for the emission of PAHs to air (68 %), which is, as for incandescent lamps, due to the assumed transport by trucks.

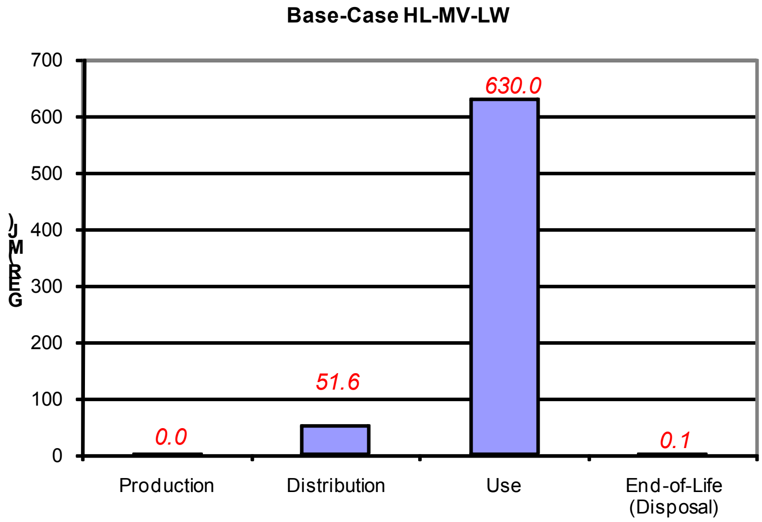

Figure 5-4: Total energy consumption during all life cycle phases

The use phase represents about 92 % of the total energy required by a typical HL-MV-LW 40 W over its whole life cycle, and about 86 % of its global warming potential.

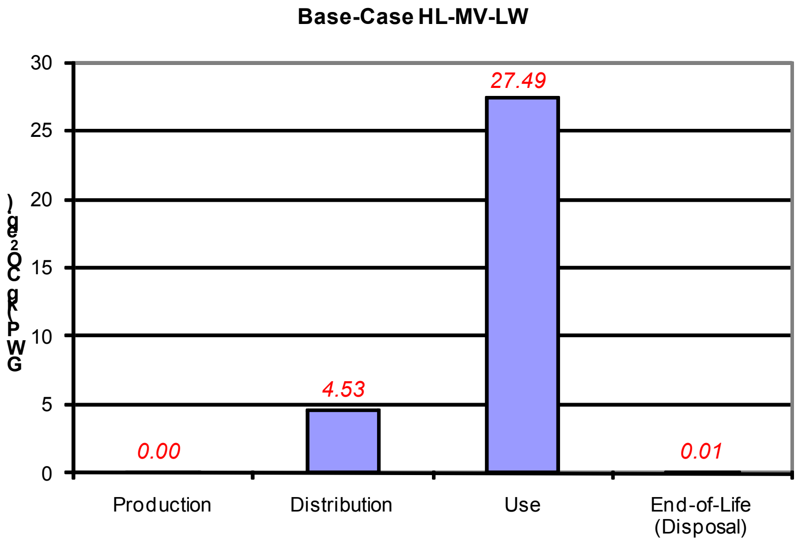

Figure 5-5: Total Global Warming Potential during all life cycle phases

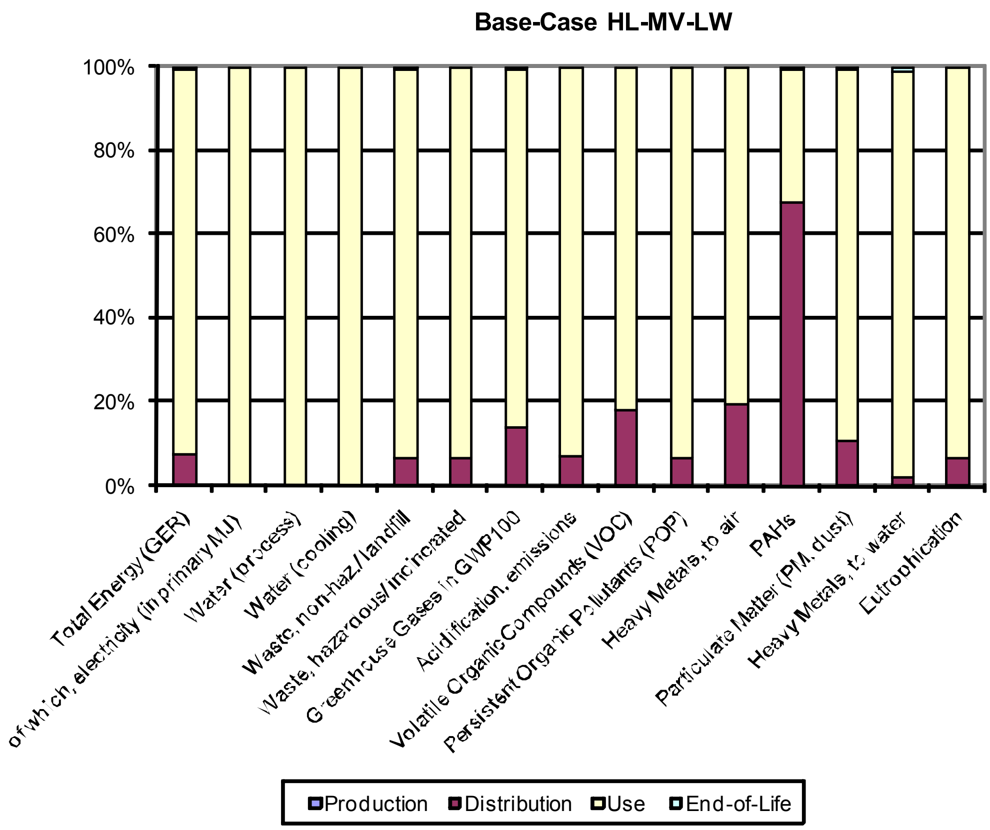

Figure 5-6: Distribution of environmental impacts per life cycle phase

As expected, the three previous figures confirm that the use phase is predominant with at least 80 % of the environmental impacts (except for the emissions of PAHs and of Particulate Matter).

Over its entire life cycle (1500 hours), the base-case HL-MV-LW (40 W) emits 0.96 mg of mercury to air, due to electricity generation. Mercury emissions in other phases than the use phase are assumed to be negligible for this lamp type.

5.2.3 Base-case HL-MV-HW

The outcomes of the "life cycle assessment" of the base-case HL-MV-LW carried out with the EcoReport tool are presented in Table 5-8 below.

Table 5-8: Environmental assessment results from EcoReport (base-case HL-MV-HW)

Life cycle Impact per product:							Date	Author		
Base-Case HL-MV-HW							0	BIO		

Life Cycle phases -->		PRODUCTION			DISTRI-	USE	END-OF-LIFE*			TOTAL
Resources Use and Emissions		Material	Manuf.	Total	BUTION		Disposal	Recycl.	Total	
Materials	**unit**									
Bulk Plastics	g			**0**			0	0	**0**	**0**
TecPlastics	g			**0**			0	0	**0**	**0**
Ferro	g			**0**			0	0	**0**	**0**
Non-ferro	g			**0**			0	0	**0**	**0**
Coating	g			**0**			0	0	**0**	**0**
Electronics	g			**0**			0	0	**0**	**0**
Misc.	g			**9**			9	0	**9**	**0**
Total weight	g			**9**			9	0	**9**	**0**
								see note!		
Other Resources & Waste							debet	credit		
Total Energy (GER)	MJ	0	0	**0**	**52**	**4725**	1	0	**1**	**4777**
of which, electricity (in primary MJ)	MJ	0	0	**0**	**0**	**4725**	0	0	**0**	**4725**
Water (process)	ltr	0	0	**0**	**0**	**315**	0	0	**0**	**315**
Water (cooling)	ltr	0	0	**0**	**0**	**12600**	0	0	**0**	**12600**
Waste, non-haz./ landfill	g	0	0	**0**	**51**	**5478**	11	0	**11**	**5541**
Waste, hazardous/ incinerated	g	0	0	**0**	**1**	**109**	0	0	**0**	**110**
Emissions (Air)										
Greenhouse Gases in GWP100	kg CO2 eq.	0	0	**0**	**5**	**206**	0	0	**0**	**211**
Ozone Depletion, emissions	mg R-11 eq					negligible				
Acidification, emissions	g SO2 eq.	0	0	**0**	**12**	**1217**	0	0	**0**	**1229**
Volatile Organic Compounds (VOC)	g	0	0	**0**	**0**	**2**	0	0	**0**	**2**
Persistent Organic Pollutants (POP)	ng i-Teq	0	0	**0**	**0**	**31**	0	0	**0**	**31**
Heavy Metals	mg Ni eq.	0	0	**0**	**3**	**81**	0	0	**0**	**84**
PAHs	mg Ni eq.	0	0	**0**	**3**	**9**	0	0	**0**	**12**
Particulate Matter (PM, dust)	g	0	0	**0**	**1**	**26**	1	0	**1**	**28**
Emissions (Water)										
Heavy Metals	mg Hg/20	0	0	**0**	**0**	**30**	0	0	**0**	**31**
Eutrophication	g PO4	0	0	**0**	**0**	**0**	0	0	**0**	**0**
Persistent Organic Pollutants (POP)	ng i-Teq					negligible				

The total energy consumption (GER) and the Global Warming Potential (GWP) of the base-case HL-MV-HW are presented in Figure 5-7 and Figure 5-8 for each stage of the entire life cycle of the product. It is clearly visible that the use phase is predominant for both environmental indicators. As the BOM of this base-case only contains 9 g of glass, the production and end-of-life phases have negligible environmental impacts.

The distribution phase (assumed transport by trucks) is only significant for the emission of PAHs to air (22 %) and does not exceed 3 % for the other environmental impacts.

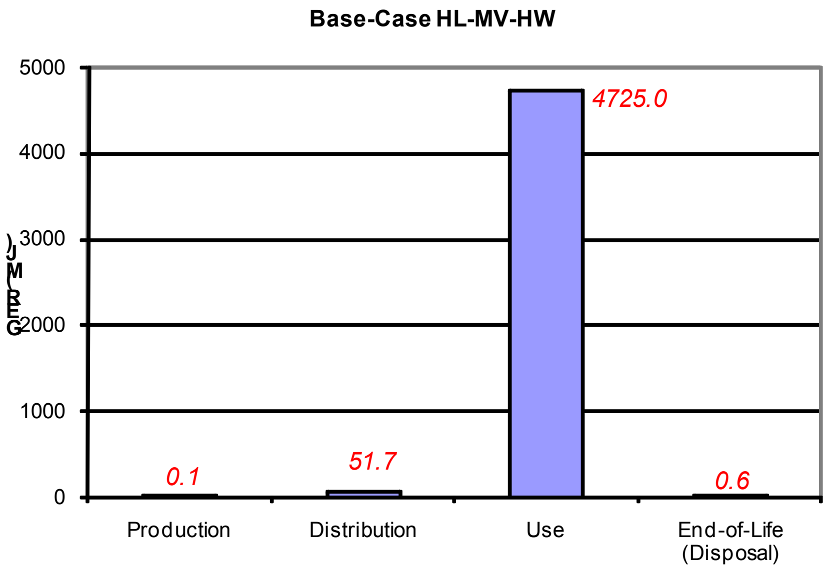

Figure 5-7: Total energy consumption during all life cycle phases

The use phase represents about 99 % of the total energy required by a typical HL-MV-HW 300 W over its whole life cycle and about 98 % of its global warming potential.

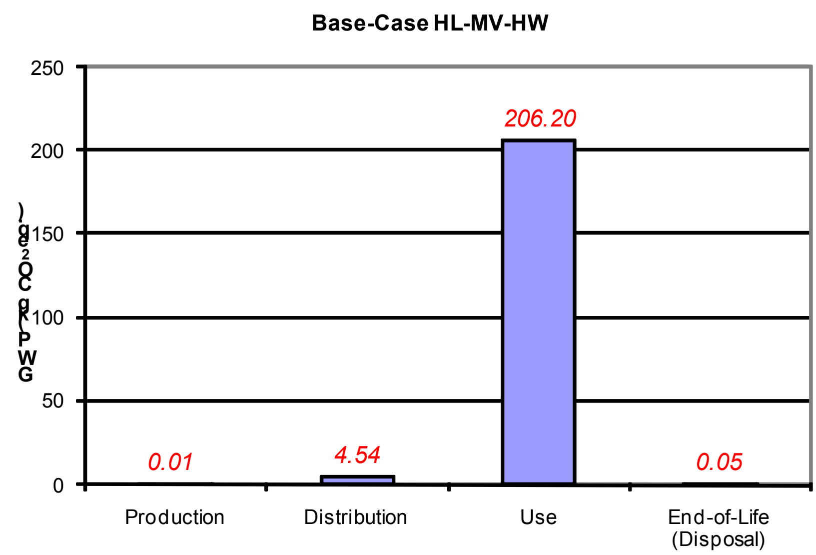

Figure 5-8: Total Global Warming Potential during all life cycle phases

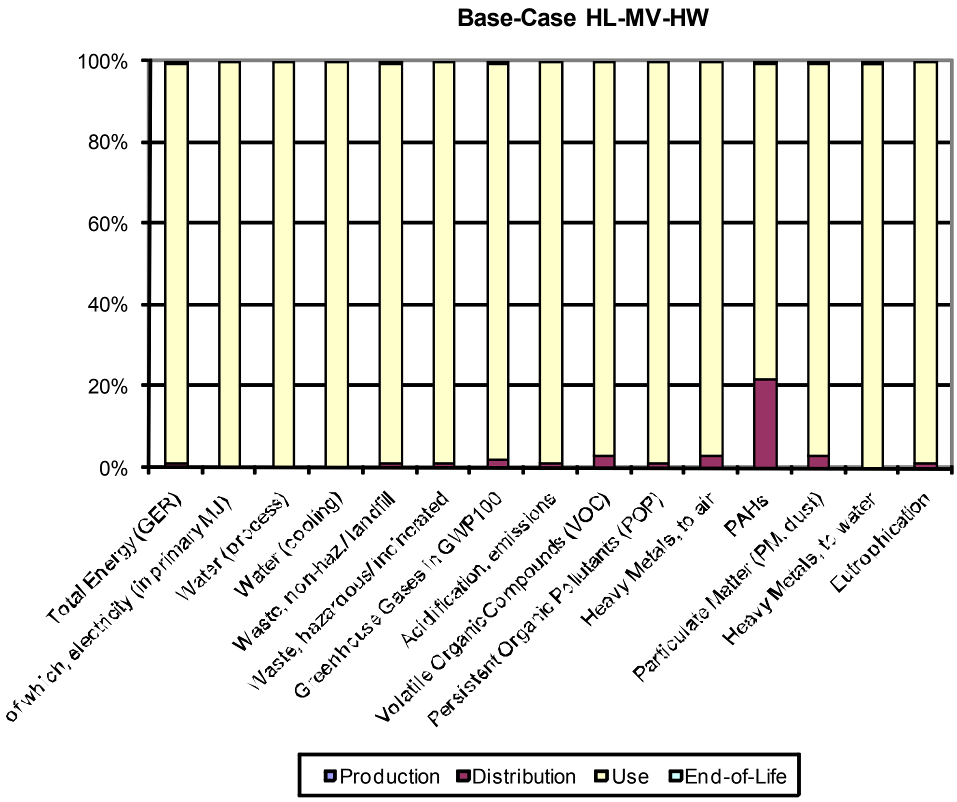

Figure 5-9: Distribution of environmental impacts per life cycle phase

Over its entire life cycle (1500 hours), the base-case HL-MV-HW (300 W) emits 7.20 mg of mercury to air, due to electricity generation. Mercury emissions in other phases than the use phase are assumed to be negligible for this lamp type.

5.2.4 Base-case HL-LV

Environmental impacts of the base-case HL-LV 30 W are presented in Table 5-9 for 15 environmental impact indicators. Two of them are shown in Figure 5-10 and Figure 5-11. As for the previous base-cases, the use phase is clearly the most impacting stage of the life cycle, except for the emissions of PAHs to air. Nevertheless, in the absolute terms, the total PAHs emissions over the whole life cycle are low (less than 4 mg Nickel equivalent).

Table 5-9: Environmental assessment results from EcoReport (base-case HL-LV)

Life cycle Impact per product:											Date	Author
Base-Case HL-LV											0	BIO

Life Cycle phases -->		PRODUCTION			DISTRI-	USE	END-OF-LIFE*			TOTAL
Resources Use and Emissions		Material	Manuf.	Total	BUTION		Disposal	Recycl.	Total	
Materials	**unit**									
Bulk Plastics	g			**0**			0	0	**0**	**0**
TecPlastics	g			**0**			0	0	**0**	**0**
Ferro	g			**0**			0	0	**0**	**0**
Non-ferro	g			**0**			0	0	**0**	**0**
Coating	g			**0**			0	0	**0**	**0**
Electronics	g			**0**			0	0	**0**	**0**
Misc.	g			**2**			2	0	**2**	**0**
Total weight	g			**2**			2	0	**2**	**0**
								see note!		
Other Resources & Waste							debet	credit		
Total Energy (GER)	MJ	0	0	**0**	**52**	**1049**	0	0	**0**	**1101**
of which, electricity (in primary MJ)	MJ	0	0	**0**	**0**	**1049**	0	0	**0**	**1049**
Water (process)	ltr	0	0	**0**	**0**	**70**	0	0	**0**	**70**
Water (cooling)	ltr	0	0	**0**	**0**	**2797**	0	0	**0**	**2797**
Waste, non-haz./ landfill	g	0	0	**0**	**51**	**1216**	2	0	**2**	**1270**
Waste, hazardous/ incinerated	g	0	0	**0**	**1**	**24**	0	0	**0**	**25**
Emissions (Air)										
Greenhouse Gases in GWP100	kg CO2 eq.	0	0	**0**	**5**	**46**	0	0	**0**	**50**
Ozone Depletion, emissions	mg R-11 eq				negligible					
Acidification, emissions	g SO2 eq.	0	0	**0**	**12**	**270**	0	0	**0**	**282**
Volatile Organic Compounds (VOC)	g	0	0	**0**	**0**	**0**	0	0	**0**	**0**
Persistent Organic Pollutants (POP)	ng i-Teq	0	0	**0**	**0**	**7**	0	0	**0**	**7**
Heavy Metals	mg Ni eq.	0	0	**0**	**3**	**18**	0	0	**0**	**21**
PAHs	mg Ni eq.	0	0	**0**	**3**	**2**	0	0	**0**	**5**
Particulate Matter (PM, dust)	g	0	0	**0**	**1**	**6**	0	0	**0**	**7**
Emissions (Water)										
Heavy Metals	mg Hg/20	0	0	**0**	**0**	**7**	0	0	**0**	**7**
Eutrophication	g PO4	0	0	**0**	**0**	**0**	0	0	**0**	**0**
Persistent Organic Pollutants (POP)	ng i-Teq				negligible					

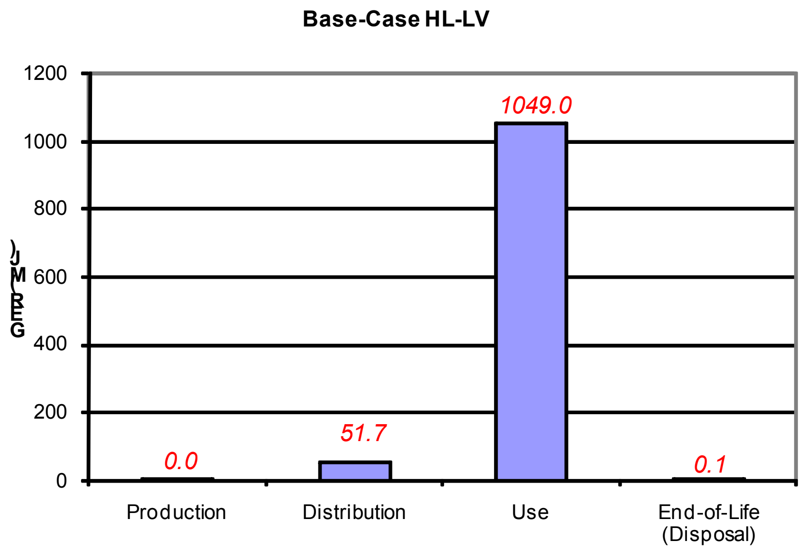

Figure 5-10: Total energy consumption during all life cycle phases

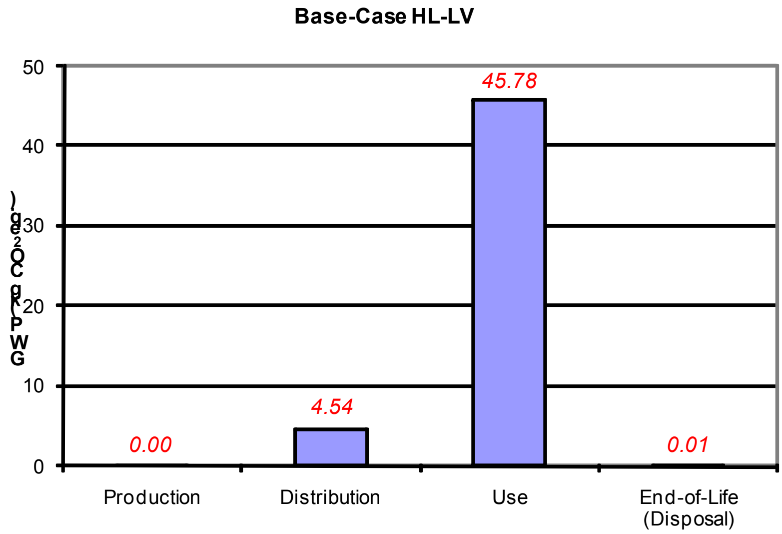

Figure 5-11: Total Global Warming Potential during all life cycle phases

The production and end-of-life phases have negligible environmental impact as pointed out by Figure 5-12 since the bill of material of the base-case HL-LV contains only 2 grams of glass. Taking tungsten wire and the caps into account could slightly increase the impact of these phases, but from the life cycle perspective, the impact of production and end-of-life would remain insignificant.

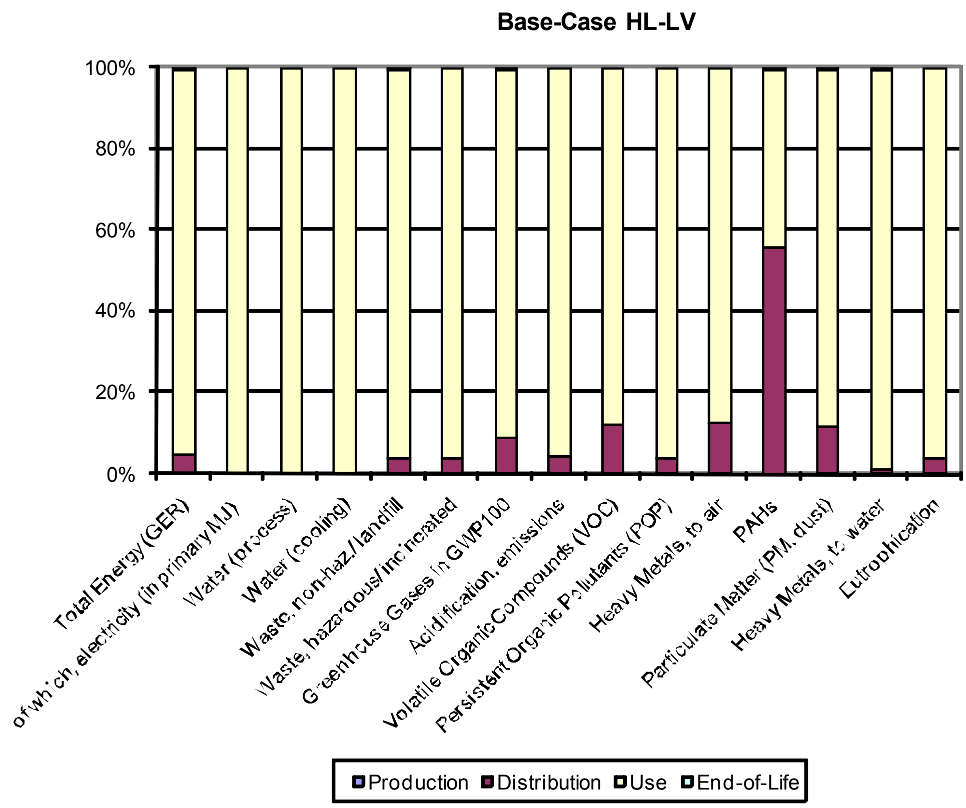

Figure 5-12: Distribution of environmental impacts per life cycle phase

As the electricity consumption of the base-case HL-LV during its entire life cycle is about 99.9 kWh and assuming that mercury emissions in other phases than the use phase are negligible for this lamp type, about 1.60 mg of mercury is emitted to air over its whole life cycle.

5.2.5 Base-case CFLi

As for the previous base-cases, an environmental assessment was carried out for the base-case CFLi 13 W with the EcoReport tool. Results of this analysis are presented in Table 5-10. Compared to the other base-cases one can notice that the column "End-of-Life Recycling" is not equal to zero, as 95 % of the metals and glass is recycled. The total of this stage of the life cycle is the difference between "disposal" and "recycling".

Table 5-10: Environmental assessment results from EcoReport (base-case CFLi)

Life cycle Impact per product:	Date	Author
Base-Case CFLi	0	BIO

Life Cycle phases -->		PRODUCTION			DISTRI-	USE	END-OF-LIFE*			TOTAL
Resources Use and Emissions		Material	Manuf.	**Total**	**BUTION**		Disposal	Recycl.	**Total**	
Materials	**unit**									
Bulk Plastics	g			**0**			0	0	**0**	**0**
TecPlastics	g			**0**			0	0	**0**	**0**
Ferro	g			**0**			0	0	**0**	**0**
Non-ferro	g			**1**			0	1	**1**	**0**
Coating	g			**0**			0	0	**0**	**0**
Electronics	g			**18**			14	5	**18**	**0**
Misc.	g			**31**			2	30	**31**	**0**
Total weight	g			**51**			15	35	**51**	**0**
								see note!		
Other Resources & Waste							debet	credit		
Total Energy (GER)	MJ	10	2	**12**	**53**	**860**	1	1	**0**	**925**
of which, electricity (in primary MJ)	MJ	6	0	**7**	**0**	**860**	0	1	**-1**	**866**
Water (process)	ltr	8	0	**8**	**0**	**57**	0	0	**0**	**65**
Water (cooling)	ltr	2	1	**3**	**0**	**2293**	0	0	**0**	**2296**
Waste, non-haz./ landfill	g	48	2	**50**	**52**	**998**	4	2	**3**	**1103**
Waste, hazardous/ incinerated	g	78	0	**78**	**1**	**21**	5	1	**4**	**103**
Emissions (Air)										
Greenhouse Gases in GWP100	kg CO2 eq.	0	0	**1**	**5**	**38**	0	0	**0**	**43**
Ozone Depletion, emissions	mg R-11 eq				negligible					
Acidification, emissions	g SO2 eq.	4	1	**5**	**12**	**221**	0	0	**0**	**239**
Volatile Organic Compounds (VOC)	g	0	0	**0**	**0**	**0**	0	0	**0**	**0**
Persistent Organic Pollutants (POP)	ng i-Teq	0	0	**0**	**0**	**6**	0	0	**0**	**6**
Heavy Metals	mg Ni eq.	1	0	**1**	**3**	**15**	0	0	**0**	**18**
PAHs	mg Ni eq.	0	0	**0**	**3**	**2**	0	0	**0**	**5**
Particulate Matter (PM, dust)	g	0	0	**0**	**1**	**5**	1	0	**1**	**7**
Emissions (Water)										
Heavy Metals	mg Hg/20	6	0	**6**	**0**	**6**	0	0	**0**	**11**
Eutrophication	g PO4	0	0	**0**	**0**	**0**	0	0	**0**	**0**
Persistent Organic Pollutants (POP)	ng i-Teq				negligible					

Figure 5-13 and Figure 5-14 show the contribution of each of the life cycle phases for the GER (Gross Energy Requirement) and the GWP (Global Warming Potential). As expected, the use phase is the major contributor of these environmental impact indicators.

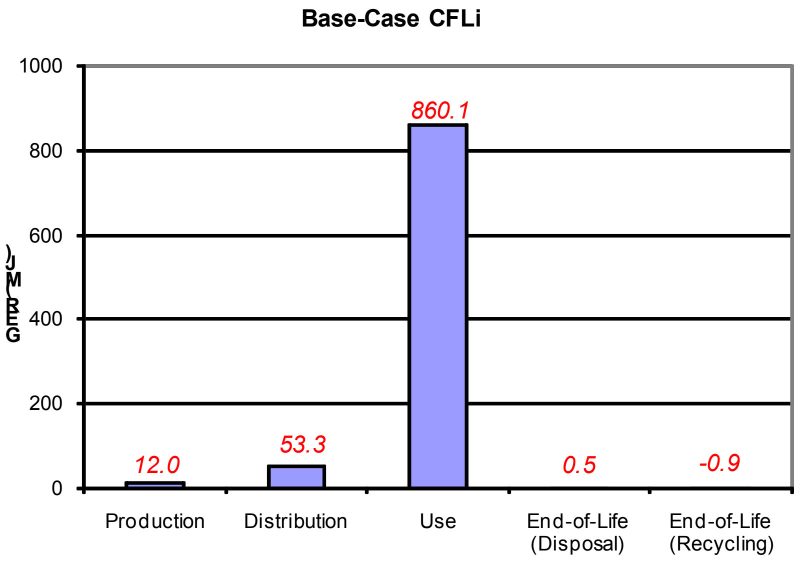

Figure 5-13: Total energy consumption during all life cycle phases

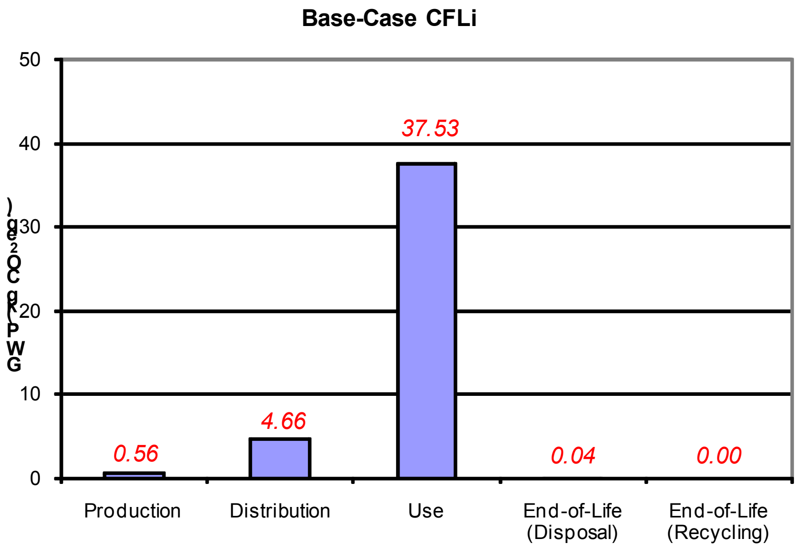

Figure 5-14: Total Global Warming Potential during all life cycle phases

Figure 5-15 shows that the production phase also contributes to the environmental impacts. This difference compared to other base-cases, where production phase has negligible impact, can be explained by two factors:

- The BOM of the base-case CFLi contains electronics (PWB: Printed Wiring Board) due to the integrated ballast, which has a greater environmental impact than glass or aluminium, especially for the emissions of heavy metals to water.
- A share of the materials is not recycled. Thus, the production phase represents 75 % of the indicator "waste, hazardous/incinerated".

Once again, the environmental indicator "eutrophication" is negligible over the life cycle of the base-case CFLi even if the production phase represents about 71 % of the total.

The relatively high impacts of CFLi in the production phase for the three indicators "hazardous waste", "eutrophication" and "emissions of heavy metals to water" are due to the integrated electronic ballast (modelled with a PWB in the EcoReport). The inventories for the electronic components are characterised by relatively high environmental impacts compared to "basic" materials such as glass and metal. This is a typical example of a case where adding electronics can improve efficiency, but this may create more impacts in the production phase. But thanks to the life cycle approach, using a common functional unit (lumen per hour), it can be concluded that despite this trade-off in production, the CFLi has the best performance over the life cycle (see section 5.6 for the comparison of the base-cases).

Of course, it could be possible to focus on the ballast in order to reduce the impacts on the three indicators. However, the improvement options are limited. In theory, one option would be to reduce the weight of the ballast, but technically this seems difficult. The bulky ballasts already cause problems e.g. in retrofitting some existing luminaires with CFLi, and if it was possible to make smaller ballasts they would surely exist already. Another possibility in real life is to improve the production process itself, in order to reduce the quantity of hazardous waste created in production of electronic components. Such real-life changes in production are, however, out of the scope of eco-design of lamps and cannot be taken into account in the context of the MEEuP.

Regarding the distribution phase, its environmental impacts concern the impact categories related to the transport of the product by trucks (PAHs, VOC and particulate matter).

According to the EcoReport tool, emissions of heavy metals to air at the end-of-life due to the mercury contained in the base-case CFLi (4 mg) represents a negligible share of the total of this impact over the whole life cycle (about 1.2 %) with the assumption that 80 % of CFLi are not recycled (based on data provided by various EU countries) and thus emitted mercury to air at the end-of-life (as explained in chapter 4, section 4.5). Indeed, heavy metals emissions to air, including mercury, during the production of electricity (i.e. during the use phase) has the most significant impact (about 81 % over the whole life cycle).

However, if the focus is only on mercury emissions, 3.20 mg is emitted to air at end-of-life (i.e. 80 % of 4 mg), whereas 1.31 mg is emitted during the use phase as the base-case CFLi consumes 81.9 kWh during this stage (and as the production of 1 kWh emits 0.016 mg of mercury to air).
Thereby, over the entire life cycle of the base case CFLi , 4.51 mg of mercury is emitted to air.

The production phase is predominant for the three indicators "hazardous waste", "eutrophication" and "emissions of heavy metals to water". As mentioned, we consider that the eutrophication impact is negligible compared to other products such as a 32'' LCD TV (cf. EuP Lot 5). Furthermore, when comparing per lumen and per hour, a CFLi is 'better' than an incandescent lamp and even better than a halogen lamp (except for eutrophication).

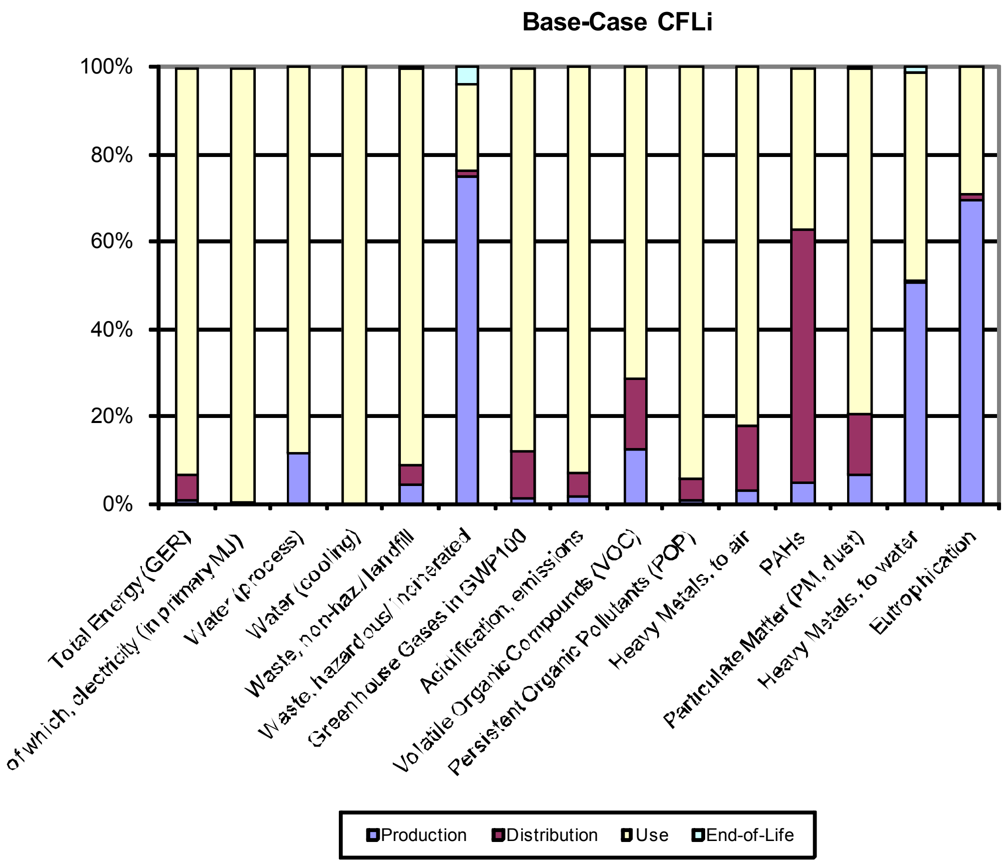

Figure 5-15: Distribution of environmental impacts per life cycle phase

5.3 Base-case Life Cycle Costs

Economic data used for the calculation of the Life Cycle Costs (LCC) were elaborated in chapters 2 and 4. Table 5-11presents the summary of the LCC input data and results for the 6 base-cases. Electricity tariff, discount rate, and overall improvement ratio are common inputs for all base-cases, of which the parameter "overall improvement ratio" equal to 1 reflects the fact that there have not been improvements related to energy efficiency of the average European lamp types in the recent years (i.e. the average products in 2004/2005 and in 2007 are quite similar in terms of energy efficiency).

Table 5-11: Inputs and outcomes of the calculation of the LCC

	GLS-C	GLS-F	HL-MV-LW	HL-MV-HW	HL-LV	CFLi
Lamp lifespan (years)	2.50	2.50	3.33	3.33	3.00	7.50
Lamp wattage (W)	54	54	40	300	30	13
Lumen output per lamp (lm)	594.0	572.4	480.0	5177.3	435.0	559.0
Electricity tariff (€/kWh)	0.1528					
Discount rate	1.8%					
Overall improvement ratio	1.00					
Product price	0.60 €	0.60 €	5.50 €	3.00 €	3.00 €	4.63 €
Electricity	8.00 €	8.00 €	8.82 €	66.16 €	14.35 €	11.61 €
Life Cycle Cost	**8.60 €**	**8.60 €**	**14.32 €**	**69.16 €**	**17.35 €**	**16.23 €**

For the base-cases GLS-C and GLS-F, life cycle costs are equal as their electricity consumption and the product prices are assumed to be same for both base cases.
One has to keep in mind that lifespan, lamp wattage and lumen output vary for different lamp types, thus a straightforward comparison with the outcomes of Table 5-11 has to be made with caution. The comparison of the LCC of the 6 base-cases is provided in section 5.5, Table 5-22.

5.4 EU Totals for the domestic sector

This section provides the environmental assessment of the base-cases at the EU-27 level using stock and market data from chapter 2. The reference year for the EU totals is 2007 for environmental impacts.
The term 'EU' is synonymous to 'EU-27'. The total impacts cover:

- The life cycle environmental impact of the new products designed in 2006 (this relates to a period of 2007 up to 2007 + product life) (i.e. impacts of the sales).
- The annual (2007) impact of production, use and (estimated) disposal of the product group, assuming post-RoHS and post-WEEE conditions and the total LCC (i.e. impact and LCC of the stock).

■ Environmental impacts of the domestic stock in 2007

Table 5-12 shows the total environmental impact of all products in operation in EU-27 in 2007, assuming that all the products have the same impacts as the base-case of their category. These figures come from the EcoReport tool by multiplying the individual environmental impacts of a base-case with the domestic stock of this base-case in 2007.

Table 5-12: Environmental impacts of the EU domestic stock in 2007

		GLS-C	GLS-F	HL-MV-LW	HL-MV-HW	HL-LV	CFLi	TOTAL
main environmental indicators	**unit**	**Value**	**value**	**value**	**value**	**value**	**value**	**value**
Total Energy (GER)	PJ	**124.678**	**407.087**	**27.700**	**161.336**	**86.827**	**138.775**	**946.404**
of which, electricity	TWh	**10.962**	**35.785**	**2.262**	**15.094**	**7.827**	**11.234**	**83.163**
Water (process)	mln.m3	**7.700**	**25.139**	**1.585**	**10.570**	**5.480**	**10.331**	**60.805**
Waste, non-haz./ landfill*	kton	**148.161**	**483.786**	**31.650**	**187.157**	**100.114**	**171.431**	**1122.300**
Waste, hazardous/ incinerated*	kton	**2.835**	**9.257**	**0.625**	**3.708**	**1.985**	**31.988**	**50.398**
Emissions (Air)								
Greenhouse Gases in GWP100	mt CO2eq.	**5.858**	**19.129**	**1.383**	**7.166**	**3.994**	**6.893**	**44.423**
Acidifying agents (AP)	kt SO2eq.	**31.846**	**103.979**	**7.035**	**41.470**	**22.242**	**35.907**	**242.479**
Volatile Org. Compounds (VOC)	kt	**0.054**	**0.178**	**0.013**	**0.063**	**0.036**	**0.089**	**0.432**
Persistent Org. Pollutants (POP)	g i-Teq.	**0.840**	**2.742**	**0.179**	**1.059**	**0.566**	**0.896**	**6.282**
Heavy Metals (HM)	ton Ni eq.	**2.521**	**8.234**	**0.611**	**2.872**	**1.649**	**3.203**	**19.089**
PAHs	ton Ni eq.	**0.718**	**2.349**	**0.247**	**0.455**	**0.397**	**1.223**	**5.389**
Particulate Matter (PM, dust)	kt	**1.164**	**3.803**	**0.177**	**0.957**	**0.537**	**1.320**	**7.957**
Emissions (Water)								
Heavy Metals (HM)	ton Hg/20	**0.786**	**2.565**	**0.160**	**1.029**	**0.538**	**2.814**	**7.892**
Eutrophication (EP)	kt PO4	**0.005**	**0.016**	**0.001**	**0.005**	**0.003**	**0.026**	**0.057**

Summary of environmental impacts of base-cases as a % of total impact for these lamp types, as well as the lot 19 (part 1) totals are presented in Figure 5-16.
For most of the environmental indicators presented in this figure, the share of the incandescent lamps (both clear and frosted) is about 56 %.

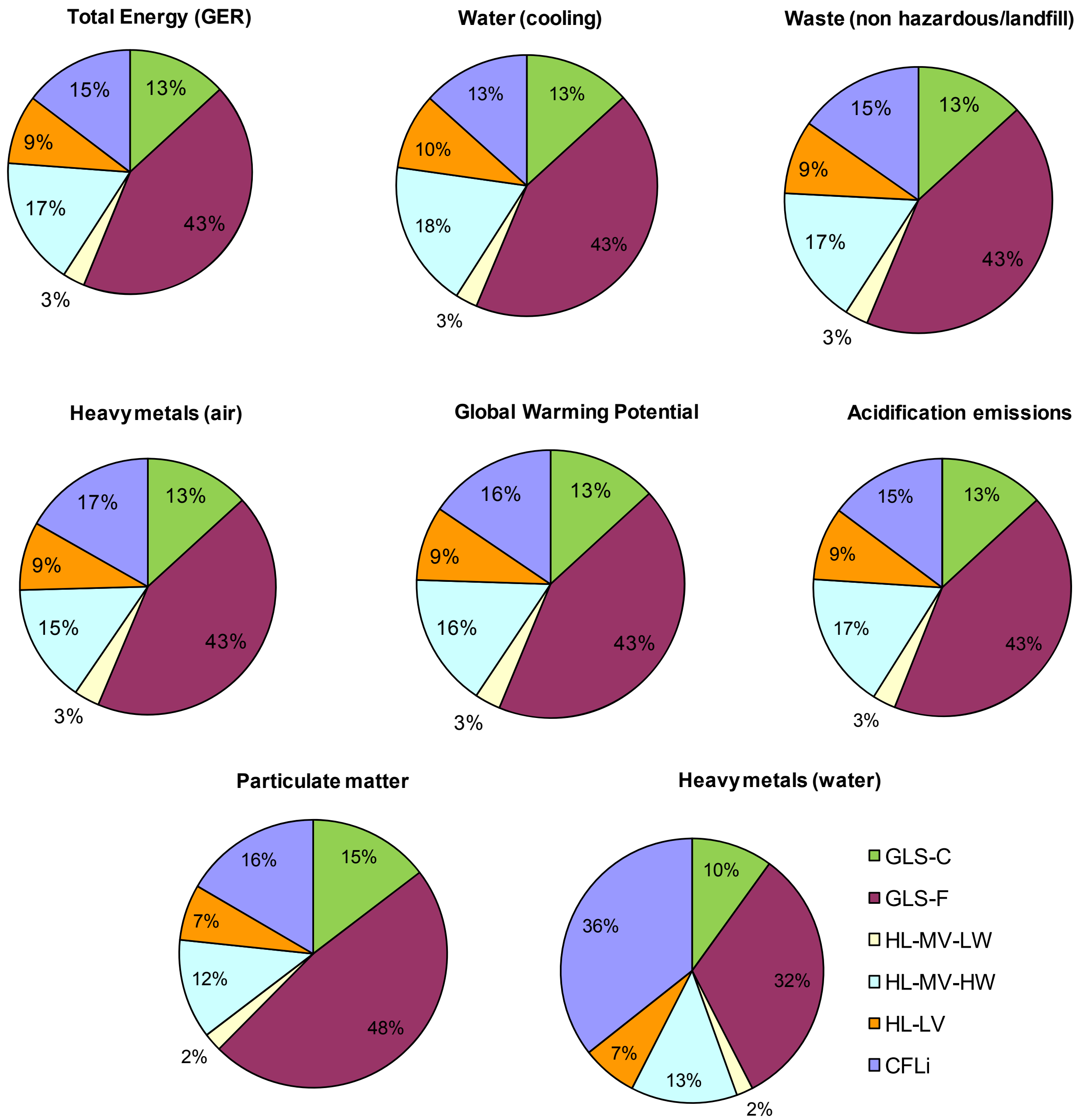

Figure 5-16: Base-cases' share of the environmental impacts of the 2007 stock

Table 5-13 summarises the total electricity consumption (during the use phase) of each base-case, assuming that the whole stock is composed of base-cases. Therefore, the total electricity consumption in 2007 of domestic non-directional lighting sources which are in the scope of this study (part 1) is about 83.16 TWh (1 TWh = 1 million MWh). This represents about 2.95 % of the EU-27 total electricity consumption[72].

[72]Source Eurostat: EU-27 electricity consumption in 2006 = 242 million toe = 2,815 TWh
http://epp.eurostat.ec.europa.eu/portal/page?_pageid=1996,39140985&_dad=portal&_schema=PORTAL&screen=detailref&language=en&product=Yearlies_new_environment_energy&root=Yearlies_new_environment_energy/H/H2/H24/ebc22288

Table 5-13: Total electricity consumption for the year 2007

Base-case	**EU 27 stock electricity consumption in 2007 (TWh)**	**Share of the total electricity consumption of the 6 lamp types**
Base-case GLS-C	10.96	13.2%
Base-case GLS-F	35.78	43.0%
Base-case HL-MV-LW	2.26	2.7%
Base-case HL-MV-HW	15.09	18.2%
Base-case HL-LV	7.83	9.4%
Base-case CFLi	11.23	13.5%
TOTAL	**83.16**	**100.0%**

■ **Total consumer expenditure in 2006**

Regarding the total consumer expenditure in 2007 related to the 6 base-cases, about 81 % of the 15.6 billion euros is due to the electricity costs. The distribution per base-case is given in Figure 5-17, and details on consumer expenditure are presented in Table 5-14.

Table 5-14: Comparison of total consumer expenditure (EU 27) in 2007

	GLS-C	***GLS-F***	***HL-MV-LW***	***HL-MV-HW***	***HL-LV***	***CFLi***	***TOTAL***
Lumen output per lamp (lm)	594.0	572.4	480.0	5177.3	435.0	559.0	
EU 27 sales (mln unit)	179	585	76	54	90	353	1337
Share of the EU 27 sales	13.4%	43.7%	5.7%	4.1%	6.7%	26.4%	100.0%
Product price (mln €)	107	351	420	163	269	1633	2943
Electricity (mln €)	1674	5466	346	2306	1196	1685	12673
Total (mln €)	**1782**	**5817**	**766**	**2469**	**1465**	**3318**	**15616**

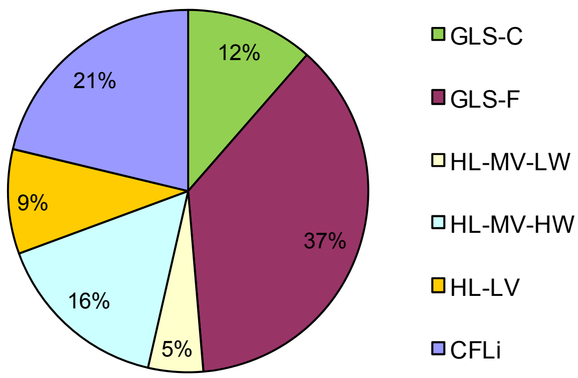

Figure 5-17: Base-cases' share of the total consumer expenditure in 2007

Total consumer expenditure in 2006 related to incandescent lamps (both clear and frosted) represent 49 %, whereas these lamp types represent about 57 % of the sales. However, it is not surprising that these values differ, as the power outputs and the annual operational times are different for the 6 base-cases.

5.5 EU Totals for all sectors

Lamp types identified as base-cases in this study (part 1) are also used in other sectors than the domestic one. Therefore, this section presents environmental and economic results for the "other sectors" keeping the lamp lifetime, the average wattage and the lamp price constant.

- **Market data for all sectors**

In order to carry out the environmental and economic assessment with the EcoReport tool of the base-cases at the EU-27 level for all sectors, it is required to have sales data, stock data as well as annual burning hours. They are presented in Table 5-15.

Sales in the "other sectors" were calculated by making the difference between the total sales and sales in the domestic sectors, which were presented in chapter 2 (see section 2.2.5). Total sales were not provided for the base-cases HL-MV-LW and HL-MV-HW, but only for the sum. Thus, the same ratio between HL-MV-LW sales and HL-MV-HW sales as for the domestic sector was used. Regarding CFLi, it was assumed that sales in the non-domestic sector (offices, shops, restaurants, hotels…) were negligible compared to the sales in the domestic sector, and CFLni (analysed in Lot 8) are mostly used in this sector.

We assumed the same shares of NDLS and DLS in the other sectors as in the domestic sector, i.e. for NDLS: 99 % for GLS-F, 66 % for GLS-C, 55 % for HL-MV, and 41 % for HL-LV.

For the calculation of the stock in 2007 for each base-case, following formulas were used:

1) Replacement sales = Share of Replacement Sales x Total Sales

2) Replacement sales = Stock x Annual Burning hours / Lifetime

The shares of replacement sales for the non-domestic sector were assumed to be the same as in the domestic sector: 131 % for GLS-F, 125 % for GLS-C, 28 % for HL-MV-LW, 45 % for HL-MV-HW, and 85 % for HL-LV.

Further, we assumed that all base-cases in the non-domestic sector operated 1800 hours per year, based on an average of 250 days per years and around 7 operating hours per day.

Thus, based on formula 1) and 2) the formula allowing obtaining the stock of lamps for "other sectors" is:

Total Stock = (Lifetime/Annual Burning hours) x Share of Replacement Sales x Total Sales

By combining market data for both the domestic and the non-domestic sectors, it was possible to obtain data for the 6 base-cases used in all sectors (see Table 5-16). Annual burning hours were calculated based on a weighted average as detailed in the following formula:

$$Burning\ Hours_{All} = (Burning\ Hours_{Dom} \times Sales_{Dom} + Burning\ Hours_{Other} \times Sales_{Other}) / Sales_{All}$$

Table 5-15: Market and technical data for the non-domestic sectors in 2007

	Other sectors					
	GLS-F	**GLS-C**	**HL-MV LW**	**HL-MV HW**	**HL-LV**	**CFLi**
Stock NDLS (mln)	144.1	61.2	8.8	7.6	88.2	0
Sales NDLS (mln)	182.4	118.2	21.0	29.7	57.3	0
Average wattage (W)	54	54	40	300	30	13
Lifetime (h)	1000	1000	1500	1500	3000	6000
Annual burning hours (h)	1800	1800	1800	1800	1800	1800

Table 5-16: Market and technical data for all sectors in 2007

	All sectors (domestic + other)					
	GLS-F	**GLS-C**	**HL-MV LW**	**HL-MV HW**	**HL-LV**	**CFLi**
Stock NDLS (mln)	**1800.1**	**568.5**	**134.4**	**119.4**	**558.3**	**1010.1**
Sales NDLS (mln)	**767.4**	**297.0**	**97.4**	**84.1**	**147.0**	**353.0**
Average wattage (W)	**54**	**54**	**40**	**300**	**30**	**13**
Lifetime (h)	**1000**	**1000**	**1500**	**1500**	**3000**	**6000**
Annual burning hours (h)	**505**	**551**	**538**	**536**	**705**	**800**

- **Environmental impacts of the stock in 2007 for all sectors**

Table 5-17 shows the total environmental impact of all products in operation in EU-27 in 2007, assuming that all the products have the same impacts as the base-case of their category. These figures come from the EcoReport tool by multiplying the individual environmental impacts of a base-case with the stock of this base-case in 2007 for all sectors.

Table 5-17: Environmental impacts of the EU stock in 2007 for all sectors

		GLS-C	GLS-F	HL-MV-LW	HL-MV-HW	HL-LV	CFLi	TOTAL
main environmental indicators	**unit**	**Value**	**value**	**value**	**value**	**value**	**value**	**value**
Total Energy (GER)	PJ	**193.539**	**556.582**	**35.407**	**206.204**	**145.320**	**138.775**	**1275.826**
of which, electricity	TWh	**16.917**	**49.092**	**2.892**	**19.219**	**13.114**	**11.234**	**112.468**
Water (process)	mln.m3	**11.887**	**34.481**	**2.026**	**13.459**	**9.182**	**10.331**	**81.367**
Waste, non-haz./ landfill*	kton	**230.383**	**660.795**	**40.456**	**239.232**	**167.577**	**171.431**	**1509.875**
Waste, hazardous/ incinerated*	kton	**4.397**	**12.663**	**0.799**	**4.736**	**3.323**	**31.988**	**57.906**
Emissions (Air)								
Greenhouse Gases in GWP100	mt CO2eq.	**9.139**	**26.078**	**1.767**	**9.192**	**6.678**	**6.893**	**59.747**
Acidifying agents (AP)	kt SO2eq.	**49.407**	**142.210**	**8.992**	**52.984**	**37.230**	**35.907**	**326.729**
Volatile Org. Compounds (VOC)	kt	**0.085**	**0.242**	**0.017**	**0.081**	**0.060**	**0.089**	**0.573**
Persistent Org. Pollutants (POP)	g i-Teq.	**1.306**	**3.745**	**0.229**	**1.354**	**0.948**	**0.896**	**8.477**
Heavy Metals (HM)	ton Ni eq.	**3.955**	**11.188**	**0.780**	**3.698**	**2.754**	**3.203**	**25.579**
PAHs	ton Ni eq.	**1.167**	**3.126**	**0.315**	**0.618**	**0.657**	**1.223**	**7.106**
Particulate Matter (PM, dust)	kt	**1.858**	**5.112**	**0.226**	**1.242**	**0.897**	**1.320**	**10.655**
Emissions (Water)								
Heavy Metals (HM)	ton Hg/20	**1.217**	**3.510**	**0.205**	**1.312**	**0.901**	**2.814**	**9.960**
Eutrophication (EP)	kt PO4	**0.008**	**0.022**	**0.001**	**0.007**	**0.005**	**0.026**	**0.069**

Summary of environmental impacts of base-cases as a % of total impact for these lamp types, as well as the lot 19 (part 1) totals are presented in Figure 5-18.
For most of the environmental indicators presented in this figure, the share of the incandescent lamps (both clear and frosted) is about 59 %, in the same order of magnitude as for the domestic sector.

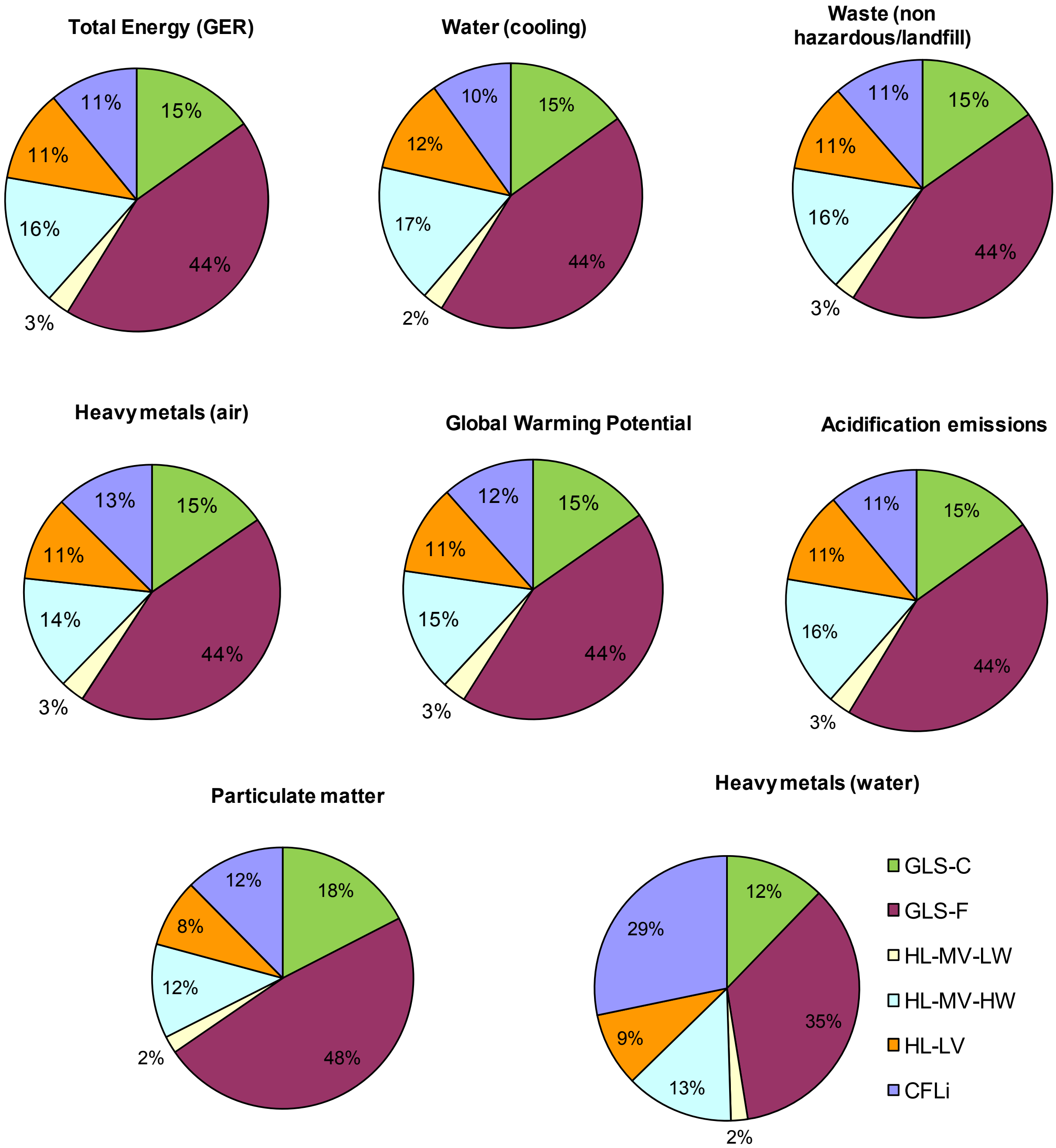

Figure 5-18: Base-cases' share of the environmental impacts of the 2007 stock for all sectors

Table 5-18 summarises the total electricity consumption (during the use phase) of each base-case, assuming that the whole stock is composed of base-cases. Therefore, the total electricity consumption in 2007 of non-directional lighting sources which are in the scope of this study (part 1) and used in all sectors (not only the domestic sector) is about 112.5 TWh. This represents about 4.00 % of the EU-27 total electricity consumption[73]. Therefore, it can be deducted that the electricity consumption in the non-domestic sector for these 5 lamp types represents about 1.05 % (= 4.0 % - 2.95 %) of the EU-27 total electricity consumption.

[73]Source Eurostat: EU-27 electricity consumption in 2006 = 242 million toe = 2,815 TWh

Table 5-18: Total electricity consumption for the year 2007 for all sectors

Base-case	**EU 27 stock electricity consumption in 2007 for all sectors (TWh)**	**Share of the total electricity consumption of the 6 lamp types**
Base-case GLS-C	16.92	15.0%
Base-case GLS-F	49.09	43.6%
Base-case HL-MV-LW	2.89	2.6%
Base-case HL-MV-HW	19.22	17.1%
Base-case HL-LV	13.11	11.7%
Base-case CFLi	11.23	10.0%
TOTAL	**112.47**	**100.0%**

- **Total consumer expenditure in 2007**

Regarding the total consumer expenditure in 2007 related to the 6 base-cases, about 83 % of the 20.7 billion euros (i.e. 5.1 billion euros concern the non-domestic sectors) is due to the electricity costs. This share is almost similar to the one for the domestic sector. The distribution per base-case is given in Figure 5-19, and details on consumer expenditure are presented in Table 5-19.

Table 5-19: Comparison of total consumer expenditure (EU 27) in 2007 for all sectors

	GLS-C	***GLS-F***	***HL-MV-LW***	***HL-MV-HW***	***HL-LV***	***CFLi***	***TOTAL***
Lumen output per lamp (lm)	594.0	572.4	480.0	5177.3	435.0	559.0	
EU 27 sales (mln unit)	297	767	97	84	147	353	1746
Share of the EU 27 sales	17.0%	44.0%	5.6%	4.8%	8.4%	20.2%	100.0%
Product price (mln €)	178	460	536	252	441	1633	3500
Electricity[74] (mln €)	2584	7498	442	2937	2004	1685	17150
Total (mln €)	**2762**	**7959**	**978**	**3189**	**2445**	**3318**	**20650**

[74] The electricity tariff used for the calculation is the same as for domestic purpose, i.e. 0.1528 €/kWh.

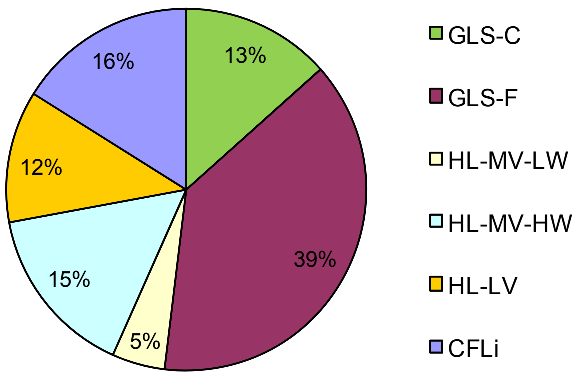

Figure 5-19: Base-cases' share of the total consumer expenditure in 2007 for all sectors

Total consumer expenditure in 2007 related to incandescent lamps (both clear and frosted) in all sectors represent 52 %, whereas these lamp types represent about 61 % of the total sales.

5.6 "Comparison" of the base-cases

As the luminous efficacy of the 6 base-cases defined in this chapter differs, it is interesting and relevant to compare their environmental impacts as well as their life cycle cost taking account this difference. Therefore, Table 5-20, Table 5-21 and Table 5-22 present data per lumen and per hour**.** In Table 5-20, for each environmental indicator, variations with reference to the base-case GLS-F are also given.

Table 5-20: Environmental impacts per lumen and per hour

		GLS-C	***GLS-F***	***HL-MV-LW***	***HL-MV-HW***	***HL-LV***	***CFLi***
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	**1045.2**	**1084.6**	**946.9**	**615.2**	**843.5**	**275.8**
	variation with GLS-F	***-3.6%***	***0.0%***	***-12.7%***	***-43.3%***	***-22.2%***	***-74.6%***
of which, electricity	J	**955.0**	**991.0**	**875.0**	**608.4**	**803.8**	**258.2**
	variation with GLS-F	***-3.6%***	***0.0%***	***-11.7%***	***-38.6%***	***-18.9%***	***-73.9%***
Water (process)	µltr	**63.9**	**66.3**	**58.4**	**40.6**	**53.6**	**19.3**
	variation with GLS-F	***-3.6%***	***0.0%***	***-12.0%***	***-38.8%***	***-19.2%***	***-70.9%***
Waste, non-haz./ landfill*	µg	**2545.5**	**2641.5**	**2333.3**	**1622.5**	**2143.4**	**684.5**
	variation with GLS-F	***-3.6%***	***0.0%***	***-11.7%***	***-38.6%***	***-18.9%***	***-74.1%***
Waste, hazardous/ incinerated*	µg	**1245.8**	**1292.8**	**1089.3**	**713.5**	**973.3**	**328.7**
	variation with GLS-F	***-3.6%***	***0.0%***	***-15.7%***	***-44.8%***	***-24.7%***	***-74.6%***
Emissions (Air)							
Greenhouse Gases in GWP100	mg CO2 eq.	**49.5**	**51.4**	**44.5**	**27.1**	**38.6**	**12.7**
	variation with GLS-F	***-3.6%***	***0.0%***	***-13.5%***	***-47.2%***	***-25.0%***	***-75.2%***
Acidifying agents (AP)	µg SO2 eq.	**266.7**	**276.8**	**242.0**	**158.2**	**216.2**	**71.2**
	variation with GLS-F	***-3.6%***	***0.0%***	***-12.6%***	***-42.8%***	***-21.9%***	***-74.3%***
Volatile Org. Compounds (VOC)	ng	**463.7**	**481.2**	**402.4**	**236.4**	**344.5**	**134.7**
	variation with GLS-F	***-3.6%***	***0.0%***	***-16.4%***	***-50.9%***	***-28.4%***	***-72.0%***
Persistent Org. Pollutants (POP)	10^{-3} pg i-Teq	**7.06**	**7.33**	**6.16**	**4.04**	**5.50**	**1.80**
	variation with GLS-F	***-3.6%***	***0.0%***	***-15.9%***	***-44.9%***	***-24.9%***	***-75.5%***
Heavy Metals (HM)	ng Ni eq.	**21.53**	**22.34**	**18.71**	**10.80**	**15.83**	**5.43**
	variation with GLS-F	***-3.6%***	***0.0%***	***-16.3%***	***-51.7%***	***-29.1%***	***-75.7%***
PAHs	ng Ni eq.	**6.51**	**6.76**	**5.36**	**1.54**	**3.59**	**1.35**
	variation with GLS-F	***-3.6%***	***0.0%***	***-20.6%***	***-77.3%***	***-46.8%***	***-80.1%***
Particulate Matter (PM, dust)	µg	**10.25**	**10.63**	**5.65**	**3.55**	**5.15**	**1.99**
	variation with GLS-F	***-3.6%***	***0.0%***	***-46.8%***	***-66.6%***	***-51.6%***	***-81.3%***
Emissions (Water)							
Heavy Metals (HM)	ng Hg/20	**6.57**	**6.81**	**5.77**	**3.94**	**5.25**	**3.41**
	variation with GLS-F	***-3.6%***	***0.0%***	***-15.3%***	***-42.2%***	***-22.9%***	***-50.0%***
Eutrophication (EP)	ng PO4	**43.2**	**44.8**	**29.7**	**19.3**	**26.3**	**27.3**
	variation with GLS-F	***-3.6%***	***0.0%***	***-33.7%***	***-57.0%***	***-41.4%***	***-38.9%***

Table 5-20 highlights that a typical frosted incandescent lamp represents highest environmental impacts over its life cycle compared to the others lamp types. This can be explained by two factors:

- the use phase is the most significant stage of the life cycle for any type of lamp, and
- the base-case GLS-F has the lowest lumen efficacy (10.6 lm/W).

For all environmental indicators, the base-case GLS-C presents a decrease of 3.6 % compared to the base-case GLS-F. This observation is logical as these two types of lamps have the same bill of materials, power output (54 W), and lifespan (2.5 years). The only difference is in their luminous efficacy (11.0 lm/W for the GLS-C and 10.6 lm/W for the GLS-F, i.e. a difference of about 3.6 %).

For two main environmental impact indicators (GER and GWP), Figure 5-20 and Figure 5-21 show the results per lumen and per year for the 6 base-cases with reference to the base-case GLS-F. As expected, incandescent lamps, being the least energy efficient, have the highest magnitude of impacts.

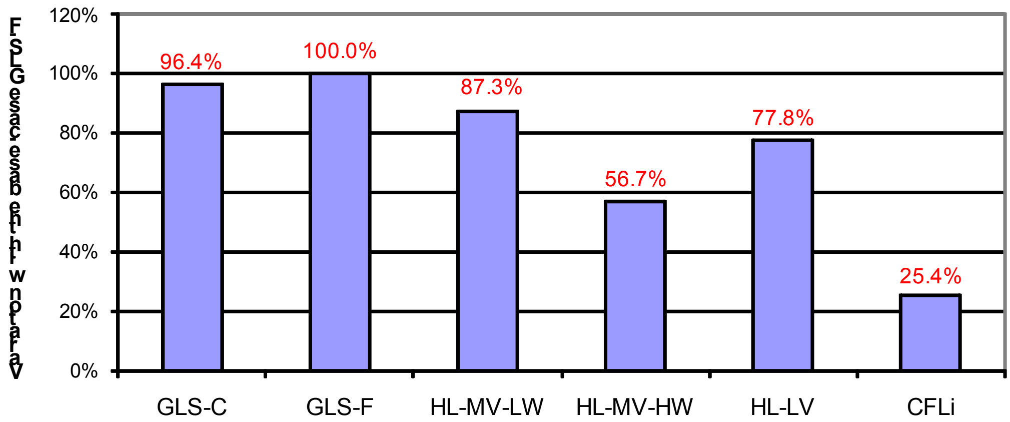

Figure 5-20: Comparison of the base-cases for the GER indicator

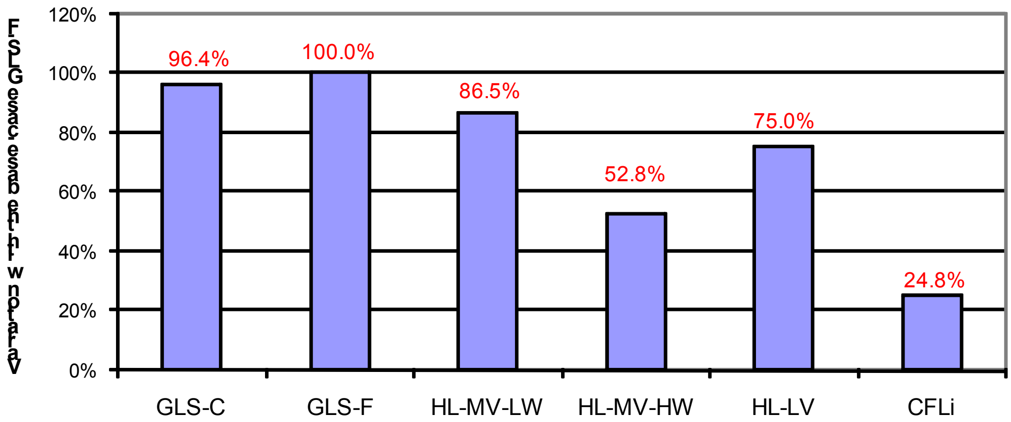

Figure 5-21: Comparison of the base-cases for the GWP indicator

Based on Figure 5-20 and Figure 5-21, one can be surprised that the base-case HL-MV-HW is “more efficient” than the base-case HL-LV. The explanations can be that GER and GWP of the distribution phase are almost equal for both base-cases (52 MJ and 4.5 kg CO_2 eq.) whereas they do not have the same lumen output (435 lm for the base-case HL-LV and 5177 lm for the base-case HL-MV-HW). Thus, to obtain GER and GWP per lumen and per hour for the distribution phase, total values have to be divided by 0.65×10^6 for the base-case HL-LV and 7.77×10^6 for the base-case HL-MV-HW. Therefore, when comparing the two base-cases for these environmental indicators over their entire life cycle, the base-case HL-MV-HW seems “more efficient” than the base-case HL-LV.

Moreover, the power output of the two base-cases is very different (300 W for HL-MV-HW and 30 W for HL-LV). As the lamp efficacy increases with the power output, the comparison between these two base-cases should be made carefully.

Regarding mercury emissions, Table 5-21 compares values per lumen and per hour for the 6 base-cases. As already discussed in section 5.2, only the base-case CFL with integrated ballast emits mercury to air during end-of-life.

Table 5-21: Mercury emissions to air for each base-case per lumen and per hour

	GLS-C	***GLS-F***	***HL-MV-LW***	***HL-MV-HW***	***HL-LV***	***CFLi***
Product life time (hours)	1000	1000	1500	1500	3000	6000
Lumen output per lamp (lm)	594.0	572.4	480.0	5177.3	435.0	559.0
Mercury emitted to air for the production of 1 kWh (mg)	0.016					
Mercury emitted during the use phase (mg)	0.86	0.86	0.96	7.20	1.60	1.31
Mercury emitted during the end-of-life (mg)	0	0	0	0	0	3.2
Mercury emitted over lifetime per lumen per hour (ng)	**1.45**	**1.51**	**1.33**	**0.93**	**1.22**	**1.34**
Difference with the base-case GLS-F	*-3.6%*	*0.0%*	*-11.7%*	*-38.6%*	*-18.9%*	*-10.9%*

Due to emissions occurring at its end-of-life (3.2 mg) the base-case does not have the lowest amount of mercury emissions (per lumen and per hour) during its entire life cycle even if it is the most efficient lamp type. The reduction is ‘only’ of 10.9 % compared to the base-case frosted incandescent lamp.

As shown in Figure 5-22, the base-case HL-MV-HW is the ‘best’ lamp when focusing on mercury emissions. However, improvements can be expected for recycling CFLi in order to increase the share of CFLi recycled (20 % nowadays). Therefore, if all CFLi were recycled, this lamp type would be the best choice in terms of mercury emissions due to low electricity consumption per lumen and per hour.

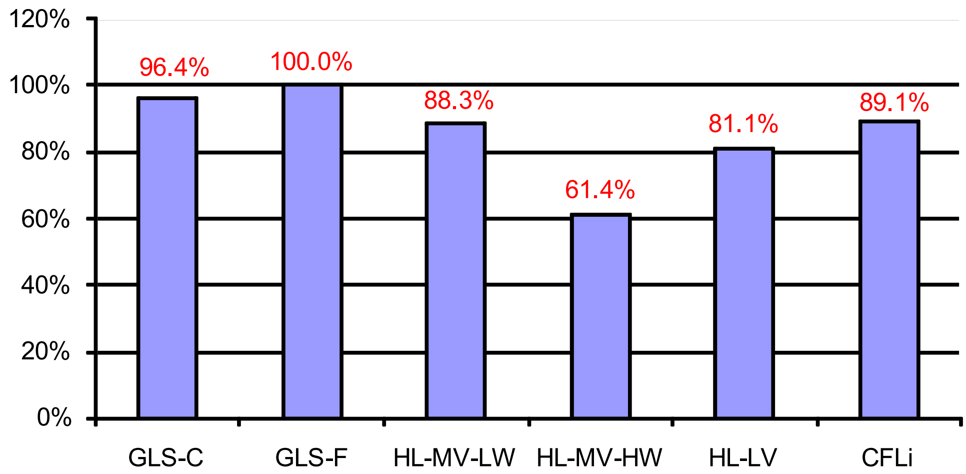

Figure 5-22: Comparison of the base-cases for mercury emissions over lifetime

Table 5-22: Economic data per lumen and per hour

	GLS-C	***GLS-F***	***HL-MV-LW***	***HL-MV-HW***	***HL-LV***	***CFLi***
Product life time (hours)	1000	1000	1500	1500	3000	6000
Lumen output per lamp (lm)	594.0	572.4	480.0	5177.3	435.0	559.0
Product price per lumen per hour (10^{-6} €)	1.01	1.05	7.64	0.39	2.30	1.38
Electricity per lumen per hour (10^{-6} €)	13.46	13.97	12.25	8.52	10.99	3.46
LCC per lumen per hour (10^{-6} €)	**14.47**	**15.02**	**19.89**	**8.91**	**13.29**	**4.84**
Difference with the LCC of the base-case GLS-F	*-3.64%*	*0.0%*	*32.4%*	*-40.7%*	*-11.5%*	*-67.8%*

The life cycle cost per lumen and per hour for each base-case is highlighted in Figure 5-23. It is clearly visible that the use of the base-case HL-MV-LW implies the highest cost over lifetime (product price + electricity cost): 19.89×10^{-6} €. Due to its relatively high purchase price, its life cycle cost is even higher than the LCC of the base-case GLS-F ($15.02\text{x}10^{-6}$ €). On the contrary, the base-case HL-MV-HW presents a significant reduction compared to the base-case HL-MV-LW (- 55.2 %) due to its low product price even with a high wattage (300 W).

As expected and demonstrated already, incandescent and halogen lamps are less efficient and less cost-effective than compact fluorescent lamps with integrated ballast as shown in Figure 5-23. The use of a typical compact fluorescent lamp (CFLi) instead of a typical frosted incandescent lamp allows decreasing the life cycle cost by about 67.8 %.

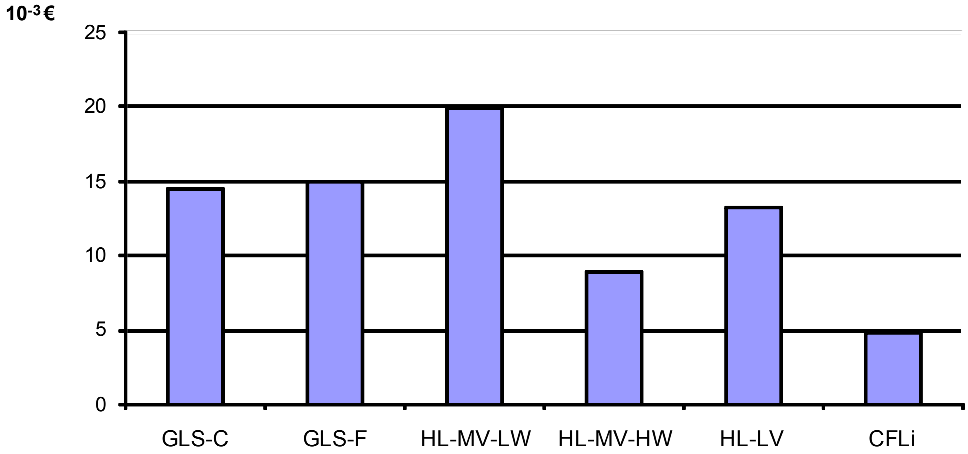

Figure 5-23: Life Cycle Cost per lumen and per hour

The environmental and economical analysis of the 6 base-cases shows that the compact fluorescent lamp with integrated ballast is the “best choice” in terms of LCC and environmental impacts, except for the mercury emissions for which the base-case HL-MV-HW is the least impacting.

5.7 EU-27 Total System Impact

This analysis is elaborated in part 2 of the study (sections 8.1.2.8 and 8.1.2.9 taking into account luminaires).

5.8 Conclusions

The environmental impact assessment carried out with the EcoReport tool for each base-case shows that the use phase is, not surprisingly, the most significant stage of the life cycle in terms of energy and resource consumption as well as for environmental impacts. Therefore, the analysis of the improvement potential in chapter 7 will primarily focus on technologies that reduce the electricity consumption, for instance by increasing the lamp efficacy. Regarding environmental impacts, the CFLi is, not surprisingly, the best lamp choice and incandescent lamps the worst choice.

Furthermore, mercury is a hazardous substance and the environmental impacts arising from its use in certain lamps should be limited. Therefore, the improvement options that will be identified in chapter 7 should also allow the reduction of mercury emissions over the entire life cycle. The base-case HL-MV-HW allows the lowest amount of mercury emissions even if its lamp efficacy and lamp lifetime is lower compared to the base-case CFLi, as a CFLi emits mercury at end-of-life.

Regarding the Life Cycle Cost of the 6 base-cases, compared per lumen and per hour, the base-case CFLi appears as the "best lamp" due to its low electricity consumption, i.e. its high lamp efficacy. Moreover, as incandescent lamps (both GLS-C and GLS-F) have the lowest lamp efficacy these lamps present the highest LCC.

6 TECHNICAL ANALYSIS BAT AND BNAT

Scope: This entails a technical analysis and description of the Best Available Technology (BAT) and Best Not yet Available Technology (BNAT) that can be implemented on product or component level. The described BAT is in many cases already available on the market, but is less frequently used because of the purchase price. It partly provides the input for the identification of part of the improvement potential (task 7), i.e. especially the part that relates to the best available technology. In chapter 7, also cost, intellectual property and availability are taken into account for the selection of options. This is not the case in this chapter and many of the presented technologies are intellectual property or linked to individual companies. The input of this chapter is partially the result of an organised visit to the Light and Building trade fare in Frankfurt 2006 (see also chapter 9 stakeholder consultation). Additional information was collected by consulting manufacturer's catalogues and technical publications. Much research is ongoing and information is not always publicly available, therefore this chapter can never claim to be complete but aims to give a general overview. For commercial reasons brand names are avoided in the text as far as possible.

6.1 BAT State-of the art

6.1.1 Compact fluorescent lamps (CFLi) with enhanced efficacy

The electronic control circuit in the lamp can have a serious impact on the lamp efficacy. These control circuit can be composed of a very simple low cost system up to a circuit based on sophisticated integrated control circuit. The power consumption of this incorporated electronic circuit and the efficiency of the switching semiconductor can influence lamp efficacy.
The base case lamp has an efficacy of 50lm/W (for the bare lamps) while there are lamps that have an efficacy of 55-57lm/W or 10% more.
Price and efficacy data can be found in the following Table 6-1. We assumed that mainly the price has an impact and that the BOM impact is negligible for this product, as could already be concluded from chapter 5.
These data can be used for the improvement options assessment in chapter 7.

Table 6-1: Data for CFLi's with enhanced efficacy.

Lamp type Acronym	Wattage rated [W]	Colour Temp [K]	Colour rend Ra	LWFt [75]	ηlamp @25 °C [lm/W]	Operational Life time [h]	Unit price (for end user) [€]	ILCOS-code
Compact fluorescent lamp, bare, E27/B22d CFLi	15	2700	80≤Ra<90	1,05	57	6000	5	FBT-15/27/1B-220/240-E27
Compact fluorescent lamp, bare, E14/B15d CFLi	11	2700	80≤Ra<90	1,05	55	6000	5	FBT-10/27/1B-220/240-E14

6.1.2 Compact fluorescent lamps (CFLi) with enhanced efficacy and long or very long lifetime

The incorporated electronic control circuit in the lamp can also have a serious impact on the lamp life. It is again the sophisticated integrated control circuit and the quality of the components that influences lamp life. Lamp lifes of 10.000, 12.000 and 15.000h are declared by manufacturers.
It is clear that these lamps always have enhanced efficacies. The higher grade ballasts use semiconductors with higher efficacy (e.g. MOSFET half bridge instead of bipolar transistors) and more sophisticated control circuits (e.g. IC).

Price and efficacy data about these lamps are included in Table 6-2 hereafter. These data can also be used for the improvement options assessment in chapter 7. We assumed that mainly the price has an impact and that the BOM impact (printed circuit board assembled) is negligible for this product, as could already be concluded from chapter 5.

[75] LWFt = Total Lamp Wattage Factor = LWFp x LWFe (see section 4.3.2).

Table 6-2: Data for CFLi's with long and very long lifetime.

Lamp type Acronym	Wattage rated [W]	Colour Temp [K]	Colour rend Ra	LWFt[76]	ηlamp @25 °C [lm/W]	Operational Life time [h]	Unit price (for end user) [€]	ILCOS-code
Compact fluorescent lamp, bare, E27/B22d CFLi	15	2700	80≤Ra<90	1,05	57	10000	9	FBT-15/27/1B-220/240-E27
Compact fluorescent lamp, bare, E14/B15d CFLi	11	2700	80≤Ra<90	1,05	55	10000	9	FBT-10/27/1B-220/240-E14
Compact fluorescent lamp, bare, E27/B22d CFLi	15	2700	80≤Ra<90	1,05	57	15000	11	FBT-15/27/1B-220/240-E27
Compact fluorescent lamp, bare, E14/B15d CFLi	11	2700	80≤Ra<90	1,05	55	15000	11	FBT-10/27/1B-220/240-E14

6.1.3 Compact fluorescent lamps (CFLi) with reduced mercury content compared to ROHS directive requirements and use of leachable mercury compounds

The health risks and environmental risks related to the use of mercury were the focus of several studies (RPA (2002))[77] The use of mercury is limited by the RoHS directive (2002/95/EC) and recycling by the WEEE directive (2002/96/EC), see also chapter 1.

Most manufacturers market CFLi's with reduced mercury content compared to the maximum level of 5 mg specified in the ROHS directive.
Currently, there are lamps on the market with mercury content values of less than 1.25 mg.

[76] LWFt = Total Lamp Wattage Factor = LWFp x LWFe (see section 4.3.2).
[77] RPA (2002): ' Risks to Health and the Environment Related to the Use of Mercury Products', 9 August 2002, Final Report (see http://ec.europa.eu/enterprise/chemicals/studies_en.htm).

It is also possible to add substances (e.g. mercury amalgam) to fluorescent lamps that reduce the impact of mercury from disposal of fluorescent lamps that might leach into surface and subsurface water, a method followed by the US as alternative for recycling.
The U.S. Environmental Protection Agency established a maximum concentration level for mercury at 0.2 milligrams of leachable mercury per liter of extract fluid. The concentration level for mercury is generally determined by a standard analysis known as the Toxicity Characteristic Leaching Procedure (TCLP), a well known test procedure implemented in 1990 by the Environmental Protection Agency.

When carrying out the TCLP test, test lamps are pulverized to form lamp waste material similar to that which would result from lamp disposal in land fills or other disposal locations. The ambient conditions in disposal locations may be such as to promote formation of leachable mercury. The TCLP test conditions themselves tend to allow for formation of leachable mercury in amounts greater than the established limit of 0.2 milligrams per liter. During the disposal of the lamp, and in the TCLP test, the glass enclosure of the lamp is broken. Elemental mercury that is contained in the lamp is then exposed to the metal components in an aqueous environment. Elemental mercury, when exposed to both the metal components and the aqueous environment, is oxidized to leachable mercury. The metal components in the lamp provide the source of oxidizable iron and oxidizable copper that promotes the formation of leachable mercury. Several techniques have been developed which prevent the formation of mercury that can leach into the environment. The methods currently used are concerned with a method of delivering a chemical agent or metal upon disposal of a lamp or during the TCLP test. For instance, Fowler et al. (U.S. Pat. No. 5,229,686 and U.S. Pat. No. 5,229,687) describe methods that incorporate chemical agents in the lamp in either a glass capsule or the basing cement. These chemical agents include various salts such as bromide anions, chloride anions, iodide anions, iodate anions, periodate anions, and sulfide anions, to name a few. Other chemical agents include powders such as iron powder, copper powder, tin powder, and titanium powder. In U.S. Pat. No. 5,821,682 Foust et al. describe the addition of a mercury antioxidant for superior TCLP test performance. Mercury antioxidants include, for example, ascorbic acid, sodium ascorbate, and sodium gluconate. These materials have been found to reduce or prevent the formation of leachable mercurous and mercuric compounds resulting from the oxidation of elemental mercury. Unfortunately, manufacturing processes typically use a separate dispensing step to introduce the mercury antioxidant. In US Patent US20020190646 A1, another method is described which provides in the lamp structure an effective amount of a silver salt, a gold salt or combination thereof.

Price and BOM data about these lamps are included hereafter in Table 6-3 and Table 6-4 and can be used for the improvement options assessment in chapter 7.

Table 6-3: Data for CFLi's with reduced mercury content

Lamp type *Acronym*	*Wattage rated* *[W]*	*Colour Temp* *[K]*	*Colour rend* *Ra*	*LWFt*[78]	*ηlamp @25 °C* *[lm/W]*	*Operational Life time* *[h]*	*Unit price (for end user)* *[€]*	*ILCOS-code*
Compact fluorescent lamp, bare, E27/B22d ***CFLi***	*15*	*2700*	*80≤Ra<90*	*1,05*	*50*	*6000*	*5*	*FBT-15/27/1B-220/240-E27*
Compact fluorescent lamp, bare, E14/B15d ***CFLi***	*11*	*2700*	*80≤Ra<90*	*1,05*	*50*	*6000*	*5*	*FBT-10/27/1B-220/240-E14*

[78] LWFt = Total Lamp Wattage Factor = LWFp x LWFe

Table 6-4: BOM data for CFLi's with reduced mercury content.

MATERIALS Extraction & Production ***Description of component***	Compact fluorescent lamp, bare, E27/B22d - **15W**	Compact fluorescent lamp, bare, E14/B15d - **11W**	**Category**	**Material or Process MEEUP**
Glass	25	17,5	7-Misc.	**54-Glass for lamps**
Aluminium for caps	1,5	1	4-Non-ferro	**26-Al sheet/extrusion**
Copper for caps			4-Non-ferro	**30-CU tube/sheet**
Metal Mercury	0,002	0,002		
Plastic housing	25	22		**PBT**[79]
Lamp envelope				**54-Glass for lamps**
Printed circuit board, assembled	20	17		**53-PWB assembly**
Total weight				

6.1.4 Compact fluorescent lamps (CFLi) with long lifetime and reduced mercury content

These lamps combine a more sophisticated control circuit that enhances lifetime (and consequently also efficacy) with the reduced mercury content of lamps from section 6.1.3.

Price and efficacy data about these lamps are included in Table 6-5 hereafter. These data can be used for the improvement options assessment in chapter 7.
The BOM data can also be taken from section 6.1.3.

[79] **PBT** PolyButyleneTerephtalate

Table 6-5: Data for CFLi's with long lifetime and reduced mercury content

Lamp type Acronym	Wattage rated [W]	Colour Temp [K]	Colour rend Ra	LWFt[80]	ηlamp @25 °C [lm/W]	Operational Life time [h]	Unit price (for end user) [€]	ILCOS-code
Compact fluorescent lamp, bare, E27/B22d **CFLi**	15	2700	80≤Ra< 90	1,05	57	10000	10	FBT-15/27/1B-220/240-E27
Compact fluorescent lamp, bare, E14/B15d **CFLi**	11	2700	80≤Ra< 90	1,05	55	10000	10	FBT-10/27/1B-220/240-E14

6.1.5 Dimmable compact fluorescent lamps (CFLi) and CFLi compatibility with electronic switches/dimmers

Currently, dimming in domestic lighting is mostly not inspired by energy saving, but, as mentioned in chapter 3, mainly for comfort reasons However, other types of electronic switches are commonly used, which are targeted at energy savings, such as presence detectors or timers.

Common to both dimmers and many electronic switches, is that ordinary CFLi's should not be operated on them. Lamp manufacturers warn against doing so with any CFLi, which is not specifically designed and certified for this use. The reasons for this have been explained in chapter 3.4.5.

The dimmers, which are found in the existing installations, are designed for dimming GLS lamps, MV-HL and LV-HL via iron-core or electronic transformers. Dimmers work by cutting out a part of the mains voltage sine wave, either at the beginning or the end of each half-cycle (respectively "leading edge" and "trailing edge" dimmers). Beside leading and trailing edge phase cut dimmers also 'top sine cutters' exist in the market, commercialised to dim ordinary CFLi's.

More background information on installed dimmers in domestic lighting:
The majority of installed dimmers are based on triac semiconductors and are leading edge phase cut dimmers, which means that they always operate in "leading edge" mode. This kind of dimming technology is not suitable for the type of ballast circuits found in ordinary CFLi's, i.e. a diode bridge input rectifier. This is not due to the dimmer as such, but due to the

[80] LWFt = Total Lamp Wattage Factor = LWFp x LWFe (see section 4.3.2).

nature of the ballast circuit, when connected to this type of device. They can operate in a "two-wire" system as explained in chapter 3 and need therefore a small continuous supply current for their internal circuits provided through a certain minimum load, typically minimum a 20 W GLS lamp. Some triac-based dimmers may require even higher minimum loads (>40W), because the triac needs a certain current in order to stay in the conducting mode.
The remaining dimmers are based on transistor technology, for the most part operating in “trailing edge” or "top sine cutting" mode and able to control:

- Inductive loads, such as magnetic (iron-core) transformers for LV-HL, can be dimmed with leading edge phase-cutting dimmers (if certified for this use).
- Capacitive loads, such as electronic transformers for LV-HL, can be dimmed with trailing edge phase-cutting dimmers.
- Resistive loads, such as GLS lamps and MV-HL, can be dimmed with either of these technologies.

In addition, transistor dimmers have certain advantages, such as electronic protection. Some high-end transistor dimmers automatically detect the type of load, and adjust the operating mode accordingly. Nevertheless a problem occurs in providing supply power to those transistor dimmers. They need a “three-wire” electrical system or a battery, see also chapter 3. A three wire systems means that the neutral wire is present at the switch/dimmer. Unfortunately, the "two-wire" system is the most commonly found system in domestic electrical lighting circuits in the European market. It appears also that many ordinary CFLi’s can be dimmed to a certain extent (30-40%) by three-wire trailing-edge dimmers or "top sine cutters". "Top sine cutters" are beneficial to reduce CFLi peak input currents and loading the CFLi input circuit. However, lamp manufacturers warn against attempting to do so. Paradoxally, certain 'dimmable CFLi's' do not dim on those dimmers.

About dimmable CFLi's:
Dimming fluorescent lamps below 30 % requires special techniques such as injection of a small DC current[81] and selection of the operation frequency, this is not complicated but currently not done in existing CFLi ballast circuits.
In order to overcome these problems, special CFLi’s have been developed for dimming. There are two main types of “dimmable CFLi” in the market:

- Dimmable CFLi’s that can be operated on standard dimmers (and/or other electronic switches).
- CFLi’s with a built-in dimming function, which can be controlled via on ordinary switch (flicking on and off rapidly can be used for selecting one or more steps of dimming level, or for starting a continuous dimming ramp, which can then be stopped at the desired level).

Both types are based on advanced electronic circuits (e.g.: US Patent 5686799 - Ballast circuit for compact fluorescent lamp, ..), which will detect dimmer settings and adjust the light output accordingly. They contain significantly more electronics than ordinary CFLi’s, and are consequently also more expensive to the user.

General remarks:

- Please note that the halogen lamp with integrated transformer can be dimmed on all those dimmers.

[81] US Patent 5001386 - 'Circuit for dimming gas discharge lamps without introducing striations' (1989)

- When CFLi's are dimmed the colour temperature increases slightly, the opposite of filament lamps (Halogen, GLS) (see chapter 3).
- Inherent in the sophisticated, integrated control circuit and the quality of the components, the lamps found on the market have also enhanced efficacy and long lifetime.
- "Three-wire" electronic switches (e.g. presence detectors) can use a mechanical relay for switching the lamp, which means that ordinary CFLi's can be used (although with derating due to inrush currents and peak factor).

Price and efficacy data about dimmable CFLi's is included in Table 6-6 hereafter and can be used in the impact assessment in chapter 8.
The influence on the BOM's (printed circuit board assembled) is also assumed to be negligible.

Table 6-6: Data for dimmable CFLi's.

Lamp type Acronym	Wattage rated [W]	Colour Temp [K]	Colour rend Ra	LWFt[82]	ηlamp @25 °C [lm/W]	Operational Life time [h]	Unit price (for end user) [€]	ILCOS-code
Compact fluorescent lamp, bare, dimmable, E27/B22d CFLi	20	2700	80≤Ra<90	1,05	61	15000	20	FBT-20/27/1B-220/240-E27

6.1.6 Other compact fluorescent lamp (CFLi) improvements

The following information is included in order to assess the recent technical developments that were made in lamp technology for CFLi. This information is useful to assess whether consumer acceptance barriers indentified in chapter 3 will be justified in future scenarios when evaluating policy options in chapter 8.

6.1.6.1 Amalgam technology

Common fluorescent lamps as well as CFLi's use mercury vapour to generate light. In lamps which are subjected to extreme temperatures (away from the optimum of 25°C), these lamps can loose up to 50% of their nominal lightoutput. This occurs when lamps are used outdoor (e.g. porch lighting) or in indoor luminaires (ambient temp. >> 25°). The latter is particularly a problem for very compact CFLi's in GLS shapes (enveloped types). Amalgam (a lead/mercury alloy) ensures a high light output, regardless the ambient temperature. The

[82] LWFt = Total Lamp Wattage Factor = LWFp x LWFe.

lead/mercury alloy increases the melting point compared to pure mercury, it is not liquid at room temperature.
An additional benefit is that in case of breakage of a cold lamp mercury cannot dissipate in the environment, see also 6.1.3.
The use of solid mercury amalgam compared to liquid mercury is also beneficial in CFLi production because a dripping method is more difficult to control the mercury amount and amalgam is more easy to handle without production losses.
The only drawback of amalgam is that lamps typically need a slightly longer run-up period to reach their maximum light output; possibly the incorporation of better electronic control circuits that boost the lamp at start up can overcome this disadvantage, see also 6.1.6.6.

6.1.6.2 Triphosphor versus halophosphate CFLi's

First introduced energy saving CFLi's had low colour rendering and were based on so-called halophosphate technology. By introducing the triphosphor, Ra was ameliorated to values ≥80. All currently available CFLi's on the market have that good colour rendering.

6.1.6.3 Multiphosphor lamps

There is an interest on the market for lamps with multiphosphors and correlated Ra≥90. Some manufacturers are already producing them.

6.1.6.4 Lamps with different colour temperature

Most used colour temperature for CFLi's is 2700 K in Northern Europe, in accordance with the warm light of the replaced incandescent lamps. Nevertheless in Southern Europe, people also like cooler light (4000 K). For this reason, manufacturers are producing lamps with higher colour temperature. This is not possible for GLS or HL lamps unless a couloured outer filter is applied that reduces lamp efficacy even more.

6.1.6.5 Electronic circuit for direct start

Some CFLi's start with a start delay between 0,5 to 1 second. This delay is introduced for preheating lamp electrodes and increasing the CFLi life time (e.g. in long life lamps 15000 h). This phenomenon can cause inconvenience for some people in comparison with the direct starting incandescent lamp.
Most of the lower cost CFLi on the market have 'direct start' or 'instant start', those CFLi have typically a shorter life time (e.g. 6000 h).

6.1.6.6 Improved electronic circuit for shorter warm-up time

Some CFLi's have long warm-up times (definition see chapter 1). This phenomenon could causes inconvenience for some people (see chapter 3). Longer warm-up times are mainly caused by the amalgam technology that is necessary for small size CFLi's because the amalgam needs more time to evaporate (higher temperature required). By improving the integrated electronic circuit warm-up time can be shortened the same way as electronic ballasts do for LFL or CFLni. Most of all a preheating is beneficial, but this needs a start delay (see 6.1.6.5). Data on warm up times is included in chapter 3, the best compact amalgam lamps with preheating easily obtain above 80 % light output in less then a minute (see also chapter 3).

6.1.6.7 CFLi with integrated halogen lamp for direct lighting

There are hybrid CFLi's on the market that are combined with a halogen lamp. The halogen lamp is only switched on during the warm up period of the CFLi and therefore provide full light output immediately after switching on the lamp.

6.1.6.8 Improved electronic input control circuit for power factor control and light output insensitive to line voltage fluctuations

As mentioned in section 4.3.2.1, the low value of the power factor for CFLi's below 25W causes additional losses in the electrical grid. Typical data for CFLi found on the market is included in chapter 3. The power factor of low power CFLi (<25 W) could be ameliorated by incorporating an electronic input circuit, the same as currently all light sources above 25 W need according to EN 61000-3-2. In this case the power factor is between 0,95 and 0,99. Some smaller CFLi manufacturers brought such CFLi (<25 W) on the market, however they are significantly more expensive(about 20 euro). It should be taken into account that the need of an improved power factor for CFLi is arguable because many loads in the electrical grid are inductive and a capacitive CFLi can provide compensation as discussed in chapter 3. A complementary benefit of this circuit is that the light output does not vary with the line voltage, such as lower cost CFLi and all GLS lamps do.

6.1.7 Cold Cathode Compact Fluorescent lamps with integrated balllast (CCFLi)

Cold cathodes fluorescent lamps (CCFL) are fluorescent lamps that do not employ a cathode heater. Nowadays, miniature CCFLs are extensively used as backlights for computer liquid crystal displays or flatscreen television sets but more recently lamps for general illumination appeared on the market They claim a longer life time, dimmability and improved light distribution with only a slightly lower lamp efficacy compared to usual CFLi's. Please note that these lamps also contain mercury. More technical information can be found in the final report of preparatory study for ecodesign of EuP products lot 5 for television sets[83].

Figure 6-1: CCFL reflector lamp.

[83] www.ecotelevision.org

6.1.8 Pin based compact fluorescent lamps (CFLni)

It is possible to design new luminaires (e.g. halogen torchieres or uplighters) with CFLni instead of HL-MV or GLS lamps. This is a technical improvement that needs to be done at systems level (luminaire) as defined in this study (see chapter 1). More technical information can be found in the final report of preparatory study for ecodesign of EuP products lot 8 on office lighting.

6.1.9 Directional or reflector Compact fluorescent lamps (CFLi-R)

Please also consult the related section in part 2 of this study. Both CFLi-R-NDLS and CFLi-R-DLS can be found on the market, NDLS (definition in chapter 1) versions are treated as CFLi with a second lamp envelope (see chapter 8).

6.1.10 Mains voltage halogen lamps with xenon

Incandescent lamps have an inert filling gas to reduce the evaporation of the filament (IESNA (1993)). The usual filling gas is a mixture of argon and nitrogen. Argon is slightly less heat conductive than nitrogen and therefore more suitable, however a small amount of nitrogen is often needed to impair formation of destructive electric arcs. Incadescent lamp efficacy is related to life time and line voltage, e.g.: a 100 W-230 VAC (rated life time 1000 h) clear GLS has 1340 lm and a 100 W-120 VAC (rated life time 750 h) has 1710 lm; lower voltage GLS lamps show a higer lamp efficacy (e.g. a 60 W GLS for 24 VAC has a 30 % higher lamp efficacy compared to a 60 W GLS for 230 VAC).
An halogen lamp is a modified incandescent lamp where the filling gas include a halogen gas (iodine, bromide, chlorine, fluorine) in order to induce a tungstenhalide cycle, which impede the lamp envelope blackening and extend the lifetime of the tungsten filament wire. Due to that, the size of the lamp envelope can be considerably reduced, which enables some remarkable improvements . As a result of that, halogen lamps have in general higher efficacies and a longer lifetime compared to incandescent lamps. Of course, all types of halogen lamps can be fully dimmed A further improvement of the halogen lamps performance can be achieved by the reduction of thermal losses. This can be obtained by using a less heat conductive inert filling gas, e.g. krypton or xenon. The highest efficacy can be obtained with xenon filling gas. Actual mains voltage halogen lamps filled with Xenon show an improvement in efficacy up to 20% compared to standard halogen lamps at the same lamp life. Recently not only linear (R7s) and compact (G9) Xenon filled HL-MV lamps were introduced on the market but also replacement lamps for GLS (see Figure 6-2), providing 30% energy saving compared to an IEC 60064 standard GLS (60W, 620 lm, 1000 h). These newly introduced lamps have identical outer measurements and are available as well with clear bulbs (important for decorative types) for easy one-to-one replacement of the incandescent lamps available today on the market.
These lamps have an excellent colour rendering (CRI=100) and can easily be dimmed as long as the wattage is above the minimum wattage of the dimmer.

Figure 6-2: Xenon HL-MV-lamp, form A and form B.

The lamp data can be found in Table 6-7.

Table 6-7: Data for selected xenon filled HL-MV lamps.

Lamp type *Acronym*	*Wattage rated [W]*	*Colour Temp [K]*	*Colour rend Ra*	*LWFt* [84]	*ηlamp @25 °C [lm/W]*	*Operational Life time [h]*	*Unit price (for end user) [€]*	*ILCOS-code*
Halogen lamp, clear, 230V, Xenon, form A, E27/B22d *HL-MV*	*42*	*2800*	*100*	*1*	*15*	*2000*	*3.6*	*HSGSA/C/UB-42-230-E27*
Halogen lamp, clear, 230V, Xenon, form B, E14/B15d *HL-MV*	*28*	*2800*	*100*	*1*	*12,3*	*2000*	*5*	*HSGSB/C/UB-28-230-E14*
Halogen lamp, clear, 230V, Xenon, G9 *HL-MV*	*33*	*2900*	*100*	*1*	*13,9*	*2000*	*8,9*	*HSG/C/UB-33-230-G9-44*
Halogen lamp, clear, 230V, Xenon, linear, R7s *HL-MV*	*230*	*2800*	*100*	*1*	*22,0*	*2000*	*3,8*	*HDG-230-230-R7s-114,2*

6.1.11 Replacing low voltage halogen lamps (HL-LV) with low voltage halogen lamps with infrared coating and xenon

A further development that has increased halogen lamp efficacy is applying an infrared-reflective coating. The basic infra-red coating technology to increase lamps efficacy[85] is over 30 years old. In lighting it was first commercially used in the early eighties to increase the efficacy of low pressure sodium lamps. The quartz lamp filament envelope is coated with a

[84] LWFt = Total Lamp Wattage Factor = LWFp x LWFe (see section **0**).

[85] United States Patent 4,017,758 (1977) 'Incandescent lamp with infrared filter'

multi-layered dichroic coating which allows visible light to be emitted while reflecting a portion of the infrared radiation or heat back onto the filament. Therefore the lamp filament wire is heated more efficiently. Such lamps are called halogen-infrared lamps, and they require less power than standard halogen lamps to produce any given light output. The efficiency increase can be as much as 40% when compared to its standard equivalent. This technology is mainly applied to low voltage halogen lamps (see also next point for a solution for mains voltage applications). Several lamp manufacturers have these lamps in their HL-LV product portofolio.
In Table 6-8 the data for the selected lamps are shown.

Table 6-8: Data for the selected infrared-coated HL-LV.

Lamp type *Acronym*	*Wattage rated* *[W]*	*Colour Temp* *[K]*	*Colour rend* *Ra*	*LWFt*[86]	*ηlamp @25 °C* *[lm/W]*	*Operational Life time* *[h]*	*Unit price (for end user)* *[€]*	*ILCOS-code*
Halogen lamp, clear, 12V, infra-red coating GY6,35 *HL-LV*	*35*	*3000*	*100*	*1,11*	*23,2*	*4000*	*7*	*HSGST/UB/IB-35-12-GY6,35*
Halogen lamp, clear, 12V, infra-red coating GY6,35 *HL-LV*	*20*	*3000*	*100*	*1,11*	*18,9*	*4000*	*7*	*HSGST/UB/IB-35-12-GY6,35*

6.1.12 Mains voltage halogen lamps (HL-MV) with infrared coating and integrated electronic transformer

In Europe where the line voltage is about 230 VAC, halogen main voltage (HL-MV) lamps have relative long filament wires; therefore it is diffucult to focus back the infrared radiation to the filament wire and as a consequence this technology could not succesfully be applied to main voltage halogen lamps (HL-MV). The basic idea[87] to incorporate a transformer for this purpose in the socket is over 20 years old.
A recent development to overcome the problem for applying succesful infrared coating technology in main voltage lamps is to integrate an electronic transformer in the lamp socket (see Figure 6-3) and use a HL-LV bulb with infrared coating. The efficacy of these lamps is almost twice the efficacy of a normal incandescent lamp of the same wattage. So a 30W

[86] LWFt = Total Lamp Wattage Factor = LWFp x LWFe.
[87] United States Patent 4,998,044 (1985) 'Efficacy incandescent light bulbs'

electronic HL-MV lamp is equivalent to a '53W' GLS-C lamp and a 20W electronic HL-MV lamp to a '37W' GLS-C lamp.

Figure 6-3: Electronic MV halogen lamps

These clear lamps, giving bright, sparkling light, are an energy efficient alternative for clear incandescent lamps where high luminance light bulbs are needed such as in (antique) luminaires with crystal ornaments. These lamps are dimmable with classical, household dimmers. The integrated transformer has to be able to withstand the high temperature generated by the lamp, which currently limit the maximum wattage of lamps available on the market. The data for these lamps are shown in Table 6-9 and can be used for the improvement options assessment in chapter 7. These lamps are also available with a frosted outer bulb to prevent glare. These lamps have also an excellent colour rendering (CRI=100) and can easily be dimmed on all dimmers also below the minimum wattage due to a special electronic circuit.

Table 6-9: Data for electronic HL-MV lamps.

Lamp type ***Acronym***	***Wattage*** ***rated*** ***[W]***	***Colour*** ***Temp*** ***[K]***	***Colour rend*** ***Ra***	***LWFt***[88]	***Hlamp @25 °C*** ***[lm/W]***	***Operational Life time*** ***[h]***	***Unit price (for end user)*** ***[€]***	***ILCOS-code***
Halogen lamp, clear, 230V, electronic, form A, E27/B22d ***HL-MV*** *(electronic)*	*30*	*2850*	*100*	*1*	*21*	*3000*	*9*	
Halogen lamp, clear, 230V, electronic, form B, E14/B15d ***HL-MV*** *(electronic)*	*20*	*2850*	*100*	*1*	*19*	*3000*	*9*	

[88] LWFt = Total Lamp Wattage Factor = LWFp x LWFe .

Table 6-10: Input data for the materials extraction and production of the lamps (expressed in g)

MATERIALS Extraction & Production ***Description of component***	Halogen lamp, clear, 230V, electronic, form B, E27/B22d - **30W**	Halogen lamp, clear, 230V, electronic, form B, E14/B15d - **20W**	**Category**	**Material or Process MEEUP**
Glass	22	12	7-Misc.	**54-Glass for lamps**
Aluminium for caps + cover	4	3,5	4-Non-ferro	**26-Al sheet/extrusion**
Copper for caps			4-Non-ferro	**30-CU tube/sheet**
Metal Mercury				
Plastic housing	15	15		**PBT**[89]
Lamp envelope				**54-Glass for lamps**
Printed circuit board, assembled	40	40		**53-PWB assembly**
Total weight				

6.1.13 Replacing mains voltage halogen lamps by more efficient low voltage halogen lamps by integrating an electronic transformer in the luminaire or furniture (system level)

It should be noted that luminaires designed for use with halogen lamps can obtain higher lamp efficacy if designed for HL-LV compared to HL-MV if this lamps use infrared coating technology, see section 6.1.10. This is a technical improvement that needs to be done at systems level (luminaire) as defined in this study (see chapter 1).
Please consult also the related section in part 2 of this study.

[89] **PBT** PolyButyleneTerephtalate

6.1.14 Reflector lamps with WLED SSL lamps

Please consult also the more updated related section in part 2 of this study.

Preliminary data:

Figure 6-4: Typical WLEDcomponent and LED lamp

White-light emitting diode (WLED) solid state lighting (SSL) lamps (see Figure 6-4) are recently becoming available on the market with increasing efficacy (up to 94 lumen/W ((Härle (2007)) and increasing life time as a result of decades of semiconductor research and progress. WLED are p art of ultra-brite (UB) LEDs that include also coloured LEDs. WLEDs are nowadays especially applied where small white light sources are needed, e.g. in display backlighting of portable devices. Also applications where coloured light is required benefit from LED's, e.g. traffic and other signs (applications with a low power density). LED's can be dimmed easily. WLED's are available in a wide range of lamp efficacies (5-80 lumen/W) even from the same manufacturing production line, the LEDs have to be sorted during manufacture by their actual characteristics.
WLED's that are nowadays on the market are mainly Solid State Lighting (SSL) devices, that rely on semiconductor material. For this SSL technology, efficacy and life time rapidly decrease with ambient temperature, therefore no high power densities or compact light sources can be obtained. SSLs are therefore primarily produced as discrete devices they are mainly available in low wattages (typical 1 to 5 Watt) and the main market products nowadays are mobile appliances (48 % in 2006, Steele (2007)). They are also sold as LED replacement lamps for existing reflector lamps(see Figure 6-4).
Dr. Shuji Nakamura of Nichia of Japan is the inventor of the white LED which took a composite YAG phosphor coating on top of a blue LED and converted it to white light. This technique is nowadays nearly used by all WLED manufacturers. A theoretical limit in efficacy can be expected in the range of 135-150 lm/W with lens and without converter (Härle (2007). The spectrum of some white LEDs differs significantly from incandescent light. There is a strong dependency of maximum efficacy on colour temperature colour coordinate (up to 20% increase) (Härle (2007)). The most efficient WLEDs appear blue (e.g. CT 6000 K) and do not meet the CRI > 80 colour rendering requirement for office lighting (EN 12464-1).
The SSL dependence on solid state semiconductor material could keep the price relatively high for these sources and the environmental impact of the production should be followed up in the near future. LED semi-conductors are crystals comprised of combinations of typically two or tree inorganic elements, such as gallium phosphide (GaP), gallium nitride (GaN), gallium indium nitride (GaInN) or gallium indium phosphide (GaInP). It should be noted that LEDs in general, thus not only WLED, are included in the environmental impact unit indicators in the MEEUP methodology report (table 29 material 48) and herein the production energy requirement or GWP per kg is very high compared to other materials. This can be explained by the high energy (GWP) and environmental impact that is typical for the

production of semiconductor material, see also material 47 (ICs SMD) in table 29 in the MEEUP methodology report. The WLEDs in particular make use of the rare raw materials gallium and indium that are used in many other high tech applications (PV panels, monitors, LCD displays with coatings of indium tin oxide) ('Only united are we strong: supply problems await areas other than silicon', Photon International, July 2006). The world annual indium production was estimated(2005) at 455 ton at 650 €/kg with about 6000 ton global reserves only(US Geological Survey, Mineral Commodity Summaries, January 2006). The indium price did rise with a factor 8 from 2002 to 2005. The world annual gallium production is estimated in 2005 at 208 tons at 410 €:kg and the global reserve is more difficult to estimate. Gallium occurs in very small concentrations in ores of other metals and is produced as a byproduct (e.g. bauxite). Based on the world resource of bauxite the reserve exceeds 1 million ton but probably only a small percentage of this metal is economically recoverable (US Geological Survey, Mineral Commodity Summaries, January 2006). The required energy (GWP) and material for the particular high efficacy WLEDs can only be modelled very approximate nowadays because it is unclear how many % of the production reach the high efficacy rating and there are many different and new production processes involved from which no data is made available due to intellectual property concerns. In this study the environmental impact will be modelled with the unit indicator (material 48 'SMD/LED's Avg per kg') from the MEEUP methodology (table 29). It is also clear from the unit indicator in the MEEUP methodology that environmental impact from the production may not be neglected in future assessments.

6.1.15 HID lamps to retrofit HL-MV high wattage lamps

HL-MV high wattage lamps can be replaced by more efficient HID lamp solutions.

The main advantage compared to CFLi is that the HID lamp is a point source that performs better when the light needs to be focused by optics, e.g. in reflector lamps (see 6.1.14) or a luminaire. The HID lamps are mainly available in high lumen output versions (> 1000 lm) and hence users are also forced to use luminaires or reflector lamps to prevent glare and distribute the light. There currently exist HID reflector lamp versions (see 6.1.16) that directly offers cost effective integrated solutions. As a conclusion, it is more likely that the domestic users will move to those HID reflector lamps (see 6.1.16) (part 2 of this study).

No retrofit lamps for HL-MV are available up to date, the main obstacle for a simple retrofit lamp is the need for an HID lamp ballast and igniter. As opposed to CFLi the ballast and igniter has never been integrated so far, probably due to the typical high lamp power. As a consequence the user needs to replace the luminaire, therefore this section will be updated in part 2 of the study on luminaires.

The lowest lumen output versions have a typical lamp power of 20 Watt with about 1000 lumen after 10000 h operation, hence the lamp efficacy is comparable to CFLi.

Today's commercial HID lamps requiire warm up times in excess of 40 s and restrike times of several minutes. This makes them not very suitable for domestic applications. Instant start and hot restrike HID lamps are demonstrated in car headlights but are not yet available for general lighting applications. Please note also that several HID lamp types such as HPS lamps and car headlights do not have the good colour rendering requirements expected for general indoor lighting.

It is unlikely that much lower lumen output HID lamps will appear on the market in the near future. It is a strong technological challenge. Simply downscaling can compromise life expectancy. Obstacles are the thermal conduction losses from the arc and the electrode losses that become more important for low wattages. Another problem for miniaturization are the required dimensional tolerances -that determine the light colour variation- since they become very hard to control at the small arc tube size needed for sub 20W HID lamps.

Please note that white HID lamps also contain mercury, for more information on HID lamps see the preparatory study on street lighting lot 9 for more information.

6.1.16 HID reflector lamps

Please consult the related section in part 2 of this study.

6.1.17 Luminares with improved light output ratio (system level)

Please consult also the related section in part 2 of this study.

6.2 State-of the art of best existing product technology outside the EU

The EU has premises of leading international companies in the field of lighting with also important R&D related to office lighting within the EU. For the cited BAT above, similar technology exists around the world, mainly in the US and in Asia. Many European companies are also internationally active and it is difficult to allocate their activities and achievements exclusively to the EU. The production of CFL is often located in China.
On the longer term (above 5 years), the proliferation of more advanced electronic lamp technology and solid state lighting such as LEDs could be allocated to technology resulting from Asian technological developments.

6.3 BNAT in applied research

6.3.1 OLED lamps

OLEDs (Organic LED) are a new upcoming technology,and are considered BNAT in the scope of this study concerning general domestic lighting illumination.This technology is intrinsically well suited for indoor area illumination and could appear as 'glowing wall paper' without the need for 'luminaires'. OLEDs (Organic Light-Emitting Diodes) are a flat display technology (see Figure 6-5), made by placing a series of organic thin films between two conductors. When electrical current is applied, a bright light is emitted. OLED's could tackle in the future the material and cost problem currently encountered in SSL LED's. The first OLED's are already on the market for particular, very flat illuminated displays in portable devices. OLED's based on organic material are still part of current R&D. OLED efficiencies under particular operational conditions have been reported up to 64 lm/W at 1000 Cd/m² (Budde (2007)). The actual OLED's still have a to prove efficacy in working conditions (e.g. temperature and required life time).

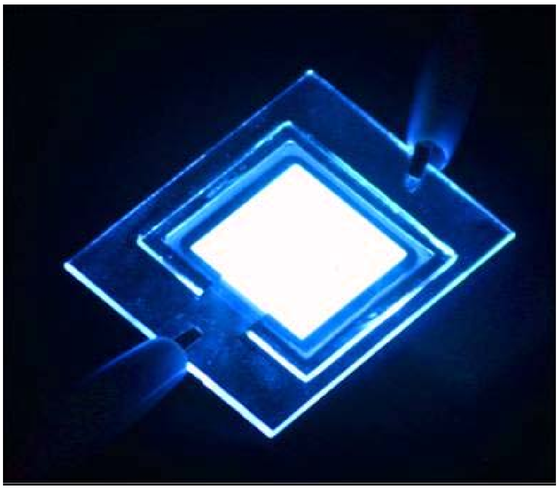

Figure 6-5: OLED prototype (Picture courtesy of OLLA project)

Conclusion:

The reported OLED performance in scientific papers is interesting but the product is not yet on the market for domestic general lighting applications but the technology might appear on the market in future. OLED's are classified therefore BNAT and there will be no case study for OLED's in further chapters.

6.3.2 Incandescent lamps using tungsten photonic lattice

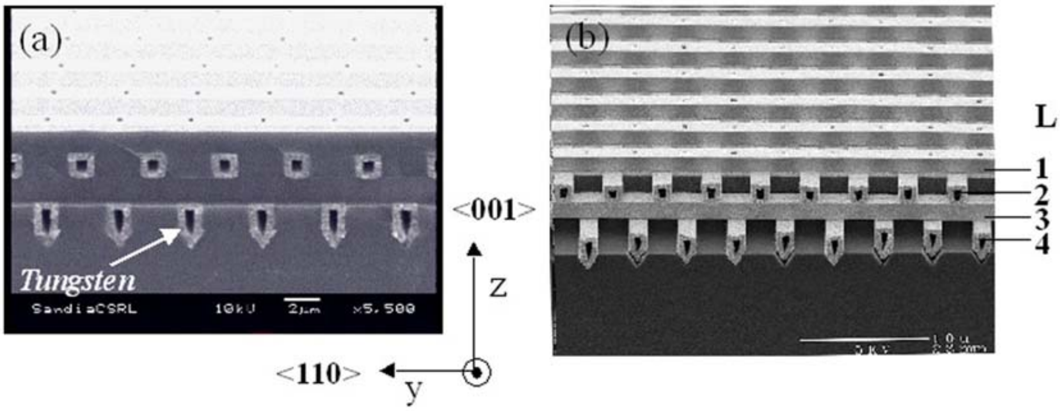

Figure 6-6: Images of a Sandia 3-D tungsten photonic crystal, taken by a scanning electron microscope The dimensional scale is in microns

New microscopic tungsten lattice could contribute to futher efficacy improvements of incadescent lamps These could benefit from a tungsten filament fabricated with an internal crystalline pattern (Figure 6-6) could transmute the majority of wasted infrared energy into the frequencies of visible light[90]. No prototypes were available on the market in 2007.

6.3.3 Mercury free dielectric barrier discharge lamps

DBD or Dielectric Barrier Discharge lamps are mercury free discharge lamps.
These are lamps with an electrical plasma discharge between two electrodes separated by an insulating dielectric barrier. A frequent used filling gas is Xenon and no mercury is needed. A special high voltage inverter is needed. There is no loss of electrode material and lamps can be constructed with high service life. The plasma discharge produces UV radiation that is converted in visible light similar to other fluorescent lamps. The technology is also used in plasma displays. One flat panel lamp is on the market (, the efficacy is about 35 lm/W. Also new lamp constructions are investigated for general illumination (e.g. EP1596420 in 2005).

[90] Sandia (2002): 'A cool tungsten light bulb may be possible 'Tungsten photonic lattice changes heat to light', press release Sandia National Laboratories, May 2002

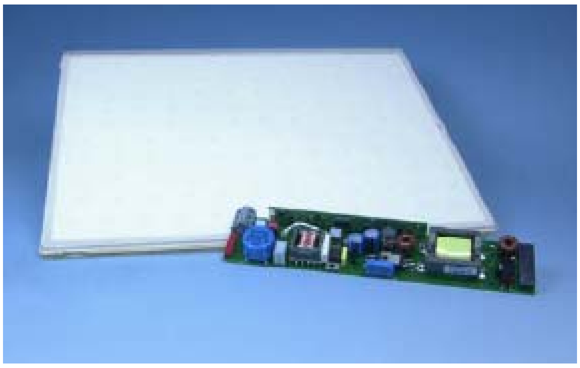

Figure 6-7: Planon (R) DBD lamp

6.3.4 Theoretical maximum lamp efficacy

It is important to note that the lamp efficacy has a physical upper limit, this is when all light is converted into visible electromagnetic radiation.
This maximum lamp efficacy is related to the colour due to the definition of lumen and the relative spectral sensivity of the human eye that was taken into account.
The maximum lamp efficacy for a perfect cool white light source is 348 lm/W and the absolute maximum for monochromatic yellow-green light (555 nm) sources is 683 lm/W (IESNA (1993), p. 204).

7 IMPROVEMENT POTENTIAL

Important remark: *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[91]	Lamp efficacy (lm/W)	Lumen output (lm)	LWFt[92]	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

[91] Lamp Lumen Maintenance Factor
[92] Total Lamp Wattage Factor

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".

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.

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

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 €).

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.

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.

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.

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.

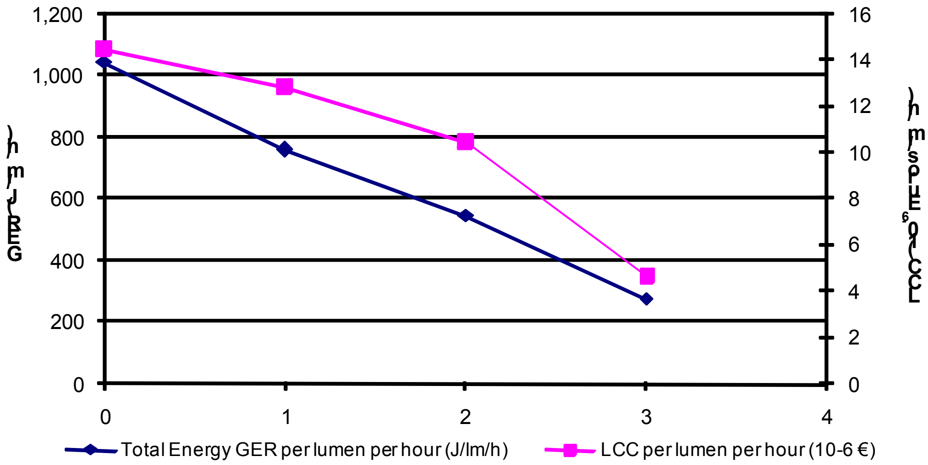

Figure 7-1: LCC curve – environmental performance expressed in total energy consumption (GER) for the improvement options for the base-case GLS-C

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.

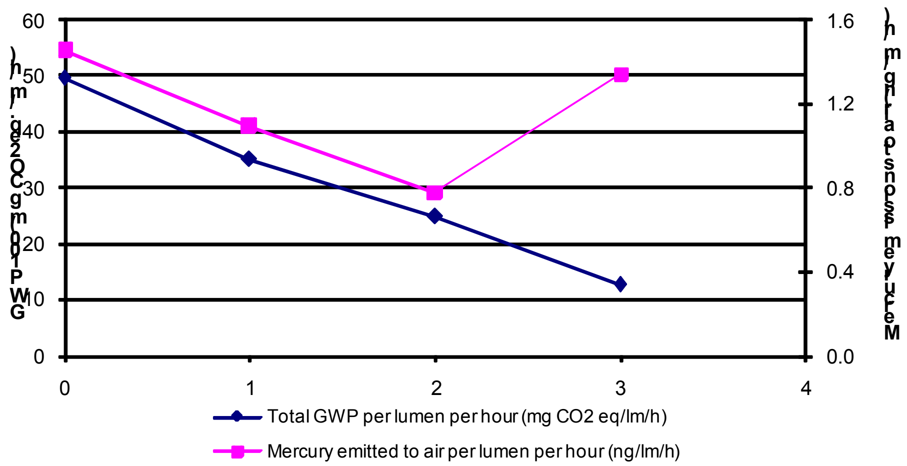

Figure 7-2: Environmental performance expressed in GWP and in mercury emissions for the improvement options for the base-case GLS-C

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.

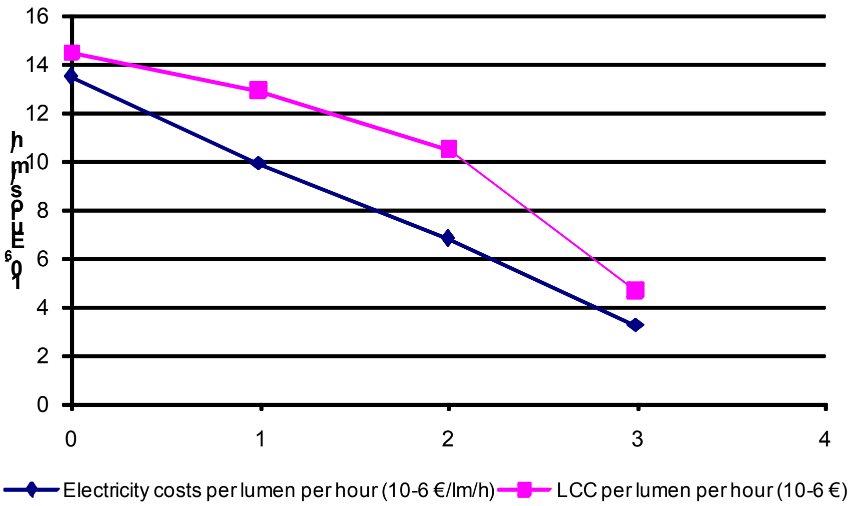

Figure 7-3: LCC curve – environmental performance expressed in total electricity costs for the improvement options for the base-case GLS-C

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.

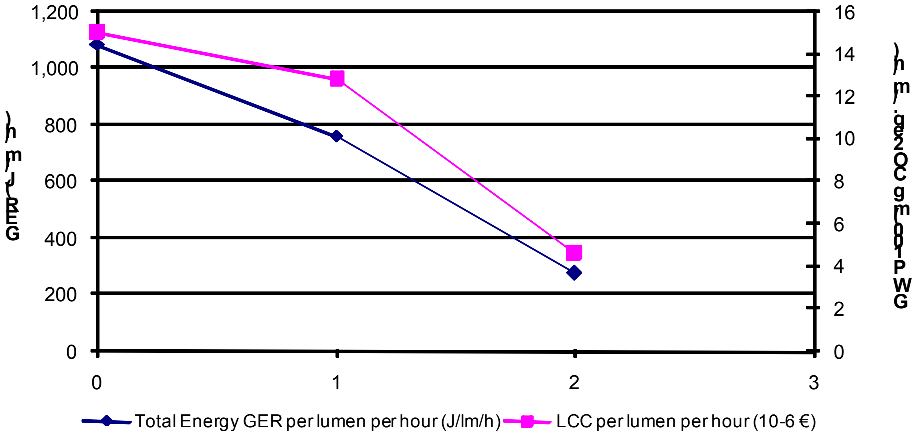

Figure 7-4: LCC curve – environmental performance expressed in total energy consumption (GER) for the improvement options for the base-case GLS-F

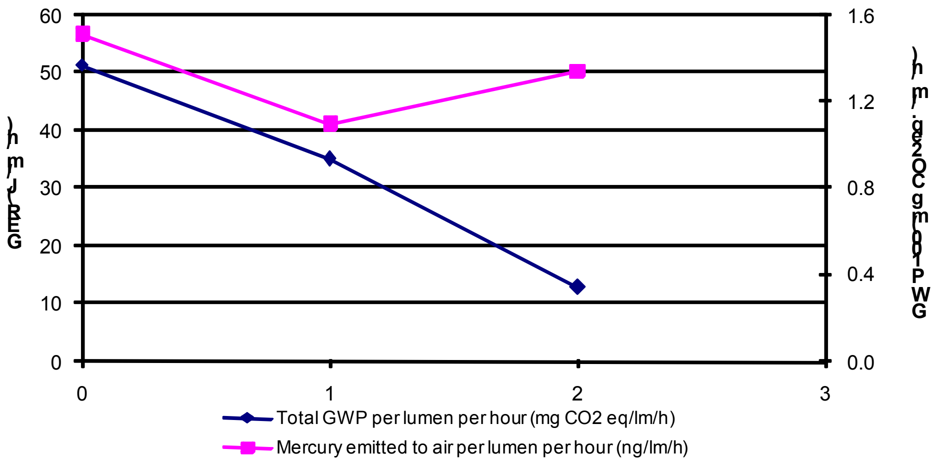

Figure 7-5: Environmental performance expressed in GWP and in mercury emissions for the improvement options for the base-case GLS-F

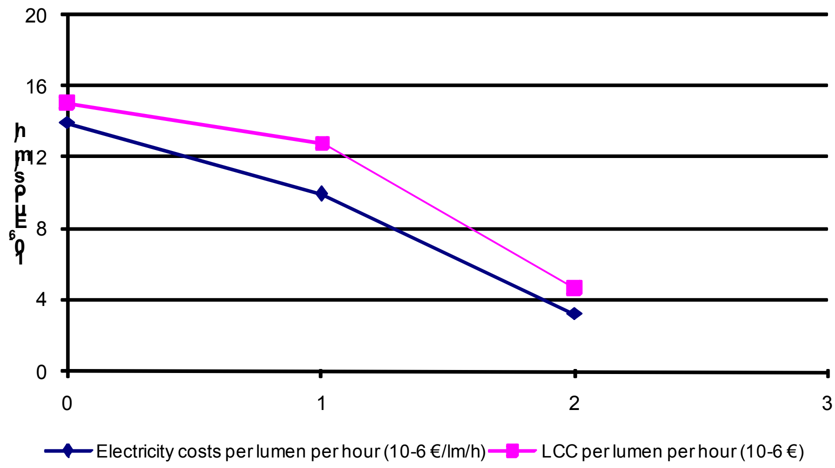

Figure 7-6: LCC curve – environmental performance expressed in total electricity costs for the improvement options for the base-case GLS-F

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

		Base-case GLS-F	***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	**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 %.

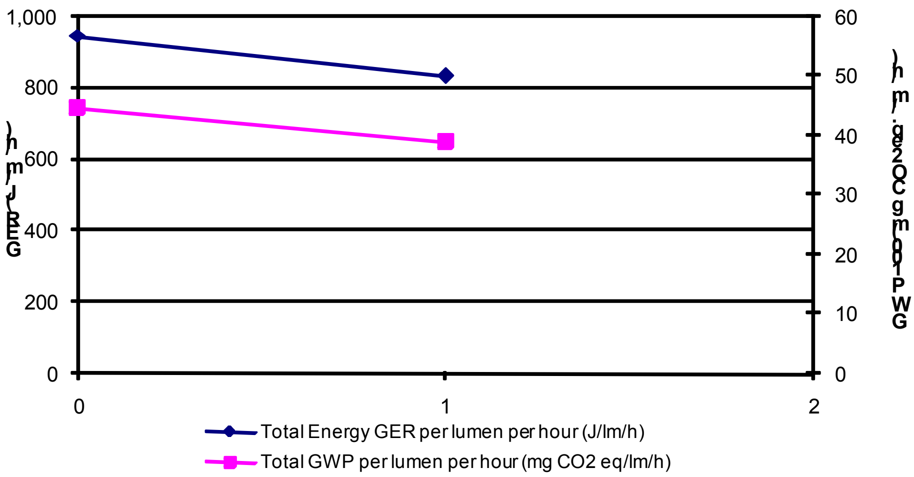

Figure 7-7: Environmental performances expressed in GER and in GWP for the improvement option for the base-case HL-MV-LW

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.

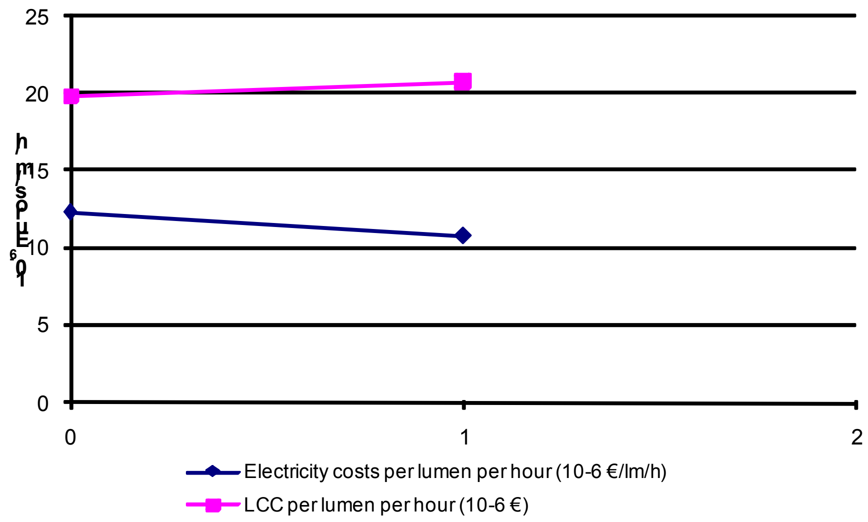

Figure 7-8: LCC curve – environmental performance expressed in total electricity costs for the improvement option for the base-case HL-MV-LW

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 CO_2 eq.	**44.5**	**38.9**
	variation with the base-case	*0.0%*	*-12.6%*
Acidifying agents (AP)	μg SO_2 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 PO_4	**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 %.

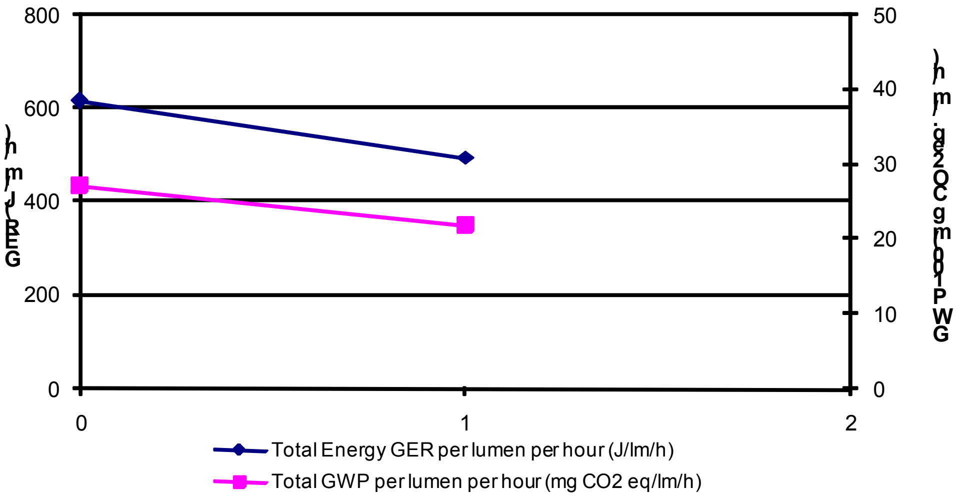

Figure 7-9: Environmental performances expressed in GER and in GWP for the improvement option for the base-case HL-MV-HW

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 %.

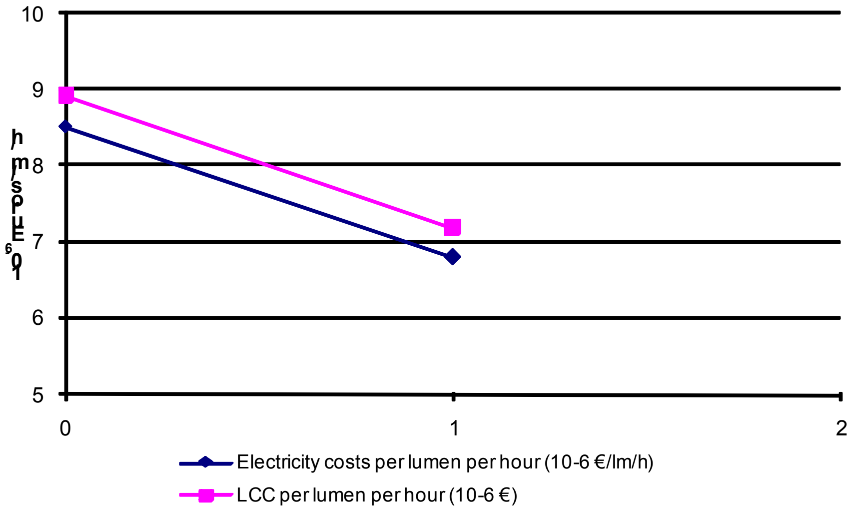

Figure 7-10: LCC curve – environmental performance expressed in total electricity costs for the improvement option for the base-case HL-MV-HW

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.

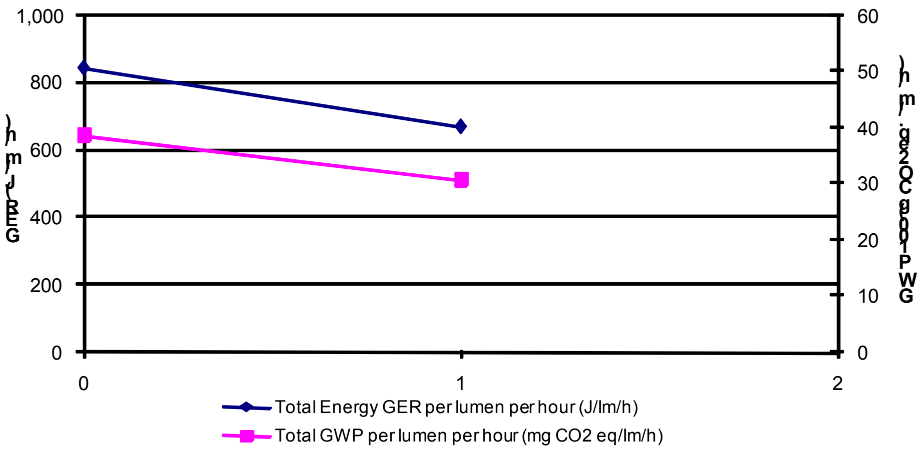

Figure 7-11: Environmental performances expressed in GER and in GWP for the improvement option for the base-case HL-LV

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.

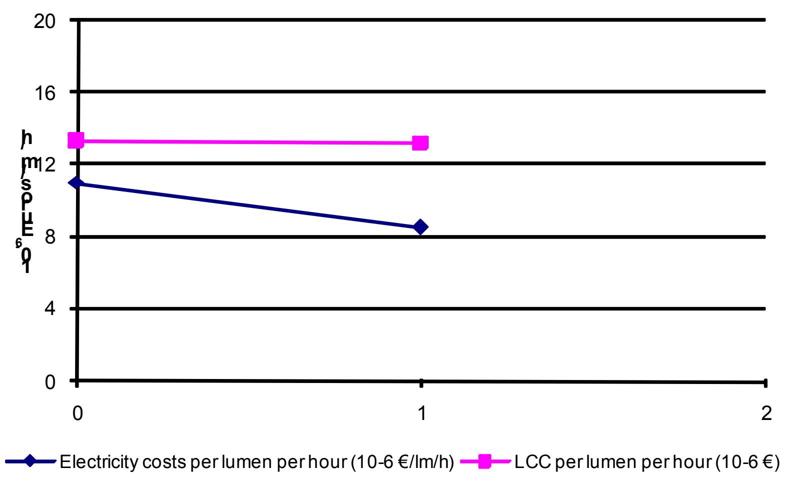

Figure 7-12: LCC curve – environmental performance expressed in total electricity costs for the improvement option for the base-case HL-LV

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.

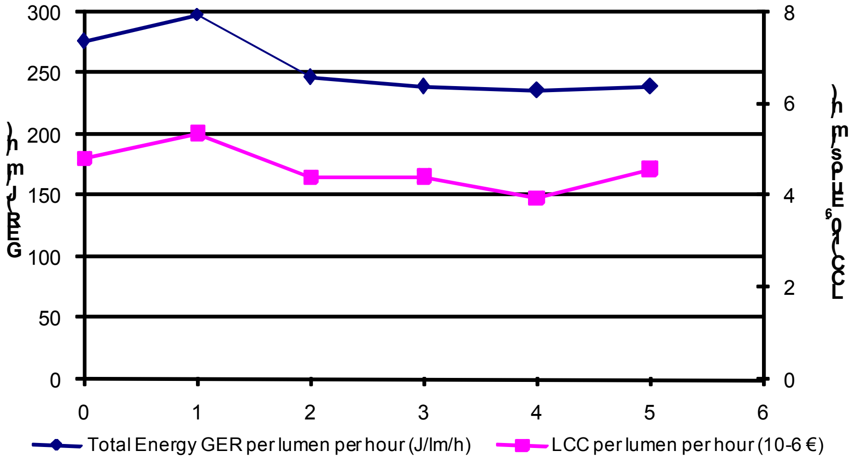

Figure 7-13: LCC curve – environmental performance expressed in total energy consumption (GER) for the improvement options for the base-case CFLi

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.

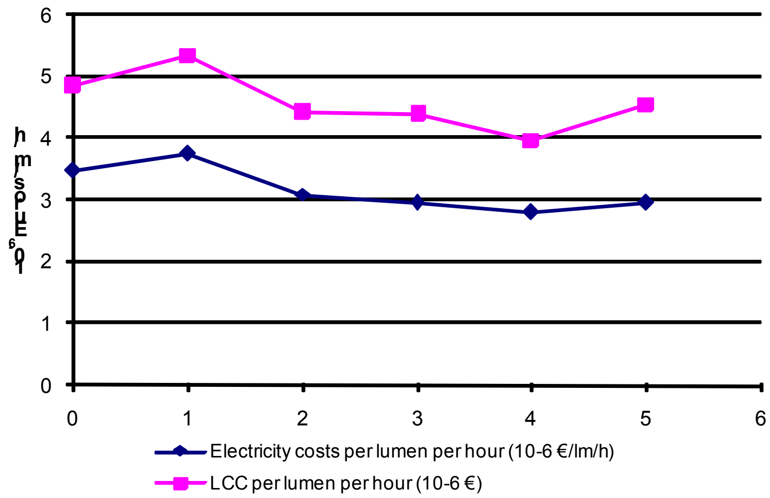

Figure 7-14: LCC curve – environmental performance expressed in total electricity costs for the improvement options for the base-case CFLi

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.

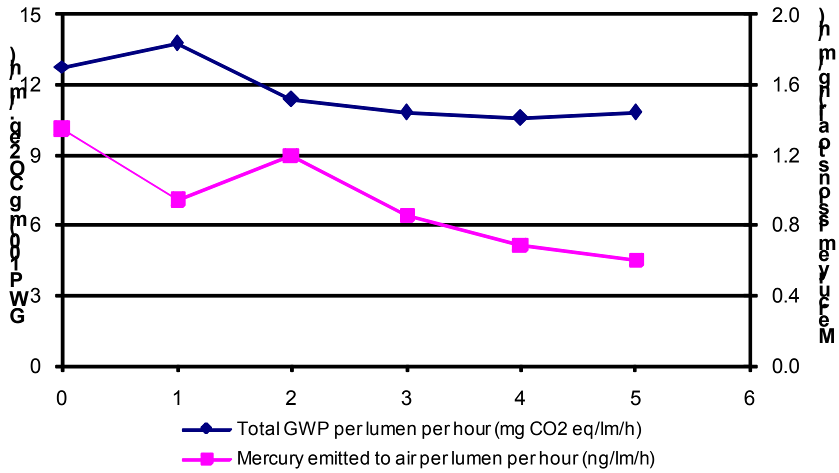

Figure 7-15: Environmental performance expressed in GWP and in mercury emissions for the improvement options for the base-case CFLi

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 is elaborated in part 2 of the study (in sections 8.1.2.8 and 8.1.2.9 taking into account luminaires).

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 SCENARIO- POLICY- IMPACT- AND SENSITIVITY ANALYSIS

Important remark: This preliminary chapter 8 only discusses part 1 of the study concerning non directional light sources. Directional light sources, such as reflector lamps, and luminaires will be treated in part 2 of the study.

Scope: This chapter summarizes and totals the outcomes of all previous tasks. It looks at suitable policy means to achieve the improvement potential e.g. implementing LLCC as a minimum and BAT as a promotional target, using legislative or voluntary agreements, labelling and promotion. It draws up scenarios 2007 – 2020 quantifying the improvements that can be achieved vs. Business-as-Usual. It makes an estimate of the impact on consumers and industry as explicitly described in Annex 2 of the Directive.
Finally, in a sensitivity analysis of the main parameters and robustness of the outcomes is studied.

It has to be kept in mind that the conclusions represent solely the point of view of the consortium and they do not reflect the opinion of the European Commission in any way. Unlike chapters 1-7, which will serve as the baseline data for the future work (impact assessment, further discussions in the EuP Consultation Forum, and development of implementing measures, if any) conducted by the European Commission, the chapter 8 simply serves as a summary of policy implications as seen by the consortium. Further, some elements of this chapter may be analysed again in a greater depth during the impact assessment.

8.1 Policy- and scenario analysis

8.1.1 Eco-design requirements

In this chapter generic and specific product related eco-design requirements are described that can be used as suitable policy means to achieve BAT or LLCC scenario targets.
Please note that there are finalised preparatory studies on 'street' (lot 9) and 'office' (lot 8) lighting that include mainly topics related to HID lamps and fluorescent lamps with non integrated ballasts. In this study (lot 19) horizontal measures are recommended for any lamp type or light source, including in principle also office and/or street lighting products. The proposed minimum requirements formulated for street and office lighting are normally higher and related implementing measures are already under consideration by the EC.
Because domestic lighting products can also be used in many other general lighting applications, the proposed measures hereafter obviously have a wider scope. Therefore, it is important to assess the potential negative impact beyond domestic lighting sector (see 8.2).

8.1.1.1 Generic Eco-design requirements on the supply of information

Optimal use of domestic lighting starts with adequate information on existing products. Therefore, it is proposed that the manufacturers provide information on the following 'most relevant' eco-design parameters and follow the proposals for the appropriate means for communicating these parameters to the consumer. The provision of information on these 'most relevant' parameters should satisfy article 15.4 (f) to reduce unnecessary administrative burden and allow verifying compliance with proposed specific implementing measures.
In many cases it is impossible to distinguish, at the 'placing on the market' stage, lamps and luminaires that are intended for 'domestic' lighting from other indoor lighting applications as in restaurants, hotels, etc. It is therefore recommended to define a broader scope for lamps and luminaires within the specific eco-design requirements.
Lamps, luminaires and ballasts for office lighting can also be used in certain domestic applications but they were already discussed in the dedicated preparatory study on office lighting (lot 8), and thus will not be considered again. Street and office lighting products have other needs for the provision of information, see preparatory study on lot 8 and lot 9. In order to distinguish these products, it is recommended to exclude certain light sources, e.g. by light source (above 2000 lumen) or by lamp type (HID and LFL lamps).

Information available to the end-users at the moment of purchase and on free access websites for any white light source (Annex 9.1.1) within the scope of this study:

a) When the nominal lamp power is displayed outside the energy label in accordance with Directive 98/11/EC, the nominal luminous flux of the lamp shall be also displayed separately in a font at least twice as large as the nominal lamp power display outside the label *(the nominal luminous flux shall never be higher than the rated luminous flux)*;
b) Nominal life time of the lamp in hours *(not higher than the rated life time)*;
c) Number of switching cycles before premature lamp failure;
d) Colour temperature *(does not need to be expressed as a value)*;
e) Colour rendering *(does not need to be expressed as a value)*. Only CRI = 100 can be shown as excellent or perfect, only CRI ≥ 90 can be shown as good or improved, and CRI < 80 must be shown as poor;
f) Warm-up time up to 80% of the full light output *(may be indicated as "instant full light" if less than 1 second)*;
g) A warning if the lamp cannot be dimmed or can be dimmed only on specific dimmers;
h) If designed for optimal use in non-standard conditions (such as ambient temperature Ta ≠ 25 °C), information on those conditions;
i) Lamp dimensions in millimetres (length and diameter);
j) If equivalence with an incandescent lamp is claimed on the packaging, the claimed equivalent incandescent lamp power (rounded to 1W) shall be at least that corresponding in Table 8-1 to the default values for rated luminous flux(Φ_{100})or the average luminous flux(Φav) of the lamp contained in the packaging. The average luminous flux can only be used when test data about the lumen maintenance factor is available and shall be equivalent to the initial luminous flux multiplied by the lumen maintenance factor at half its rated lifetime. The intermediate values of both the luminous flux and the claimed incandescent lamp power (rounded to 1W) have to be calculated by linear interpolation between the two adjacent values. Values below 15 W and above 200 W shall not be claimed. It is not obligatory to put the equivalence on the package (because GLS could become obsolete in the future).

The values for the average luminous flux of the standard GLS-C lamp used for comparison can also be taken from Table 8-1 and corresponding graph in Figure 8-1.

Table 8-1: Average Luminous Flux any lamp in relation to Φ_{100} for a GLS-lamp and a CFLi

Rated lamp luminous flux CFLi Default Φ_{100} [lm]	**Rated lamp luminous flux Halogen Default Φ_{100} [lm]**	**Rated lamp luminous flux Solid State LED Default Φ_{100} [lm]**	**Average lamp luminous flux All Φ_{av} [lm]**	**Claimed equivalent incandescent lamp power [W]**
125	119	136	116	15
229	217	249	212	25
432	410	470	400	40
741	702	806	685	60
970	920	1055	897	75
1398	1326	1521	1293	100
2253	2137	2452	2084	150
3172	3009	3452	2934	200

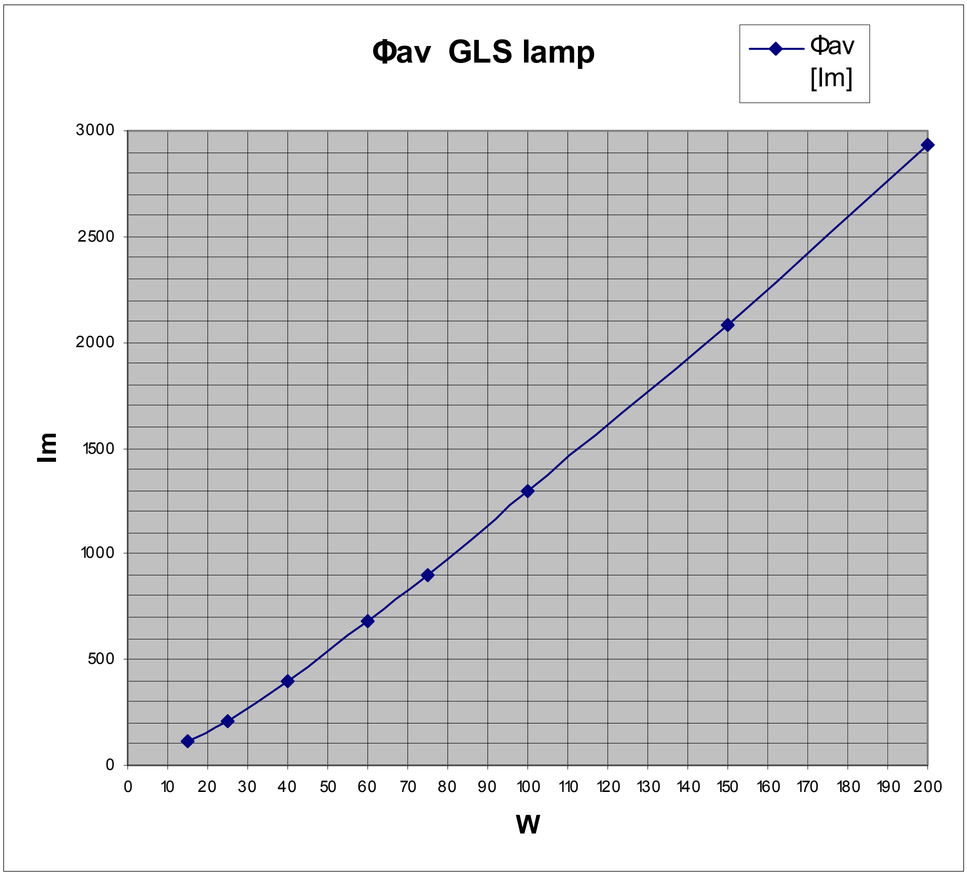

Figure 8-1: Diagram of Φ_{av} for a GLS-C lamp

The term "energy saving lamp":
This can only be provided if the lamp meets the class A efficacy requirements taking into account the correction factors in Table 8-3.

Information to be made publicly available on free-access websites:

The information shall also be expressed as values.

a) The information specified above in points a-j;
b) Rated wattage (0.1 W precision);
c) Rated luminous flux;
d) Rated lamp life time (from Stage 2 if lifetime > 2000 h);
e) Lamp power factor;
f) Lumen maintenance factor at the end of the nominal life
g) Starting time (seconds);

If the lamp contains mercury:
i) Lamp mercury content as X,X mg;
j) Instructions on how to clean up the lamp debris in case of accidental lamp breakage.

Proposed timing for this measure:

As soon as possible, except for the new energy labelling, which requires an update of the relevant Directive.

8.1.1.2 Specific eco-design requirements for reducing losses in the electrical distribution grid due to a poor power factor

The lamp power factor (see chapter 4) should be at least[93] 0,5 in Tier 1; a staged requirement on enhanced power factor is proposed in Table 8-2. The value of Tier 2 is equivalent to Lamp specification Version 6 (2007) of the Energy Saving Trust (UK). The power factor of several CFLi lamps was measured and this showed that above 0.6 is realistic, see chapter 4. Please note also that additional losses due to a poor power factor were taken into account in the assessment in chapter 4, 5, and 7.

Table 8-2: Staged requirements for the power factor

Performance parameter	Tier 1	Tier 2	Tier 3	Benchmark
Lamp power factor	> 0,50[94]	> 0,50	> 0,60	≥ 0,95 (> 0,65)

8.1.1.3 Specific ecodesign requirement for increasing lamp efficacy

The proposed ecodesign requirement is to set minimum efficacy level (ηlamp) for all lamps as a horizontal entry requirement for all lamps to the EU market, independent of technology and application as far as possible. It is proposed to use the existing household lamp labelling values that are connected to lamp efficacy and where appropriate, correction factors should be applied. It is also proposed to have significant lower requirements (label B) for dimmable bright point sources below 1000 lm.

To enable manufacturers and distributors to reorganize, a tiered approach is proposed in the section with the scenarios (see 8.1.2). This also gradually enables the users and distributors to adapt the switch to more efficient light sources. A Life Cycle Cost (LCC) based gradual phase out is proposed in 8.1.2, which means that high wattage inefficient light sources should be phased out first because the payback period or LCC is better as the lamp price is poorly related to lamp power (see chapter 4).
The reason and the proposed corrections factors on the minima are displayed in Table 8-3.

[93] A higher value in Tier 3 would require a more complicated electronic input circuit that compromises the efficiency of the integrated ballast.
[94] In line with 'EcoProfile 070924 CFLi' for ELC federation

Table 8-3: Proposed correction factors for the minimum criteria on label values

Correction factors	
Scope of the correction	**Maximum rated power (W)**
filament lamp requiring external power supply for mains connection	P_{max} / 1.06
CFLi lamp with colour rendering index ≥ 90	P_{max} / 0.85
CFLi lamp with colour rendering index ≥ 90 and Tc >=5000K	P_{max} / 0.75
CFLi lamp with second envelope	P_{max} / 0.95
CFLi with cap GX53	P_{max} / 0.75
light emitting diode requiring external power supply	P_{max} / 1.1

The following lamp types are outside the scope of general illumination and should be excluded from this efficacy requirement:

- Lamps that don't satisfy the 'White light source' criterion (see Annex 9.1.1);
- Lamps with less than 200 lumen in bright point sources (as the light output is too low for general illumination) or else 150 lumen;

Some lamp caps are nowadays frequently used in general illumination but have no energy efficient alternative with an efficacy level equivalent to label B or A. It is connected to the so-called luminaire lock-in effect (see 8.1.1.5). Phasing out these lamps would repeal retrofit lamps from the market for existing luminaires. Therefore in certain scenarios it is proposed to phase out these luminaires first and to introduce special luminaire requirements (see 8.1.1.5) for the time being (see section 8.1.2). It is also possible to announce this phase out and allow people to stock sufficient retrofit lamps for existing luminaires (see 8.1.4.2). The lamp types are:

Lamp type	**Lamp cap**	**Lamp power [W]**	**Minimum label**
Halogen mains voltage (HL-MV)	R7s or Rx7s	50 ≤ W ≤ 300	C
Halogen mains voltage (HL-MV)	G9	all wattages	C

- Minimum level for lamps with cap R7s or Rx7s is label C, for linear HL-MV lamps with a wattage from 150 till 300W the minimum label C. (Comment: The reason for this exception is that these lamps are often used in outdoor lighting with presence detection switches for security application. For such applications, there are currently few efficient alternatives with short warm up time. As a consequence, the ecodesign requirement for luminaires with cap R7s is recommended, see 8.1.1.5.). If luminaire and lamp manufacturers come up with alternative solutions, this requirement might be reviewed in future.
- HL-MV lamps with lamp cap G9, because as of today no label B energy efficient solutions exist with similar dimensions;

Further considerations for setting the level of the requirements::

- For lumen output below 1000 lm, fully dimmable bright point sources may have to remain available with existing technology. Therefore, the proposed minimum level may have to be kept at label B for such lamps as currently no technology exists that could match these requirements. For the 'Bright point source' definition see Annex 9.2.2. These sources are often needed for decorative purposes. It is assumed that fully dimmable lamps for decorative purposes, that have an higher lumen output and that satisfy the 'Bright point source' (see Annex 9.2.2) criterion, are less needed; the reason is that they would cause too much glare in the field of view. HID lamps can provide a very efficient 'Bright point source' but are not fully dimmable. For high lumen outputs it is still possible to use luminaires with several lamps or to install several luminaires. HID lamps need an extra ballast or control gear to be installed in the luminaire, therefore in exceptional cases, some users will need to change luminaires on the long run. Dimming as such can also be achieved with dimmable CFLi (see chapter 6).
- Please note that the mains voltage halogen lamps with xenon (see also chapter 6) have label D below 450 lumen and label C above.
- The most critical known efficient GLS lamp application are oven lamps, however a 200 lumen version still remains available for domestic application in existing ovens. According to our knowledge, the 40 Watt oven lamp is not useful in domestic ovens. However, in industrial ovens it is used and only lamps with special caps (e.g. BA20s) have to be used. Such usage is possible only after replacement of the sockets which is not a complicated measure in the professional market or one could install a transformer to use low voltage filament lamps that are available with label B efficacy.
- Inefficient halophosphate fluorescent lamps have a Colour Rendering Index below 80 and could also be phased out by this proposal (see the Working Document on office lighting lot 8). The proposed 'Bright point source' criterion is needed to prevent phasing out HPS lamps with a clear envelope (see working document on street lighting lot 9).
- The reason for the exception on lamps with cap R7s is that halogen main voltage lamps with R7s cap are often applied in luminaires with presence detection and they have to give instant light, what other lamp types cannot for the moment. Lamps above 300 W are mainly used for general lighting where warm-up time is no problem; as a consequence lamps can be replaced by HID-lamps in appropriate luminaires. The lot 9 study on street lighting already revealed that for high wattage solutions an efficient HID based replacement including the luminaire is justified for LCC and ecological impact; the very low efficacy of HL-MV compared to HID justifies this even more.
- The reason for the exception on lamps with cap G9 is that no label B energy efficient solutions exist nowadays with G9 socket and the same lamp dimensions. This socket is mainly used for HL-MV lamps. It is recommended to review this requirement as soon as existing luminaires are outdated and consumers hopefully move towards luminaires that can host more efficient lamps. (e.g. in Tier 3 or later)..

8.1.1.4 Specific ecodesign requirements for minimum lamp performance and mercury content

For Tier 1 values Table 8-4 were chosen in accordance with the ELC Federation Eco-Profile (EcoProfile 070924 CFLi). In Tier 2, these values may not significantly increase as there will be a possible temporary overshoot in CFLi demand due to the phase out of GLS lamps. The Tier 3 requirements are based on evaluation of existing products and from different quality charters:

- The European Compact Fluorescent Lamps Quality Charter (draft version 2008);
- Lamp specification Version 6 (2007) of the Energy Saving Trust (UK);
- Directive (2002/747/EC) on ecological criteria for the award of the Community eco-label to light bulbs;
- ELI Voluntary Technical Specification for Self-Ballasted Compact Fluorescent Lamps (CFLs) (First edition 2006-03-01); and
- Draft (December 2007) Australian MEPS on CFLs and proposals.

The values in parenthesis in Table 8-4 indicate the requirements for mercury-containing lamps if they are different from the requirements on all lamps. For HID, CFLni and LFL lamps, specific criteria were elaborated in the street lighting preparatory study (lot 9) or office lighting preparatory study (lot 8).

Lifetime should be tested according to lamp related EN standards (see chapter 1), please note that this includes the standard on/off switching cycle and hence a minimum amount of on/off switching cycles is requested (e.g. for CFLi this is 2h45 on and 0h15 off). For the fast cycle test please consult Directive (2002/747/EC).

Table 8-4: Staged performance requirements

Performance parameter	Tier 1	Tier 2	Tier 3	Benchmark
Minimum rated lamp lifetime & lamp survival factor (LSF)	1000h&LSF=0.5 (6000h&LSF=0,5)	1000h&LSF=0.5 (6000h&LSF=0.5)	2000h&LSF=0.5 (6000h&LSF=0.7)	4000h&LSF=0.5 (15000h&LSF=0.5)
Lumen maintenance	85% at 1000h (85% at 2000h or 80% at 2000h for lamps with second lamp envelope)	85% at 1000h (85% at 2000h or 80% at 2000h for lamps with second lamp envelope)	85% at 1000h (88% at 2000h and 83% at 2000h for lamps with second lamp envelope))	90% at the minimum lamp lifetime
Number of switching cycles[95]	≥ four times the rated lamp life expressed in hours (≥ half the lamp lifetime expressed in hours ≥ 10,000 if lamp starting time > 0,3s)	≥ four times the rated lamp life expressed in hours (≥ half the lamp lifetime expressed in hours ≥ 10,000 if lamp starting time > 0,3s)	≥ four times the rated lamp life expressed in hours (≥ lamp lifetime expressed in hours ≥ 50,000 if lamp starting time > 0,3)s	As defined in EN lamp test standards (Unlimited with versions that have a start delay)
Starting time	<0,2s (< 2,0s)	<0,2s (< 2,0s)	<0,2s (< 1,0s)	< 0,2s
Lamp warm-up time to 60% Φ	1,0s (120s)	1,0s (60s or < 120s if the diameter is less than 65mm and the length below 108mm for lamp flux ≥ 400 lm[96])	1,0s (60s or < 120s if the diameter is less than 65mm and the length below 108mm for lamp flux ≥ 400 lm[96])	1,0s (15s or 4s for special mixed CFLi+HL lamps)
Maximum premature failure rate	5,0%@100h (2%@200h)	2,0%@100h (1%@200h)	2,0%@100h (1%@200h)	
Maximum UVA+UVB radiation[97]	2mW/klm	2mW/klm	2mW/klm	

A proposal for requirements on mercury content in CFLi lamps is included in Table 8-5.
It is the current value in the RoHS Directive for Tier 1 and on the value of the Community Decision (2002/747/EC) for Tier 2.
For Tier 3, it is based on measurements made by VITO on CFLi's that are currently available on the market (see chapter 4) and confirmed by the statement of ELC at the stakeholder meeting in Brussels on 23rd November 2007 that 'a maximum of 1mg of mercury for CFLi's is possible'.

[95] Switching cycles for CFLi's as defined in the method for fast cycle testing, proposed by ELC.
[96] Lamps with the dimension of a standards GLS form A, because amalgam technology is used.
[97] In line with the International Commission on Non-Ionizing Radiation protection (http://www.icnirp.de)

Table 8-5: Requirements on mercury content in CFLi lamps

Tier 1	Tier 2	Tier 3	Benchmark
Hg ≤ 5,0 mg	Hg ≤ 4,0 mg	Hg ≤ 2,0 mg (or 3,0 mg if lamp life > 15000 h or 4,0 mg if lamp life > 20000 h)[98]	Hg ≤ 1,0 mg

8.1.1.5 Specific ecodesign requirements for household luminaires with sockets (e.g. R7s, Rx7s, G9, ..) with special luminaire application requirements

Requirements for any luminaire with socket R7s or Rx7s:

The sales of all luminaires with holders R7s or FA4 without an incorporated presence detector and an ingress protection below IP65 should be prohibited from Tier 1 because these lamps were exempted from the minimum lamp efficacy criteria, see also section 8.1.1.4.
Also all luminaires with RX7s can only be brought on the market if they have a build-in HID ballast.

Requirements for any luminaire with socket G9:

This socket is used for HL-MV lamps and no label B energy efficient retrofit solutions exist nowadays. This will force luminaire manufacturers to move to GY6.35 luminaires that can host efficacy label B HL-LV lamps.

Timing: Tier 1 (in order to avoid that consumers buy luminaires for which no efficient lamps are available)

Please consult also the related section in part 2 of this study.

8.1.1.6 Specific ecodesign requirements for wall-mounted dimmers and electronic control switches

See section 8.1.4.3 on recommendations.

[98] Mercury consumption depends - among others - also from lamp life. There are two main loss mechanisms:
(1) First loss mechanism is related to the formation of Ba-Amalgams, process happening with sputtered and/or evaporated emission mix (mainly Ba atoms) on the glass tube close to the electrode. As long life lamps have in general more emission mix on the coil there is more Ba sputtered/evaporated on the wall, which needs then more mercury for compensation.
(2) Second loss mechanism is the diffusion of Hg into the glass, which is also related to lamp life. To minimize this effect, the glass can be coated with a protective layer like Alumina oxide, slowing down this process.
Other factors affecting mercury consumption are lamp start (preheated or instant start), glass temperature and gas purity.

8.1.2 Scenario analysis

Different policy scenarios 2007-2020 are drawn up to illustrate quantitatively the improvements that can be achieved through the replacement of the base-cases with lamps with higher energy efficiency at EU level by 2020 versus a business-as-usual scenario (reference scenario). Due to the specific properties of the lamp market the scenarios were calculated from 2007.

Eight scenarios listed below have been analysed in order to provide an assessment of various alternative policy options as close as possible within the limits of the model of this study to three options presented in the Working Document and discussed during the Consultation Forum held in Brussels on the 28th March 2008, they are:

- Business-as-Usual (BAU)
- Best Available Technology
- Option 1 Fast (with 3 Tiers: 2009, 2011 and 2013)
- Option 1 Fast B (with 3 Tiers: 2009, 2011 and 2013)
- Option 2 Clear B Fast (with 3 Tiers: 2009, 2011 and 2013)
- Option 2 Clear B Slow (with 5 Tiers: 2009, 2011, 2013, 2015 and 2017)
- Option 2 Clear C Fast (with 3 Tiers: 2009, 2011 and 2013)
- Option 3 Slow (with 5 Tiers: 2009, 2011, 2013, 2015 and 2017)

These scenarios are presented and analysed in the following sections. For each of them, results are presented for each year between 2007 and 2020 per lamp technology (i.e. GLS-F, GLS-C, HL-MV-LW, HL-MV-HW, HL-LV and CFLi) in terms of stock, sales, electricity consumption (during the use phase), CO_2 emissions[99] (during the use phase), and mercury emissions (due to electricity generation during the use phase and emissions at end-of-life for CFLi).

Finally, a comparison of scenarios is presented in section 8.1.2.11 as variation of environmental impacts in reference with the BAU scenario both for the specific year 2020, and for the cumulated total between 2009 (i.e. entry into force of the implementing measure) and 2020.

<u>**General remarks**</u>**:**

- **The first Tier for an implementing measure was supposed in 2009 because this was the earliest possible date. In reality, however, a time shift will occur depending on the real timing of implementation measures.**
- **Scenarios are calculated not for the domestic sector only but for all sectors; they are based on the lamp technology and not the end application.**
- **The scenarios analysis is based on outcomes of chapters 1 to 7, and one has to keep in mind than they are average results based on assumptions (e.g. annual burning hours, wattage, and lamp efficacy).**

[99] The emissions factor used is 0.43kg/kWh according to the MEEuP methodology.

- **The used model is a simplification of reality based on 'discrete' base-cases as defined in chapter 5 and connected discrete improvement options as defined in chapter 7. This discrete base-case model approach is reflected in abrupt changes in calculated energy consumption and lamp sales. In reality, this will be smoother due to spreading in lamp wattages, operational hours, new products, and proactive user behaviour (storing phase out lamps, green procurement, promotional campaigns, choice of retrofit options, etc.). These items will be discussed qualitatively in sections 8.1.4 and 8.2.**
- **In some scenarios, a base-case is replaced with a lamp that also requires luminaire replacement, e.g. the base-case HL-MV-LW (socket G9) with a CFLi. Environmental impacts due to the luminaire replacement are not assessed and thus not taken into account in the scenario analysis. This will be done in the Part 2 of the study.**
- **In some scenarios, a base-case is replaced with a lamp, identified as an improvement option for reducing life cycle cost and environmental impacts, whereas the light quality is not exactly similar, e.g. a GLS-F replaced with a CFLi. Therefore, the scenario analysis is done in a quantitative way as the qualitative assessment was already done in chapter 3.**
- **In the tables presenting the scenarios (except for the BAU), minimum requirements (i.e. minimum energy class) are set for each tier. In order to analyse these scenarios, a specific lamp technology is used as replacement lamp, e.g. HL-LV IRC (infrared coating technology) replacing the base-case HL-LV in the first tier (2009-2011) for the scenario 'Option 2 Clear B Fast'. This assumption, based on improvement options identified in chapter 7, does not mean that this technology (HL-LV IRC) is the only possible way to meet the requirement (i.e. energy class C).**
- **The tables should be interpreted from the point of view of the defined base-cases and improvement options. For this reason, it was not required to discuss upper or lower lamp lumen limits for future legislation in this section.**
- **In some scenarios, sales of an improvement option for base-case are similar for several years (e.g. sales of the improvement option 'CFLi combination 1' for the base-case CFLi in 2018 and 2019 in the scenario 'Option 2 Clear B Fast'). This is due to an assumed linear increase of stocks between 2017 and 2020 for all base-cases in the BAU scenario. Therefore, when replacing a base-case with an improvement option, sales are constant (e.g. in 2018 and 2019 in the previous example) as the gaps between the stocks are also constant. This is not fully realistic but results from the limits of the model used for the scenarios analysis.**
- **In some scenarios, sales of CFLi are lower than those forecasted in the BAU scenario for a specific year. For instance, sales of CFLi in 2020 in the scenario 'Option 2 Clear B Fast' are about 45 million units whereas they are assumed to be about 307 million units in the BAU scenario. This difference is due to a high increase of CFLi sales in the previous years (e.g. 605 million units in 2010 for the 'Option 2 Clear B Fast' scenario compared 335 million units in the BAU scenario) for replacing other base-cases (e.g. GLS-F) which compensates the**

demand in 2020 as the lifetime of a CFLi is much longer than the lifetime of a GLS-F.

8.1.2.1 Assumptions used for the scenarios analysis

Several assumptions had to be made in order to define scenarios and to assess economic and environmental impacts:

- As the scenario analysis concerned all sectors, annual burning hours used for each base-case are those defined in chapter 5 (section 5.5, Table 5-16): 505 h for GLS-C, 551 h for GLS-F, 538 h for HL-MV-LW, 536 h for HL-MV-HW, 705 h for HL-LV and 800 h for CFLi). These values were based on a weighted average of sales and annual burning hours for both the "domestic sector" and "other sectors". Please note also that the same annual burning hours were used for the improvement options (see chapter 7) as for the base-case, e.g. even if we replace a GLS with a CFLi as an improvement option, the original annual burning hours were used.
- When a lamp with a specific technology is removed from the market, for the year 'n' (‘n’ being any year after the removal from the market), the stock of this lamp was calculated with the following formula, assuming that the lamp lifetime is X.YZ years:

  *Stock (n) = Stock (n-1) - 0.YZ*Sales (n-1-X) - (1-0.YZ)*Sales (n-X)*

  When the result of this calculation is null or negative, it means that no more lamp is operating in EU-27.
- Mercury emissions to air due to electricity consumption were calculated using the emission factor of 0.016 mg Hg/kWh, as in chapters 5 and 7.
- For CFLi, we assumed that only 20% of lamps are recycled for all years and that the mercury content is 4 mg in the base-case and 2 mg in the CFLi-combination 1 (high lamp efficacy and less mercury content, as defined in chapter 7).
- Mercury emissions occurring at the end-of-life (EoL) for CFLi sold during the year ‘n’ were integrated in the calculation of mercury emissions for the year ‘n’ and not for the year ‘n+CFLi lifetime’, in order to facilitate the model. This assumption may have an influence when looking at mercury emissions for a specific year, but has a negligible impact when looking at total, cumulative mercury emissions from 2009 to 2020. Therefore, the formula for CFLi is:

  *Mercury emissions (n) = 0.016*Electricity consumption (n) + 80%*4*Sales (n),*

  where mercury emissions is in kg, electricity consumption in GWh and sales in million units. For CFLi-combination 1, the number 4 (mg) is replaced with 2 (mg).
- Sales and stock data (and therefore environmental impacts) are similar for all scenarios (including the BAU) for the years 2007 and 2008, as the entry into force of any legislation is assumed to be in 2009.
- It was assumed that the share of HL-MV-LW lamps being frosted was negligible, and therefore 100% of this lamp technology was assumed to be clear with a socket type G9.
- In some scenarios (‘Option 2 Clear B Slow’ and ‘Option 3 Slow’), minimum requirements only concern the lumen output higher than 450 lm or 1000 lm (only for base-cases GLS-F, GLS-C and HL-MV-LW). Based on sales data provided in chapter

2 per wattage for each lamp technology, the following market shares, average wattage and average lumen output according to the lumen output were assumed:

		X < 450 lm	450 lm < X < 1000 lm	1000 lm < X
GLS-F	Market share	48.4 %	38.8 %	12.8 %
	Wattage	35 W	62 W	102 W
	Lumen output	322 lm	694 lm	1284 lm
GLS-C	Market share	48.4 %	38.8 %	12.8 %
	Wattage	35 W	62 W	102 W
	Lumen output	339 lm	718 lm	1333 lm
HL-MV-LW	Market share	55.0 %	35.0 %	10.0 %
	Wattage	28 W	50 W	75 W
	Lumen output	302 lm	645 lm	1046 lm

For some scenarios ('Option 1 Fast', 'Option 1 Slow', 'Option 2 Clear B Fast', and 'Option 2 Clear C Fast'), a separation was made only at a lumen output of 450 lm and following assumptions were used:

		X < 450 lm	450 lm < X
GLS-F	Market share	48.4 %	51.6 %
	Wattage	35 W	72 W
	Lumen output	322 lm	855 lm
GLS-C	Market share	48.4 %	51.6 %
	Wattage	35 W	72 W
	Lumen output	339 lm	878 lm
HL-MV-LW	Market share	55.0 %	45.0 %
	Wattage	28 W	60 W
	Lumen output	302 lm	798 lm

Furthermore, it was assumed that the annual burning hours were similar for a base-case, whatever the lumen output. For instance, GLS-F with a lumen output lower or higher than 450 lm have an annual burning hours of 505 h.

8.1.2.2 Calculation principle used for the scenarios analysis

The general principle of the environmental analysis for 7 scenarios (excluding the BAU) is that the total annual lumen needed for each base-case (obtained in the BAU scenario) has to be kept constant and it is the key parameter to estimate changes in sales when switching from a base-case to its improvement option(s). For a specific year 'n' the annual lumen needed for a base-case A is calculated in the BAU as follow:

$$\textit{Annual lumen needed}_A\ (n) = \textit{Stock}_A\ (n)\ x\ \textit{Annual Burning hours}_A\ x\ \textit{Lumen output}_A$$

Therefore, when analysing one of the 7 scenarios, for the year 'n', for the base-case A with its improvement options (i.e. replacement lamps) A_1, A_2, A_3, the following formula was used:

$$\textit{Annual lumen needed}_A\ (n) = \textit{Annual lumen provided}_A\ (n) + \textit{Annual lumen provided}_{A1}\ (n) + \textit{Annual lumen provided}_{A2}\ (n) + \textit{Annual lumen provided}_{A3}\ (n)$$

And the 'Annual lumen provided$_{Ai}$' for the lamp Ai is computed with the following formula:

$$\textit{Annual lumen provided}_{Ai}\ (n) = \textit{Stock}_{Ai}\ (n) \times \textit{Annual Burning hours}_{Ai} \times \textit{Lumen output}_{Ai}$$

Until the base-case A is removed from the market, and therefore not replaced with an improvement option, the following equality has to be verified:

$$\textit{Annual lumen needed}_A\ (n) = \textit{Annual lumen provided}_A\ (n)$$

When the base-case is replaced with an improvement option (e.g. GLS-F < 450 lm with CFLi) in the year 'n', the total amount of annual lumen provided by the GLS-F < 450lm, i.e. the base-case GLS-F, decreases gradually from the year 'n' onwards, until the stock of this specific lamp reaches zero. At the same time, the amount of annual lumen provided by the improvement option CFLi is rising year by year in order to compensate decrease GLS-F sales and to keep the 'Annual lumen needed$_{GLS\text{-}F}$' constant.

In some scenarios, the replacement of the base-cases GLS-F and GLS-C (with CFLi or Xenon HL-MV-LW), may lead to an excess lumen output compared to the annual lumen needs of these base-cases in the BAU. On one hand, this is due to the constant reduction of the 'Annual lumen needed' for these base-cases from 2009 to 2020, as their stocks decrease, and on the other hand, to the higher lifetime of the replacement lamps, mainly with the CFLi. In this case, the 'lumen surplus' is compensated by adjusting the sales of the corresponding base-case(s). For instance, when the base-case GLS-F is replaced with a CFLi (combination 1), which some years after the replacement provides more annual lumen than needed by the GLS-F according to the BAU, e.g. difference of 100 billion lumen, the number of new CFLi (combination 1) used as replacement lamp for the base-case CFLi is adjusted so as to provide 100 billion lumen less that needed for this base-case in BAU. Therefore, the total annual lumen needed for all base-cases remains constant.

8.1.2.3 Scenario "BAU"

The first step required in order to build scenarios, is to define the Business-as-Usual scenario that will serve as reference.

First, the number of NDLS lamps per household (i.e. in the domestic sector) per lamp type for the year 2011 and 2020 was estimated as specified in chapter 2, section 2.2.6. Moreover, data in 2006 is already know and provided in chapter 2.

Data presented in Table 8-6 show that the total number of lamps in the domestic sector was assumed to constantly increase (+31% in 2020 compared to 2006).

Table 8-6: Forecasts of number of lamps per household in the domestic sector (BAU)

	GLS-F	GLS-C	HL-MV-LW	HL-MV-HW	HL-LV	CFLi	TOTAL
	Nb/hh	Nb/hh	Nb/hh	Nb/hh	Nb/hh	Nb/hh	Nb/hh
2006	9.11	2.61	0.34	0.39	2.19	3.54	**18.21**
2007	7.89	2.42	0.60	0.59	2.24	4.81	**18.48**
2008	6.89	2.22	0.86	0.72	2.30	5.85	**18.80**
2009	6.08	2.03	1.12	0.84	2.37	6.70	**19.13**
2010	5.43	1.84	1.39	0.97	2.43	7.40	**19.45**
2011	4.87	1.65	1.65	1.10	2.50	8.00	**19.77**
2012	4.47	1.64	1.76	1.13	2.55	8.47	**20.00**
2013	4.26	1.62	1.86	1.16	2.59	8.75	**20.24**
2014	4.07	1.61	1.97	1.19	2.64	9.00	**20.47**
2015	3.95	1.59	2.07	1.22	2.68	9.19	**20.71**
2016	3.83	1.58	2.18	1.25	2.73	9.38	**20.94**
2017	3.73	1.56	2.28	1.28	2.77	9.55	**21.18**
2018	3.64	1.55	2.39	1.31	2.82	9.70	**21.41**
2019	3.56	1.54	2.49	1.34	2.86	9.85	**21.65**
2020	3.48	1.52	2.60	1.37	2.91	10.00	**21.88**

Based on these lamp stocks per household, the stock and the sales per lamp type were calculated for the years from 2007 to 2020 for the domestic sector. In chapter 5 (section 5.5) sales and stock data were also computed for 2007 for all sectors (i.e. domestic sector + other sectors). For the total stock and sales from 2007 to 2020, it was assumed that the share of the domestic sector remains constant in order to calculate data for all sectors. These estimates are presented in Table 8-7., and are similar to those presented in chapter 2 (see Table 2-28 in section 2.2.7), and detailed results are presented in Annexe 8-1.

Several observations can be made from this table:

- As expected, even without any legislation, the market share and the stock of incandescent lamps (GLS-F and GLS-C) decrease in line with the chapter 2 assumptions. Between 2009 and 2020 the stock and the sales of GLS-F are assumed to be reduced by 41% (i.e. about 576 million units) and 29% (i.e. about 218 million units) respectively. For the base-case GLS-C, the decrease of the stock and sales are about 25% and 21% respectively.

Sales and stock decrease of GLS-F and GLS-C are very significant between 2007 and 2011, and less noticeable between 2011 and 2020 as highlighted in Figure 8-3 and Figure 8-5. The reasons of these trends are detailed in chapter 2, section 2.3.1.

- According to the assumptions made in chapter 2, it is expected that HL-MV-LW lamps represent a significant market share in 2020, with a 131% increase of the stock, and a 69% increase of the sales in comparison to 2009.
- Being the most energy efficient and cost-effective lamp over the whole life cycle, the stock of CFLi will increase, especially between 2007 and 2011 as explained in chapter 2, section 2.3.1. However, sales of CFLi are not assumed to increase continuously. CFLi sales is expected to peak in 2007-2008 and hereafter to decrease to a constant level around 2013 and then increase very slowly – this is a conservative forecast as the manufactures are actually inventive in order to keep the actual level of CFLi sales as described in section 2.3. However, the stock of CFLi will constantly grow as the sales in that period will be new sales - replacement sales will be delayed due to the long lifetime of this lamp type.

Sales and stock data are presented in Figure 8-2 to Figure 8-5 both in % and in units.

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Table 8-7: Market data for the BAU scenario (for all sectors)

		Base-case GLS-F	Base-case GLS-C	Base-case HL-MV-LW	Base-case HL-MV-HW	Base-case HL-LV	Base-case CFLi
2007	Total stock (mln)	1,800.1	568.5	134.4	119.4	558.3	1,010.1
	Total sales (mln)	767.4	297.0	97.4	84.1	147.0	353.0
2008	Total stock (mln)	1,580.0	523.5	193.5	151.3	571.5	1,228.5
	Total sales (mln)	687.9	273.1	115.2	89.8	149.3	353.1
2009	Total stock (mln)	1,399.9	478.4	252.5	183.1	584.7	1,407.0
	Total sales (mln)	624.9	249.2	133.0	95.5	151.5	342.3
2010	Total stock (mln)	1,251.3	433.4	311.6	214.9	597.9	1,554.0
	Total sales (mln)	573.7	225.3	150.7	101.1	153.8	334.6
2011	Total stock (mln)	1,123.7	388.3	370.6	246.8	611.1	1,680.0
	Total sales (mln)	527.8	201.5	168.5	106.8	156.0	333.2
2012	Total stock (mln)	1,038.3	385.0	394.3	253.5	622.2	1,778.7
	Total sales (mln)	444.8	200.8	174.8	107.6	158.2	322.7
2013	Total stock (mln)	992.8	381.6	418.1	260.2	633.3	1,837.5
	Total sales (mln)	446.3	200.2	181.0	108.4	160.4	296.0
2014	Total stock (mln)	953.6	378.3	441.8	267.0	644.5	1,890.0
	Total sales (mln)	434.3	199.6	187.2	109.3	162.6	297.5
2015	Total stock (mln)	927.1	374.9	465.5	273.7	655.6	1,929.9
	Total sales (mln)	431.7	199.0	193.5	110.1	164.8	291.9
2016	Total stock (mln)	900.5	371.6	489.2	280.4	666.7	1,969.8
	Total sales (mln)	423.0	198.3	199.7	110.9	166.9	297.2
2017	Total stock (mln)	878.1	368.2	512.9	287.2	677.9	2,005.5
	Total sales (mln)	418.4	197.7	206.0	111.7	169.1	298.3
2018	Total stock (mln)	859.9	364.8	536.6	293.9	689.0	2,037.0
	Total sales (mln)	416.0	197.1	212.2	112.5	171.3	298.9
2019	Total stock (mln)	841.7	361.5	560.3	300.6	700.1	2,068.5
	Total sales (mln)	411.4	196.5	218.4	113.3	173.5	303.1
2020	Total stock (mln)	823.6	358.1	584.0	307.4	711.3	2,100.0
	Total sales (mln)	406.9	195.8	224.7	114.2	175.7	307.3

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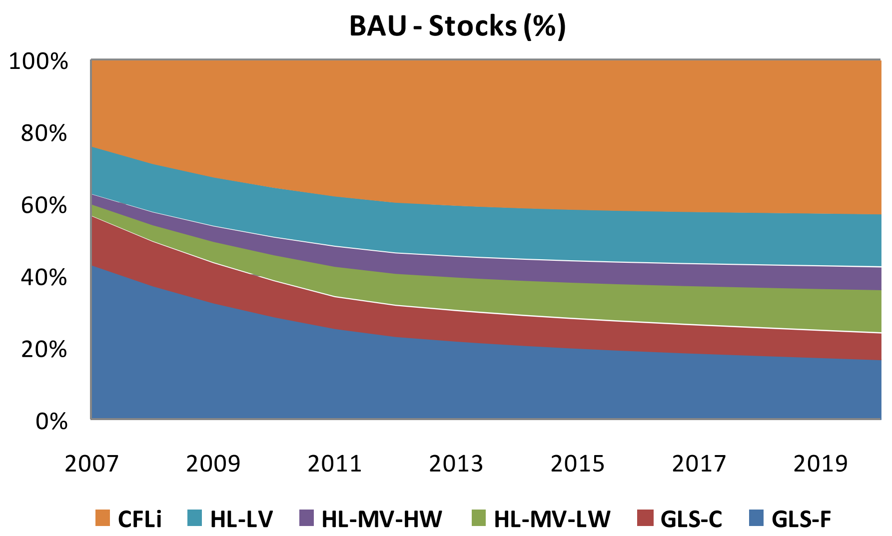

Figure 8-2: BAU – Evolution of lamps stocks (in %)

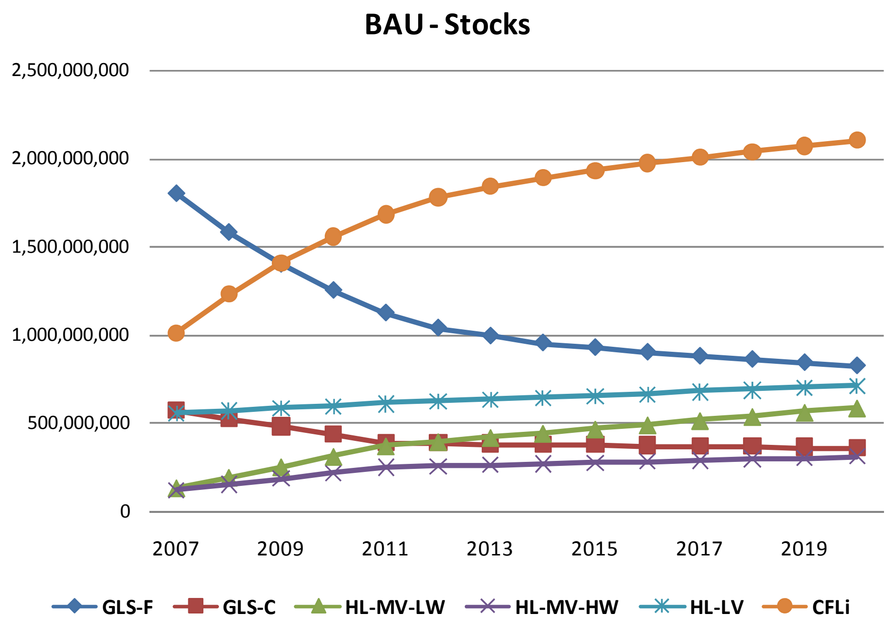

Figure 8-3: BAU – Evolution of lamps stocks (in units)

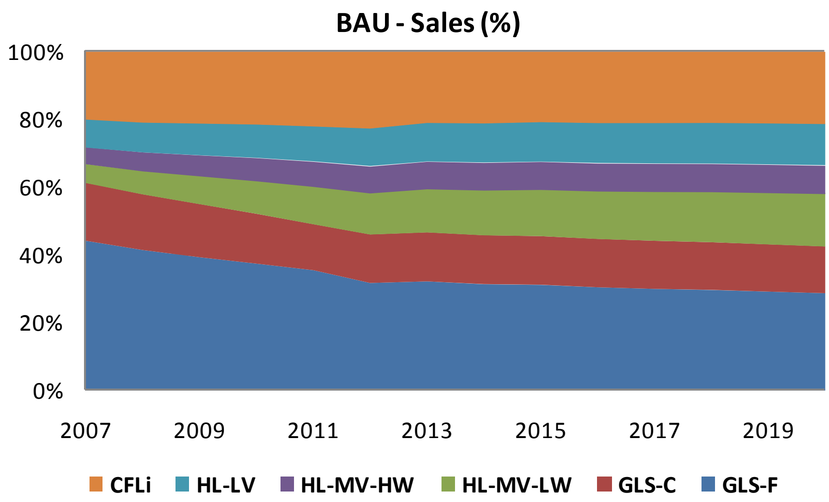

Figure 8-4: BAU – Evolution of lamps sales (in %)

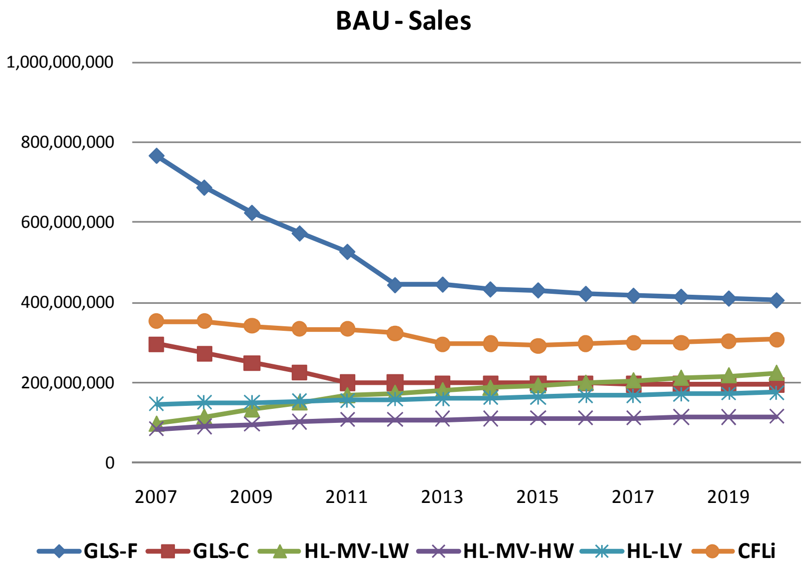

Figure 8-5: BAU – Evolution of lamps sales (in units)

The previous stock and sales analysis is required in order to proceed with the environmental analysis. Three environmental impacts were assessed:

- Electricity consumption during the use phase (this stage represents at least 91% of the total electricity consumption over the whole life cycle for the six base-cases);
- CO_2 emissions due to the electricity consumption during the use phase (proportional to the electricity consumption); and
- Mercury emissions to air due to the electricity consumption during the use phase and the end-of-life phase for CFLi, as this lamp type contains mercury.

The evolution of these environmental impacts is presented in Figure 8-6 from 2007 to 2020. It can be seen that in the Business-as-Usual scenario, the total electricity consumption will increase despite the slow replacement of GLS lamps with more efficient lamps (CFLi and

HL-MV-LW) because of an increasing use of lamps (in the domestic sector from 24.3 lamps/households in 2007 to 31 lamps/household in 2020. Thus, in 2020, the electricity consumption (during the use phase) would reach a level of 134.7 TWh owing to the use of these six lamp types whatever the sector, i.e. an increase of about 20% compared to 2007. The increase of CO_2 emissions is similar (57.9 Mton in 2020 compared to 48.3 Mton in 2007).

Regarding mercury emissions to air, after a growth between 2007 and 2011 (+3.5%), the level decrease until 2013 and then increase continuously until 2020. This evolution is due to the high increase of CFLi sales between 2007 and 2011, and the method chosen to account mercury emissions for CFLi during the EoL (see section 8.1.2.1).

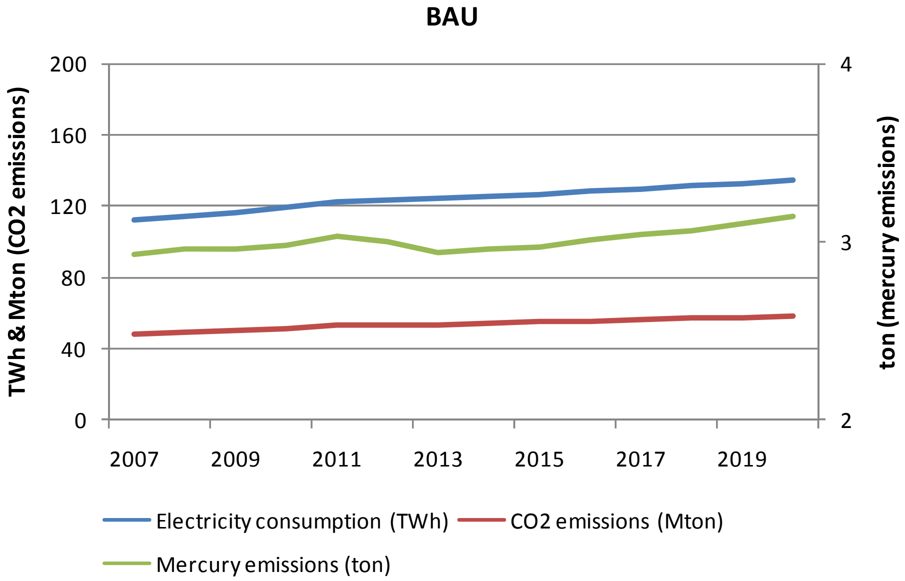

Figure 8-6: BAU – Evolution of annual environmental impacts

For the environmental impact 'Electricity consumption', Figure 8-7 presents the contribution of each lamp technology from 2007 to 2020. Due to its high wattage, and its consequently high electricity consumption per lamp, the lamp technology HL-MV-HW is the major contributor in 2020 to this impact (36.7%) followed by CFLi (17.0%) and GLS-F (16.7%).

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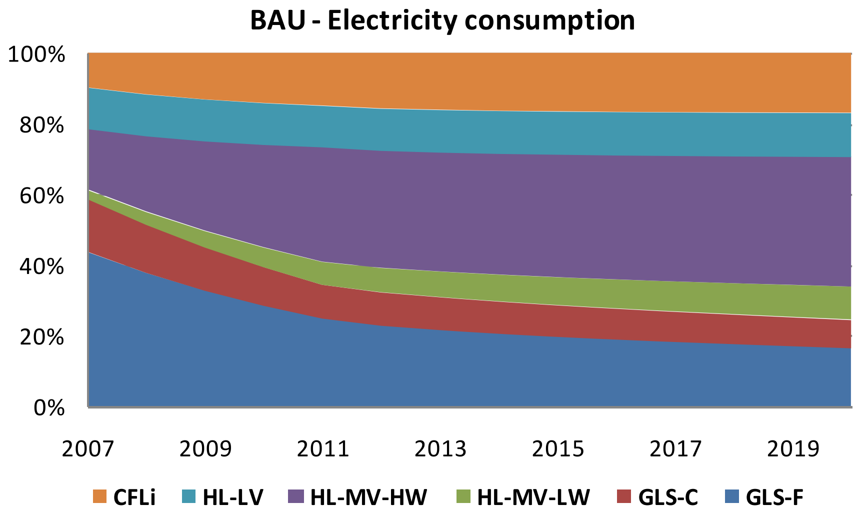

Figure 8-7: BAU - Evolution of the contribution of the lamp types to the electricity consumptions of the total lamp stock

The following sections present the analysis of the 7 scenarios setting minimum lamp efficacy requirements. For each section, the presentation of the analysis is similar and divided in three parts:

a) Presentation of the scenario with the requirements and the Tiers,

b) Presentation of sales and stocks data both in % and in units from 2007 to 2020,

c) Presentation of the environmental impact from 2007 to 2020.

For each scenario, detailed data (sales, stock and electricity consumption) are presented in Annexe 8-1.

8.1.2.4 Scenario "BAT"

The 'BAT' scenario is the most ultimate and a hypothetic scenario, as from 2009, all base-cases are replaced with CFLi (combination 1), i.e. a CFLi with high lamp efficacy and reduced mercury content (2 mg). As highlighted red in Table 8-8, the replacement of halogen lamps with CFLi (combination 1) would also probably require the replacement of the luminaires. As explained in chapter 3, CFLi lamps do not necessary offer the same level of light quality as phased out lamps.

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Table 8-8: BAT – Replacement lamps for each tier

present	2009
requirements	**A (with CFL combination1)**
Base case	**Assumed replacing base-case**
GLS-C	CFLi (combination 1)
GLS-F	CFLi (combination 1)
HL-MV-LW (G9)	CFLi (combination 1)
HL-MV-HW (R7s)	CFLi (combination 1)
HL-LV	CFLi (combination 1)
CFLi	CFLi (combination 1)

Note: in yellow = change from previous phase; in red = change that requires luminaire change

As in chapter 7, CFLi was not assessed as an improvement option for halogen lamps and following assumptions were used in the analysis of the BAT scenario.

Table 8-9: BAT – Assumptions of CFLi replacing halogen lamps

	Base-case HL-MV-LW	**Base-case HL-MV-HW**	**Base-case HL-LV**
	CFLi (comb. 1)	**CFLi (comb. 1)**	**CFLi (comb. 1)**
Wattage	10 W	55 W	10 W
Lamp lifetime	10000 h	10000 h	10000 h
Lumen output	466 lm	4662 lm	466 lm

The BAT scenario would imply that CFLi would represent 100% of the stocks from 2012 when HL-LV lamps, which have the longest lifetime (4.26 years) excluding CFLi, are phased out. In 2020, the stock of CFLi lamps was estimated to be about 4.74 billion units. Detailed results of the analysis of the BAT scenario are presented in Annexe 8-2.

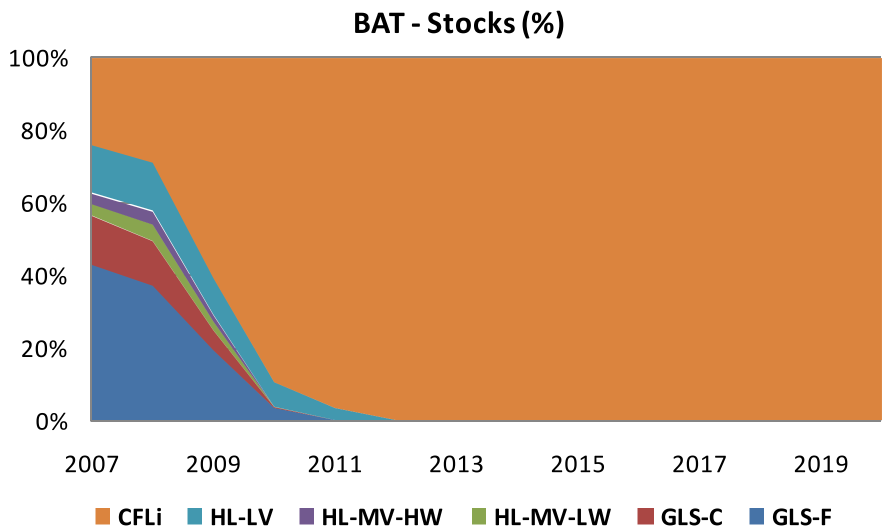

Figure 8-8: BAT - Evolution of lamps stocks (in %)

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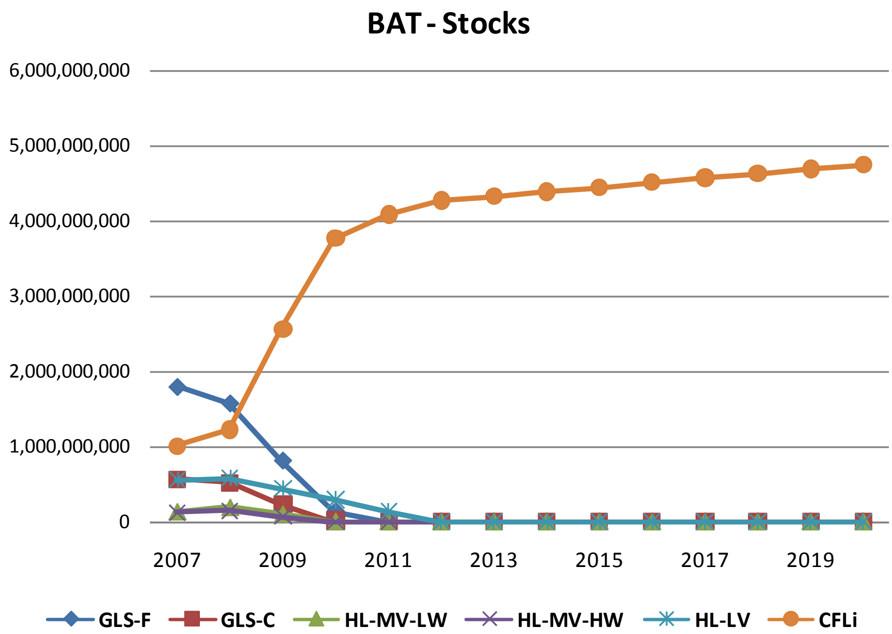

Figure 8-9: BAT - Evolution of lamps stocks (in units)

Obviously, as CFLi is the only lamp type meeting the requirements and consequently sold in the EU-27 market after 2009 in the BAT scenario, it represents 100% of the market from this year onwards (see Figure 8-10).

CFLi sales strongly increase in 2009 compared to 2008 (+349%) in order to compensate the total annual lumen needed for the five base-cases that are removed from the market. After all replacement is over, the yearly CFLi sales are much lower and stay quite constant from 2015 onwards (60.7 million units). Indeed, as the lamp lifetime of CFLi (combination 1) is much longer than the base-cases (10000 h for CFLi combination 1), replacement sales for each year are lower. Some years after 2020, CFLi sales will increase when the 10000 h lifetime is reached for the large replacement sales occurring in the first Tier.

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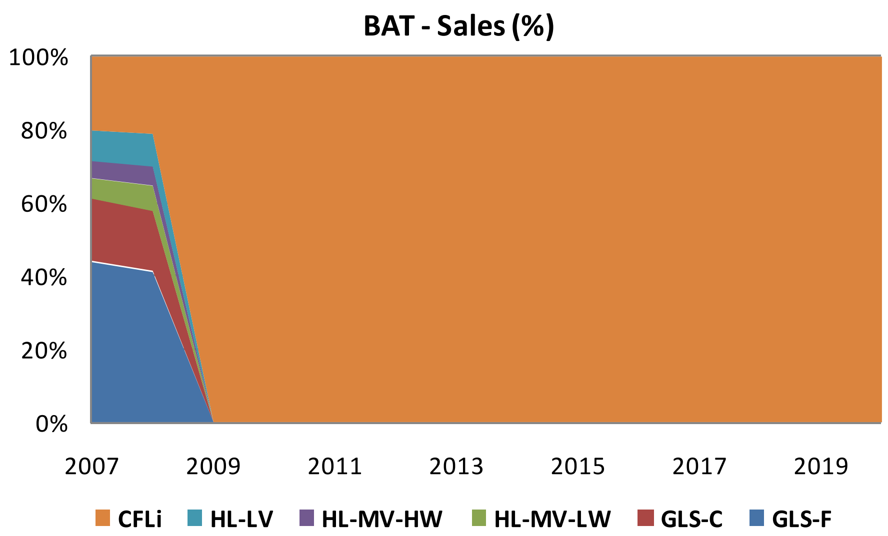

Figure 8-10: BAT - Evolution of lamps sales (in %)

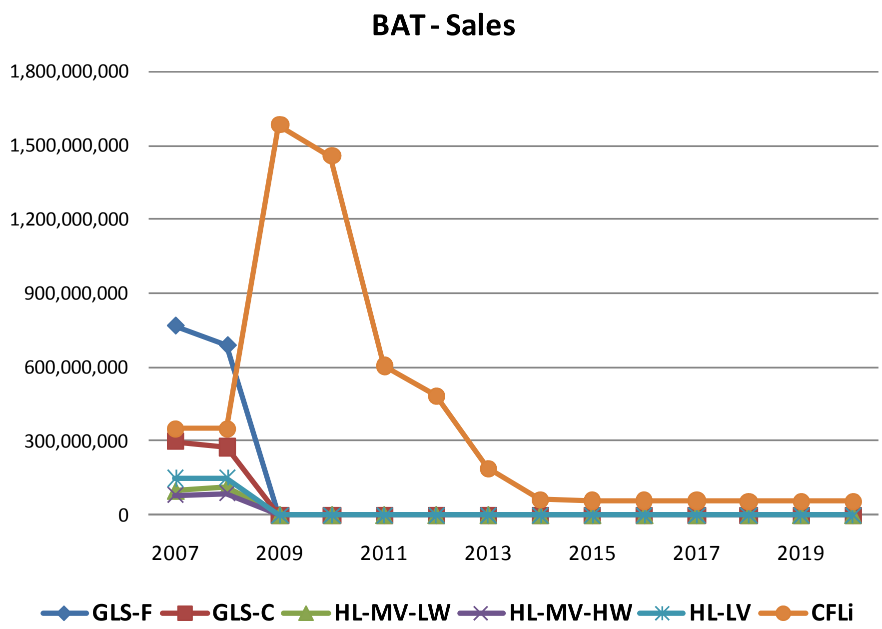

Figure 8-11: BAT - Evolution of lamps sales (in units)

From 2009 onwards, total electricity consumption (and therefore total CO_2 emissions) decreases until 2012 and then increases slightly until 2020, at about the same rate as the CFLi stock (about +1.5% per year).

In 2020, total electricity consumption is expected to be about 47.5 TWh, i.e. 64.7% lower than in the BAU scenario. The reduction is the same for CO_2 emissions (20.4 Mton in 2020).

Regarding mercury emissions, the total amount increases in 2009 due to the high increase of CFLi sales (since mercury emissions occurring at their end-of-life are attributed to the sales year). Then, the emissions decrease until 2014 and afterwards stay relatively constant. In 2020, total mercury emissions to air due to the electricity consumption of lamps during to the use phase, and due to emissions occurring at EoL of CFLi are about 853 kg, which means a reduction of about 72.8% compared to the BAU scenario.

Figure 8-13 shows that after 2012, electricity consumption is only due to CFLi, as at this date the other lamp types have been phased out.

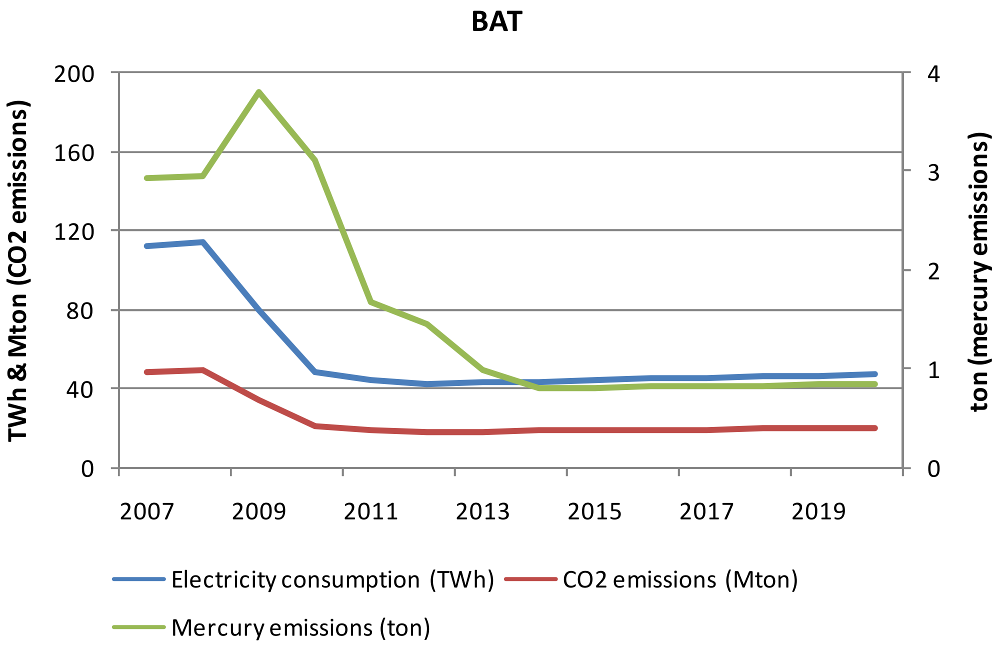

Figure 8-12: BAT – Evolution of annual environmental impacts

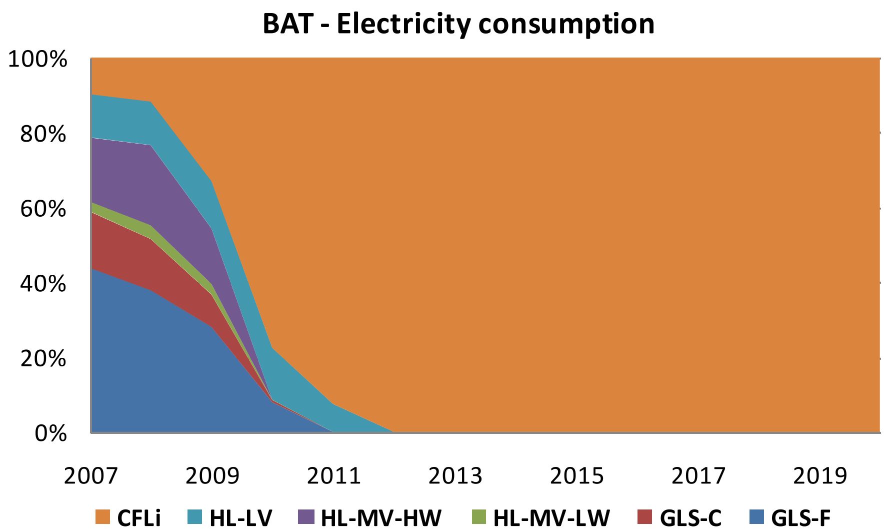

Figure 8-13: BAT - Evolution of the contribution of the lamp types to the electricity consumptions of the total lamp stock

DISCLAIMER: The statements, figures and graphs provided on this page have to be read in the context set out in the beginning of section 8.1.2 and in sections 8.1.2.1 and 8.1.2.2

8.1.2.5 Scenario "Option 1 Fast"

The 'Option 1 Fast' scenario is based on Option 1 presented in the Working Document of the European Commission, and minimum lamp efficacy requirements becoming more and more restrictive with the time, 3 Tiers are defined.

As highlighted in Table 8-10, the replacement of halogen lamps with CFLi or CFLi (combination 1) would also probably require the replacement of the luminaires (in 2009 for HL-MV-LW under 450lm and for HL-MV-HW, in 2001 for HL-MV-LW below 450lm, and in 2013 for HL-LV).

Table 8-10: Option 1 Fast – Replacement lamps for each tier

present	2009	2011	2013
requirements:	**C except below 450lm**	**C (with CFL combination1)**	**A (with CFL combination1)**
Base case	**Assumed replacing base-case**	**Assumed replacing base-case**	**Assumed replacing base-case**
GLS-C	CFLi (except below 450 lm)	CFLi (combination 1)	CFLi (combination 1)
GLS-F	CFLi (except below 450 lm)	CFLi (combination 1)	CFLi (combination 1)
HL-MV-LW (G9)	CFLi (except below 450 lm)	CFLi (combination 1)	CFLi (combination 1)
HL-MV-HW (R7s)	CFLi	CFLi (combination 1)	CFLi (combination 1)
HL-LV	HL-LV	HL-LV	CFLi (combination 1)
CFLi	CFLi	CFLi (combination 1)	CFLi (combination 1)

Note: in yellow = change from previous phase; in red = change that requires luminaire change

HL-MV-LW and HL-MV-HW were assumed to be replaced by CFLi already in 2009 (in spite of a C-class requirement only) because it was assumed that industry would not introduce an improved halogen lamp of that category just for 4 years, i.e. until 2013 as from this year the required level would be A-class.

As in chapter 7, CFLi was not assessed as an improvement option for halogen lamps. The following assumptions were used in the analysis of the 'Option 1 Fast' scenario.

Table 8-11: Option 1 Fast – Assumptions of CFLi replacing halogen lamps

	Base-case HL-MV-LW > 450 lm	**Base-case HL-MV-LW**	**Base-case HL-MV-HW**		**Base-case HL-LV**
	CFLi	**CFLi (comb. 1)**	**CFLi**	**CFLi (comb. 1)**	**CFLi (comb. 1)**
Wattage	15 W	10 W	55 W	55 W	10 W
Lamp lifetime	6000 h	10000 h	6000 h	10000 h	10000 h
Lumen output	694 lm	466 lm	4163 lm	4662 lm	466 lm

This scenario would imply that CFLi would represent 100% of the stock from 2018 onwards when HL-LV lamps would be removed from the EU-27 market. In 2020, the stock of CFLi lamps (including CFLi and CFLi-combination 1) was estimated to be about 4.4 billion units. Detailed outcomes of the analysis of 'Option 1 Fast' scenario are presented in Annexe 8-3.

DISCLAIMER: The statements, figures and graphs provided on this page have to be read in the context set out in the beginning of section 8.1.2 and in sections 8.1.2.1 and 8.1.2.2

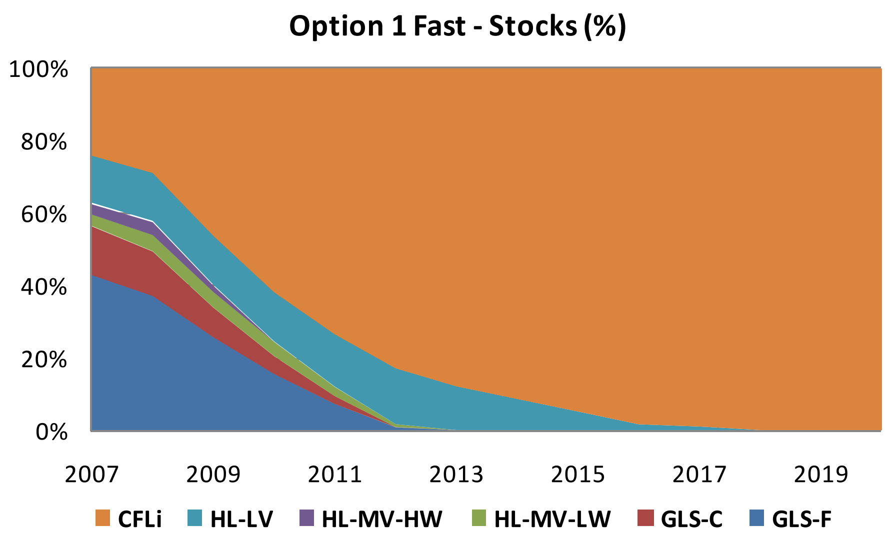

Figure 8-14: Option 1 Fast - Evolution of lamps stocks (in %)

As CFLi is the only lamp type meeting the requirements after 2018 in the 'Option 1 Fast' scenario, it represents 100% of the market (see Figure 8-14) from this date onwards. Previously, there is a continuous decrease of the stocks of the other lamp types that are phased out earlier.

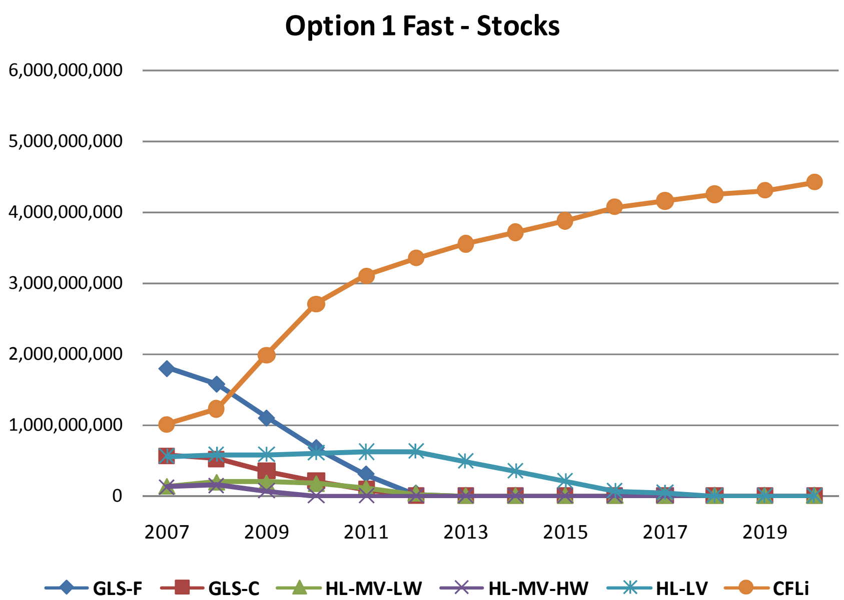

Figure 8-15: Option 1 Fast - Evolution of lamps stocks (in units)

DISCLAIMER: The statements, figures and graphs provided on this page have to be read in the context set out in the beginning of section 8.1.2 and in sections 8.1.2.1 and 8.1.2.2

Due to the minimum requirements set from 2009 onwards, CFLi present the highest share of the sales from this date. In Figure 8-16, the market share of HL-LV grows in 2012, the reason being that this figure presents relative distribution of sales: the higher market share of HL-LV is due to a decrease of CFLi sales in 2012 while HL-LV sales stay constant.

In 2020, CFLi sales increase (see Figure 8-17) as some of these lamps which were sold in 2009 to replace GLS and HL-MV are in their end-of-life stage and therefore have to be replaced with new CFLi in order to keep the parameter 'annual lumen needed' similar to the BAU scenario.

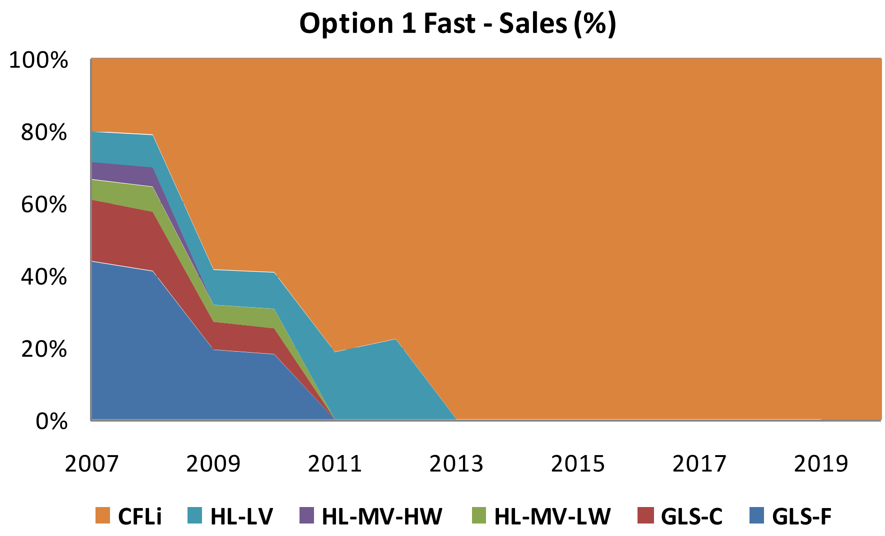

Figure 8-16: Option 1 Fast - Evolution of lamps sales (in %)

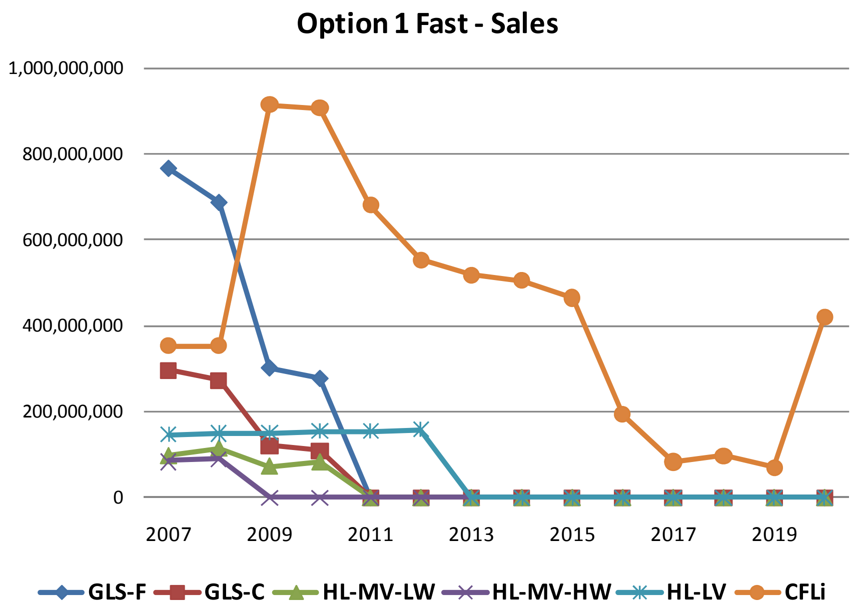

Figure 8-17: Option 1 Fast - Evolution of lamps sales (in units)

After 2009, total electricity consumption (and therefore total CO_2 emissions) decreases until 2016 and then remains quite constant until 2020. In 2020, total electricity consumption is expected to be about 48.3 TWh, i.e. 64.2% lower than in the BAU scenario. The reduction is the same for CO_2 emissions (20.8 Mton in 2020).

Regarding mercury emissions, the total amount increases in 2009 due to the high increase of CFLi sales to replace GLS and HL-MV lamps (the lamp mercury being attributed to the sales year). Then, this total decreases until 2019 and then further slightly increases in 2020 corresponding to the CFLi sales raise at this date. In 2020, total mercury emissions to air due to the electricity consumption of lamps during to the use phase, and due to emissions occurring at EoL of CFLi is about 1444 kg, i.e. a reduction of about 54.0% compared to the BAU scenario.

Figure 8-19 shows that after 2010, CFLi are the major contributor to the electricity consumption due to the phasing-out of GLS-F, and become the only contributor from 2018 as all other lamps are removed from the EU-27 market.

Please note that the abrupt changes in lamp sales are in part due to the discrete model used (see general remarks).

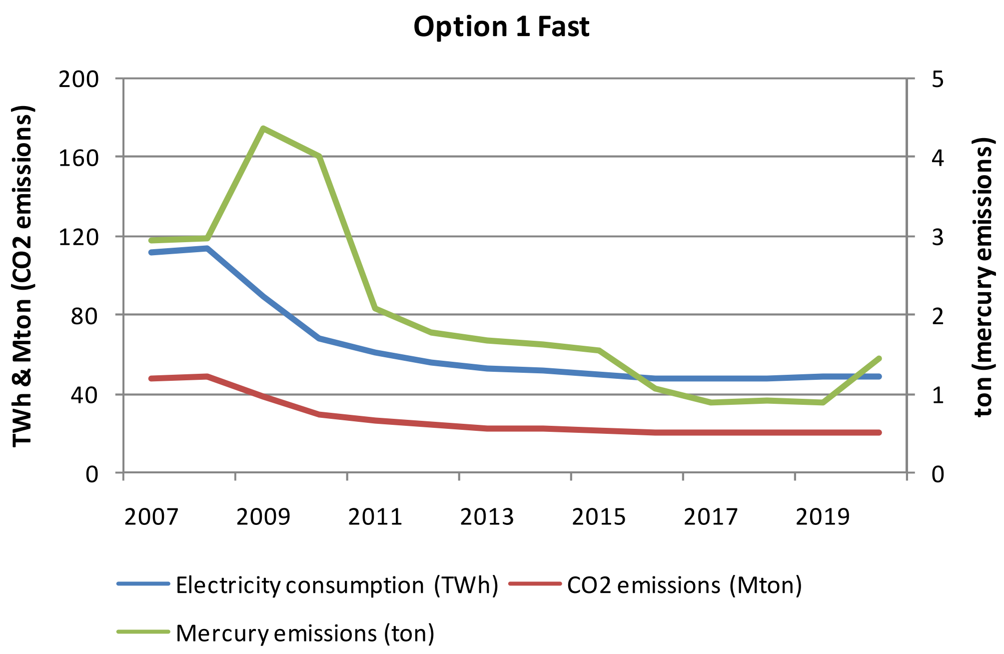

Figure 8-18: Option 1 Fast – Evolution of annual environmental impacts

DISCLAIMER: *The statements, figures and graphs provided on this page have to be read in the context set out in the beginning of section 8.1.2 and in sections 8.1.2.1 and 8.1.2.2*

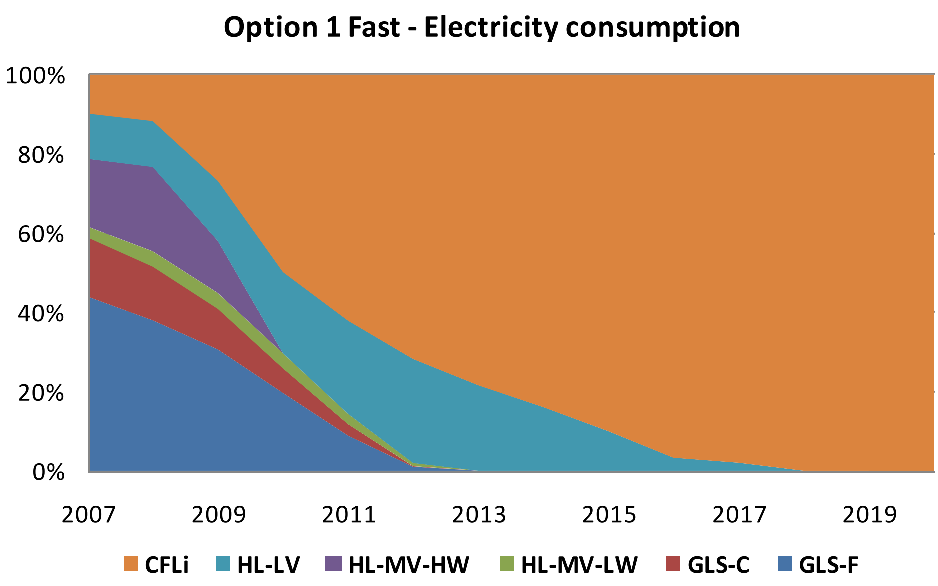

Figure 8-19: Option 1 Fast - Evolution of the contribution of the lamp types to the electricity consumptions of the total lamp stock

8.1.2.6 Scenario "Option 1 Fast B"

Compared to 'Option 1 Fast' scenario, 'Option 1 Fast B' scenario presents some differences for halogen lamps: HL-MV-LW and HL-MV-HW are only replaced with CFLi lamps in the last Tier (i.e. 2013), and are improved from 2009 (in 2009 only for lumen output above 450 lm, and in 2011 for all HL-MV lamps) until 2013 with the Xenon technology.

Further, in the first Tier, the HL-LV base-case is replaced with HL-LV with infrared coating. Requirements set for GLS and CFLi are similar to those defined in 'Option 1 Fast'.

In the last Tier of this 'Option 1 Fast B' scenario (i.e. 2013) the minimum level of both clear and frosted lamps is A.

Table 8-12: Option 1 Fast B – Replacement lamps for each tier

present	2009	2011	2013
requirements:	**C except below 450lm**	**C (with CFL combination1)**	**A (with CFL combination1)**
Base case	**Assumed replacing base-case**	**Assumed replacing base-case**	**Assumed replacing base-case**
GLS-C	CFLi (except below 450 lm)	CFLi (combination 1)	CFLi (combination 1)
GLS-F	CFLi (except below 450 lm)	CFLi (combination 1)	CFLi (combination 1)
HL-MV-LW (G9)	Xenon HL-MV-LW	Xenon HL-MV-LW	CFLi (combination 1)
HL-MV-HW (R7s)	Xenon HL-MV-HW	Xenon HL-MV-HW	CFLi (combination 1)
HL-LV	HL-LV IRC	HL-LV IRC	CFLi (combination 1)
CFLi	CFLi	CFLi (combination 1)	CFLi (combination 1)

Note: in yellow = change from previous phase; in red = change that requires luminaire change

Characteristics of replacement lamps used in this scenario are those presented in chapter 7.

Stock trends for the six lamp technologies shown in Figure 8-20 and Figure 8-21 are very close to those of the 'Option 1 Fast' scenario, with a constant decrease of incandescent and halogen lamps: GLS-F and GLS-C are removed from the market in 2013, HL-MV in 2017 and HL-LV in 2018, in line with their lifetimes.

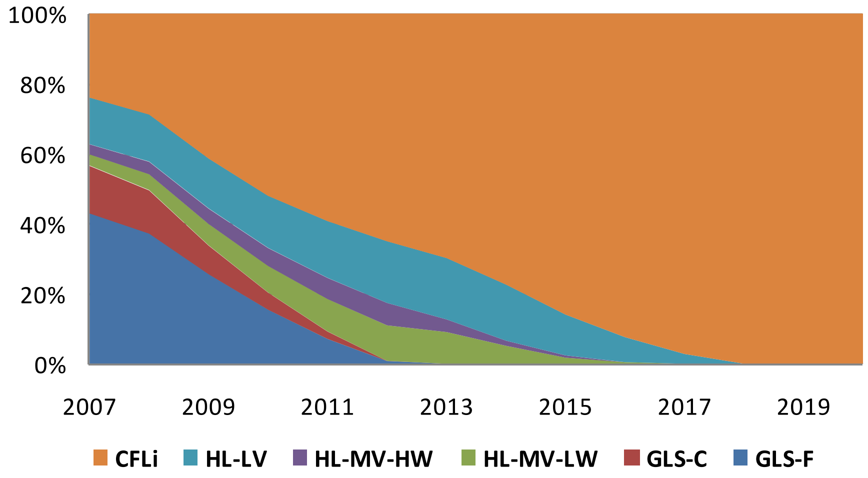

Figure 8-20: Option 1 Fast B - Evolution of lamps stocks (in %)

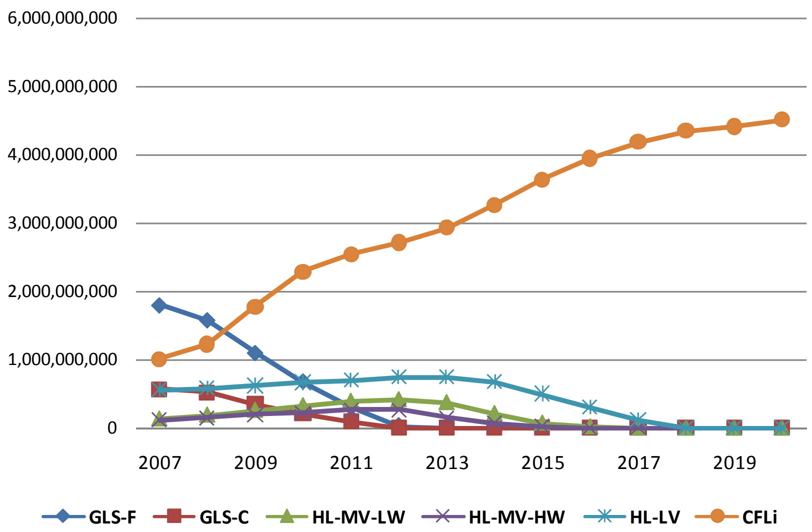

Figure 8-21: Option 1 Fast B - Evolution of lamps stocks (in units)

Figure 8-22 and Figure 8-23 clearly show the progressive phasing-out of incandescent and halogen lamps: in two stages for GLS-F, GLS-C, HL-MV-LW and HL-MV-HW and in three stages for HL-LV.

HL-LV sales slightly increase in 2009, as this base-case is replaced with a more energy efficient lamp variant, HL-LV IRC. The lumen output of this improvement option is lower than its base-case as the wattage is lower (30W-435lm for the base-case and 20W-369lm for the HL-LV IRC). Therefore, to keep the 'annual lumen needed for HL-LV' constant, more HL-LV IRC lamps are required, and therefore sales (in units) of this lamp technology increase.

CFLi sales clearly rise in 2009 as this lamp type replace GLS lamps (with lumen output above 450 lm), and in 2014 to compensate the phasing-out of halogen lamps. Moreover, as in the 'Option 1 Fast' scenario, CFLi sales see a new increase in 2020 corresponding to the replacement of lamps that were sold in 2009.

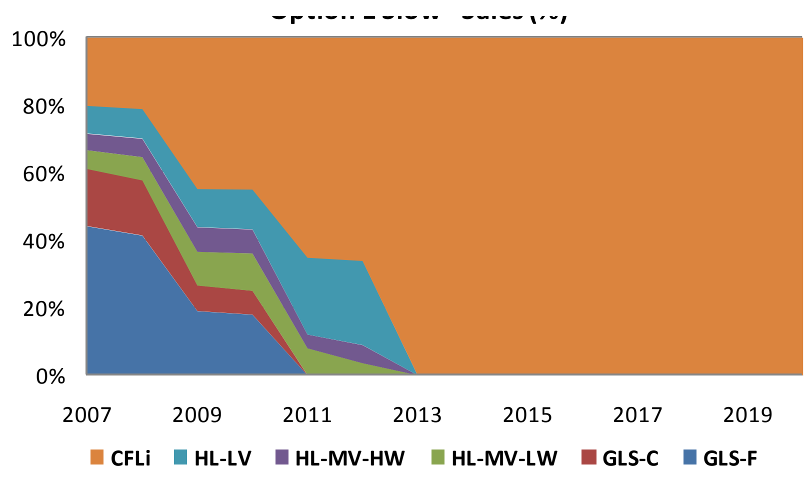

Figure 8-22: Option 1 Fast B – Evolution of lamps sales (in %)

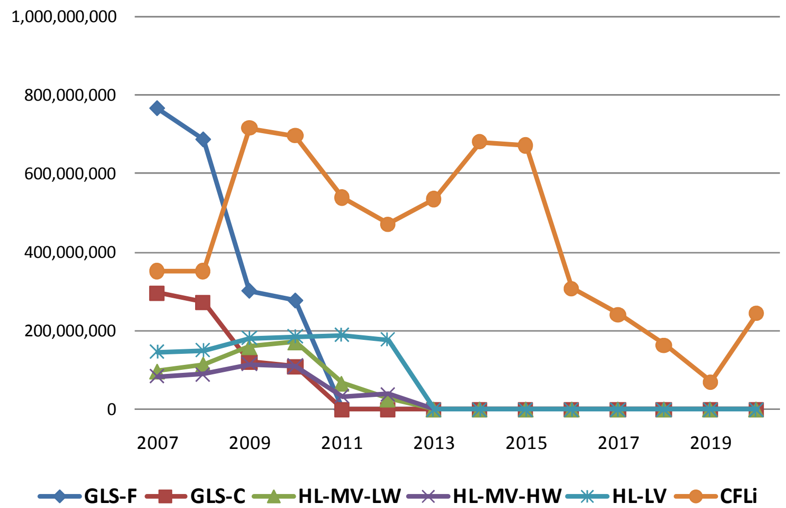

Figure 8-23: Option 1 Fast B – Evolution of lamps sales (in units)

Requirements set in the context of the 'Option 1 Fast B' scenario allow a reduction of environmental impacts in 2020 compared to 2007. Indeed, electricity consumption and CO_2 emissions are 56.9% lower (48.3 TWh and 20.8 Mton in 2020), and mercury emissions are 60.2% lower (1165 kg in 2020).

As in the other scenarios, CFLi lamps become gradually the major and then the sole contributor to the electricity consumption and other environmental impacts. An increase in the contribution of HL-MV-HW lamps is noticeable in Figure 8-25 in 2012, due to an increase in the stock (in units and in %) of this lamp technology in this year. Even a small increase of the stock of HL-MV-HW has significant impacts in terms of electricity consumption, as the average wattage is 230W for the improvement option (Xenon HL-MV-HW).

Please note that the abrupt changes in lamp sales are partly due to the discrete model used (see general remarks).

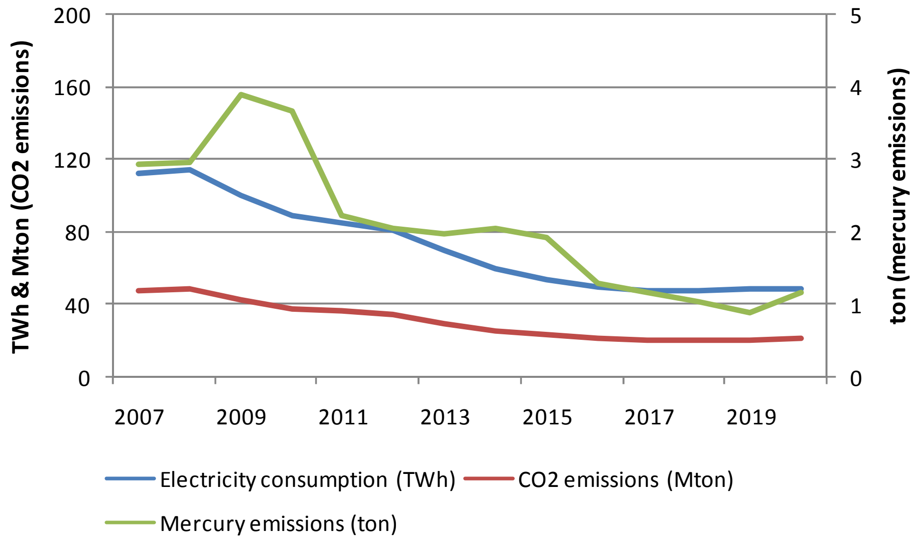

Figure 8-24: Option 1 Fast B – Evolution of annual environmental impacts

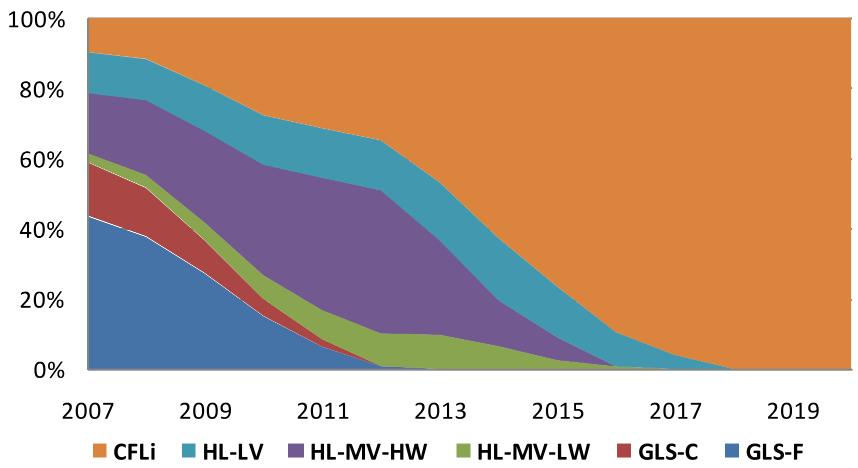

Figure 8-25: Option 1 Fast B - Evolution of the contribution of the lamp types to the electricity consumptions of the total lamp stock

8.1.2.7 Scenario "Option 2 Clear B Fast"

This scenario is less ambitious in terms of reducing life cycle cost and environmental impacts than the previous ones, which is clearly visible in the requirements set in each Tier and the replacement options proposed for each base-case (see Table 8-13). Indeed, amongst

incandescent and halogen lamps, only the base-case GLS-F has to be replaced with a CFLi, as it was assumed that this is the only frosted lamp. These options "2" simulate, to the extent possible in the model of this study, a more constant light quality for a replacement option. Issues related to light quality are discussed in chapter 3.
In the last Tier (i.e. 2013), the minimum level of lamp is set to B for clear lamps and A for frosted lamps.

Further, a difference of this scenario in comparison to the previous ones is that 'Option 2 Clear B Fast' does not require any luminaire change.

Table 8-13: Option 2 Clear B Fast – Replacement lamps for each tier

present	2009	2011	2013
requirements:	**C except below 450lm**	**clear: C; frosted: A (CFL combination1)**	**clear: B; frosted: A (CFL combination1)**
Base case	**Assumed replacing base-case**	**Assumed replacing base-case**	**Assumed replacing base-case**
GLS-C	Xenon HL-MV-LW (except below 450 lm)	Xenon HL-MV-LW	HL-MV IRC with integrated electronic transformer
GLS-F	CFLi (except below 450 lm)	CFLi (combination 1)	CFLi (combination 1)
HL-MV-LW (G9)	Xenon HL-MV-LW	Xenon HL-MV-LW	Xenon HL-MV-LW
HL-MV-HW (R7s)	Xenon HL-MV-HW	Xenon HL-MV-HW	Xenon HL-MV-HW
HL-LV	HL-LV IRC	HL-LV IRC	HL-LV IRC
CFLi	CFLi	CFLi (combination 1)	CFLi (combination 1)

Note: in yellow = change from previous phase

Replacement lamps used in this 'Option 2 Clear B Fast' scenario are described in chapter 7.

In this 'Option 2 Clear B Fast' scenario, only incandescent lamps (i.e. GLS-F and GLS-C) are removed from the market. Therefore, in 2020 the stock of lamps comprises of CFLi and halogen lamps; CFLi representing 54.1% of the stock, HL-LV 25.5%, HL-MV-LW 13.5%, and HL-MV-HW 6.9%.

The share of CFLi in the stock is the highest in 2012 with 57.1%, and then slightly decreases until 2020 to the benefit of HL-LV, as this lamp technology is also used to replace GLS-C in 2013 with the infrared coating technology and an integrated electronic transformer. However, this reflects a relative change and does not mean that the stock of CFLi in units decreases from 2013 to 2020, as shown in Figure 8-27.

Detailed data of this scenario is presented in Annexe 8-5.

DISCLAIMER: The statements, figures and graphs provided on this page have to be read in the context set out in the beginning of section 8.1.2 and in sections 8.1.2.1 and 8.1.2.2

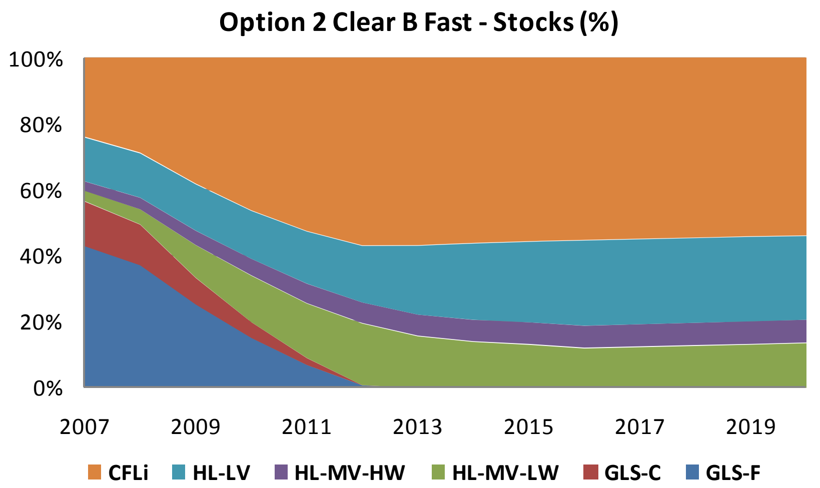

Figure 8-26: Option 2 Clear B Fast - Evolution of lamps stocks in (%)

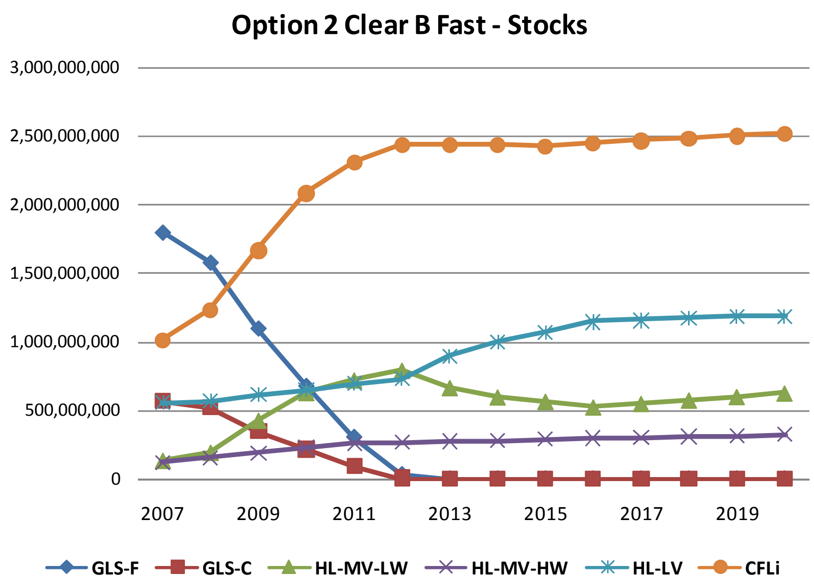

Figure 8-27: Option 2 Clear B Fast - Evolution of lamps stocks (in units)

Market shares of lamp types are quite variable over time, especially after 2011. This is mainly due to the replacement sales which vary from one lamp technology to another as their lamp lifetimes differ significantly.

DISCLAIMER: The statements, figures and graphs provided on this page have to be read in the context set out in the beginning of section 8.1.2 and in sections 8.1.2.1 and 8.1.2.2

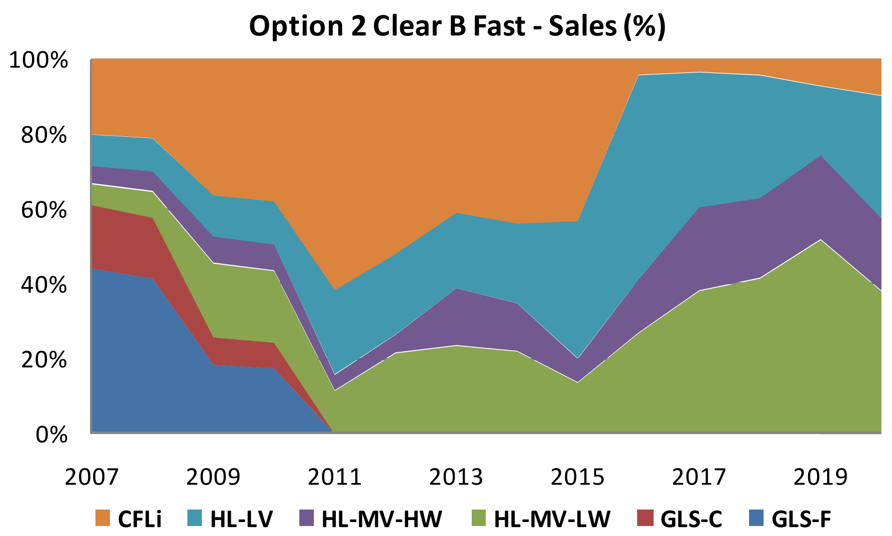

Figure 8-28: Option 2 Clear B Fast - Evolution of lamps sales (in %)

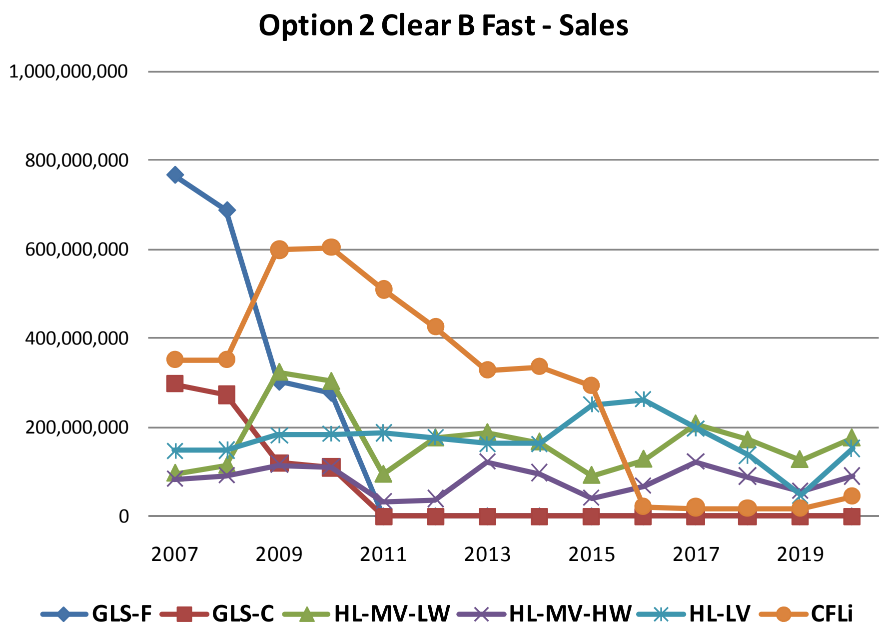

Figure 8-29: Option 2 Clear B Fast - Evolution of lamps sales (in units)

In 2020, electricity consumption and CO_2 emissions are expected to be about 28.8% lower than in the BAU scenario (96.0 TWh and 41.3 Mton CO_2). This reduction is more modest than in the previously analysed scenarios, as CFLi, which is the most energy efficient lamp, are not the only ones existing on the EU-27 market in 2020.

Further, these environmental impacts slightly rise from 2012 onwards as it was shown that the CFLi share of lamps stock decrease from this date (see Figure 8-26).

After a high increase in 2009 due to a peak in CFLi sales, mercury emissions reduce until 2017, then slowly increase until 2020 due to the growth of CFLi sales. In 2020, the amount of mercury emissions to air is about 1609 kg in this scenario.

DISCLAIMER: The statements, figures and graphs provided on this page have to be read in the context set out in the beginning of section 8.1.2 and in sections 8.1.2.1 and 8.1.2.2

Please note that the abrupt changes in lamp sales are in part due to the discrete model used (see general remarks), e.g. in reality CFLi sales will not drop to zero.

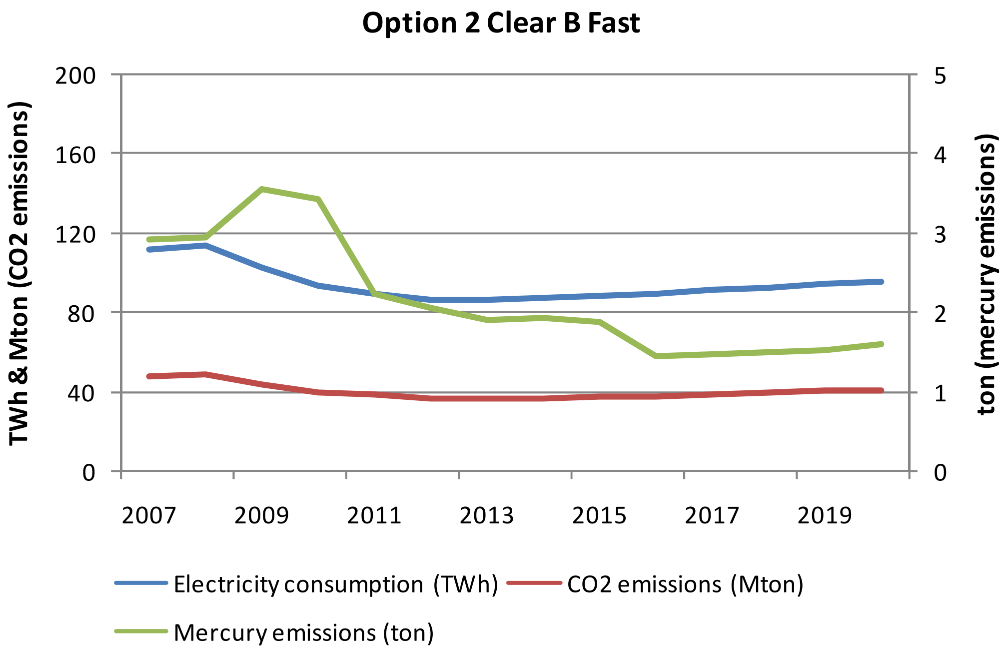

Figure 8-30: Option 2 Clear B Fast – Evolution of annual environmental impacts

Due to the high wattage of HL-MV-HW compared to the other lamp types, this technology is responsible of about 41.4% of the total electricity consumption (and of total CO_2 emissions) in 2020, followed by CFLi (27.3%) and HL-LV (19.6%).

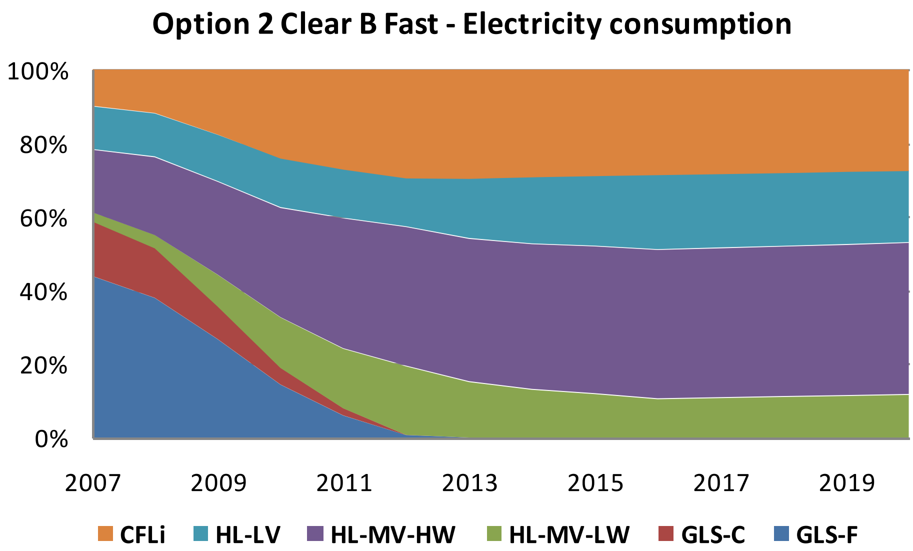

Figure 8-31: Option 2 Clear B Fast - Evolution of the contribution of the lamp types to the electricity consumptions of the total lamp stock

8.1.2.8 Scenario “Option 2 Clear B Slow”

As specified in its title, the ‘Option 2 Clear B Slow’ scenario is derived from the ‘Option 2 Clear B Fast’ scenario presented above. The difference is mainly in the number of Tiers: 5 in this scenario and 3 in the previous ‘Fast’ one. Further, in the last Tier (i.e. 2017), HL-MV-LW are replaced with HL-LV IRC (infrared coating technology), and HL-MV-HW with CFLi (combination 1). These replacements would require luminaire changes. These options "2" simulate, to the extent possible in the model of this study, a more constant light quality for a replacement option. Issues related to light quality are discussed in chapter 3.

With ‘Option 2 Clear B Slow’, in 2017, the minimum level required for all clear lamps would be B, and level A for frosted lamps (i.e. GLS-F).

As in chapter 7, some of the replacement lamps were not assessed as an improvement option. The following assumptions were used in the analysis of the ‘Option 2 Clear B Slow’ scenario.

Table 8-14: Option 2 Clear B Slow – Assumptions of replacement lamps

	Base-case HL-MV-LW	**Base-case HL-MV-HW**
	HL-LV IRC	**CFLi (comb. 1)**
Wattage	25 W	55 W
Lamp lifetime	4000 h	10000 h
Lumen output	488 lm	4662 lm

Detailed outcomes of the analysis of ‘Option 2 Clear B Slow’ scenario are presented in Annexe 8-6.

DISCLAIMER: The statements, figures and graphs provided on this page have to be read in the context set out in the beginning of section 8.1.2 and in sections 8.1.2.1 and 8.1.2.2

Table 8-15: Option 2 Clear B Slow – Replacement lamps for each tier

present	2009	2011	2013	2015	2017
requirements:	**C except below 1000 lm**	**C except below 450lm**	**clear: C (GLS); clear: B (HL-MV); frosted: A (CFL combination1)**	**clear: C (GLS); clear: B (HL-MV); frosted: A (CFL combination1)**	**clear: B; frosted: A (CFL combination1)**
Base case	**Assumed replacing base-case**	**Assumed replacing base-case**	**Assumed replacing base-case**	**Assumed replacing base-case**	**Assumed replacing base-case**
GLS-C	Xenon HL-MV-LW (except below 1000 lm)	Xenon HL-MV-LW (except below 450 lm)	HL-MV IRC with integrated electronic transformer	HL-MV IRC with integrated electronic transformer	HL-MV IRC with integrated electronic transformer
GLS-F	Xenon HL-MV-LW (except below 1000 lm)	Xenon HL-MV-LW (except below 450 lm)	CFLi (combination 1)	CFLi (combination 1)	CFLi (combination 1)
HL-MV-LW (G9)	Xenon HL-MV-LW (except below 1000 lm)	Xenon HL-MV-LW (except below 450 lm)	Xenon HL-MV-LW	Xenon HL-MV-LW	HL-LV IRC
HL-MV-HW (R7s)	Xenon HL-MV-HW	Xenon HL-MV-HW	Xenon HL-MV-HW	Xenon HL-MV-HW	CFLi (combination 1)
HL-LV	HL-LV	HL-LV IRC	HL-LV IRC	HL-LV IRC	HL-LV IRC
CFLi	CFLi	CFLi	CFLi (combination 1)	CFLi (combination 1)	CFLi (combination 1)

Note: in yellow = change from previous phase; in red = change that requires luminaire change

As in the last Tier, only HL-LV and CFLi lamps will be available on the EU-27 market, they would make up the lamps stock with respectively, 36.7% and 63.3%. From 2009 onwards, the shares of these two technologies would continuously grow as highlighted in Figure 8-32 and Figure 8-33.

In 2012, HL-MV-LW lamps would represent a high share of the stock (29.4%), behind CFLi, as this lamp type would replace both GLS-F and GLS-C. Then, in 2013 GLS-C and GLS-F would be replaced with HL-LV IRC with integrated electronic ballast and with CFLi (combination 1), respectively.

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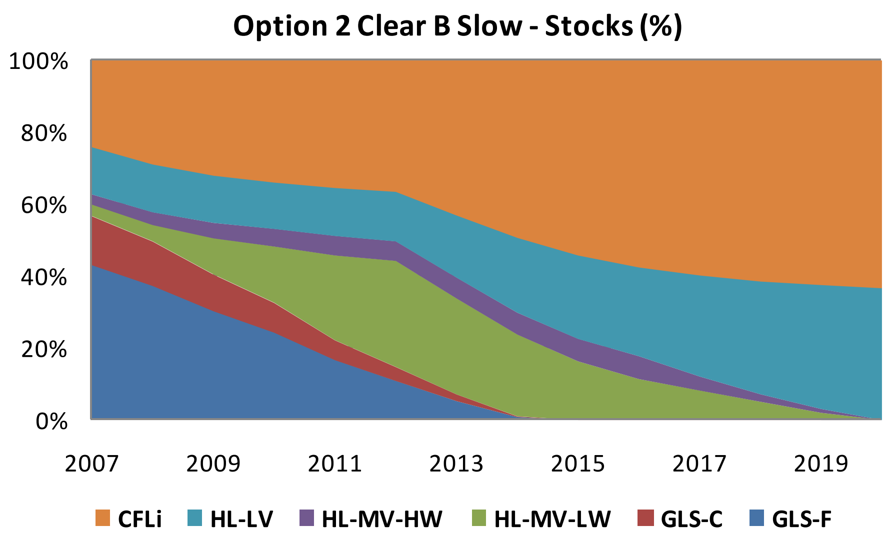

Figure 8-32: Option 2 Clear B Slow - Evolution of lamps stocks (in %)

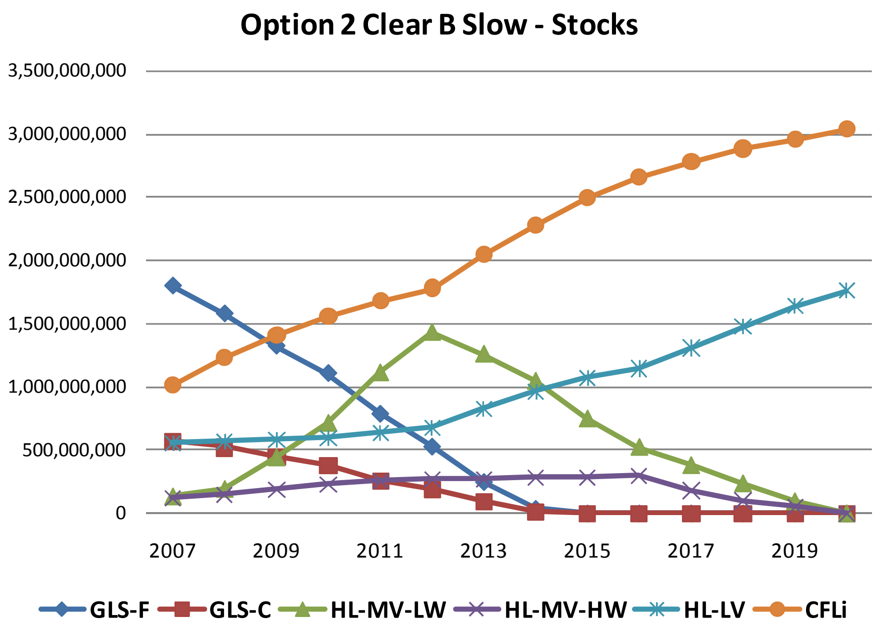

Figure 8-33: Option 2 Clear B Slow - Evolution of lamps stocks (in units)

As mentioned before, from 2017 onwards, only HL-LV and CFLi would be sold. Thus, in 2020 the market share of HL-LV would be about 78.7%, and CFLi (combination 1) ‘only’ 21.3%, as the lifetime of the latter (10000 h) is 2.5 longer than the lifetime of the HL-LV IRC (4000 h).

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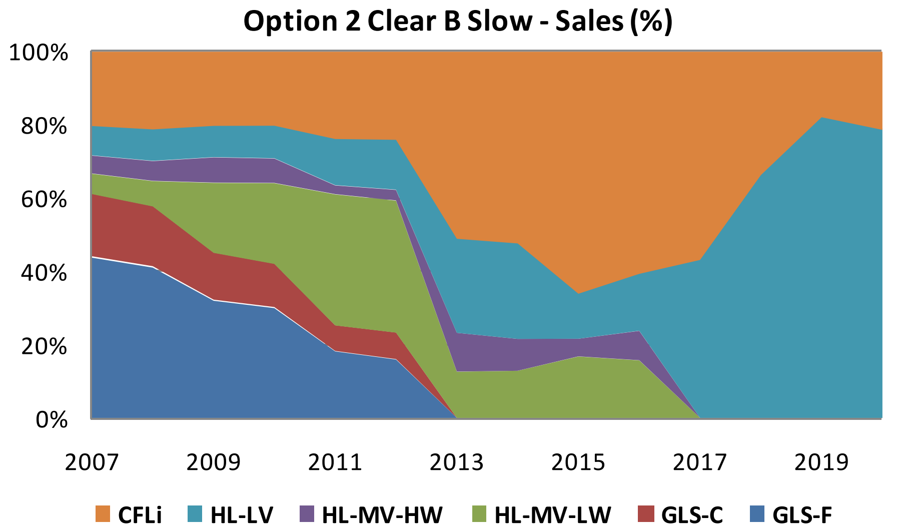

Figure 8-34: Option 2 Clear B Slow - Evolution of lamps sales (in %)

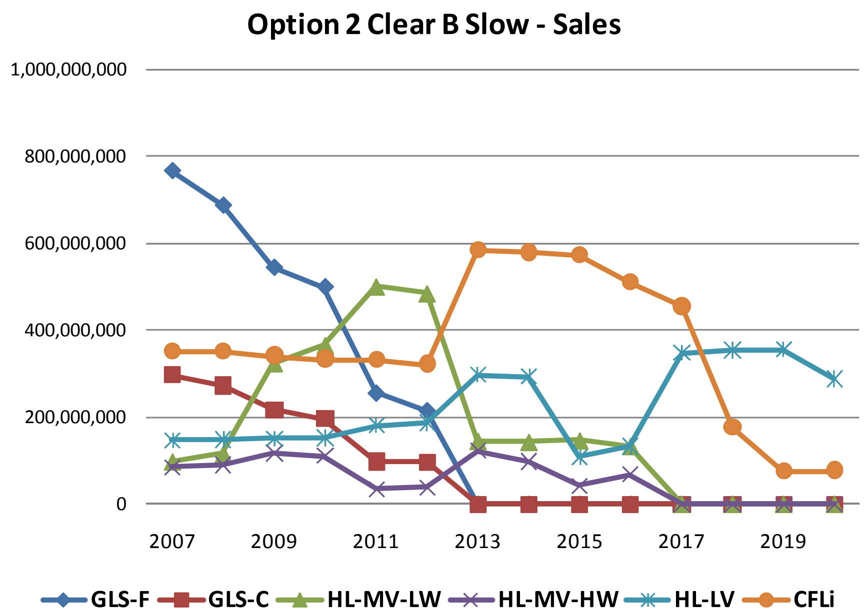

Figure 8-35: Option 2 Clear B Slow - Evolution of lamps sales (in units)

Energy savings as well as the reduction of CO_2 and mercury emissions are greater with the 'Option 2 Clear B Slow' scenario than with the 'Option 2 Clear B Fast' scenario in 2020. Indeed, in 'Option 2 Clear B Slow' compared to the BAU scenario, electricity consumption and CO_2 emissions are 37.8% lower and mercury emissions are 53.3% lower. This may seem surprising, as the 'Slow' scenario is considered less ambitious. However, the cumulative environmental impacts from 2009 (i.e. the entry into force of the legislation) to 2020, provide a more logical comparison and the Fast scenario allows more environmental benefits than the Slow scenario.
Please note that the abrupt changes in lamp sales are in part due to the discrete model used (see general remarks), e.g. CFLi sales in reality will not drop to zero.

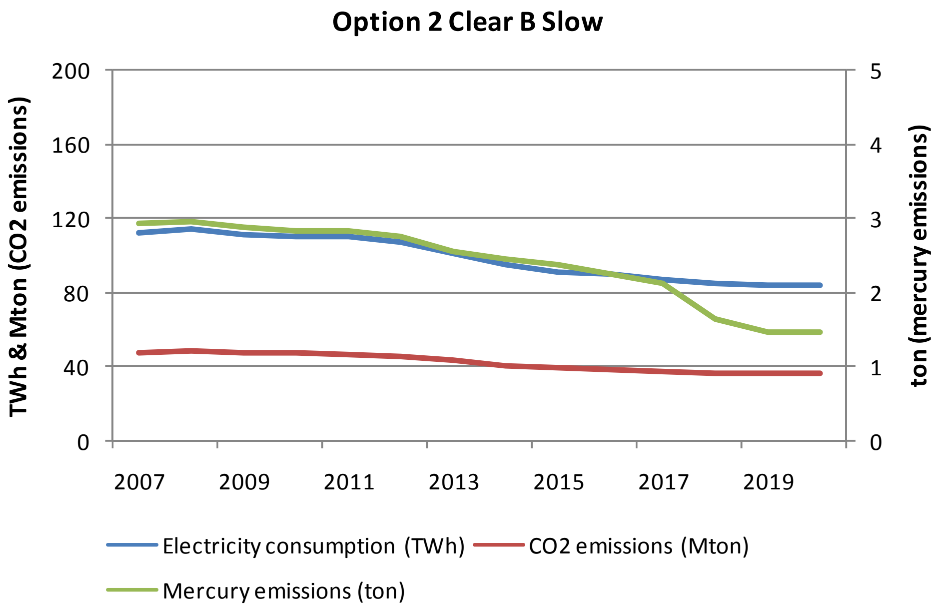

Figure 8-36: Option 2 Clear B Slow – Evolution of annual environmental impacts

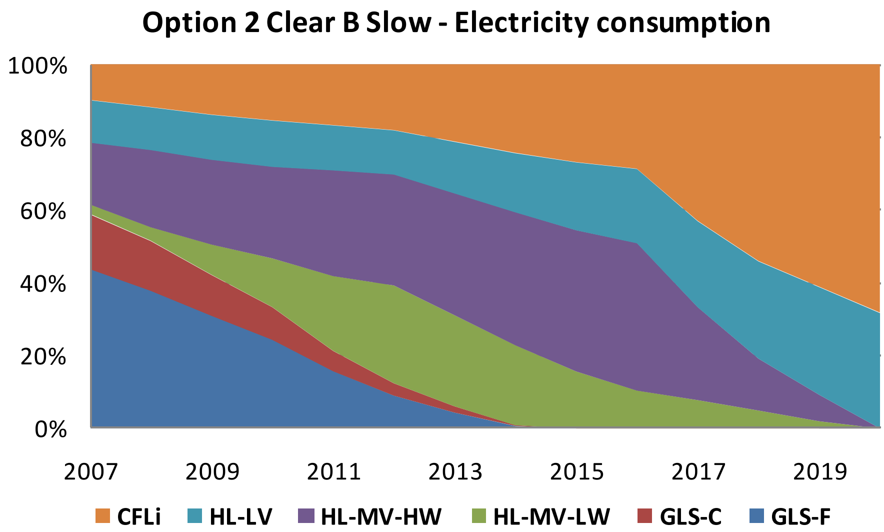

Figure 8-37: Option 2 Clear B Slow - Evolution of the contribution of the lamp types to the electricity consumptions of the total lamp stock

8.1.2.9 Scenario "Option 2 Clear C Fast"

In this scenario, lumen output is taken into account for incandescent lamps (i.e. GLS-F and GLS-C) for the setting of minimum requirements. Further, in the first Tier, HL-MV-LW and CFLi are not replaced with an improvement option. Moreover, the notable difference of this scenario compared to the others is that the base-case HL-LV is not improved as there is no requirement for this lamp type. These options "2" simulate, in the extend possible in the model of this study, a more constant light quality for a replacement option. Issues related to light quality are discussed in chapter 3.

Table 8-16: Option 2 Clear C Fast – Replacement lamps for each tier

present	2009	2011	2013
requirements:	**C except below 450 lm + G9**	**C with CFLi combi1**	**clear: C; frosted: A (CFL combination1)**
Base case	**Assumed replacing base-case**	**Assumed replacing base-case**	**Assumed replacing base-case**
GLS-C	Xenon HL-MV-LW (except below 450 lm)	Xenon HL-MV-LW	Xenon HL-MV-LW
GLS-F	Xenon HL-MV-LW (except below 450 lm)	Xenon HL-MV-LW	CFLi (combination 1)
HL-MV-LW (G9)	HL-MV-LW	Xenon HL-MV-LW	Xenon HL-MV-LW
HL-MV-HW (R7s)	Xenon HL-MV-HW	Xenon HL-MV-HW	Xenon HL-MV-HW
HL-LV	HL-LV	HL-LV	HL-LV
CFLi	CFLi	CFLi (combination 1)	CFLi (combination 1)

Note: in yellow = change from previous phase

As presented in Figure 8-38, HL-MV-LW would represent a significant share of the stock (and of sales), especially in 2011 and 2012, as this technology would replace all GLS-F and GLS-C during this period. Therefore, the stock of HL-MV-LW would represent 35.5 % in 2011 and 39.9% in 2012 of the total lamp stock. For these same years, the stock of CFLi would be 36.5% and 39.0%, respectively.

Afterwards, in 2013, HL-MV-LW that were used to replace GLS-F in Tier 1 and 2, would be replaced with CFLi (combination 1), which would imply a decrease of the stock of HL-MV-LW to the benefit of CFLi.

Figure 8-38 and Figure 8-39 also show that starting from 2016, the growth of the stock of HL-MV-LW, HL-MV-HW, HL-LV and CFLi would be similar and constant.

Detailed data for the 'Option 2 Clear C Fast' scenario is presented in Annexe 8-7.

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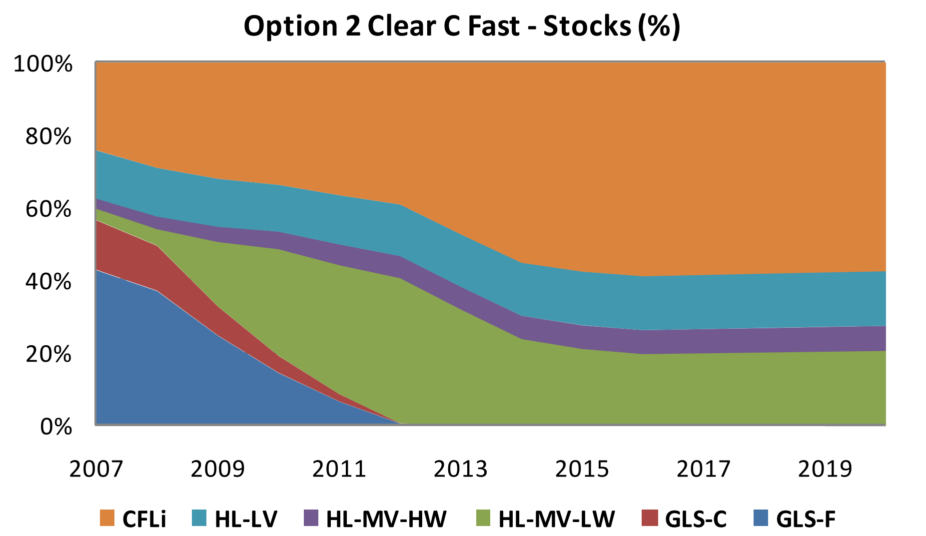

Figure 8-38: Option 2 Clear C Fast - Evolution of lamps stocks (in %)

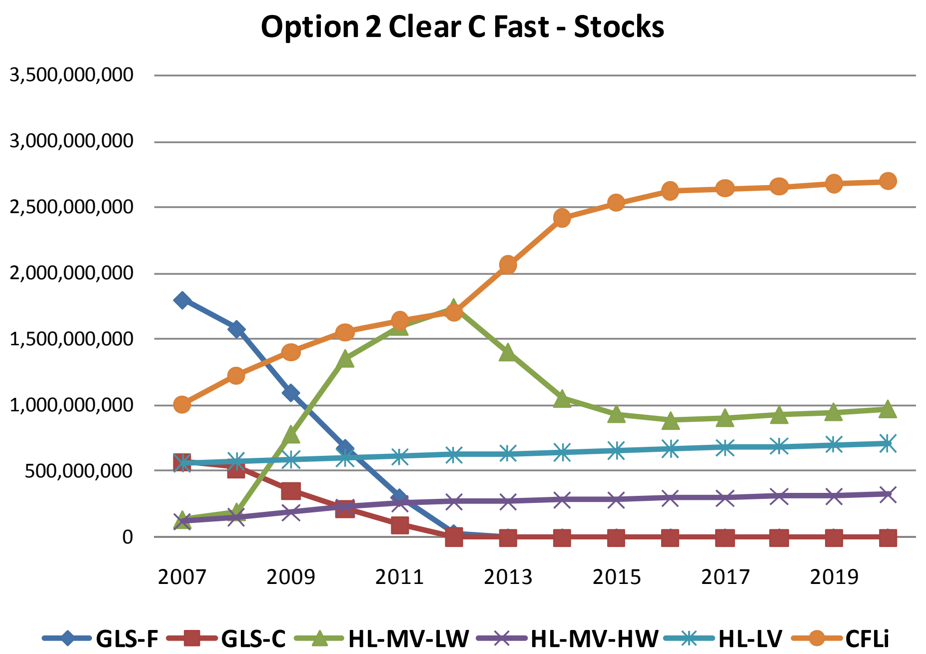

Figure 8-39: Option 2 Clear C Fast - Evolution of lamps stocks (in units)

Sales data are calculated according to the principle detailed in section 8.1.2.2 and are presented both in % and in units in Figure 8-40 and Figure 8-41. In 2020, the EU-27 market is made up as follows: 51.4% of lamp sales are HL-MV-LW (299 million units), 30.2% HL-LV (176 million units), 15.3% HL-MV-HW (89 million units) and 3.1% CFLi (18 million units).

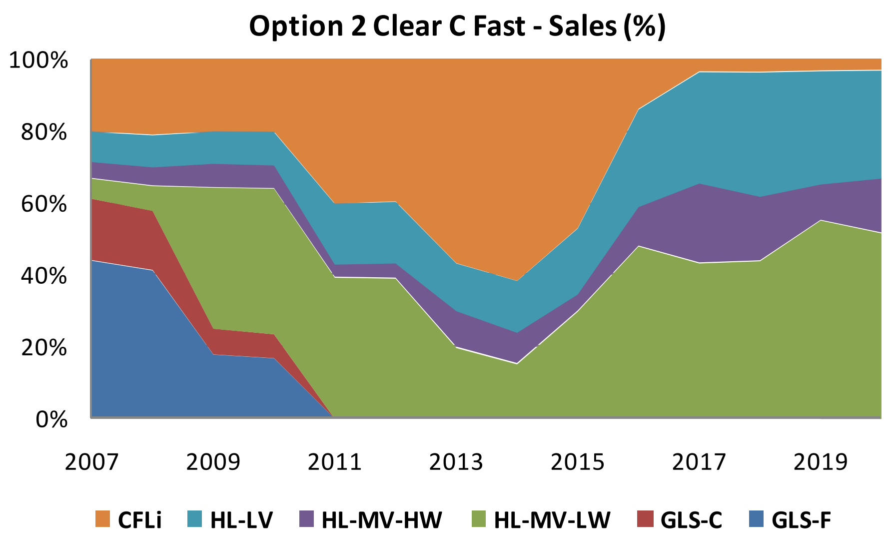

Figure 8-40: Option 2 Clear C Fast - Evolution of lamps sales (in %)

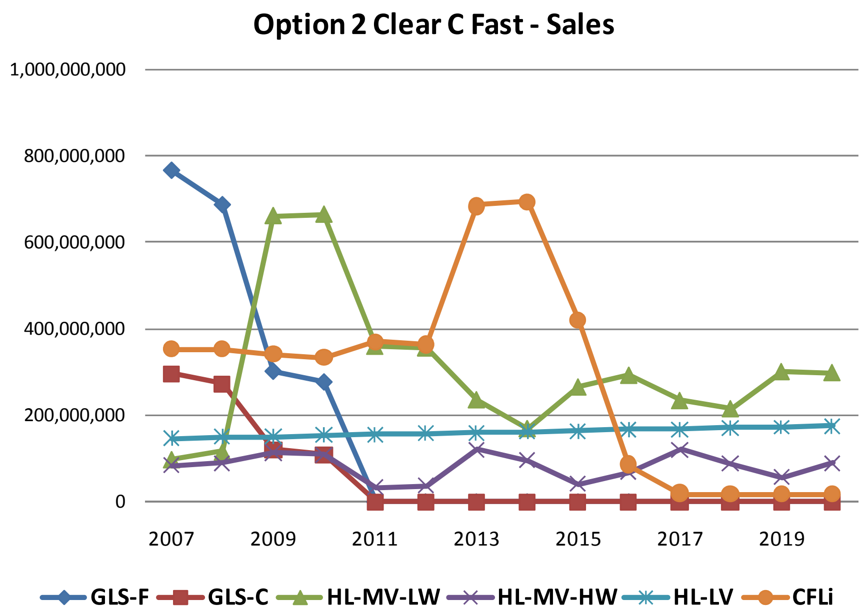

Figure 8-41: Option 2 Clear C Fast - Evolution of lamps sales (in units)

In 2020, reduction of environmental impacts in the 'Option 2 Clear C Fast' scenario compared to the BAU scenario is as follows:

- -24.5% for electricity consumption (101.7 TWh in 2020);
- -24.5% for CO_2 emissions (43.7 Mton in 2020);
- -46.6% for mercury emissions to air (1656 kg in 2020).

HL-MV-HW lamps are mainly responsible of the electricity consumption since 2013, and in 2020, the contribution of this lamp type is about 39.1%, followed by CFLi (25.6%) and HL-MV-LW (18.8%).

Please note that the abrupt changes in lamp sales are in part due to the discrete model used (see general remarks), e.g. CFLi sales in reality will not drop to zero

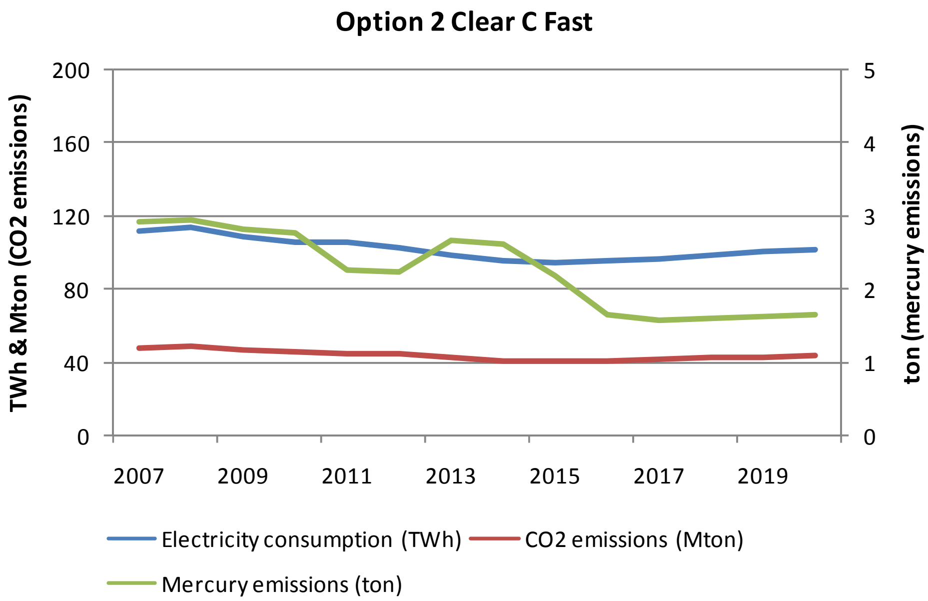

Figure 8-42: Option 2 Clear C Fast – Evolution of annual environmental impacts

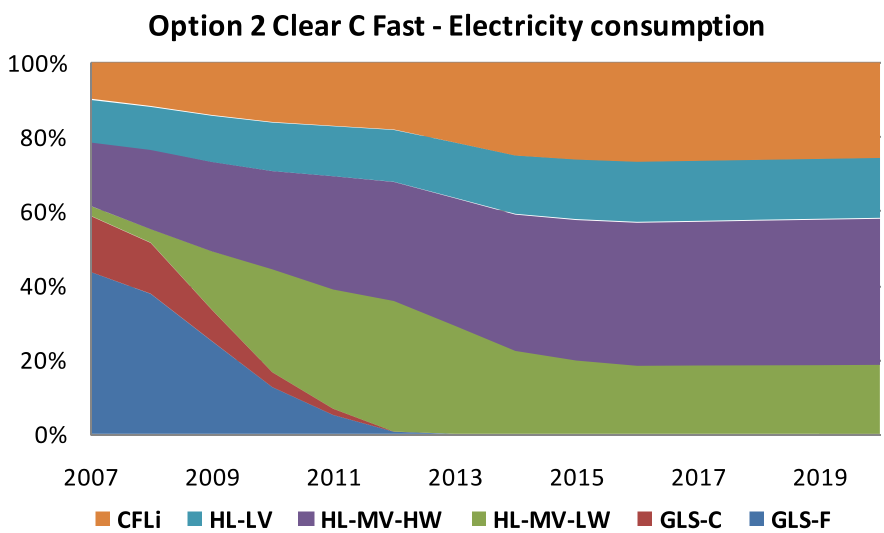

Figure 8-43: Option 2 Clear C Fast - Evolution of the contribution of the lamp types to the electricity consumptions of the total lamp stock

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8.1.2.10 Scenario "Option 3 Slow"

'Option 3 Slow' scenario is the least ambitious scenario and is composed of five Tiers. In 2017, the minimum level required would be C for both clear and frosted lamps. Furthermore, this scenario sets requirements according to the lumen output for incandescent lamps and HL-MV-LW lamps. Two thresholds values are set for the lumen output: 1000 lm in 2009 and 450 lm in 2015.

As in 'Option 2 Clear C Fast', no minimum requirement is set for HL-LV.

Table 8-17: Option 3 Slow – Replacement lamps for each tier

present	2009	2011	2013	2015	2017
requirements:	**C except below 1000lm + G9/R7s**	**C except below 1000lm + G9/R7s**	**C except below 1000lm + G9/R7s**	**C except below 450lm**	**clear: C**
Base case	**Assumed replacing base-case**	**Assumed replacing base-case**	**Assumed replacing base-case**	**Assumed replacing base-case**	**Assumed replacing base-case**
GLS-C	Xenon HL-MV-LW (except below 1000 lm)	Xenon HL-MV-LW (except below 1000 lm)	Xenon HL-MV-LW (except below 1000 lm)	Xenon HL-MV-LW (except below 450 lm)	Xenon HL-MV-LW
GLS-F	Xenon HL-MV-LW (except below 1000 lm)	Xenon HL-MV-LW (except below 1000 lm)	Xenon HL-MV-LW (except below 1000 lm)	Xenon HL-MV-LW (except below 450 lm)	Xenon HL-MV-LW
HL-MV-LW (G9)	Xenon HL-MV-LW (except below 1000 lm)	Xenon HL-MV-LW (except below 1000 lm)	Xenon HL-MV-LW (except below 1000 lm)	Xenon HL-MV-LW (except below 450 lm)	Xenon HL-MV-LW
HL-MV-HW (R7s)	HL-MV-HW	HL-MV-HW	HL-MV-HW	Xenon HL-MV-HW	Xenon HL-MV-HW
HL-LV	HL-LV	HL-LV	HL-LV	HL-LV	HL-LV
CFLi	CFLi	CFLi	CFLi	CFLi (combination 1)	CFLi (combination 1)

Note: in yellow = change from previous phase

As highlighted in Table 8-17, HL-MV-LW (with Xenon) would be considered as the replacement lamp for incandescent lamp. Therefore, it is logical to see the continuous growth of this lamp type in Figure 8-44 and in Figure 8-45.

This trend is also visible when looking at market shares (see Figure 8-46), where HL-MV-LW lamps represent about 46.4% of total lamps sold in 2020.

Stock shares of CFLi, HL-MV-HW and HL-LV stay quite constant after 2012, even if Figure 8-45 shows that stocks of these two halogen lamp types slowly increase beyond this date.

In this scenario, incandescent lamps are totally removed from the market in 2019, where GLS-F and GLS-C with a lumen output below 450 lm would be totally replaced with Xenon HL-MV-LW.

Detailed data is presented in Annexe 8-8 for this scenario.

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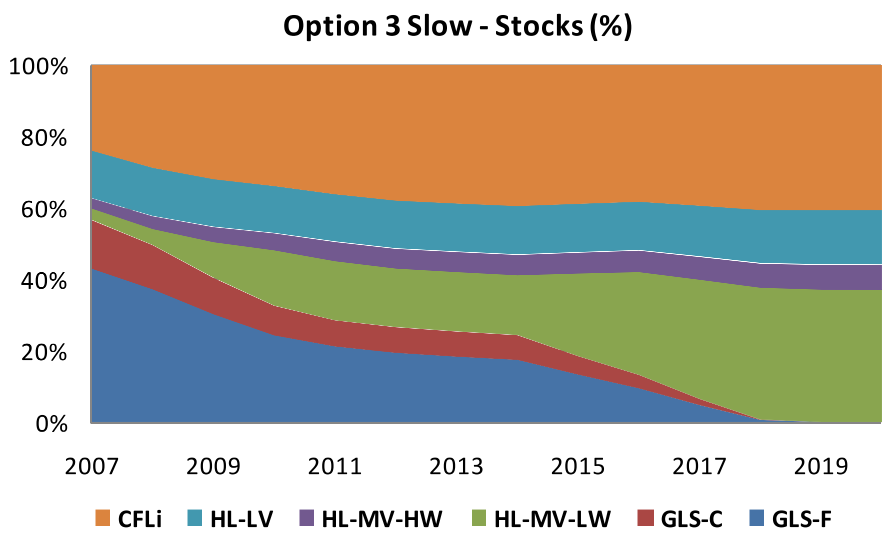

Figure 8-44: Option 3 Slow - Evolution of lamps stocks (in %)

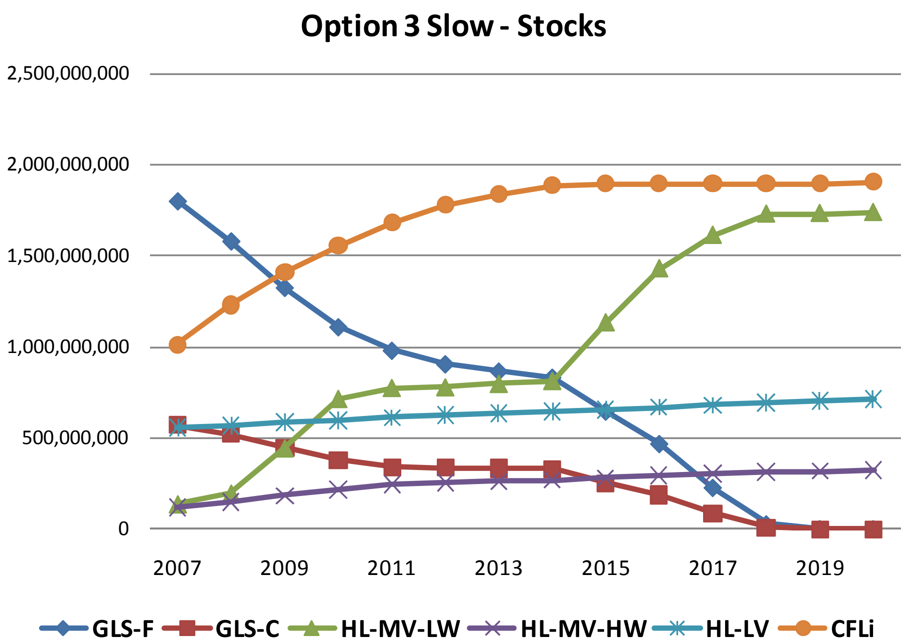

Figure 8-45: Option 3 Slow - Evolution of lamps stocks (in units)

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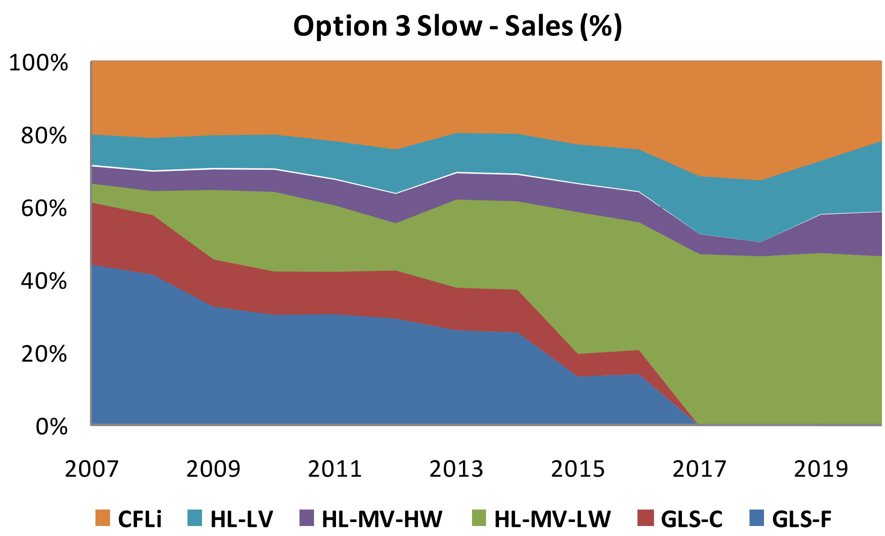

Figure 8-46: Option 3 Slow - Evolution of lamps sales (in %)

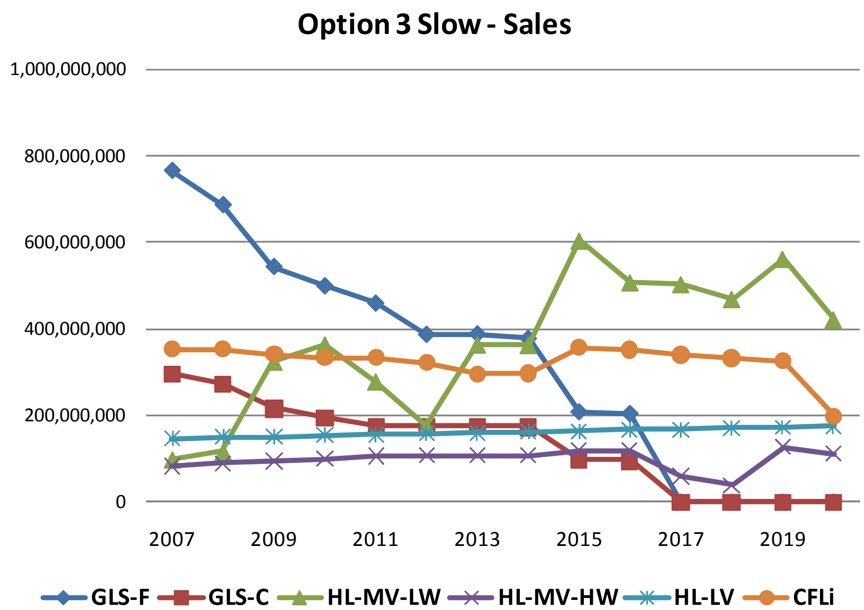

Figure 8-47: Option 3 Slow - Evolution of lamps sales (in units)

Variation of the total electricity consumption, and thus of total CO_2 emissions, are low from 2009 to 2020. Compared to the BAU scenario, 'Option 3 Slow' scenario allows in 2020 a reduction of 16.4% for these environmental impacts (112.7 TWh and 48.5 Mton CO_2 in 2020). These values are slightly higher than those in 2007 (112.2 TWh and 48.3 Mton).

Contributors to these two impacts are, in descending order: HL-MV-HW (35.3%), HL-MV-LW (31.4%), CFLi (18.5%), and HL-LV (14.8%).

However, this scenario implies a significant decrease of mercury emissions in 2020, with a reduction of about 32.4% compared to the BAU scenario (2123 kg in 'Option 3 Slow' and 3139 kg in BAU).

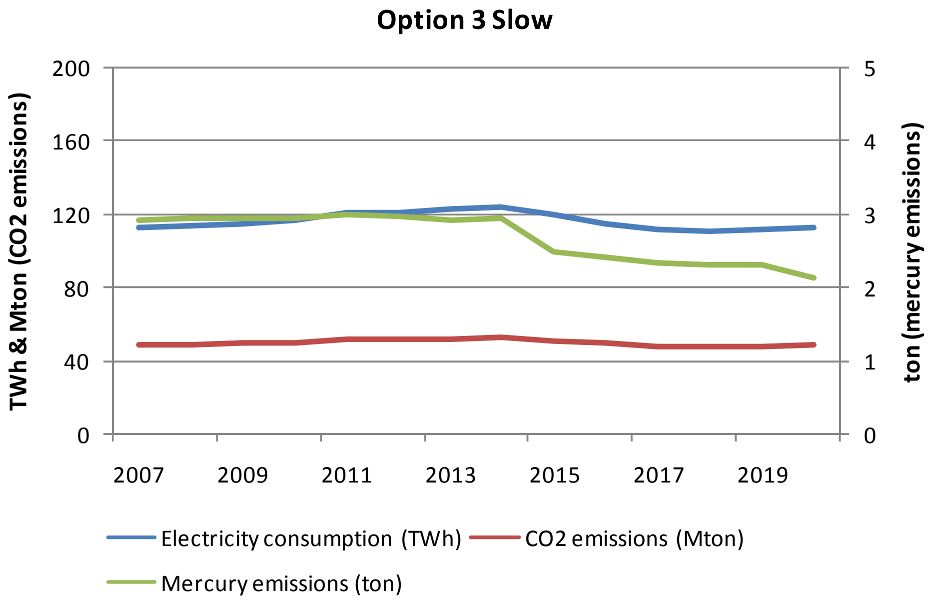

Figure 8-48: Option 3 Slow – Evolution of annual environmental impacts

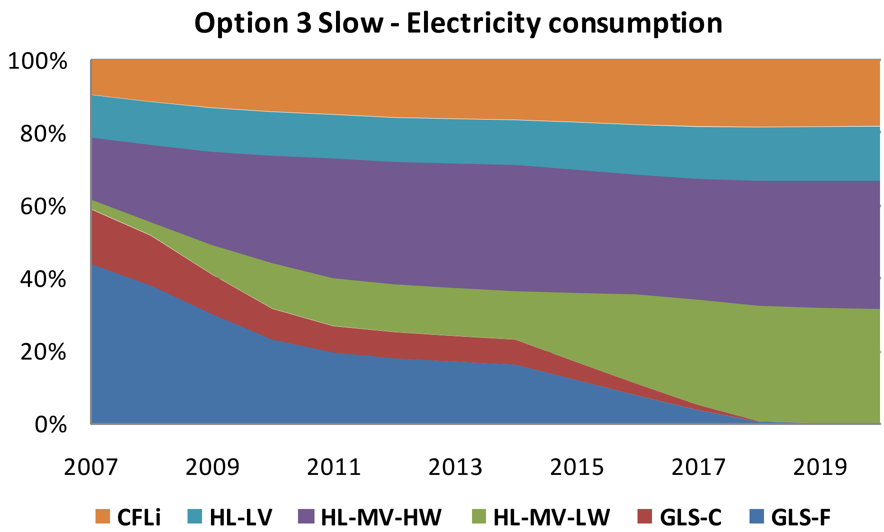

Figure 8-49: Option 3 Slow - Evolution of the contribution of the lamp types to the electricity consumptions of the total lamp stock

8.1.2.11 Comparison of scenarios

Based on the analysis of the eight scenarios (BAU + 7 'improvement' scenarios), environmental impacts in 2020 are presented in the following table, including variations both in units and in % with reference to the BAU scenario, and illustrated in Figure 8-50.

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Table 8-18: Environmental impacts in 2020 for each scenario

		Electricity consumption (GWh) in 2020	CO2 emissions (kton) in 2020	Mercury emissions (kg) in 2020
BAU	**Value**	134,736	57,936	3,139
	Difference to BAU	*0.0%*	*0.0%*	*0.0%*
BAT	**Value**	47,544	20,444	853
	Difference to BAU (units)	*-87,192*	*-37,493*	*-2,286*
	Difference to BAU (%)	*-64.7%*	*-64.7%*	*-72.8%*
Option 1 Fast	**Value**	48,270	20,756	1,444
	Difference to BAU (units)	*-86,465*	*-37,180*	*-1,695*
	Difference to BAU (%)	*-64.2%*	*-64.2%*	*-54.0%*
Option 1 Slow	**Value**	48,336	20,784	1,165
	Difference to BAU (units)	*-86,400*	*-37,152*	*-1,974*
	Difference to BAU (%)	*-64.1%*	*-64.1%*	*-62.9%*
Option 2 Clear B Fast	**Value**	95,999	41,279	1,609
	Difference to BAU (units)	*-38,737*	*-16,657*	*-1,530*
	Difference to BAU (%)	*-28.8%*	*-28.8%*	*-48.8%*
Option 2 Clear B Slow	**Value**	83,841	36,052	1,466
	Difference to BAU (units)	*-50,894*	*-21,885*	*-1,673*
	Difference to BAU (%)	*-37.8%*	*-37.8%*	*-53.3%*
Option 2 Clear C Fast	**Value**	101,677	43,721	1,656
	Difference to BAU (units)	*-33,058*	*-14,215*	*-1,484*
	Difference to BAU (%)	*-24.5%*	*-24.5%*	*-47.3%*
Option 3 Slow	**Value**	112,681	48,453	2,123
	Difference to BAU (units)	*-22,055*	*-9,484*	*-1,016*
	Difference to BAU (%)	*-16.4%*	*-16.4%*	*-32.4%*

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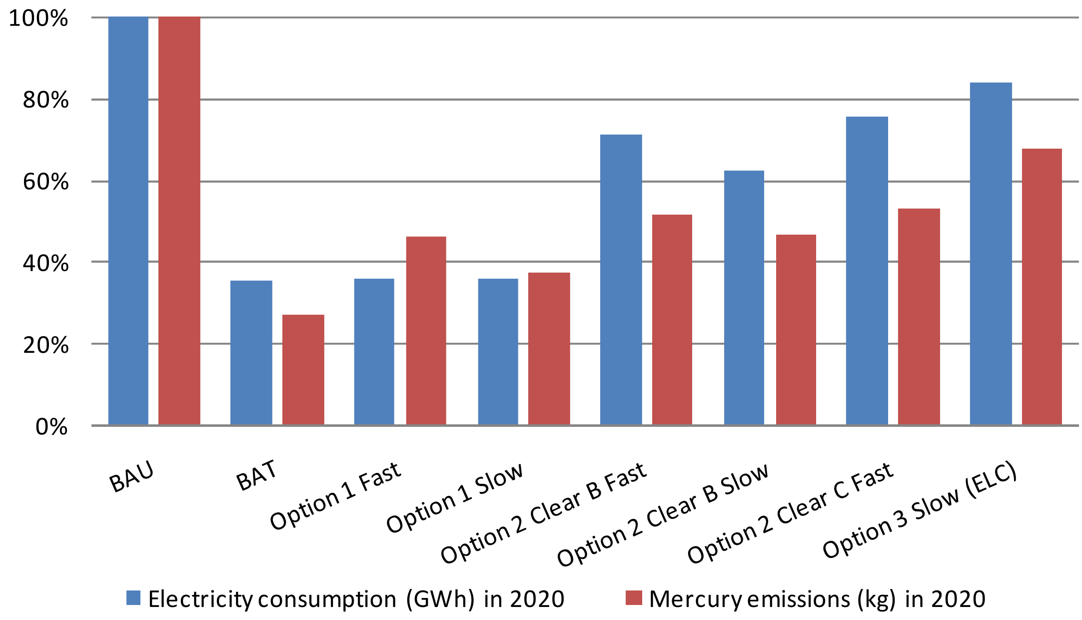

Figure 8-50: Comparison of scenarios in 2020

As already mentioned, looking only at the environmental impacts in 2020 can be confusing. For instance, 'Option 2 Clear B Slow' presents higher energy savings in 2020 than 'Option 2 Clear B Fast', although the previous was considered a less ambitious scenario. Therefore, in order to allow a 'fair' comparison, cumulated environmental impacts from 2009 (assumed as the entry into force of the legislation) to 2020 need to be analysed. Such a comparison presents more logical results and the resulting ranking of 'the most environmental friendly scenario' is as expected: the BAT scenario allowing for the highest reductions of environmental impacts, and 'Option 3 Slow' scenario being the least efficient one.

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Table 8-19: Cumulated environmental impacts from 2009 to 2020 for each scenario

		Electricity consumption (GWh) from 2009 until 2020	CO2 emissions (kton) from 2009 until 2020	Mercury emissions (kg) from 2009 until 2020
BAU	**Value**	1,515,593	651,705	36,163
	Difference to BAU	*0.0%*	*0.0%*	*0.0%*
BAT	**Value**	577,408	248,285	16,828
	Difference to BAU (units)	*-938,185*	*-403,419*	*-19,335*
	Difference to BAU (%)	*-61.9%*	*-61.9%*	*-53.5%*
Option 1 Fast	**Value**	665,953	286,360	22,216
	Difference to BAU (units)	*-849,639*	*-365,345*	*-13,947*
	Difference to BAU (%)	*-56.1%*	*-56.1%*	*-38.6%*
Option 1 Slow	**Value**	775,259	333,361	23,223
	Difference to BAU (units)	*-740,334*	*-318,343*	*-12,940*
	Difference to BAU (%)	*-48.8%*	*-48.8%*	*-35.8%*
Option 2 Clear B Fast	**Value**	1,096,319	471,417	24,628
	Difference to BAU (units)	*-419,274*	*-180,288*	*-11,535*
	Difference to BAU (%)	*-27.7%*	*-27.7%*	*-31.9%*
Option 2 Clear B Slow	**Value**	1,154,534	496,450	27,597
	Difference to BAU (units)	*-361,059*	*-155,255*	*-8,566*
	Difference to BAU (%)	*-23.8%*	*-23.8%*	*-23.7%*
Option 2 Clear C Fast	**Value**	1,201,422	516,612	25,702
	Difference to BAU (units)	*-314,170*	*-135,093*	*-10,461*
	Difference to BAU (%)	*-20.7%*	*-20.7%*	*-28.9%*
Option 3 Slow (ELC)	**Value**	1,399,616	601,835	31,605
	Difference to BAU (units)	*-115,977*	*-49,870*	*-4,558*
	Difference to BAU (%)	*-7.7%*	*-7.7%*	*-12.6%*

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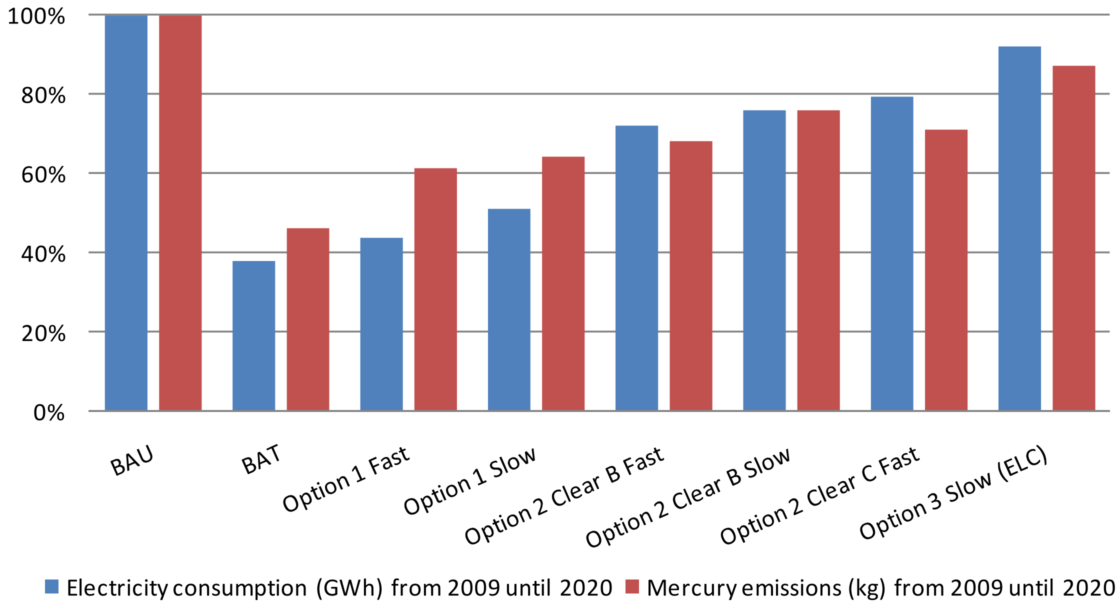

Figure 8-51: Comparison of scenarios between 2009 and 2020

8.1.3 Sensitivity analysis

The robustness of the outcomes of the study depends on the underlying assumptions. These assumptions have been explicitly mentioned at the relevant steps of the study. In this section, the sensitivity of the results to the most critical parameters and assumptions is tested, related namely to:

- The economic data, such as the electricity tariff which has an influence on the LCC when implementing improvement options,
- The assumption made on mercury emissions for CFLi at their end-of-life (80% of CFLi not recycled),
- The electricity consumption which for the purposes of the scenario analysis was considered for the use phase alone and not for the whole life cycle. In Chapters 5 and 7 the whole life cycle was considered.

8.1.3.1 Assumptions related to the electricity tariff

For the base-cases, an average EU-27 electricity tariff of 0.1528 €/kW was used, based on the data from Eurostat (see chapter 2, section 2.4.2). However, if the lowest electricity tariff (i.e. 0.0658 €/kW in Latvia) and the highest electricity tariff (i.e. 0.2580 €/kW in Denmark) are applied, this could lead to different LCC for the base-cases.

As shown in Table 8-20, the modifications in the electricity tariff have a strong impact on the LCC. Indeed, the major part of the LCC is due to the electricity costs during the use phase of the six lamp types as specified in chapter 5 (section 5.3). With lower electricity price the savings in LCC of the improvement options are more modest, but they remain greater than the additional costs of these options, thus bringing net benefits regardless of the electricity price.

Table 8-20: Impacts of the electricity tariff on the LCC of the base-cases

Electricity tariff (€/kWh)		GLS-C	GLS-F	HL-MV-LW	HL-MV-HW	HL-LV	CFLi
0.1528	**LCC**	8.60 €	8.60 €	14.32 €	69.16 €	17.35 €	16.23 €
	LCC per lumen per hour	*14.47 10^{-6} €*	*15.02 10^{-6} €*	*19.89 10^{-6} €*	*8.91 10^{-6} €*	*13.29 10^{-6} €*	*4.84 10^{-6} €*
0.0658	**LCC**	4.07 €	4.07 €	9.32 €	31.53 €	9.27 €	9.62 €
	LCC per lumen per hour	*6.85 10^{-6} €*	*7.11 10^{-6} €*	*12.94 10^{-6} €*	*4.06 10^{-6} €*	*7.10 10^{-6} €*	*2.87 10^{-6} €*
0.2580	**LCC**	14.19 €	14.19 €	20.47 €	115.24 €	27.60 €	24.23 €
	LCC per lumen per hour	*23.89 10^{-6} €*	*24.79 10^{-6} €*	*28.43 10^{-6} €*	*14.84 10^{-6} €*	*21.15 10^{-6} €*	*7.22 10^{-6} €*

8.1.3.2 Assumptions related to mercury emissions of CFLi EoL

In chapters 5 and 7, it was assumed that 80% of the used CFLi's are not collected and as a consequence 80% of the mercury present in lamps is emitted during the end-of-life (EoL) processing, i.e. 3.2 mg for the base-case CFLi (= 4 mg x 80% per lamp).

The following table shows the impact of the EoL assumptions on the total mercury emitted over the whole life cycle of a lamp (i.e. the use phase for all base-cases and EoL for CFLi), with two extremes: 100% CFLi not recycled (pessimistic assumption) and 30% (optimistic assumption in line with the objective set by the WEEE Directive).

With a pessimistic assumption, the base-case CFLi is the one emitting the highest amount of mercury to air per lumen and per hour (+4.9% compared to the base-case GLS-F). On the contrary, when assuming that only 30% of CFLi are not recycled, and therefore that 30% mercury is dumped at the end-of-life stage, the base-case CFLi becomes the most "environmental friendly" lamp type regarding this impact (-50.4% compared to the base-case GLS-F).

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Table 8-21: Impacts of the share of CFLi recycled on total mercury emissions

share of CFLi not recycled		GLS-C	GLS-F	HL-MV-LW	HL-MV-HW	HL-LV	CFLi
80%	**Mercury emissions over lifetime per lumen per hour (ng)**	1.45	1.51	1.33	0.93	1.22	1.34
	Variation with the base-case GLS-F	*-3.6%*	*0.0%*	*-11.7%*	*-38.6%*	*-18.9%*	*-10.9%*
100%	**Mercury emissions over lifetime per lumen per hour (ng)**	1.45	1.51	1.33	0.93	1.22	1.58
	Variation with the base-case GLS-F	*-3.6%*	*0.0%*	*-11.7%*	*-38.6%*	*-18.9%*	*+4.9%*
30%	**Mercury emissions over lifetime per lumen per hour (ng)**	1.45	1.51	1.33	0.93	1.22	0.75
	Variation with the base-case GLS-F	*-3.6%*	*0.0%*	*-11.7%*	*-38.6%*	*-18.9%*	*-50.4%*

8.1.3.3 Assumptions related to the life cycle stage considered in the scenario analysis

The scenario analysis carried out in section 8.1.2 presents the electricity consumption during the use phase for each year and for each scenario. The limitation of the energy consumption during this specific stage was decided based on outcomes of the environmental assessments of the six base-cases in chapter 5. Indeed, the share of the use phase for the indicator "energy consumption" is:

- GLS-F & GLS-C: 91.3%
- HL-MV-LW: 92.4%
- HL-MV-HW:98.9%
- HL-LV: 95.3%
- CFLi: 93.0%

However, when taking into account for the scenario analysis the total energy consumption over the whole life-cycle, the variations of energy consumption (in %) of the seven scenarios analysed with the BAU scenario are quite similar to those observed when only looking at the use phase. Results are presented in the Table 8-22 and Figure 8-52.

DISCLAIMER: The statements, figures and graphs provided on this page have to be read in the context set out in the beginning of section 8.1.2 and in sections 8.1.2.1 and 8.1.2.2

Table 8-22: Energy consumption in 2020 for each scenario(use phase and life-cycle)

		Electricity consumption (GWh) during the use phase in 2020	Total energy consumption (GWh) over the life-cycle in 2020
BAU	**Value**	134,736	142,024
	Variation with the BAU	*0.0%*	*0.0%*
BAT	**Value**	47,544	51,122
	Variation with the BAU (units)	*-87,192*	*-90,902*
	Variation with the BAU	*-64.7%*	*-64.0%*
Option 1 Fast	**Value**	48,270	51,904
	Variation with the BAU (units)	*-86,465*	*-90,121*
	Variation with the BAU	*-64.2%*	*-63.5%*
Option 1 Slow	**Value**	48,336	51,974
	Variation with the BAU (units)	*-86,400*	*-90,050*
	Variation with the BAU	*-64.1%*	*-63.4%*
Option 2 Clear B Fast	**Value**	95,999	100,262
	Variation with the BAU (units)	*-38,737*	*-41,762*
	Variation with the BAU	*-28.8%*	*-29.4%*
Option 2 Clear B Slow	**Value**	83,841	89,462
	Variation with the BAU (units)	*-50,894*	*-52,562*
	Variation with the BAU	*-37.8%*	*-37.0%*
Option 2 Clear C Fast	**Value**	101,677	106,480
	Variation with the BAU (units)	*-33,058*	*-35,544*
	Variation with the BAU	*-24.5%*	*-25.0%*
Option 3 Slow	**Value**	112,681	118,426
	Variation with the BAU (units)	*-22,055*	*-23,599*
	Variation with the BAU	*-16.4%*	*-16.6%*

DISCLAIMER: The statements, figures and graphs provided on this page have to be read in the context set out in the beginning of section 8.1.2 and in sections 8.1.2.1 and 8.1.2.2

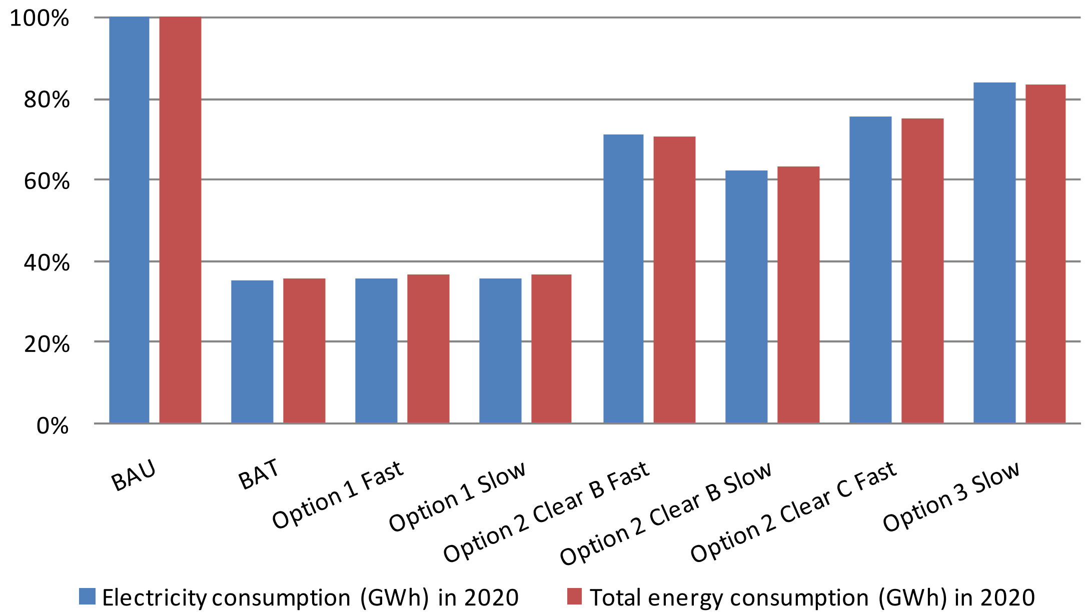


Figure 8-52: Comparison of scenarios in 2020 considering the energy consumption during the use phase (in blue) and over the whole life cycle (in red)

8.1.4 Suggested additional requirements for the appropriate implementation

8.1.4.1 Additional recommendations for the lamp labelling (Directive 98/11/EC)

It is recommended that the labelling also includes:

- lamps not operated on the mains voltage
- reflector lamps or directional light sources (see also part 2 of this study). *(As in principle, LED's are 'directional light sources', it is also recommended to include them and the luminaires with integrated LED's in the labelling scheme in part 2 of this study).*

It is recommended to switch to a new, dynamic labelling scheme, e.g. similar with the CECED[100] proposal and to redefine the label minimum requirements in order to:

- introduce a label between the current B and A as the gap between both is too large (see Figure 8-53: Defined lamp efficacy levels 4 - 9
- where level 5 = B and level 7 = A),
- streamline the A-label formula with the B label formula,
- have more ambitious labels compared to A .

In the new, dynamic labelling system, it is proposed to use lamp efficacy levels[101] that are as far as possible compatible with the existing household labelling Directive 98/11/EC levels.
The newly proposed lamp efficacy levels and the current energy labels are presented in Table 8-23 and they are graphically shown in Figure 8-53 and Figure 8-54.

[100] Conseil Européen de la Construction d'appareils Domestiques, see www.ceced.org, position 4 December 2007.
[101] The levels used in this study are subject to the ongoing revision of the Energy Labelling Framework Directive (92/75/EEC). The discussion at this stage should focus on the values behind the levels.

Table 8-23: New definition of lamp efficacy levels (lamps above 34 lm) compared to existing labels of Directive 98/11/EC

Level (this study)	Label (Directive 98/11/EC)	Maximum system power demand (P_{system}) related to lamp luminous flux (Φ) [W]		Minimum light source efficacy (including control gear losses) $\eta_{source} = \Phi / P_{system}$ [lm/W]	
0	G	>1,30	x (0,88√Φ+0,049Φ)		
1	F	1,30		Φ / 1,30	x 1/(0,88√Φ + 0,049Φ)
2	E	1,10		Φ / 1,10	
3	D	0,95		Φ / 0,95	
4	C	0,80		Φ / 0,80	
5	B	0,6		Φ / 0,6	
6	B (B+)*	0,4		Φ / 0,4	
7	***A ****	0,225		Φ / 0,225	
8	***A (A+)****	0,209		Φ / 0,209	
9 =BAT level	***A (A++)****	0,178		Φ / 0,178	
10	***A (A+++)****	0,116		Φ / 0,116	

* *It must be noted that the formula for the current label **A** as defined in Directive 98/11/EC does not completely corresponds with the proposed new formula, but the difference is very small (the current formula is 0.24√Φ+0.0103Φ).*
It must also be noted that in the proposed formula, system power (= lamp + control gear / power supply) is used. As a consequence the same formula can be used for all lamps GLS-lamps, CFLi's, HL-MV as well as fluorescent lamps, HL-LV and HID-lamps.

The values should be measured in compliance with EN and CIE standards (see chapter 1) (i.e. lamp lumen output (@100 h operation) with the following additional corrections:

- for low voltage lamps (HL-LV, LED) the correction factors proposed in 8.1.1.3 should be taken into account,
- for lamps that have an optimum working temperature above 25°C, lumen output should be corrected[102] for the optimum working temperature up to 60°C (e.g. most T5 lamps have their optimum working temperature at 35°C where the efficacy is about 10 % more compared to the efficacy at 25°C),
- for fluorescent lamps without integrated ballast the wattage has to be corrected for the ballast losses by the correction factor of 1,12 ,
- for HID lamps without integrated ballast, the wattage has to be corrected for the ballast losses by the correction factor LWFe =1,1 for wattages > 100 W and 1,12 for wattages ≤ 100W.

The highest levels are useful for green procurement or proportional targets.

[102] Because these lamps are typically designed for indoor luminaires that optimise the lamp working temperature above the ambient temperature.

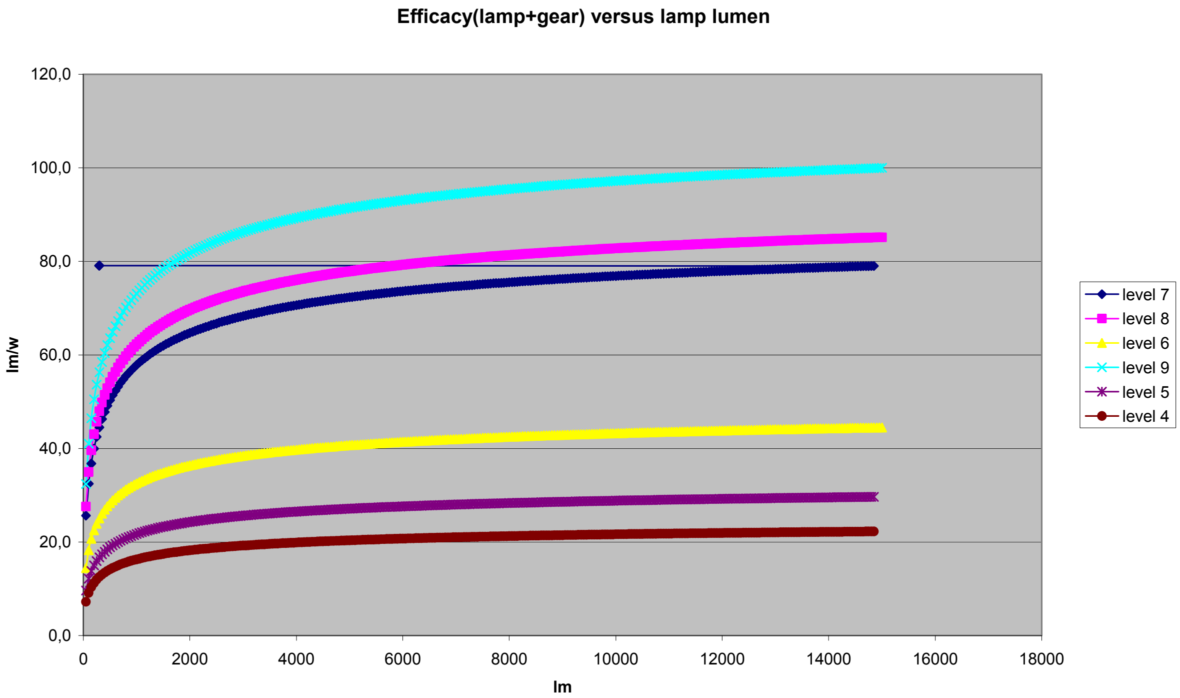


Figure 8-53: Defined lamp efficacy levels 4 - 9

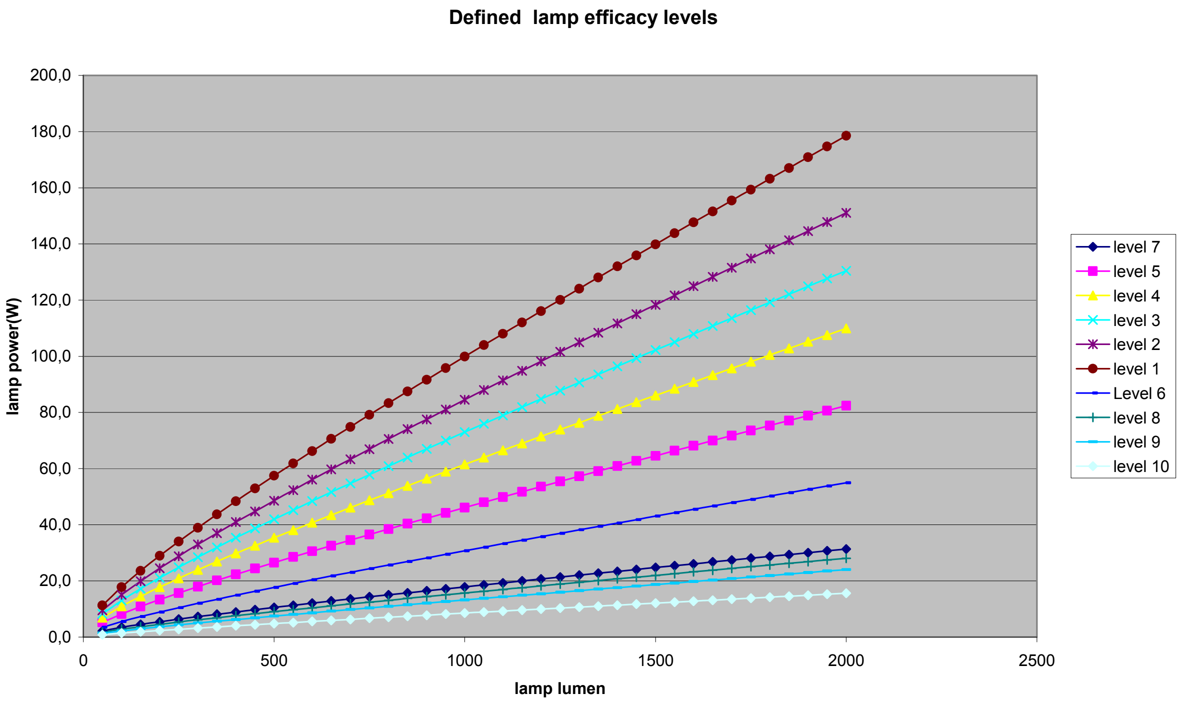
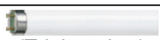


Figure 8-54: Power demand for the defined lamp efficacy levels (except level 0)

A table with corresponding values per defined lamp efficacy level is included in Annex 9.3.

Table 8-24: Examples of efficacy levels and labels for existing lamp types

Level (this study)	Label (Directive 98/11/EC)	Example for domestic lighting	
0	G		
1	F		
2	E	 	GLS-C or GLS-F (Incandescent lamp)
3	D		HL-MV (halogen lamps with xenon gas, some types)
4	C		HL-MV (halogen lamps with xenon gas, some types)
5	B		HL-MV BAT level (= halogen lamp with low voltage transformer and infrared coating) or HL-LV BAT level
6	B (B+)*		CFLi certain types (often those with second envelope) and some CFLi with magnetic ballast
7	A	   (Halo phosphate)	CFLi most types and some CFLni with ballast, LFL halo phosphate lamps.
8	A (A+)*	 	CFLni + electronic ballast (EEI=A2) (Equivalent to A+ in working document lot 8 on office lighting)
9 =BAT level	A (A++)*	 (Triphosphor) 	LFL (@ optimum temperature) + electronic ballast or claimed as BNAT by LED manufacturers + certain HID lamps at high lumen output (Equivalent to A++ in working document lot 8 on office lighting)
10	A (A+++)*		Please note that low pressure sodium lamps or green linear fluorescent lamps currently achieve much higher efficacies, but they have a poor colour rendering and can therefore not be used in general indoor illumination. White LED manufacturers claim to achieve above 140 lm/W in future and an extension might be considered later.

8.1.4.2 Recommendations to prevent the luminaire socket and space lock-in effect

Some luminaires can not accept an energy efficient retrofit lamp due to the lack of space and/or socket types, as explained in chapter 3. This might especially be the case for very compact luminaires with G9/R7s sockets. Therefore luminaire requirements are needed (see also part 2 of the study).
Users of existing luminaires with lock-in effect should be informed in cases when replacement lamps will become obsolete. This would allow them to store sufficient replacements lamps in the cupboard. Although the cupboard store lifetime of these G9/R7s lamps is unlimited, this solution will not hold forever as also the lifetime of a luminaire is limited.

8.1.4.3 Recommendations to prevent the electrical wiring and control system lock-in effect

It is important to inform users on the compatibility and the possible lack of compatibility of dimmers/electronic switches with replacement lamps. This is especially the case when shifting from GLS-lamps to CFLi's (see related sections in chapters 3 and 6).
There are also related 'Required new or updated measurement or product standards' in section 8.1.6.

8.1.4.4 Warning about a potential direct rebound effect caused by the introduction of new energy efficient lighting (e.g. LED)

In the case of shifting to more energy efficient lighting, a rebound effect might occur where less savings than expected are realised or the energy consumption might even increase. Availability of more efficient and flexible light sources has over centuries triggered off new applications, increased illumination or comfort levels. Attention should be paid to an 'inflation of illumination levels' as explained in chapter 3.
A current trend is to replace one or few LFL or GLS-lamps in kitchen and bathroom by a much higher number of halogen lamps (even the less efficient HL-MV); the result is an increase of energy consumption. Also LED or halogen lamps incorporated in furniture for decorative purposes can raise energy consumption.
Another example is the use of LED lighting in outdoor applications e.g. as lighting in the soil at the entrance, burning every night.
More R&D on this phenomenon is recommended.

8.1.4.5 Reduced impact caused by lack of market surveillance and loopholes in legislation

It is obvious that market surveillance is recommended with regard to the proposed minimum performance and the eco-design requirements on information in section 8.1.1 in order to achieve the calculated impact in the scenarios. It should be realised that any efficacy underperformance might lead to higher energy consumption and this parameter should be carefully monitored. Currently there is also a lack of test data, especially for halogen (both reflector as non reflector lamps) or incandescent lamps.
Besides this, it is recommended to implement a continuous monitoring on market data and technical requirements about 'exemptions on proposed eco-design requirements' (if any). They might create serious loopholes in the market with the risk that calculated energy saving

targets might not be met. For this reason, it is recommended to link product related eco-design requirements to technical criteria as much as possible, application based exemptions would create large loopholes in the market as the real application is very difficult to control.
A current application for GLS-lamps can be found in traffic lights, where B22d-caps are used to prevent unscrewing of the lamp due to vibrations. An exemption for these lamps would create an enormous loophole. This back-door can technologically be closed by using coloured lamps in traffic lights as coloured lamps are exempted from the scope of this study. Changing to LED-application is of course a better solution with lower energy consumption and much lower maintenance costs due to the very long lifetime of LED's compared to GLS-traffic lamps. But this better solution could cause substantial investments for public authorities as certain traffic controllers can't handle the safety requirements with the low electric currents for LED's and they need to be replaced. Coloured GLS-traffic lamps can only temporarily overcome this problem until the controllers can be replaced.
For domestic ovens there is no problem as these lamps (≤25W) are already exempted.
For industrial ovens, a suggested technical solution for this potential exemption is to adapt the oven for a E27 GLS Safety Extra-Low Voltage (SELV) lamp. A lower voltage GLS lamps shows a higher lamp efficacy (e.g. a 60 W/E27/710 lm clear GLS for 24 VAC has a 30 % higher lamp efficacy compared to a 60 W/E27/990 lm clear GLS for 230 VAC) equivalent to label D (with 1,06 correction factor). The extra losses in an electronic transformer are only about 6 % and the cost of about 15 Euro/100 VA are is acceptable. The risk that these low-voltage lamps are sold in the normal domestic sales channels is non-existing, because when people might plug in this lamp in a E27 socket on 230V, the lamp will be broken in a few minutes.
These low voltage lamps can also be used as reference lamps for colour rendering and other measurements.
Nevertheless, it is possible that there will stay some light sources that are marketed and used for other applications than general illumination for human vision might still be needed. These exemptions should be treated very carefully.

8.1.4.6 Complementary recommendations on users information, product developers and service providers skills

As explained in section 3.4.2. and section 3.4.3, there is, to some extent, a lack of skilled and informed users as well as a lack of skilled service providers. This problem could become worse when certain lamp types are phased out, therefore it is recommended to:

- Install 'help desks' to assist users, product developers and service providers with retrofit options (e.g. what to do for light sensitive people, dimmers, traffic signs, and horticulture applications).
- Familiarise people with 'lumen' instead of 'GLS lamp wattage' and other lamp parameters including lamp labelling.
- In general communication about CFLi versus GLS equivalence a 1 to 4 ratio should be recommended to avoid consumer dissatisfaction.
- Stimulate designers to take into account energy efficiency and eco-design in order to provide users with attractive and energy efficient designs.

8.1.4.7 Complementary recommendations on policy actions to smoothen market transformation and lamp sales

In section 8.2, the impact on industry is explained more qualitatively and measures are recommended to smoothen the volume of annual lamp sales. The annual lamp sales might be subjected to transients when minimum eco-design requirements are implemented and this might not be beneficial for the profitability of lamp production facilities.
It is recommended to:

- stimulate pre-phase outs by sectorial agreements on application and retrofitting of inefficient lamps (e.g. in the horeca sector, shops and retailers, public buildings)
- launch advanced public information campaigns on phase out (e.g. announce timely a phase out and allow people to stock spare lamps if needed for existing luminaires)
- implement the phase out gradual in time as already done to some extent in the calculated scenarios.

8.1.4.8 Complementary recommendations on policy actions to increase mercury recycling

It is recommended to stimulate users to return used CFLi’s for recycling as they contain mercury. It is not enough to inform people that they can return the CFLi’s at the recycling station (chapter 3). It is recommended to require that used CFLi’s can be returned at the point of sale; this might be stimulated by a return of a deposit, paid when buying the lamp.
The same is of course true for the many other domestic products that contain often much more mercury, e.g.: flat screen TVs with CCFL lamps, LCD screens with CCFL lamps, beamer HID lamps, HID car headlights etc.

8.1.4.9 Warning on comparing US with EU minimum lamp efficacy targets

When comparing global energy saving policy options it should be noted that in the US incandescent lamps are about 10 - 20 % more efficient than in the EU. This is mainly because of a different line voltage, see also chapter 6. Incandescent lamp efficacy is related to life time and line voltage, e.g.: a typical EU lamp of 100 W-230 VAC (rated life time 1000 h) clear GLS has 1340 lm and a typical US lamp of 100 W-120 VAC (rated life time 750 h) (US available) has 1710 lm. A reason to go in EU targets for options "2" that involve a transformer for filament lamps.

8.1.4.10 Complementary recommendations to reduce energy losses in distribution due to power factor and harmonic current

This issue of 'power factor' and 'harmonic line current' is explained in more detail in section 3.2.5. Due to specific requirements in EN 61000-3-2 lighting equipment above 25 W has already to comply with much stronger requirements in comparison with other domestic products (TVs, PCs, modems, printers, set top boxes, appliances, etc.). There is also compensation between capacitive and inductive loads as explained in section 3.2.5. It is recommended to address this issue horizontally for all typical domestic loads and it might make more sense to address first more expensive and more energy consuming products to reduce these associated problems.

8.1.4.11 Complementary recommendations to reduce the sensitivity of lighting to line voltage variations

Especially GLS and HL-MV lamps without an electronic transformer with voltage control are sensitive to line voltage fluctuations to flicker and reduced life time in case of overvoltages (see related section in chapter 3). When more distributed energy resources (DER) are installed in the future grid by 2020 it can be expected that it will become more difficult to control line voltage fluctuations. In this case, the minimum requirements for the most line voltage sensitive lamps that influence standard EN 50160 (2007) on 'Voltage characteristics of electricity supplied by public distribution networks' should be critically reviewed as well as the standard itself (if those lamps are not yet phased out).

8.1.4.12 Complementary recommendations to reduce negative impact from UV radiation

It can be considered to include limits on UV radiation to reduce impact on light sensitive people and to make an exception concerning use of low wattage (≤25W) GLS and lumen output ≤200lm.

8.1.4.13 Complementary recommendations to reduce barriers for SMEs and market surveillance authorities by improving access to EN standards and standards development related to eco-design requirements

Making the application of standards related to eco-design mandatory might create additional costs that could be significant for SMEs and people involved in market surveillance. It should be noted that international standards as defined in chapter 1 (e.g. CIE and IEC standards) and related to eco-design are not freely available and are copyright protected. These standards are sold electronically for about 1 euro per page and refer in many cases to many other standards. The trade in copies of these standards provides the main source of income to CIE and IEC. These standards are very technical and sometimes difficult to understand. It is recommended that the authorities would make this information free and easy available in electronic standard application guides.

8.1.4.14 Recommendations for the revision

A revision period of 4 years is recommended and special attention should be given to exemptions and potential loopholes in the legislation.

8.1.5 Suggested additional research

The most obvious reason for a lack of market surveillance is the lack of financial resources. Some test verifications according to the current standard methods are time consuming and hence expensive (e.g. 100 h burn in, complete goniophotometer measurement in all angles for reflector lamps, life time and the need for a large set of samples). It is recommended to research for accelerated market surveillance techniques.

It is also recommended to continue the research and consultation of stakeholders for a more universal system based lighting products regulation. This would be more independent from the light source technology compared to what currently has been proposed. Such an approach was studied and would require to link the efficacy levels to technical benefits or disadvantages with a kind of Bonus-Malus System (BMS). The main benefit is that it includes new technologies and could potentially create less loopholes in the legislation. Nevertheless it would require that all lighting component manufacturers approach their product from a system way of thinking. Therefore a good stakeholder consultation and information campaign would be need.

8.1.6 Required new or updated measurement or product standards

Increased compatibility between lamp and control switches:
The purpose is to prevent and reduce the electrical wiring and control system lock-in effect, see also section 8.1.4.3 and related sections in chapters 3 and 6.
With the increasing use of CFLi's it is necessary to provide the manufacturers of control equipment with a reliable and reproducible basis of electrical lamp behaviour parameters in order to develop compatible control switches.
This can be done by updating and extending existing EN standards, more in particular standard EN 60669-2-1 on 'Electronic switches for households and similar use', standard EN 60969 on CFLi's and EN 61047 (2004) on 'D.C. or A.C. supplied electronic step-down converters for filament lamps. Performance requirements'.
A cooperation between the control switch manufacturers (CECAPI), lamp manufacturers (ELC), and luminaire manufacturers(CELMA) is therefore recommended.

CFLi testing (EN 60969):
Include the fast cycling test in EN 60969.
Thermal requirements to provide compatibility with luminaires.

Wiring system compatibility with CFLi lamps:
Further work should be initiated in order to align relevant EN-standards for lamps and electronic switches. Manufacturers of lamps, luminaires and installation equipment need to work together and agree on relevant quality levels and safe operating criteria.

8.2 Impact analysis for industry and consumers

Implementing measures might affect light sources marketed for other applications than general illumination for human vision.

It is important to be fully aware that 'efficacy' in lumen is linked to human vision (see chapter 3) and that a light source with a low 'efficacy' is not de facto 'inefficient' for other tasks that involve light. Banning of products or technology from the market based on its 'efficacy' could therefore cause serious negative side effects for other light source applications. The background for this paradox is linked to the universal physical law of the conservation of energy that means that there is simply no energy 'loss' in a 'closed system' without a 'defined output' or target application. As a consequence this eco-design study was inevitably linked to a 'defined output' or a functional unit (lumen) as defined in chapter 1.

Hereafter is a generic description of other applications that involve 'light sources':

- Artificial light sources are also used *for non human species* such as plants and animals. These light sources are not optimised for lumen but for other light spectra or colours that correspond more to the light sensitivity of those species. Applications include plant growth (flowers, vegetables, fruit, etc.) in green houses[103]. There is also a trend to keep pets that need special light sources (including UV lighting) for living outside their natural environment. Also in animal farming, artificial light sources are widely used to increase the production of milk and eggs. Light sources used in this area are often gas discharge lamps (e.g. HID, LFL).
- *Infrared and UV light sources* have also several *non vision or technical applications*. Infrared is next to red and UV is next to blue in the visible light spectrum and they cannot avoid the emission of a small amount of visible light and vice versa. Hence these lamps have some lumen output however with a very low efficacy. Infrared light finds many applications as a deliberate heating source by providing radiated heat. They are used in many industrial applications such as food processing and domestic applications such as instant bath room heaters or ovens. Infrared light sources often use the same technology as incandescent lamps. The visible light produced by typical infrared and UV lamps have normally saturated colours (red, blue) that do not satisfy the 'white light source definition (see chapter 1). UV light sources include: sun tanning, black lights, disinfection, sterilisation, scientific and technical instrumentation, chemical reactors, pet care and chemical processing. This lamp technology is very close to LFL and CFL lamps.
- Some applications are linked to certain sockets or a socket should be reserved for an application, e.g. car headlights. If everything else fails, the last method is to prohibit the light sources intended for non-vision applications from being linked to general lighting in marketing or package information. However this could be insufficient as people could recognise easily a 'phased' out incandescent lamp in a shop in spite of contrary information on the package about the intended application. Please read also the related recommendations in section 8.1.4.5.

Global CFLi production capacity:

Part 8.1.2 informs about projected trends in lamp sales and lamp types related to policy scenario options. Below these sales are related to the global production capacity.

The very latest statistics (Eurostat, Oct. 2008) informs that the EU production of CFL is 277 M, import is 408 M and export 56 M. This gives an apparent consumption of 629 M and with subtraction of estimated sales of 110 M CFLni the current sales of CFLi is around 520 M/year. This is 167 M more than the former statistical sales number 353 M which is used in the BAU (see Annex 8.8). In 2006, China produced [104] about 2400 M CFLi and it estimated that their production capacity is currently around 3 billion CFLi.

In the BAT option, the projected yearly sales peaks at about 1600 M in 2009 and it seems unrealistic to meet this sales volume with the current global production capacity.

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[103] Please note that it is paradoxical to the objective of increasing the share of renewable energy while previously these flowers and vegetables did grow direct in the sun, nevertheless not with the same properties

[104] Chen (2006): 'CFL in China ',CHEN Yansheng', China Association of Lighting Industry (2006)

In policy option "1" the projected yearly sales peaks in the two scenarios at respectively 900 M and 700 M. In policy option “2” the projected yearly sales peaks in both scenarios at 600 M. In all of these four scenarios, it is very likely that China can fill up the extra demand of 80-280 M CFLi lamps being equal to 3-13% of the Chinese production capacity. In reality, the peaks might not be so sharp and high as calculated in the scenarios because the penetration might be slowed by the consumers have GLS in stock and that there is a lock-in effect created by luminaries that simply do not accept CFLi, see 8.1.4.2. Please also read the next section on annual sales projections.

About the projected EU27 annual sales peak and/or periodic waves :

In the proposed policy scenarios, the annual lamp sales might be subjected to a one time annual sales peak and/or even periodic “waves”. This peak or the periodic sales waves might also not be beneficial for the profitability of lamp production facilities or lamp sales channels. The annual lamp sales changes due differences in lamp life time together with phase out implementations, this can be seen in part in section 8.1.2. Please note that the lamp sales figures in section 8.1.2 are partially due to the simplified model based on 'discrete' base-cases as defined in chapter 5 and connected discrete improvement options as defined in chapter 7. This discrete base-case model approach was reflected in abrupt changes in calculated energy consumption and lamp sales. In reality, this will be more smooth due to spreading in lamp wattages, different operational hours for products in use, new products and user behaviour. The user behaviour is difficult to predict and related to: proactive storing phase out lamps, impact of green procurement, impact of promotional campaigns and also the choice of retrofit options (e.g. buy new luminaire with reflector lamp, CFLi or efficient halogen,...). As a consequence, the real annual sales are mathematically difficult to predict. Nevertheless to smoothen these annual sales please read also the recommendations in 8.1.4.7. Finally this can also be absorbed by global sales, as GLS phase-out is expected to appear over a longer period worldwide it is likely there will be a market elsewhere in the world. When the lamps have a longer life time the final annual sales will decrease because of lower replacement sales in the first years after.

A potential negative impact on EU27 GLS lamp producers, transporters and distributors:

A strong reduction of GLS lamps sales will appear in all the proposed scenarios. As a consequence less transport and distribution is needed in certain scenarios and these activities will be reduced.. These lamps are mainly produced in EU27 (see chapter 2) and these production facilities would have to close down or should shift towards the production of efficient low voltage halogen lamps with infrared coating (HL-LV) in case of options 2 (see 8.1.2).

Positive impact on lamp producers, secondary suppliers to lamp producers, niche retrofit equipment producers, retrofit installers and consultants:

Beside the negative impact described above one should realise that there will be also be a positive impact on certain lamp producers, secondary suppliers to lamp producers, niche retrofit equipment producers, retrofit installers and consultants:

- producers of power electronic components, because there will be significant more need for these components in option 1 and 2 (several of them in EU27 even when CFLi assembly is outside EU 27).

- the secondary suppliers to power electronic component manufacturer (several of them are located within the EU27 even when CFLi assembly is outside EU 27).
- the secondary suppliers to new or upgraded lamp production lines (several of them are loacted within the EU27 even when CFLi assembly is outside EU 27), among them the producers of advanced infrared coating equipment in options 2.
- producers of luminaires that accept energy efficient lamps in certain options that stimulate luminaire changes (options 1 and 2).
- consultants, designers and installers to assist phase out.

Potential barriers created by protected intellectual property:
All the proposed scenarios rely on basic technology already available for above 20 years. Hence the related basic patents and IP should be expired, for more details please read chapter 6.

Background information about the impact of mercury brought into circulation with household lamps:
About mercury pollution cited from the WHO Air Quality Guidelines - Second Edition chapter 6.2: 'Mercury is emitted to the atmosphere by natural degassing of the earth's surface and by re-evaporation of mercury vapour previously deposited on the earth's surface. Mercury is emitted in the form of elemental vapour. Annual natural emissions are estimated to be between 2700 and 6000 tonnes, some of which originate from previous anthropogenic activity. Anthropogenic sources of mercury are numerous and worldwide. Mercury is produced by the mining and smelting of cinnabar ore. It is used in chloralkali plants (producing chlorine and sodium hydroxide), in paints as preservatives or pigments, in electrical switching equipment and batteries, in measuring and control equipment (thermometers, medical equipment), in mercury vacuum apparatus, as a catalyst in chemical processes, in mercury quartz and luminescent lamps, in the production and use of high explosives using mercury fulminate, in copper and silver amalgams in tooth-filling materials (currently being phased out by several countries), and as fungicides in agriculture (especially as seed dressings). The Almaden mercury mine in Spain, which accounts for 90% of the total output of the European Union, produces more than 1000 tonnes per year, but the amount of mercury released to the environment is unknown. In total, human activities have been estimated to add 2000–3000 tonnes to the total annual release of mercury to the global environment.' Mercury is an atom existing on earth since existence that cannot be destroyed nor be created by a chemical reaction. As a consequence it should be noted that as long as measured mercury was present in water and air and this is not due to lamp mercury alone.
500 M annual sales of CFLi will contains about 1 ton mercury (2 mg per lamp), more detailed information on projected CFLi sales can be found in section 8.1.2 see also recommendation in section 8.1.4.8 on recycling.

About the potential negative impact on consumers from luminaire replacement (if needed):

In some scenarios consumers are forced to replace luminaries. This might require an initial investment that might be a barrier in regions with a less wealthy population. However this seems to be unlikely, because an efficient luminaire with fluorescent lamp can be procured from as low as 5-10 euro and the pay back is very fast. This is connected to part 2 of the study.

8.3 Annexes

Annexe 8-1: Main economic and environmental data for the scenario "BAU"

		BAU													
		GLS-F		GLS-C		HL-MV-LW		HL-MV-HW		HL-LV		CFLi		TOTAL	
2007	**Total stock (mln)**	1,800.1	43.0%	568.5	13.6%	134.4	3.2%	119.4	2.9%	558.3	13.3%	1,010.1	24.1%	4,191	100%
	Total sales (mln)	767.4	44.0%	297.0	17.0%	97.4	5.6%	84.1	4.8%	147.0	8.4%	353.0	20.2%	1,746	100%
	Electricity consumption (TWh)	49.1	43.7%	16.9	15.1%	2.9	2.6%	19.2	17.1%	13.1	11.7%	11.0	9.8%	112	100%
2008	**Total stock (mln)**	1,580.0	37.2%	523.5	12.3%	193.5	4.6%	151.3	3.6%	571.5	13.5%	1,228.5	28.9%	4,248	100%
	Total sales (mln)	687.9	41.2%	273.1	16.4%	115.2	6.9%	89.8	5.4%	149.3	8.9%	353.1	21.2%	1,668	100%
	Electricity consumption (TWh)	43.1	37.8%	15.6	13.7%	4.2	3.7%	24.3	21.3%	13.4	11.8%	13.4	11.8%	114	100%
2009	**Total stock (mln)**	1,399.9	32.5%	478.4	11.1%	252.5	5.9%	183.1	4.3%	584.7	13.6%	1,407.0	32.7%	4,306	100%
	Total sales (mln)	624.9	39.1%	249.2	15.6%	133.0	8.3%	95.5	6.0%	151.5	9.5%	342.3	21.4%	1,596	100%
	Electricity consumption (TWh)	38.2	32.8%	14.2	12.2%	5.4	4.7%	29.4	25.3%	13.7	11.8%	15.4	13.2%	116	100%
2010	**Total stock (mln)**	1,251.3	28.7%	433.4	9.9%	311.6	7.1%	214.9	4.9%	597.9	13.7%	1,554.0	35.6%	4,363	100%
	Total sales (mln)	573.7	37.3%	225.3	14.6%	150.7	9.8%	101.1	6.6%	153.8	10.0%	334.6	21.7%	1,539	100%
	Electricity consumption (TWh)	34.1	28.6%	12.9	10.8%	6.7	5.6%	34.6	29.0%	14.0	11.8%	17.0	14.2%	119	100%
2011	**Total stock (mln)**	1,123.7	25.4%	388.3	8.8%	370.6	8.4%	246.8	5.6%	611.1	13.8%	1,680.0	38.0%	4,420	100%
	Total sales (mln)	527.8	35.3%	201.5	13.5%	168.5	11.3%	106.8	7.1%	156.0	10.4%	333.2	22.3%	1,494	100%
	Electricity consumption (TWh)	30.6	25.0%	11.6	9.4%	8.0	6.5%	39.7	32.4%	14.3	11.7%	18.3	15.0%	123	100%
2012	**Total stock (mln)**	1,038.3	23.2%	385.0	8.6%	394.3	8.8%	253.5	5.7%	622.2	13.9%	1,778.7	39.8%	4,472	100%
	Total sales (mln)	444.8	31.6%	200.8	14.3%	174.8	12.4%	107.6	7.6%	158.2	11.2%	322.7	22.9%	1,409	100%
	Electricity consumption (TWh)	28.3	23.0%	11.5	9.3%	8.5	6.9%	40.8	33.1%	14.6	11.9%	19.4	15.8%	123	100%
2013	**Total stock (mln)**	992.8	21.9%	381.6	8.4%	418.1	9.2%	260.2	5.8%	633.3	14.0%	1,837.5	40.6%	4,524	100%
	Total sales (mln)	446.3	32.1%	200.2	14.4%	181.0	13.0%	108.4	7.8%	160.4	11.5%	296.0	21.3%	1,392	100%
	Electricity consumption (TWh)	27.1	21.8%	11.4	9.1%	9.0	7.2%	41.8	33.7%	14.9	12.0%	20.1	16.2%	124	100%
2014	**Total stock (mln)**	953.6	20.8%	378.3	8.3%	441.8	9.7%	267.0	5.8%	644.5	14.1%	1,890.0	41.3%	4,575	100%
	Total sales (mln)	434.3	31.2%	199.6	14.4%	187.2	13.5%	109.3	7.9%	162.6	11.7%	297.5	21.4%	1,390	100%
	Electricity consumption (TWh)	26.0	20.7%	11.3	9.0%	9.5	7.6%	42.9	34.2%	15.1	12.1%	20.6	16.4%	125	100%

2015	**Total stock (mln)**	927.1	20.0%	374.9	8.1%	465.5	10.1%	273.7	5.9%	655.6	14.2%	1,929.9	41.7%	4,627	100%
	Total sales (mln)	431.7	31.0%	199.0	14.3%	193.5	13.9%	110.1	7.9%	164.8	11.8%	291.9	21.0%	1,391	100%
	Electricity consumption (TWh)	25.3	19.9%	11.2	8.8%	10.0	7.9%	44.0	34.7%	15.4	12.1%	21.1	16.6%	127	100%
2016	**Total stock (mln)**	900.5	19.2%	371.6	7.9%	489.2	10.5%	280.4	6.0%	666.7	14.3%	1,969.8	42.1%	4,678	100%
	Total sales (mln)	423.0	30.3%	198.3	14.2%	199.7	14.3%	110.9	7.9%	166.9	12.0%	297.2	21.3%	1,396	100%
	Electricity consumption (TWh)	24.6	19.1%	11.1	8.6%	10.5	8.2%	45.1	35.1%	15.7	12.2%	21.5	16.8%	128	100%
2017	**Total stock (mln)**	878.1	18.6%	368.2	7.8%	512.9	10.8%	287.2	6.1%	677.9	14.3%	2,005.5	42.4%	4,730	100%
	Total sales (mln)	418.4	29.9%	197.7	14.1%	206.0	14.7%	111.7	8.0%	169.1	12.1%	298.3	21.3%	1,401	100%
	Electricity consumption (TWh)	23.9	18.4%	11.0	8.4%	11.0	8.5%	46.2	35.5%	15.9	12.2%	21.9	16.9%	130	100%
2018	**Total stock (mln)**	859.9	18.0%	364.8	7.6%	536.6	11.2%	293.9	6.1%	689.0	14.4%	2,037.0	42.6%	4,781	100%
	Total sales (mln)	416.0	29.5%	197.1	14.0%	212.2	15.1%	112.5	8.0%	171.3	12.2%	298.9	21.2%	1,408	100%
	Electricity consumption (TWh)	23.4	17.8%	10.9	8.3%	11.5	8.8%	47.3	35.9%	16.2	12.3%	22.2	16.9%	132	100%
2019	**Total stock (mln)**	841.7	17.4%	361.5	7.5%	560.3	11.6%	300.6	6.2%	700.1	14.5%	2,068.5	42.8%	4,833	100%
	Total sales (mln)	411.4	29.1%	196.5	13.9%	218.4	15.4%	113.3	8.0%	173.5	12.2%	303.1	21.4%	1,416	100%
	Electricity consumption (TWh)	23.0	17.2%	10.8	8.1%	12.1	9.1%	48.3	36.3%	16.4	12.3%	22.6	17.0%	133	100%
2020	**Total stock (mln)**	823.6	16.9%	358.1	7.3%	584.0	12.0%	307.4	6.3%	711.3	14.6%	2,100.0	43.0%	4,884	100%
	Total sales (mln)	406.9	28.6%	195.8	13.7%	224.7	15.8%	114.2	8.0%	175.7	12.3%	307.3	21.6%	1,425	100%
	Electricity consumption (TWh)	22.5	16.7%	10.7	7.9%	12.6	9.3%	49.4	36.7%	16.7	12.4%	22.9	17.0%	135	100%

Annexe 8-2: Main economic and environmental data for the scenario "BAT"

		BAT													
		GLS-F		GLS-C		HL-MV-LW		HL-MV-HW		HL-LV		CFLi		TOTAL	
2007	**Total stock (mln)**	1,800.1	43.0%	568.5	13.6%	134.4	3.2%	119.4	2.9%	558.3	13.3%	1,010.1	24.1%	4,190.8	100%
	Total sales (mln)	767.4	44.0%	297.0	17.0%	97.4	5.6%	84.1	4.8%	147.0	8.4%	353.0	20.2%	1,745.9	100%
	Electricity consumption (TWh)	49.1	43.7%	16.9	15.1%	2.9	2.6%	19.2	17.1%	13.1	11.7%	11.0	9.8%	112.2	100%
2008	**Total stock (mln)**	1,580.0	37.2%	523.5	12.3%	193.5	4.6%	151.3	3.6%	571.5	13.5%	1,228.5	28.9%	4,248.2	100%
	Total sales (mln)	687.9	41.2%	273.1	16.4%	115.2	6.9%	89.8	5.4%	149.3	8.9%	353.1	21.2%	1,668.4	100%
	Electricity consumption (TWh)	43.1	37.8%	15.6	13.7%	4.2	3.7%	24.3	21.3%	13.4	11.8%	13.4	11.8%	114.0	100%
2009	**Total stock (mln)**	814.2	19.3%	231.0	5.5%	103.5	2.5%	72.9	1.7%	430.1	10.2%	2,570.3	60.9%	4,222.0	100%
	Total sales (mln)	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	1,584.8	100.0 %	1,584.8	100%
	Electricity consumption (TWh)	22.2	28.0%	6.9	8.7%	2.2	2.8%	11.7	14.8%	10.1	12.7%	26.2	33.0%	79.3	100%
2010	**Total stock (mln)**	140.1	3.3%	9.8	0.2%	2.4	0.1%	0.0	0.0%	286.3	6.8%	3,764.8	89.6%	4,203.3	100%
	Total sales (mln)	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	1,457.5	100.0 %	1,457.5	100%
	Electricity consumption (TWh)	3.8	7.9%	0.3	0.6%	0.1	0.1%	0.0	0.0%	6.7	13.8%	37.6	77.6%	48.5	100%
2011	**Total stock (mln)**	0	0.0%	0	0.0%	0	0.0%	0	0.0%	139.9	3.3%	4,088.4	96.7%	4,228.3	100%
	Total sales (mln)	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0.0	0.0%	606.6	100.0 %	606.6	100%
	Electricity consumption (TWh)	0	0.0%	0	0.0%	0	0.0%	0	0.0%	3.3	7.4%	41.0	92.6%	44.3	100%
2012	**Total stock (mln)**	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	4,270.3	100.0 %	4,270.3	100%
	Total sales (mln)	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	484.9	100.0 %	484.9	100%
	Electricity consumption (TWh)	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	42.5	100.0 %	42.5	100%
2013	**Total stock (mln)**	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	4,324.4	100.0 %	4,324.4	100%
	Total sales (mln)	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	190.5	100.0 %	190.5	100%

	Electricity consumption (TWh)	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	43.1	100.0 %	43.1	100%
2014	Total stock (mln)	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	4,389.1	100.0 %	4,389.1	100%
	Total sales (mln)	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	64.7	100.0 %	64.7	100%
	Electricity consumption (TWh)	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	43.8	100.0 %	43.8	100%
2015	Total stock (mln)	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	4,449.7	100.0 %	4,449.7	100%
	Total sales (mln)	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	60.7	100.0 %	60.7	100%
	Electricity consumption (TWh)	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	44.4	100.0 %	44.4	100%
2016	Total stock (mln)	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	4,510.4	100.0 %	4,510.4	100%
	Total sales (mln)	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	60.7	100.0 %	60.7	100%
	Electricity consumption (TWh)	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	45.1	100.0 %	45.1	100%
2017	Total stock (mln)	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	4,569.7	100.0 %	4,569.7	100%
	Total sales (mln)	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	59.3	100.0 %	59.3	100%
	Electricity consumption (TWh)	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	45.7	100.0 %	45.7	100%
2018	Total stock (mln)	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	4,627.6	100.0 %	4,627.6	100%
	Total sales (mln)	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	58.0	100.0 %	58.0	100%
	Electricity consumption (TWh)	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	46.3	100.0 %	46.3	100%
2019	Total stock (mln)	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	4,685.6	100.0 %	4,685.6	100%
	Total sales (mln)	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	58.0	100.0	58.0	100%

													%		
	Electricity consumption (TWh)	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	46.9	100.0 %	46.9	100%
2020	**Total stock (mln)**	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	4,743.6	100.0 %	4,743.6	100%
	Total sales (mln)	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	58.0	100.0 %	58.0	100%
	Electricity consumption (TWh)	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	47.5	100.0 %	47.5	100%

Annexe 8-3: Main economic and environmental data for the scenario "Option 1 Fast"

		Option 1 Fast													
		GLS-F		GLS-C		HL-MV-LW		HL-MV-HW		HL-LV		CFLi		TOTAL	
2007	**Total stock (mln)**	1,800.1	44.0%	568.5	17.0%	134.4	5.6%	119.4	4.8%	558.3	8.4%	1,010.1	20.2%	4,190.8	100%
	Total sales (mln)	767.4	43.7%	297.0	15.1%	97.4	2.7%	84.1	17.1%	147.0	11.6%	353.0	9.8%	1,745.9	100%
	Electricity consumption (TWh)	49.2	43.7%	16.9	15.1%	3.1	2.7%	19.2	17.1%	13.1	11.6%	11.0	9.8%	112.5	100%
2008	**Total stock (mln)**	1,580.0	41.2%	523.5	16.4%	193.5	6.9%	151.3	5.4%	571.5	8.9%	1,228.5	21.2%	4,248.2	100%
	Total sales (mln)	687.9	37.8%	273.1	13.6%	115.2	3.9%	89.8	21.3%	149.3	11.7%	353.1	11.7%	1,668.4	100%
	Electricity consumption (TWh)	43.2	37.8%	15.6	13.6%	4.4	3.9%	24.3	21.3%	13.4	11.7%	13.4	11.7%	114.3	100%
2009	**Total stock (mln)**	1,097.7	19.4%	350.8	7.7%	185.5	4.7%	72.9	0.0%	584.7	9.7%	1,978.5	58.5%	4,270.0	100%
	Total sales (mln)	302.5	30.5%	120.6	10.3%	73.1	4.0%	0.0	13.1%	151.5	15.3%	913.8	26.8%	1,561.6	100%
	Electricity consumption (TWh)	27.3	30.5%	9.2	10.3%	3.6	4.0%	11.7	13.1%	13.7	15.3%	24.0	26.8%	89.5	100%
2010	**Total stock (mln)**	677.9	18.1%	214.8	7.1%	172.4	5.4%	0.0	0.0%	597.9	10.0%	2,698.3	59.3%	4,361.3	100%
	Total sales (mln)	277.7	19.5%	109.1	6.2%	82.9	3.8%	0.0	0.0%	153.8	20.6%	907.4	49.9%	1,530.8	100%
	Electricity consumption (TWh)	13.3	19.5%	4.2	6.2%	2.6	3.8%	0.0	0.0%	14.0	20.6%	34.0	49.9%	68.3	100%
2011	**Total stock (mln)**	303.7	0.0%	91.3	0.0%	106.0	0.0%	0.0	0.0%	611.1	18.7%	3,095.0	81.3%	4,207.0	100%
	Total sales (mln)	0.0	8.8%	0.0	2.9%	0.0	2.6%	0.0	0.0%	156.0	23.5%	679.7	62.1%	835.7	100%
	Electricity consumption (TWh)	5.4	8.8%	1.8	2.9%	1.6	2.6%	0.0	0.0%	14.3	23.5%	37.9	62.1%	60.9	100%
2012	**Total stock (mln)**	31.5	0.0%	3.0	0.0%	30.8	0.0%	0.0	0.0%	622.2	22.2%	3,345.2	77.8%	4,032.7	100%
	Total sales (mln)	0.0	1.0%	0.0	0.1%	0.0	0.8%	0.0	0.0%	158.2	26.2%	553.2	71.8%	711.4	100%
	Electricity consumption (TWh)	0.6	1.0%	0.1	0.1%	0.5	0.8%	0.0	0.0%	14.6	26.2%	40.0	71.8%	55.7	100%
2013	**Total stock (mln)**	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	486.2	0.0%	3,540.3	100.0 %	4,026.5	100%
	Total sales (mln)	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	21.6%	518.1	78.4%	518.1	100%
	Electricity consumption (TWh)	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	11.4	21.6%	41.5	78.4%	52.9	100%
2014	**Total stock (mln)**	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	348.2	0.0%	3,701.9	100.0 %	4,050.0	100%
	Total sales (mln)	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	16.0%	504.6	84.0%	504.6	100%

	Electricity consumption (TWh)	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	8.2	16.0%	42.8	84.0%	51.0	100%
2015	**Total stock (mln)**	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	208.1	0.0%	3,865.2	100.0 %	4,073.2	100%
	Total sales (mln)	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	10.0%	465.3	90.0%	465.3	100%
	Electricity consumption (TWh)	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	4.9	10.0%	44.1	90.0%	49.0	100%
2016	**Total stock (mln)**	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	66.0	0.0%	4,058.4	100.0 %	4,124.4	100%
	Total sales (mln)	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	3.3%	193.2	96.7%	193.2	100%
	Electricity consumption (TWh)	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	1.6	3.3%	45.8	96.7%	47.3	100%
2017	**Total stock (mln)**	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	40.7	0.0%	4,141.3	100.0 %	4,182.0	100%
	Total sales (mln)	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	2.0%	82.9	98.0%	82.9	100%
	Electricity consumption (TWh)	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	1.0	2.0%	46.6	98.0%	47.5	100%
2018	**Total stock (mln)**	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	4,237.2	100.0 %	4,237.2	100%
	Total sales (mln)	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	96.0	100.0 %	96.0	100%
	Electricity consumption (TWh)	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	47.5	100.0 %	47.5	100%
2019	**Total stock (mln)**	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	4,294.9	100.0 %	4,294.9	100%
	Total sales (mln)	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	70.4	100.0 %	70.4	100%
	Electricity consumption (TWh)	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	48.1	100.0 %	48.1	100%
2020	**Total stock (mln)**	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	4,407.4	100.0 %	4,407.4	100%
	Total sales (mln)	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	419.6	100.0 %	419.6	100%
	Electricity consumption (TWh)	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	48.3	100.0 %	48.3	100%

Annexe 8-4: Main economic and environmental data for the scenario "Option 1 Slow"

		Option 1 Slow													
		GLS-F		GLS-C		HL-MV-LW		HL-MV-HW		HL-LV		CFLi		TOTAL	
2007	**Total stock (mln)**	1,800.1	44.0%	568.5	17.0%	134.4	5.6%	119.4	4.8%	558.3	8.4%	1,010.1	20.2%	4,190.8	100%
	Total sales (mln)	767.4	43.7%	297.0	15.1%	97.4	2.7%	84.1	17.1%	147.0	11.6%	353.0	9.8%	1,745.9	100%
	Electricity consumption (TWh)	49.2	43.7%	16.9	15.1%	2.9	2.7%	19.2	17.1%	13.1	11.6%	11.0	9.8%	112.4	100%
2008	**Total stock (mln)**	1,580.0	41.2%	523.5	16.4%	193.5	6.9%	151.3	5.4%	571.5	8.9%	1,228.5	21.2%	4,248.2	100%
	Total sales (mln)	687.9	37.8%	273.1	13.6%	115.2	3.9%	89.8	21.3%	149.3	11.7%	353.1	11.7%	1,668.4	100%
	Electricity consumption (TWh)	43.2	37.8%	15.6	13.6%	4.2	3.9%	24.3	21.3%	13.4	11.7%	13.4	11.7%	114.1	100%
2009	**Total stock (mln)**	1,097.7	19.4%	350.8	7.7%	263.5	4.7%	188.6	0.0%	612.5	9.7%	1,780.8	58.5%	4,293.8	100%
	Total sales (mln)	302.5	30.5%	120.6	10.3%	160.0	4.0%	115.7	13.1%	182.4	15.3%	716.1	26.8%	1,597.2	100%
	Electricity consumption (TWh)	27.3	30.5%	9.2	10.3%	5.1	4.0%	26.0	13.1%	13.0	15.3%	19.2	26.8%	99.7	100%
2010	**Total stock (mln)**	677.9	18.1%	214.8	7.1%	334.3	5.4%	225.6	0.0%	654.0	10.0%	2,291.3	59.3%	4,397.8	100%
	Total sales (mln)	277.7	19.5%	109.1	6.2%	171.9	3.8%	109.9	0.0%	185.3	20.6%	698.1	49.9%	1,552.0	100%
	Electricity consumption (TWh)	13.3	19.5%	4.2	6.2%	5.9	3.8%	27.8	0.0%	12.5	20.6%	24.6	49.9%	88.4	100%
2011	**Total stock (mln)**	303.7	0.0%	91.3	0.0%	397.8	0.0%	259.0	0.0%	695.9	18.7%	2,547.6	81.3%	4,295.3	100%
	Total sales (mln)	0.0	8.8%	0.0	2.9%	65.9	2.6%	33.4	0.0%	188.3	23.5%	539.3	62.1%	826.9	100%
	Electricity consumption (TWh)	5.4	8.8%	1.8	2.9%	7.1	2.6%	31.9	0.0%	12.0	23.5%	26.7	62.1%	84.8	100%
2012	**Total stock (mln)**	31.5	0.0%	3.0	0.0%	423.3	0.0%	266.0	0.0%	734.3	22.2%	2,717.1	77.8%	4,175.2	100%
	Total sales (mln)	0.0	1.0%	0.0	0.1%	25.4	0.8%	38.3	0.0%	178.3	26.2%	472.5	71.8%	714.5	100%
	Electricity consumption (TWh)	0.6	1.0%	0.1	0.1%	7.5	0.8%	32.8	0.0%	11.5	26.2%	28.2	71.8%	80.6	100%
2013	**Total stock (mln)**	0.0	0.0%	0.0	0.0%	378.5	0.0%	151.9	0.0%	734.3	0.0%	2,930.3	100.0 %	4,195.0	100%
	Total sales (mln)	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	21.6%	536.2	78.4%	536.2	100%
	Electricity consumption (TWh)	0.0	0.0%	0.0	0.0%	6.7	0.0%	18.7	0.0%	11.5	21.6%	32.7	78.4%	69.6	100%
2014	**Total stock (mln)**	0.0	0.0%	0.0	0.0%	215.2	0.0%	62.7	0.0%	674.1	0.0%	3,268.7	100.0 %	4,220.7	100%
	Total sales (mln)	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	16.0%	681.4	84.0%	681.4	100%

	Electricity consumption (TWh)	0.0	0.0%	0.0	0.0%	3.8	0.0%	7.7	0.0%	10.6	16.0%	37.2	84.0%	59.3	100%
2015	**Total stock (mln)**	0.0	0.0%	0.0	0.0%	72.9	0.0%	28.0	0.0%	490.7	0.0%	3,638.1	100.0 %	4,229.8	100%
	Total sales (mln)	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	10.0%	671.4	90.0%	671.4	100%
	Electricity consumption (TWh)	0.0	0.0%	0.0	0.0%	1.3	0.0%	3.4	0.0%	7.7	10.0%	40.7	90.0%	53.1	100%
2016	**Total stock (mln)**	0.0	0.0%	0.0	0.0%	18.3	0.0%	0.0	0.0%	304.4	0.0%	3,947.0	100.0 %	4,269.7	100%
	Total sales (mln)	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	3.3%	308.9	96.7%	308.9	100%
	Electricity consumption (TWh)	0.0	0.0%	0.0	0.0%	0.3	0.0%	0.0	0.0%	4.8	3.3%	43.8	96.7%	48.9	100%
2017	**Total stock (mln)**	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	119.4	0.0%	4,188.9	100.0 %	4,308.4	100%
	Total sales (mln)	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	2.0%	241.9	98.0%	241.9	100%
	Electricity consumption (TWh)	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	1.9	2.0%	45.7	98.0%	47.6	100%
2018	**Total stock (mln)**	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	4,353.9	100.0 %	4,353.9	100%
	Total sales (mln)	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	165.0	100.0 %	165.0	100%
	Electricity consumption (TWh)	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	47.1	100.0 %	47.1	100%
2019	**Total stock (mln)**	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	4,412.8	100.0 %	4,412.8	100%
	Total sales (mln)	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	71.6	100.0 %	71.6	100%
	Electricity consumption (TWh)	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	47.8	100.0 %	47.8	100%
2020	**Total stock (mln)**	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	4,513.4	100.0 %	4,513.4	100%
	Total sales (mln)	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	245.0	100.0 %	245.0	100%
	Electricity consumption (TWh)	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	48.3	100.0 %	48.3	100%

Annexe 8-5: Main economic and environmental data for the scenario "Option 2 Clear B Fast"

		Option 2 Clear B Fast													
		GLS-F		GLS-C		HL-MV-LW		HL-MV-HW		HL-LV		CFLi		TOTAL	
2007	**Total stock (mln)**	1,800.1	44.0%	568.5	17.0%	134.4	5.6%	119.4	4.8%	558.3	8.4%	1,010.1	20.2%	4,190.8	100%
	Total sales (mln)	767.4	43.7%	297.0	15.1%	97.4	2.7%	84.1	17.1%	147.0	11.6%	353.0	9.8%	1,745.9	100%
	Electricity consumption (TWh)	49.2	43.7%	16.9	15.1%	2.9	2.7%	19.2	17.1%	13.1	11.6%	11.0	9.8%	112.4	100%
2008	**Total stock (mln)**	1,580.0	41.2%	523.5	16.4%	193.5	6.9%	151.3	5.4%	571.5	8.9%	1,228.5	21.2%	4,248.2	100%
	Total sales (mln)	687.9	37.8%	273.1	13.6%	115.2	3.9%	89.8	21.3%	149.3	11.7%	353.1	11.7%	1,668.4	100%
	Electricity consumption (TWh)	43.2	37.8%	15.6	13.6%	4.2	3.9%	24.3	21.3%	13.4	11.7%	13.4	11.7%	114.1	100%
2009	**Total stock (mln)**	1,097.7	19.4%	350.8	7.7%	427.7	4.7%	188.6	0.0%	612.5	9.7%	1,664.8	58.5%	4,342.0	100%
	Total sales (mln)	302.5	30.5%	120.6	10.3%	324.2	4.0%	115.7	13.1%	182.4	15.3%	600.1	26.8%	1,645.5	100%
	Electricity consumption (TWh)	27.3	30.5%	9.2	10.3%	8.9	4.0%	26.0	13.1%	13.0	15.3%	18.0	26.8%	102.2	100%
2010	**Total stock (mln)**	677.9	18.1%	214.8	7.1%	630.2	5.4%	225.6	0.0%	654.0	10.0%	2,082.4	59.3%	4,484.8	100%
	Total sales (mln)	277.7	19.5%	109.1	6.2%	303.6	3.8%	109.9	0.0%	185.3	20.6%	605.2	49.9%	1,590.7	100%
	Electricity consumption (TWh)	13.3	19.5%	4.2	6.2%	12.8	3.8%	27.8	0.0%	12.5	20.6%	22.3	49.9%	92.9	100%
2011	**Total stock (mln)**	303.7	0.0%	91.3	0.0%	722.9	0.0%	259.0	0.0%	695.9	18.7%	2,309.6	81.3%	4,382.4	100%
	Total sales (mln)	0.0	8.8%	0.0	2.9%	95.0	2.6%	33.4	0.0%	188.3	23.5%	510.3	62.1%	827.0	100%
	Electricity consumption (TWh)	5.4	8.8%	1.8	2.9%	14.6	2.6%	31.9	0.0%	12.0	23.5%	24.2	62.1%	89.8	100%
2012	**Total stock (mln)**	31.5	0.0%	3.0	0.0%	793.9	0.0%	266.0	0.0%	734.3	22.2%	2,433.7	77.8%	4,262.4	100%
	Total sales (mln)	0.0	1.0%	0.0	0.1%	176.6	0.8%	38.3	0.0%	178.3	26.2%	427.1	71.8%	820.2	100%
	Electricity consumption (TWh)	0.6	1.0%	0.1	0.1%	16.1	0.8%	32.8	0.0%	11.5	26.2%	25.3	71.8%	86.3	100%
2013	**Total stock (mln)**	0.0	0.0%	0.0	0.0%	667.1	0.0%	273.1	0.0%	898.0	0.0%	2,440.8	100.0 %	4,279.0	100%
	Total sales (mln)	0.0	0.0%	0.0	0.0%	188.8	0.0%	121.2	0.0%	163.8	21.6%	330.0	78.4%	803.7	100%
	Electricity consumption (TWh)	0.0	0.0%	0.0	0.0%	13.0	0.0%	33.7	0.0%	14.2	21.6%	25.4	78.4%	86.3	100%
2014	**Total stock (mln)**	0.0	0.0%	0.0	0.0%	598.8	0.0%	280.2	0.0%	1,001.7	0.0%	2,433.5	100.0 %	4,314.2	100%
	Total sales (mln)	0.0	0.0%	0.0	0.0%	167.7	0.0%	96.3	0.0%	163.8	16.0%	335.8	84.0%	763.6	100%

	Electricity consumption (TWh)	0.0	0.0%	0.0	0.0%	11.3	0.0%	34.5	0.0%	15.9	16.0%	25.3	84.0%	87.0	100%
2015	**Total stock (mln)**	0.0	0.0%	0.0	0.0%	566.6	0.0%	287.2	0.0%	1,069.2	0.0%	2,426.1	100.0 %	4,349.1	100%
	Total sales (mln)	0.0	0.0%	0.0	0.0%	92.6	0.0%	41.8	0.0%	250.9	10.0%	294.5	90.0%	679.9	100%
	Electricity consumption (TWh)	0.0	0.0%	0.0	0.0%	10.4	0.0%	35.4	0.0%	17.0	10.0%	25.2	90.0%	88.1	100%
2016	**Total stock (mln)**	0.0	0.0%	0.0	0.0%	525.1	0.0%	294.3	0.0%	1,146.1	0.0%	2,446.7	100.0 %	4,412.2	100%
	Total sales (mln)	0.0	0.0%	0.0	0.0%	128.9	0.0%	67.7	0.0%	263.2	3.3%	20.6	96.7%	480.4	100%
	Electricity consumption (TWh)	0.0	0.0%	0.0	0.0%	9.3	0.0%	36.3	0.0%	18.3	3.3%	25.5	96.7%	89.3	100%
2017	**Total stock (mln)**	0.0	0.0%	0.0	0.0%	550.5	0.0%	301.4	0.0%	1,159.3	0.0%	2,465.9	100.0 %	4,477.1	100%
	Total sales (mln)	0.0	0.0%	0.0	0.0%	208.3	0.0%	121.5	0.0%	198.1	2.0%	19.3	98.0%	547.2	100%
	Electricity consumption (TWh)	0.0	0.0%	0.0	0.0%	9.8	0.0%	37.2	0.0%	18.5	2.0%	25.7	98.0%	91.1	100%
2018	**Total stock (mln)**	0.0	0.0%	0.0	0.0%	576.0	0.0%	308.4	0.0%	1,172.4	0.0%	2,483.8	100.0 %	4,540.6	100%
	Total sales (mln)	0.0	0.0%	0.0	0.0%	172.1	0.0%	88.6	0.0%	136.9	0.0%	17.9	100.0 %	415.6	100%
	Electricity consumption (TWh)	0.0	0.0%	0.0	0.0%	10.2	0.0%	38.0	0.0%	18.7	0.0%	25.9	100.0 %	92.8	100%
2019	**Total stock (mln)**	0.0	0.0%	0.0	0.0%	601.4	0.0%	315.5	0.0%	1,185.6	0.0%	2,501.7	100.0 %	4,604.2	100%
	Total sales (mln)	0.0	0.0%	0.0	0.0%	128.2	0.0%	55.9	0.0%	46.1	0.0%	17.9	100.0 %	248.1	100%
	Electricity consumption (TWh)	0.0	0.0%	0.0	0.0%	10.7	0.0%	38.9	0.0%	18.9	0.0%	26.1	100.0 %	94.5	100%
2020	**Total stock (mln)**	0.0	0.0%	0.0	0.0%	626.9	0.0%	322.5	0.0%	1,185.7	0.0%	2,516.3	100.0 %	4,651.4	100%
	Total sales (mln)	0.0	0.0%	0.0	0.0%	176.6	0.0%	89.3	0.0%	153.3	0.0%	45.5	100.0 %	464.7	100%
	Electricity consumption (TWh)	0.0	0.0%	0.0	0.0%	11.1	0.0%	39.8	0.0%	18.9	0.0%	26.2	100.0 %	96.0	100%

Annexe 8-6: Main economic and environmental data for the scenario "Option 2 Clear B Slow"

		Option 2 Clear B Slow													
		GLS-F		GLS-C		HL-MV-LW		HL-MV-HW		HL-LV		CFLi		TOTAL	
2007	Total stock (mln)	1,800.1	44.0%	568.5	17.0%	134.4	5.6%	119.4	4.8%	558.3	8.4%	1,010.1	20.2%	4,190.8	100%
	Total sales (mln)	767.4	43.7%	297.0	15.1%	97.4	2.7%	84.1	17.1%	147.0	11.6%	353.0	9.8%	1,745.9	100%
	Electricity consumption (TWh)	49.3	43.7%	17.0	15.1%	2.9	2.7%	19.2	17.1%	13.1	11.6%	11.0	9.8%	112.5	100%
2008	Total stock (mln)	1,580.0	41.2%	523.5	16.4%	193.5	6.9%	151.3	5.4%	571.5	8.9%	1,228.5	21.2%	4,248.2	100%
	Total sales (mln)	687.9	37.8%	273.1	13.6%	115.2	3.9%	89.8	21.3%	149.3	11.7%	353.1	11.7%	1,668.4	100%
	Electricity consumption (TWh)	43.2	37.8%	15.6	13.6%	4.2	3.9%	24.3	21.3%	13.4	11.7%	13.4	11.7%	114.2	100%
2009	Total stock (mln)	1,325.0	19.4%	446.7	7.7%	441.8	4.7%	188.6	0.0%	584.7	9.7%	1,407.0	58.5%	4,393.7	100%
	Total sales (mln)	544.9	30.5%	217.3	10.3%	323.8	4.0%	115.7	13.1%	151.5	15.3%	342.3	26.8%	1,695.6	100%
	Electricity consumption (TWh)	34.4	30.5%	12.5	10.3%	9.2	4.0%	26.0	13.1%	13.7	15.3%	15.4	26.8%	111.2	100%
2010	Total stock (mln)	1,109.1	18.1%	379.2	7.1%	714.4	5.4%	225.6	0.0%	597.9	10.0%	1,554.0	59.3%	4,580.1	100%
	Total sales (mln)	500.2	19.5%	196.5	6.2%	365.3	3.8%	109.9	0.0%	153.8	20.6%	334.6	49.9%	1,660.2	100%
	Electricity consumption (TWh)	26.9	19.5%	9.9	6.2%	14.7	3.8%	27.8	0.0%	14.0	20.6%	17.0	49.9%	110.3	100%
2011	Total stock (mln)	787.3	0.0%	261.2	0.0%	1,112.8	0.0%	259.0	0.0%	638.7	18.7%	1,680.0	81.3%	4,739.0	100%
	Total sales (mln)	255.5	8.8%	97.5	2.9%	500.5	2.6%	33.4	0.0%	181.4	23.5%	333.2	62.1%	1,401.4	100%
	Electricity consumption (TWh)	17.3	8.8%	6.1	2.9%	22.5	2.6%	31.9	0.0%	13.6	23.5%	18.3	62.1%	109.8	100%
2012	Total stock (mln)	527.8	0.0%	188.7	0.0%	1,432.5	0.0%	266.0	0.0%	678.7	22.2%	1,778.7	77.8%	4,872.4	100%
	Total sales (mln)	215.3	1.0%	97.2	0.1%	484.7	0.8%	38.3	0.0%	188.6	26.2%	322.7	71.8%	1,346.8	100%
	Electricity consumption (TWh)	9.7	1.0%	3.7	0.1%	28.8	0.8%	32.8	0.0%	13.0	26.2%	19.4	71.8%	107.4	100%
2013	Total stock (mln)	247.9	0.0%	88.9	0.0%	1,260.7	0.0%	273.1	0.0%	826.0	0.0%	2,040.3	100.0 %	4,736.7	100%
	Total sales (mln)	0.0	0.0%	0.0	0.0%	144.6	0.0%	121.2	0.0%	298.2	21.6%	584.6	78.4%	1,148.6	100%
	Electricity consumption (TWh)	4.4	0.0%	1.7	0.0%	25.1	0.0%	33.7	0.0%	14.3	21.6%	21.3	78.4%	100.5	100%
2014	Total stock (mln)	36.9	0.0%	10.1	0.0%	1,046.6	0.0%	280.2	0.0%	966.2	0.0%	2,277.1	100.0 %	4,617.0	100%
	Total sales (mln)	0.0	0.0%	0.0	0.0%	142.6	0.0%	96.3	0.0%	293.4	16.0%	579.8	84.0%	1,112.0	100%

	Electricity consumption (TWh)	0.7	0.0%	0.2	0.0%	20.7	0.0%	34.5	0.0%	15.3	16.0%	23.0	84.0%	94.5	100%
2015	**Total stock (mln)**	0.0	0.0%	0.0	0.0%	749.7	0.0%	287.2	0.0%	1,071.6	0.0%	2,497.3	100.0 %	4,605.8	100%
	Total sales (mln)	0.0	0.0%	0.0	0.0%	145.6	0.0%	41.8	0.0%	109.9	10.0%	573.3	90.0%	870.6	100%
	Electricity consumption (TWh)	0.0	0.0%	0.0	0.0%	14.3	0.0%	35.4	0.0%	17.0	10.0%	24.5	90.0%	91.3	100%
2016	**Total stock (mln)**	0.0	0.0%	0.0	0.0%	525.1	0.0%	294.3	0.0%	1,146.1	0.0%	2,661.3	100.0 %	4,626.8	100%
	Total sales (mln)	0.0	0.0%	0.0	0.0%	132.7	0.0%	67.7	0.0%	134.4	3.3%	511.7	96.7%	846.6	100%
	Electricity consumption (TWh)	0.0	0.0%	0.0	0.0%	9.3	0.0%	36.3	0.0%	18.3	3.3%	25.7	96.7%	89.6	100%
2017	**Total stock (mln)**	0.0	0.0%	0.0	0.0%	381.0	0.0%	179.8	0.0%	1,310.6	0.0%	2,777.7	100.0 %	4,649.1	100%
	Total sales (mln)	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	348.2	2.0%	454.8	98.0%	803.1	100%
	Electricity consumption (TWh)	0.0	0.0%	0.0	0.0%	6.8	0.0%	22.2	0.0%	20.5	2.0%	37.3	98.0%	86.7	100%
2018	**Total stock (mln)**	0.0	0.0%	0.0	0.0%	237.6	0.0%	98.3	0.0%	1,474.5	0.0%	2,882.6	100.0 %	4,692.9	100%
	Total sales (mln)	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	353.3	0.0%	178.4	100.0 %	531.7	100%
	Electricity consumption (TWh)	0.0	0.0%	0.0	0.0%	4.2	0.0%	12.1	0.0%	22.7	0.0%	46.0	100.0 %	85.1	100%
2019	**Total stock (mln)**	0.0	0.0%	0.0	0.0%	95.6	0.0%	49.5	0.0%	1,637.0	0.0%	2,959.6	100.0 %	4,741.7	100%
	Total sales (mln)	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	354.7	0.0%	77.0	100.0 %	431.8	100%
	Electricity consumption (TWh)	0.0	0.0%	0.0	0.0%	1.7	0.0%	6.1	0.0%	24.9	0.0%	51.6	100.0 %	84.3	100%
2020	**Total stock (mln)**	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	1,760.8	0.0%	3,037.3	100.0 %	4,798.1	100%
	Total sales (mln)	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	287.6	0.0%	77.7	100.0 %	365.3	100%
	Electricity consumption (TWh)	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	26.6	0.0%	57.2	100.0 %	83.8	100%

Annexe 8-7: Main economic and environmental data for the scenario "Option 2 Clear C Fast"

		Option 2 Clear C Fast													
		GLS-F		GLS-C		HL-MV-LW		HL-MV-HW		HL-LV		CFLi		TOTAL	
2007	**Total stock (mln)**	1,800.1	44.0%	568.5	17.0%	134.4	5.6%	119.4	4.8%	558.3	8.4%	1,010.1	20.2%	4,190.8	100%
	Total sales (mln)	767.4	43.7%	297.0	15.1%	97.4	2.7%	84.1	17.1%	147.0	11.6%	353.0	9.8%	1,745.9	100%
	Electricity consumption (TWh)	49.2	43.7%	16.9	15.1%	2.9	2.7%	19.2	17.1%	13.1	11.6%	11.0	9.8%	112.4	100%
2008	**Total stock (mln)**	1,580.0	41.2%	523.5	16.4%	193.5	6.9%	151.3	5.4%	571.5	8.9%	1,228.5	21.2%	4,248.2	100%
	Total sales (mln)	687.9	37.8%	273.1	13.6%	115.2	3.9%	89.8	21.3%	149.3	11.7%	353.1	11.7%	1,668.4	100%
	Electricity consumption (TWh)	43.2	37.8%	15.6	13.6%	4.2	3.9%	24.3	21.3%	13.4	11.7%	13.4	11.7%	114.1	100%
2009	**Total stock (mln)**	1,097.7	19.4%	350.8	7.7%	781.9	4.7%	188.6	0.0%	584.7	9.7%	1,407.0	58.5%	4,410.6	100%
	Total sales (mln)	302.5	30.5%	120.6	10.3%	662.3	4.0%	115.7	13.1%	151.5	15.3%	342.3	26.8%	1,694.9	100%
	Electricity consumption (TWh)	27.3	30.5%	9.2	10.3%	17.0	4.0%	26.0	13.1%	13.7	15.3%	15.4	26.8%	108.5	100%
2010	**Total stock (mln)**	677.9	18.1%	214.8	7.1%	1,355.8	5.4%	225.6	0.0%	597.9	10.0%	1,554.0	59.3%	4,625.9	100%
	Total sales (mln)	277.7	19.5%	109.1	6.2%	665.6	3.8%	109.9	0.0%	153.8	20.6%	334.6	49.9%	1,650.5	100%
	Electricity consumption (TWh)	13.3	19.5%	4.2	6.2%	29.4	3.8%	27.8	0.0%	14.0	20.6%	17.0	49.9%	105.8	100%
2011	**Total stock (mln)**	303.7	0.0%	91.3	0.0%	1,596.7	0.0%	259.0	0.0%	611.1	18.7%	1,642.0	81.3%	4,503.7	100%
	Total sales (mln)	0.0	8.8%	0.0	2.9%	359.9	2.6%	33.4	0.0%	156.0	23.5%	371.0	62.1%	920.3	100%
	Electricity consumption (TWh)	5.4	8.8%	1.8	2.9%	33.9	2.6%	31.9	0.0%	14.3	23.5%	17.9	62.1%	105.2	100%
2012	**Total stock (mln)**	31.5	0.0%	3.0	0.0%	1,740.7	0.0%	266.0	0.0%	622.2	22.2%	1,703.3	77.8%	4,366.8	100%
	Total sales (mln)	0.0	1.0%	0.0	0.1%	356.1	0.8%	38.3	0.0%	158.2	26.2%	364.4	71.8%	916.9	100%
	Electricity consumption (TWh)	0.6	1.0%	0.1	0.1%	36.4	0.8%	32.8	0.0%	14.6	26.2%	18.6	71.8%	103.0	100%
2013	**Total stock (mln)**	0.0	0.0%	0.0	0.0%	1,402.9	0.0%	273.1	0.0%	633.3	0.0%	2,065.5	100.0 %	4,374.8	100%
	Total sales (mln)	0.0	0.0%	0.0	0.0%	236.1	0.0%	121.2	0.0%	160.4	21.6%	685.2	78.4%	1,202.9	100%
	Electricity consumption (TWh)	0.0	0.0%	0.0	0.0%	28.9	0.0%	33.7	0.0%	14.9	21.6%	21.2	78.4%	98.6	100%
2014	**Total stock (mln)**	0.0	0.0%	0.0	0.0%	1,051.7	0.0%	280.2	0.0%	644.5	0.0%	2,417.0	100.0 %	4,393.3	100%
	Total sales (mln)	0.0	0.0%	0.0	0.0%	169.4	0.0%	96.3	0.0%	162.6	16.0%	694.5	84.0%	1,122.8	100%

	Electricity consumption (TWh)	0.0	0.0%	0.0	0.0%	21.4	0.0%	34.5	0.0%	15.1	16.0%	23.7	84.0%	94.7	100%
2015	**Total stock (mln)**	0.0	0.0%	0.0	0.0%	936.6	0.0%	287.2	0.0%	655.6	0.0%	2,537.3	100.0%	4,416.7	100%
	Total sales (mln)	0.0	0.0%	0.0	0.0%	265.6	0.0%	41.8	0.0%	164.8	10.0%	422.3	90.0%	894.4	100%
	Electricity consumption (TWh)	0.0	0.0%	0.0	0.0%	18.8	0.0%	35.4	0.0%	15.4	10.0%	24.5	90.0%	94.2	100%
2016	**Total stock (mln)**	0.0	0.0%	0.0	0.0%	884.3	0.0%	294.3	0.0%	666.7	0.0%	2,623.0	100.0%	4,468.4	100%
	Total sales (mln)	0.0	0.0%	0.0	0.0%	292.8	0.0%	67.7	0.0%	166.9	3.3%	85.7	96.7%	613.2	100%
	Electricity consumption (TWh)	0.0	0.0%	0.0	0.0%	17.6	0.0%	36.3	0.0%	15.7	3.3%	25.3	96.7%	94.8	100%
2017	**Total stock (mln)**	0.0	0.0%	0.0	0.0%	906.6	0.0%	301.4	0.0%	677.9	0.0%	2,642.3	100.0%	4,528.0	100%
	Total sales (mln)	0.0	0.0%	0.0	0.0%	234.3	0.0%	121.5	0.0%	169.1	2.0%	19.3	98.0%	544.2	100%
	Electricity consumption (TWh)	0.0	0.0%	0.0	0.0%	18.0	0.0%	37.2	0.0%	15.9	2.0%	25.5	98.0%	96.6	100%
2018	**Total stock (mln)**	0.0	0.0%	0.0	0.0%	928.8	0.0%	308.4	0.0%	689.0	0.0%	2,660.2	100.0%	4,586.3	100%
	Total sales (mln)	0.0	0.0%	0.0	0.0%	215.3	0.0%	88.6	0.0%	171.3	0.0%	17.9	100.0%	493.2	100%
	Electricity consumption (TWh)	0.0	0.0%	0.0	0.0%	18.4	0.0%	38.0	0.0%	16.2	0.0%	25.7	100.0%	98.3	100%
2019	**Total stock (mln)**	0.0	0.0%	0.0	0.0%	951.0	0.0%	315.5	0.0%	700.1	0.0%	2,678.1	100.0%	4,644.7	100%
	Total sales (mln)	0.0	0.0%	0.0	0.0%	301.3	0.0%	55.9	0.0%	173.5	0.0%	17.9	100.0%	548.6	100%
	Electricity consumption (TWh)	0.0	0.0%	0.0	0.0%	18.8	0.0%	38.9	0.0%	16.4	0.0%	25.9	100.0%	100.0	100%
2020	**Total stock (mln)**	0.0	0.0%	0.0	0.0%	973.2	0.0%	322.5	0.0%	711.3	0.0%	2,696.0	100.0%	4,703.0	100%
	Total sales (mln)	0.0	0.0%	0.0	0.0%	299.2	0.0%	89.3	0.0%	175.7	0.0%	17.9	100.0%	582.1	100%
	Electricity consumption (TWh)	0.0	0.0%	0.0	0.0%	19.1	0.0%	39.8	0.0%	16.7	0.0%	26.1	100.0%	101.7	100%

Annexe 8-8: Main economic and environmental data for the scenario "Option 3 Slow"

		Option 3 Slow													
		GLS-F		GLS-C		HL-MV-LW		HL-MV-HW		HL-LV		CFLi		TOTAL	
2007	**Total stock (mln)**	1,800.1	44.0%	568.5	17.0%	134.4	5.6%	119.4	4.8%	558.3	8.4%	1,010.1	20.2%	4,190.8	100%
	Total sales (mln)	767.4	43.7%	297.0	15.1%	97.4	2.7%	84.1	17.1%	147.0	11.6%	353.0	9.8%	1,745.9	100%
	Electricity consumption (TWh)	49.3	43.7%	17.0	15.1%	2.9	2.7%	19.2	17.1%	13.1	11.6%	11.0	9.8%	112.5	100%
2008	**Total stock (mln)**	1,580.0	41.2%	523.5	16.4%	193.5	6.9%	151.3	5.4%	571.5	8.9%	1,228.5	21.2%	4,248.2	100%
	Total sales (mln)	687.9	37.8%	273.1	13.6%	115.2	3.9%	89.8	21.3%	149.3	11.7%	353.1	11.7%	1,668.4	100%
	Electricity consumption (TWh)	43.2	37.8%	15.6	13.6%	4.2	3.9%	24.3	21.3%	13.4	11.7%	13.4	11.7%	114.2	100%
2009	**Total stock (mln)**	1,325.0	19.4%	446.7	7.7%	441.8	4.7%	183.1	0.0%	584.7	9.7%	1,407.0	58.5%	4,388.3	100%
	Total sales (mln)	544.9	30.5%	217.3	10.3%	323.8	4.0%	95.5	13.1%	151.5	15.3%	342.3	26.8%	1,675.4	100%
	Electricity consumption (TWh)	34.4	30.5%	12.5	10.3%	9.2	4.0%	29.4	13.1%	13.7	15.3%	15.4	26.8%	114.7	100%
2010	**Total stock (mln)**	1,109.1	18.1%	379.2	7.1%	713.4	5.4%	214.9	0.0%	597.9	10.0%	1,554.0	59.3%	4,568.5	100%
	Total sales (mln)	500.2	19.5%	196.5	6.2%	363.5	3.8%	101.1	0.0%	153.8	20.6%	334.6	49.9%	1,649.8	100%
	Electricity consumption (TWh)	26.9	19.5%	9.9	6.2%	14.7	3.8%	34.6	0.0%	14.0	20.6%	17.0	49.9%	117.1	100%
2011	**Total stock (mln)**	979.8	0.0%	338.6	0.0%	773.7	0.0%	246.8	0.0%	611.1	18.7%	1,680.0	81.3%	4,630.0	100%
	Total sales (mln)	460.3	8.8%	175.7	2.9%	278.2	2.6%	106.8	0.0%	156.0	23.5%	333.2	62.1%	1,510.1	100%
	Electricity consumption (TWh)	23.3	8.8%	8.8	2.9%	15.9	2.6%	39.7	0.0%	14.3	23.5%	18.3	62.1%	120.4	100%
2012	**Total stock (mln)**	905.4	0.0%	335.7	0.0%	777.4	0.0%	253.5	0.0%	622.2	22.2%	1,778.7	77.8%	4,672.9	100%
	Total sales (mln)	387.9	1.0%	175.1	0.1%	173.9	0.8%	107.6	0.0%	158.2	26.2%	322.7	71.8%	1,325.4	100%
	Electricity consumption (TWh)	21.5	1.0%	8.7	0.1%	15.9	0.8%	40.8	0.0%	14.6	26.2%	19.4	71.8%	121.0	100%
2013	**Total stock (mln)**	865.7	0.0%	332.8	0.0%	796.2	0.0%	260.2	0.0%	633.3	0.0%	1,837.5	100.0 %	4,725.7	100%
	Total sales (mln)	389.2	0.0%	174.6	0.0%	363.9	0.0%	108.4	0.0%	160.4	21.6%	296.0	78.4%	1,492.4	100%
	Electricity consumption (TWh)	20.6	0.0%	8.6	0.0%	16.2	0.0%	41.8	0.0%	14.9	21.6%	20.1	78.4%	122.2	100%
2014	**Total stock (mln)**	831.6	0.0%	329.8	0.0%	811.9	0.0%	267.0	0.0%	644.5	0.0%	1,890.0	100.0 %	4,774.7	100%
	Total sales (mln)	378.7	0.0%	174.0	0.0%	362.6	0.0%	109.3	0.0%	162.6	16.0%	297.5	84.0%	1,484.6	100%

	Electricity consumption (TWh)	19.8	0.0%	8.6	0.0%	16.5	0.0%	42.9	0.0%	15.1	16.0%	20.6	84.0%	123.5	100%
2015	**Total stock (mln)**	645.6	0.0%	250.6	0.0%	1,134.5	0.0%	279.4	0.0%	655.6	0.0%	1,893.4	100.0%	4,859.1	100%
	Total sales (mln)	209.0	0.0%	96.3	0.0%	604.5	0.0%	120.2	0.0%	164.8	10.0%	356.4	90.0%	1,551.1	100%
	Electricity consumption (TWh)	14.1	0.0%	5.9	0.0%	22.7	0.0%	40.4	0.0%	15.4	10.0%	20.7	90.0%	119.2	100%
2016	**Total stock (mln)**	467.7	0.0%	186.2	0.0%	1,431.8	0.0%	291.8	0.0%	666.7	0.0%	1,897.2	100.0%	4,941.4	100%
	Total sales (mln)	204.7	0.0%	96.0	0.0%	507.7	0.0%	121.0	0.0%	166.9	3.3%	351.6	96.7%	1,447.9	100%
	Electricity consumption (TWh)	8.7	0.0%	3.7	0.0%	28.3	0.0%	37.9	0.0%	15.7	3.3%	20.7	96.7%	115.0	100%
2017	**Total stock (mln)**	227.0	0.0%	83.6	0.0%	1,615.7	0.0%	301.4	0.0%	677.9	0.0%	1,898.1	100.0%	4,803.6	100%
	Total sales (mln)	0.0	0.0%	0.0	0.0%	503.6	0.0%	60.1	0.0%	169.1	2.0%	339.4	98.0%	1,072.2	100%
	Electricity consumption (TWh)	4.0	0.0%	1.6	0.0%	32.3	0.0%	37.2	0.0%	15.9	2.0%	20.7	98.0%	111.8	100%
2018	**Total stock (mln)**	26.3	0.0%	5.8	0.0%	1,732.0	0.0%	308.4	0.0%	689.0	0.0%	1,895.7	100.0%	4,657.3	100%
	Total sales (mln)	0.0	0.0%	0.0	0.0%	469.1	0.0%	39.5	0.0%	171.3	0.0%	331.4	100.0%	1,011.4	100%
	Electricity consumption (TWh)	0.5	0.0%	0.1	0.0%	35.2	0.0%	38.0	0.0%	16.2	0.0%	20.7	100.0%	110.7	100%
2019	**Total stock (mln)**	0.0	0.0%	0.0	0.0%	1,735.3	0.0%	315.5	0.0%	700.1	0.0%	1,893.8	100.0%	4,644.7	100%
	Total sales (mln)	0.0	0.0%	0.0	0.0%	562.2	0.0%	127.5	0.0%	173.5	0.0%	326.0	100.0%	1,189.2	100%
	Electricity consumption (TWh)	0.0	0.0%	0.0	0.0%	35.4	0.0%	38.9	0.0%	16.4	0.0%	20.7	100.0%	111.4	100%
2020	**Total stock (mln)**	0.0	0.0%	0.0	0.0%	1,740.6	0.0%	322.5	0.0%	711.3	0.0%	1,904.8	100.0%	4,679.1	100%
	Total sales (mln)	0.0	0.0%	0.0	0.0%	421.6	0.0%	111.7	0.0%	175.7	0.0%	200.0	100.0%	908.9	100%
	Electricity consumption (TWh)	0.0	0.0%	0.0	0.0%	35.4	0.0%	39.8	0.0%	16.7	0.0%	20.8	100.0%	112.7	100%

9 ANNEXES

9.1 Common eco-design criteria in lighting

Some functional technology independent criteria are applicable to all light sources and are described in this annex. As explained in the related background notes these functional criteria do often compromise or trade off the lamp efficacy or other parameters. As a consequence they are useful to decide on correction factors to minimum, bench mark or BAT performance parameter values or exemptions on implementing measures, either final or temporary with amendments on implementing measures.

9.1.1 'White light source' criterion

The SI unit for luminous flux is related to the sensitivity of the human eye (see chapter 3). The human eye is much more sensitive to green light than to blue light (see chapter 3) and as a consequence it seems to be energy efficient to use green light for illumination. But if a light source for illumination is only monochromatic, the appearance of all objects that have any other colour changes into an undefined grey. So, for general lighting, we cannot require green light lumen output. As explained in chapter 1, this study focuses on 'white light' that can be used for general illumination; a white light source contains all colours of the visible light spectrum and gives a natural appearance to all different colours.
Visible light can also be a non intended side effect of the desired application, for example in an infrared lamp used as heating device or an UV lamp used as disinfection lamp. These effects are either connected to the transition zone between visible and non visible long wave length light (red - infrared light) or to the transition zone between visible and non visible short wave length light (violet - ultraviolet light). On the other side, an incandescent lamp also generates a huge amount of heat in the form of infrared radiation or infrared light. Therefore a definition of a white light source is needed. This definition, based on the CIE chromaticity coordinates, can be found in chapter 1.

9.1.2 Definition of a 'white' light source

Currently there is no scientific definition nor for a white, neither for a coloured light source. The following chromaticity specification has therefore been developed. This specification is compatible with existing fluorescent lamp colour temperature definitions for white lamps (EN 60901, EN 60081) (see chapter 1) and with the proposal developed in the framework of the

ENERGY STAR® Program Requirements for Solid State Lighting Luminaires[105] taking into account colour and binning capabilities from white LEDs. The black body Planckian radiation (10° viewing angle) for colour temperatures from 2000K up to 12300K has been taken as reference; this curves typically fits with incandescent lamps. The upper and lower limit have been deducted from the widest colour tolerances found for white lamps; in practice these were LEDs[106] as they have currently the broadest tolerances. These boundaries also include white fluorescent lamps and white HID lamps. LPS and most HPS lamps are outside this product definition.

A white light source is defined in this study as a light source having CIE 1931 x,y chromaticity coordinates that satisfy the following requirement:

- $0,270 < x < 0,530$
- $-2,3172.x^2 + 2,3653.x - 0,2199 < y < -2,3172.x^2 + 2,3653.x - 0,1595$

The corresponding zone in the CIE chromaticity space diagram (Figure 9-1) is situated between the upper and lower limit lines.

[105] ENERGY STAR® Program Requirements for Solid State Lighting Luminaires, see http://www.netl.doe.gov/ssl/energy_star

[106] ENERGY STAR® Program Requirements for Solid State Lighting Luminaires ENERGY STAR® Program Requirements for Solid State Lighting Luminaires Eligibility Criteria – Version 1.0(12/9/2007), see http://www.netl.doe.gov/ssl/energy_star

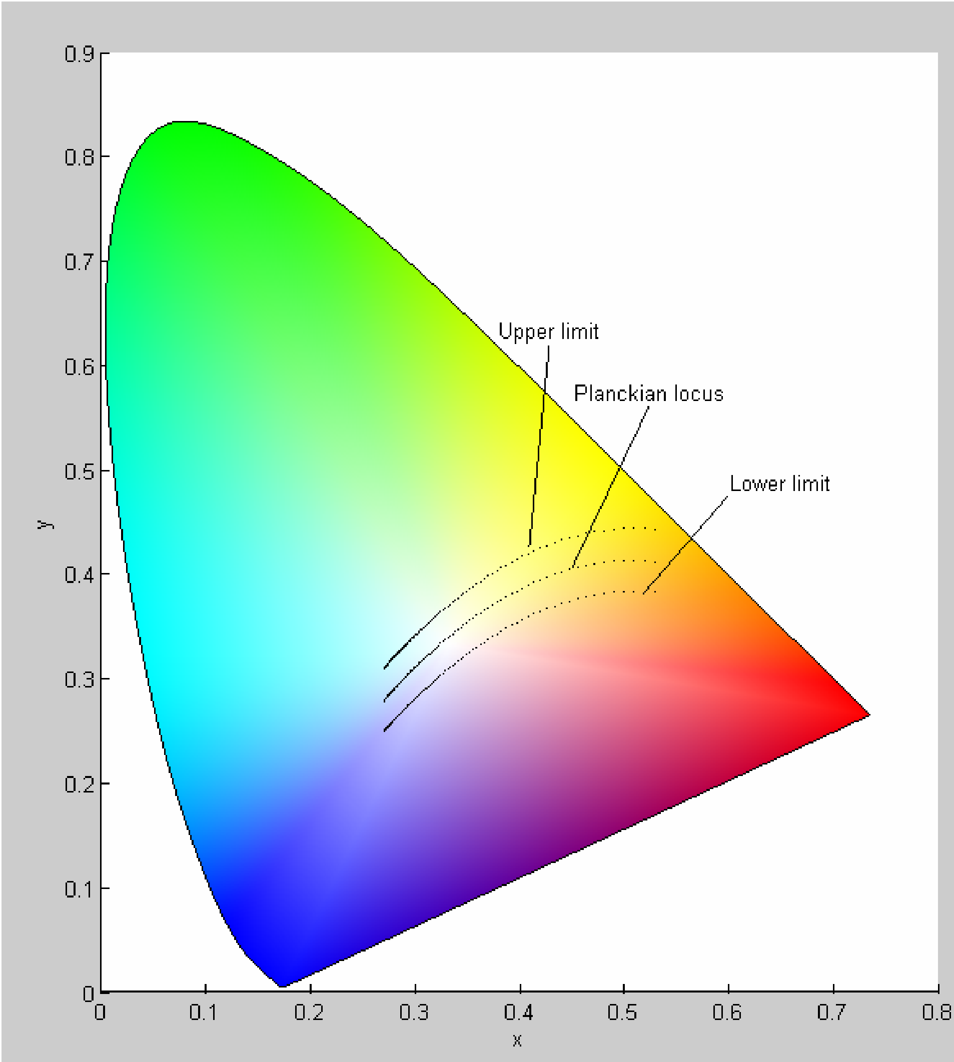

Figure 9-1: The CIE 1931 x,y chromaticity space, showing the chromaticities of the black-body Planckian locus (10° viewing angle) for colour temperatures from 2000K up to 12300K and the new proposed upper and lower limits for defining a white light source (printed colours are indicative only).

Please note that CIE 1931 x,y chromaticity space diagram represents all of the chromaticities for *visible light* to the average person. These are shown in colour and this region is called the gamut of human vision. The gamut of all visible chromaticities on the CIE plot is the tongue-shaped or horseshoe-shaped figure shown in colour.
The corresponding CIE 1931 x,y chromaticity coordinates can be found in Table 9-1, only the white coloured cells.

9.1.3 Definition of a light source for general illumination

Purpose: This definition is an extension of the previous definition of white light to all light sources used in general illumination, including the (monochromatic) LPS (low pressure sodium) lamps.

A light source for general lighting is defined in this study as a light source having CIE 1931 x,y chromaticity coordinates that satisfy the following requirement (see Figure 9-2):

- $0{,}270 < x < 0{,}575$
- $-2{,}3172.x^2 + 2{,}3653.x - 0{,}2199 < y < -2{,}3172.x^2 + 2{,}3653.x - 0{,}1595$ and being a visible colour[107]

Please note that monochromatic light sources can per definition not be considered as 'white' light. The curved edge is called the spectral locus and corresponds to monochromatic light. Less saturated colours appear in the interior of the figure with white at the centre.

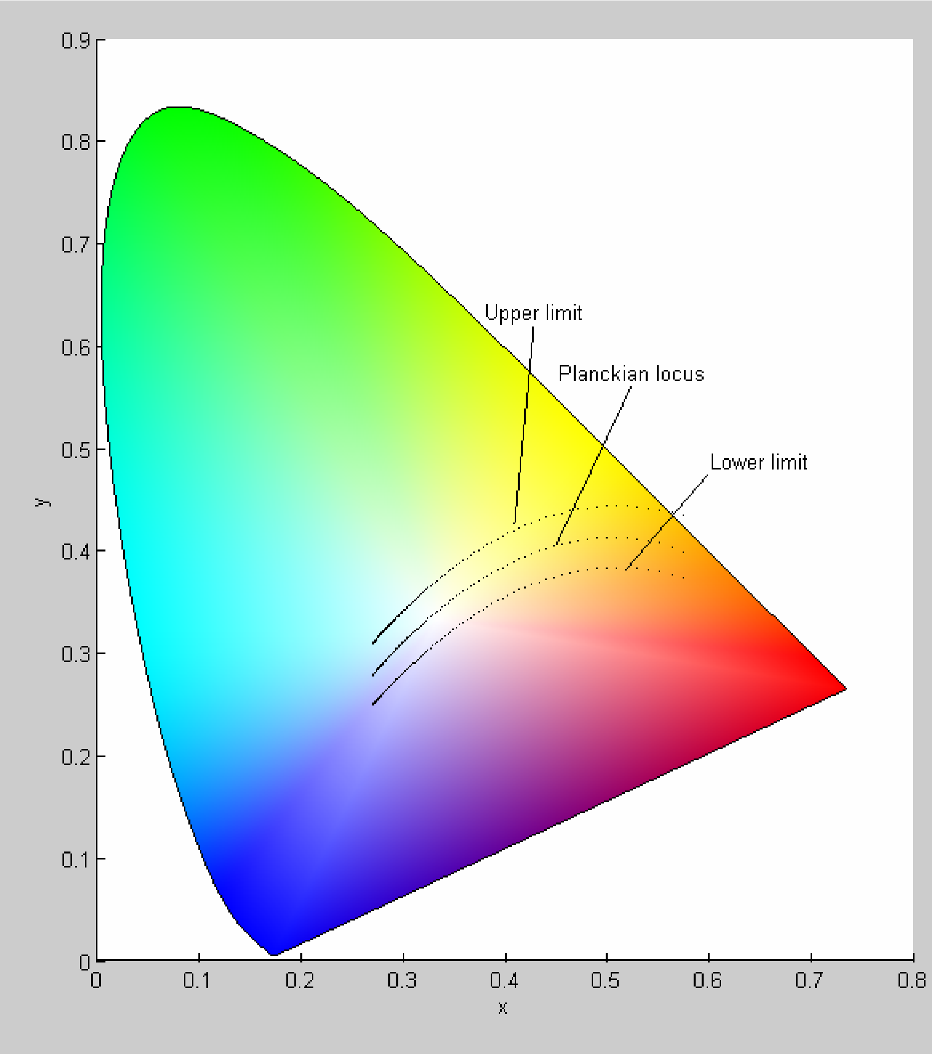

Figure 9-2: The CIE 1931 x,y chromaticity space, showing the chromaticities of the black-body Planckian locus (10° viewing angle) for colour temperatures from 1600K up to 12300K and the new proposed upper and lower limits for defining a light sources used in general illumination (printed colours are indicative only).

A table with corresponding CIE 1931 x,y chromaticity coordinates is provided in Table 9-1, the yellow cells included.

[107] This requirement has been introduced as the y upper limit formula can result in none visible light coordinates at x > 0,56 (see figure).

Table 9-1: CIE 1931 x,y chromaticity coordinates table with the proposed upper and lower y limits for defining a light source for general illumination and for white light from x≤ 0,53

x	y-maximum	y-minimum		x	y-maximum	y-minimum
0,575	0,435	0,374		0,307	0,348	0,287
0,563	0,438	0,377		0,305	0,347	0,286
0,552	0,440	0,380		0,304	0,345	0,285
0,541	0,442	0,382		0,303	0,344	0,284
0,530	0,443	0,383		0,302	0,343	0,283
0,520	0,444	0,384		0,300	0,342	0,282
0,509	0,444	0,384		0,299	0,341	0,280
0,500	0,444	0,383		0,298	0,340	0,279
0,490	0,443	0,383		0,297	0,339	0,278
0,481	0,442	0,382		0,296	0,338	0,277
0,472	0,441	0,380		0,295	0,337	0,276
0,464	0,439	0,379		0,294	0,336	0,275
0,456	0,437	0,377		0,293	0,335	0,274
0,448	0,435	0,375		0,292	0,334	0,273
0,440	0,433	0,372		0,291	0,333	0,273
0,433	0,430	0,370		0,291	0,332	0,272
0,427	0,428	0,367		0,290	0,331	0,271
0,420	0,425	0,365		0,289	0,330	0,270
0,414	0,423	0,362		0,288	0,330	0,269
0,408	0,420	0,360		0,287	0,329	0,268
0,403	0,417	0,357		0,287	0,328	0,268
0,397	0,414	0,354		0,286	0,327	0,267
0,392	0,412	0,351		0,285	0,327	0,266
0,387	0,409	0,349		0,285	0,326	0,265
0,383	0,406	0,346		0,284	0,325	0,265
0,378	0,404	0,343		0,283	0,325	0,264
0,374	0,401	0,341		0,283	0,324	0,263
0,370	0,399	0,338		0,282	0,323	0,263
0,366	0,396	0,336		0,281	0,322	0,262
0,363	0,393	0,333		0,281	0,322	0,262
0,359	0,391	0,331		0,280	0,321	0,261
0,356	0,389	0,328		0,280	0,321	0,260
0,352	0,386	0,326		0,279	0,320	0,260
0,349	0,384	0,324		0,279	0,320	0,259
0,346	0,382	0,321		0,278	0,319	0,259
0,344	0,380	0,319		0,278	0,318	0,258
0,341	0,378	0,317		0,277	0,318	0,257
0,338	0,375	0,315		0,277	0,317	0,257
0,336	0,373	0,313		0,276	0,317	0,257
0,333	0,372	0,311		0,276	0,316	0,256
0,331	0,370	0,309		0,275	0,316	0,255
0,329	0,368	0,307		0,275	0,315	0,255
0,327	0,366	0,306		0,274	0,315	0,255
0,325	0,364	0,304		0,274	0,314	0,254
0,323	0,363	0,302		0,273	0,314	0,254
0,321	0,361	0,301		0,273	0,314	0,253
0,319	0,359	0,299		0,273	0,313	0,253
0,317	0,358	0,297		0,272	0,313	0,252
0,316	0,356	0,296		0,272	0,312	0,252
0,314	0,355	0,294		0,272	0,312	0,251
0,312	0,353	0,293		0,271	0,311	0,251
0,311	0,352	0,291		0,271	0,311	0,251
0,309	0,351	0,290		0,270	0,311	0,250
0,308	0,349	0,289		0,270	0,310	0,250

9.2 'Directional light source' or 'reflector lamp' criterion

Background:
The proportion of the light emitted by the light source itself transmitted by the incorporated lamp reflector or optic system has an impact on energy efficiency. If the lamp reflector or optic system does not let through enough light, higher power lamps will have to be installed. These lamp types are more proliferated nowadays and it does not make sense to continue to exclude these lamp types from further legislation or labelling, they will be elaborated in part 2 of this study. Please note that these lamps are an alternative for omni directional light sources with a functional luminaire. As a general rule, in the medium term it seems sensible to state that these lamps should let through at least half of the light luminous flux (stakeholder please confirm). However, benchmarks values are difficult to set, as reflector lamps can be of various beam angles and used in different applications. For example, a reflector lamp is often used to direct the light without glare or spill to the target. A narrow beam angle requires needs to use more the optic system and hence has a lower efficacy. As a consequence a correction factor might be needed to compare with bench mark values for non directional light sources.
Criterion:
"Directional Light Source" (DLS) shall mean light sources having at least 80% light output within a solid angle of π sr (corresponding to a cone with angle of 120°). A DLS uses a reflector or an optical component (e.g. lens for LED) to align the luminous flux, 'all reflector lamps' are considered as DLS.

9.2.1 'Colour rendering' criterion

Background:
Not all light sources are capable to provide good colour rendering and it is most often a compromise with the lamp efficacy(see chapter 3 and 6).

Criterion:
Level 'CRI -' = Poor colour rendering: CRI < 80
Level 'CRI +' = Good colour rendering: 80 ≤ CRI < 90
Level 'CRI ++' = Excellent colour rendering: 90 ≤ CRI.

9.2.2 'Bright point source' criterion

Background:
For certain applications a 'point source' lamp might be more beneficial and for others completely not.
First, low lumen lamps as bright 'point sources' are also useful for decorative lighting applications where shiny reflections are desired in the luminaire or its surroundings (e.g. in decorative 'crystal' luminaires). Nevertheless, these lamps are not beneficial when no glare is desired and no glare reducing luminaires are applied, e.g. in this case a frosted incandescent lamp without luminaire could be preferred over a clear lamp. A CFLi, even with a decorative

envelope, can never achieve the same effect as a bright point source from a small halogen lamp (see also chapter 3).
Second, point sources are often beneficial for use in reflector luminaires as this allows a better light control (e.g. as needed in street lighting luminaires). HID lamps are efficient bright point sources, however they have a long warm up time and can often not reignite within minutes. Therefore high wattage halogen lamps can still be useful even with a low efficacy.

Criterion:
The bright point source is defined as a light source that has only clear glass covers.
This is a clear GLS, clear halogen, clear HID lamp, not including frosted or silicated GLS, frosted or silicated halogen lamp, frosted or fluorescent HID, LPS, HPM, LFL, CFLi or CFLni lamps or other light sources with a luminance above 25000 cd/m² for lamps below 2000 lm and above 100000 cd/m² for lamps with more lumen output.

9.2.3 'Second lamp envelope' criterion

Background:
In certain applications lamps can contain a second outer lamp envelope that is not required for the normal functioning of the lamp. There are mainly two reasons for this application:

- when breakage of the lamp can cause danger e.g. in the food processing where the glass can drop on the food or in any other situation when the lamp contains hazardous substances,
- for decorative purposes e.g. the look-alike CFLi etc.

This second envelope adsorbs some light and hence the lamp efficacy is lower.

Criterion:
These are lamps that contain a second outer lamp envelope that is not required for the normal functioning of the lamp.

9.3 Defined lamp efficacy level

Table 9-2: Defined lamp efficacy level with maximum input power versus lumen output

efficacy level	9	8	7	6	5	4	3	2	1
lamp lumen	Watt	Watt	Watt	Watt	Watt	Watt	Watt	Watt	Watt
50,0	1,4	1,8	2,2	3,5	5,2	6,9	8,2	9,5	11,3
100,0	2,2	2,8	3,4	5,5	8,2	11,0	13,0	15,1	17,8
150,0	3,0	3,7	4,5	7,3	10,9	14,5	17,2	19,9	23,6
200,0	3,7	4,5	5,5	8,9	13,3	17,8	21,1	24,5	28,9
250,0	4,3	5,3	6,4	10,5	15,7	20,9	24,9	28,8	34,0
300,0	5,0	6,1	7,2	12,0	18,0	24,0	28,4	32,9	38,9
350,0	5,6	6,9	8,1	13,4	20,2	26,9	31,9	37,0	43,7
400,0	6,2	7,6	8,9	14,9	22,3	29,8	35,3	40,9	48,4
450,0	6,9	8,3	9,7	16,3	24,4	32,6	38,7	44,8	52,9
500,0	7,5	9,0	10,5	17,7	26,5	35,3	42,0	48,6	57,4
550,0	8,1	9,7	11,3	19,0	28,6	38,1	45,2	52,3	61,9
600,0	8,6	10,4	12,1	20,4	30,6	40,8	48,4	56,1	66,2
650,0	9,2	11,1	12,8	21,7	32,6	43,4	51,6	59,7	70,6
700,0	9,8	11,8	13,6	23,0	34,5	46,1	54,7	63,3	74,9
750,0	10,4	12,4	14,3	24,3	36,5	48,7	57,8	66,9	79,1
800,0	11,0	13,1	15,0	25,6	38,5	51,3	60,9	70,5	83,3
850,0	11,5	13,7	15,8	26,9	40,4	53,8	63,9	74,0	87,5
900,0	12,1	14,4	16,5	28,2	42,3	56,4	67,0	77,6	91,7
950,0	12,7	15,0	17,2	29,5	44,2	58,9	70,0	81,0	95,8
1000,0	13,2	15,7	17,9	30,7	46,1	61,5	73,0	84,5	99,9
1050,0	13,8	16,3	18,6	32,0	48,0	64,0	76,0	88,0	104,0
1100,0	14,3	17,0	19,3	33,2	49,9	66,5	78,9	91,4	108,0
1150,0	14,9	17,6	20,0	34,5	51,7	69,0	81,9	94,8	112,0
1200,0	15,4	18,2	20,7	35,7	53,6	71,4	84,8	98,2	116,1
1250,0	16,0	18,9	21,4	36,9	55,4	73,9	87,7	101,6	120,1
1300,0	16,5	19,5	22,0	38,2	57,3	76,3	90,7	105,0	124,1
1350,0	17,1	20,1	22,7	39,4	59,1	78,8	93,6	108,3	128,0
1400,0	17,6	20,7	23,4	40,6	60,9	81,2	96,5	111,7	132,0
1450,0	18,1	21,4	24,1	41,8	62,7	83,6	99,3	115,0	135,9
1500,0	18,7	22,0	24,7	43,0	64,5	86,1	102,2	118,3	139,9
1550,0	19,2	22,6	25,4	44,2	66,4	88,5	105,1	121,7	143,8
1600,0	19,8	23,2	26,1	45,4	68,2	90,9	107,9	125,0	147,7
1650,0	20,3	23,8	26,7	46,6	70,0	93,3	110,8	128,3	151,6
1700,0	20,8	24,4	27,4	47,8	71,7	95,7	113,6	131,5	155,5
1750,0	21,4	25,0	28,1	49,0	73,5	98,1	116,4	134,8	159,3
1800,0	21,9	25,6	28,7	50,2	75,3	100,4	119,3	138,1	163,2
1850,0	22,4	26,2	29,4	51,4	77,1	102,8	122,1	141,4	167,1
1900,0	23,0	26,8	30,0	52,6	78,9	105,2	124,9	144,6	170,9
1950,0	23,5	27,4	30,7	53,8	80,6	107,5	127,7	147,9	174,7
2000,0	24,0	28,0	31,3	54,9	82,4	109,9	130,5	151,1	178,6

9.4 Some current MEPS and quality parameters for CFLi's

	ELC Ecoprofile	EU CFL Quality Charter	EU Ecolabel on light bulbs
Scope / Subcategories	Non-covered, covered, reflector (although no measurement and values yet)	covered / non-covered also when lamp and adapter supplied as a single entity	except CFLs with magnetic ballast
Base	EN 60061	Edison screw or bayonet cap	any
Compliance with standards and laws	IEC 60061, 60968-9, 61000-3-2, 61547, EN 55015 + Product Safety, EMC, LVD, EuP, WEEE, RoHS	EN 60968 **OR** EN 61999 + 60598 AND relevent CE legislation	
MEPS (compared to energy label)	varies between low-level A and B, derating factor for: - cover 0.85, - CRI>90 0.85, - Tc>5000K 0.9	without cover: A, derating 0.85 for cover	A
Lamp life	>= 6000h	6000h, long life claim: 12.000h	>10.000h
Lumen maintenance	85% at 2000h	at least 75% at EoL, 2000h: 88% for non-covered, 83% for covered	> 70% at 10.000h
CRI	>= 80	>= 80 new: maybe higher	>= 80
Tc	derating under MEPS		
Lamp orientation			
Physical dimensions			
Warm up time		60s to 60% of stabilised light output (new for non-covered: 2s to 30%, 60s to 80% covered: 60s to 80%)	
Number of ignitions		equal to lamp life in hours (special test)	> 20.000 (special test)
Dimmability			
Information on packaging		life, EE class	disposal, dimming, size and shape vs. GLS, optional: high EE, long life, no Hg
Equivalence with GLS	no fixed ratio, table on basis of lumen output with frosted GLS	no fixed ratio, table on basis of lumen output with clear GLS taking into account aging	
Lifetime in hours put in years			
Warranty		24 months	
Power Factor	0.5 minimum, lamps claiming high power factor: 0.85 < 25W, otherwise comply with IEC 61000		
Operating frequency			
Hazardous substances	RoHS (Hg <= 5 mg, some flame retardants restricted to 0.1% of weight)	RoHS (implicit reference through CE marking)	max. 4 mg Hg, no flame retardants (longer list than in RoHS)
Conformity assessment		Module Aa if not known lamp	third party

	UK EST "ESR logo"	US Energy Star	Efficient Lighting Initiative
Scope / Subcategories	Bare stick, spiral, bulb, reflector (even in two parts, 8 categories defined)	bare, covered, reflectors, circline/square lamps	bare and covered, no reflectors
Base	EN 60061 + any on request	E26/24	Edison screw or bayonet cap
Compliance with standards and laws	IEC 60061, 60968-9, 61000-3-2, 61547, CE legislation including LVD, EMC, labelling, RoHS, WEEE	US standards and laws	IEC 61000, 61547, CISPR 15 (EMC)
MEPS (compared to energy label)	bare: A, bulb: A or B (detailed graphs provided), derating for Tc>5000K 0.9 reflector lamps: at least 4x the peak beam efficacy of filament lamp claimed to be equivalent	bare: slightly below A < 15 W, strong A (8) >= 15 W + covered: slightly below A + reflector: B	strong A (8) for P < 9W, minimum A for P > 9W, derating for Tc > 5000K 0.92-95 (depends on P), 0.85 for cover
Lamp life	bare: >= 10.000h, bulb: 8000h, spiral: 6000h	>= 6000h	>=6000h
Lumen maintenance	several values for 1000-15000h and by class, eg bare: 94% at 1000h, 88.1% at 2000h, 75.1% at 10000h (overall higher > EU QC)	> 90% at 1000h, > 80% at 40% rated life	> 80% at 40% rated life
CRI	>= 80	> 80	>= 80
Tc	2700K prefer-red, derating under MEPS	2700K prefer-red	derating under MEPS
Lamp orientation	no significant change in light output (or else indication)		
Physical dimensions	detailed requirements on weight, width, length / category		
Warm up time	non-covered: 2s to 20%, 60s to 70% + **covered**: 2s to 10%, 60s to 60%	3 minutes to 80 %, 1s to "start"	1.5 seconds to "start"
Number of ignitions		equal to half of lamp life in hours (special test)	
Dimmability			
Information on packaging	dimmability, if light decrease > 5% with orientation change, warning	wattage, lumen output, life, Tc if not GLS like, starting temperature, EMC data	starting temperature, enclosability in luminaires, life, Tc, power, light output
Equivalence with GLS	no fixed ratio, two graphs on basis of lumen output with clear/frosted GLS	no fixed ratio, table on basis of lumen output with giant output GLS	no fixed ratio, table on basis of lumen output with clear GLS
Lifetime in hours put in years		table setting equivalences on basis of 3 h / day use	
Warranty		24 months for residential, 12 months for commercial	12 months
Power Factor	0.55 minimum, lamps claiming high power factor: 0.9	0.5 minimum	0.5 minimum
Operating frequency		>= 40 kHz	
Hazardous substances	RoHS (implicit reference through CE marking)		
Conformity assessment	third party	third party	accredited laboratory

	Australian MEPS	Salvador MEPS	VITO proposal
Scope / Subcategories	not defined - all CFLs	bare, covered, reflectors, circline/square lamps, not modular or movement detectors	bare and covered, no reflectors, >100 lm
Base	all bases	Edison screw or bayonet cap	full list with excep-tions provided
Compliance with standards and laws	harmonics standard (AUS or IEC 61000)		
MEPS (compared to energy label)	bare: A, covered: 0.85 * A, reflector: 0.6 * A	slightly below A (8) for bare, halfway between A and B for covered, approx. 0.7 derating for reflector lamps	strong A (8) for bare lamps > 1000 lm; A (7) for bare lamps < 1000 lm or covered/good CRI lamps > 1000 lm; strong B (6) for covered/good CRI lamps < 1000 lm.
Lamp life	>=6000h		>=6000h
Lumen maintenance	2000h: 0.88, 5000h: 0.8, 10000h: 0.75		>=88% at 2000h, 75% at EoL
CRI	>= 80		
Tc	must comply with IEC 60081		
Lamp orientation			
Physical dimensions			
Warm up time	2 s to start, 1 min to 60%		< 1 sec to "start", < 1 minute to 60% (80% for temperature sensitive CFLs)
Number of ignitions	1000 cycles		>10.000 if start delay higher than 0.2 sec
Dimmability			ban all dimmers not dimming CFLi
Information on packaging		body: energy class, voltage, frequency, power, current (this one only if power factor < 0.9, dimming, package: graphic comparison with GLS, life	wattage, lumen output, life, CRI, starting delay, warmup time, Hg in mg, lumen maintenance, disposal, light distribution
Equivalence with GLS		graphic comparison with GLS	no fixed ratio, table on basis of lumen output with clear GLS, rounded off to 1 W + conditions for displaying "energy saving lamp"
Lifetime in hours put in years			
Warranty			
Power Factor	0.55 minimum, lamps claiming high power factor: 0.9	lamps claiming high power factor: 0.92	0.5 minimum
Operating frequency			
Hazardous substances	max 5 mg Hg		1.23 mg for 6000h, 1.8 mg for 10000h
Conformity assessment	registration through self-declaration		self-declaration

Part 2

Directional lamps and household luminaires

1 PRODUCT DEFINITION

Scope: This task should define the product category and define the system boundaries of the ‘playing field’ for eco-design. It is important for a realistic definition of design options and improvement potential and it is also relevant in the context of technically defining any implementing legislation or voluntary measures (if any).

The objective of this task is to discuss definition and scope issues related to the EuP preparatory study for the lot 19. It consists of categorisation of products, description of product definitions, scope definition as well as identification of key parameters for the selection of relevant products to perform detailed analysis and assessment during the next steps of the study.

Further, the harmonised test standards and additional sector-specific procedures for product-testing are identified and discussed, covering the test protocols for:

- Primary and secondary functional performance parameters;
- Resource use (energy, etc.) during product-life;
- Safety (electricity, EMC, stability of the product, etc.);
- Other product specific test procedures.

Finally, it aims to identify existing legislations, voluntary agreements and labelling initiatives at the EU level, in the Member States and outside Europe.

1.1 Product category and performance assessment

1.1.1 System boundary and technical product definition

<u>Proposed product definition, scope and system boundary:</u>

The proposal is to use a product definition derived from existing European standards and the Prodcom classification.

A 'domestic lighting' product system can more generally be considered as 'lighting equipment' as defined in standard EN 12665 (Light and lighting - Basic terms and criteria for specifying lighting requirements) for domestic application, containing:

3. A “*lamp”* as *“source made in order to produce an optical radiation, usually visible*”;
4. A *”luminaire*” as *“apparatus which distributes, filters or transforms the light transmitted from one or more lamps and which includes, except the lamps themselves, all parts necessary for fixing and protecting the lamps and, where necessary, circuit auxiliaries together with the means for connecting the lamps to the electric supply”.*

In this study, "lamp" means a source made in order to produce an optical radiation, usually visible, including any additional components necessary for starting, power supply or stable operation of the lamp or for the distribution, filtering or transformation of the optical radiation, where those components cannot be removed without permanently damaging the unit.

It must be explicitly stated that only lamps and luminaires for general lighting that use electrical energy are in the scope of this study; lamps for torches, bicycles, motorcycles and motor vehicles are excluded.

Furthermore it is proposed to exclude coloured lamps that are typically used for decorative purposes, therefore the definition of a white light source in part 1 is used.

It is important to note that the definition of domestic lighting in this eco-design study covers products with similar characteristics. Moreover, many so-called 'domestic lighting' products are also used in other areas (e.g. hotels, shops, offices). According to the MEEuP Methodology Report, these product groups that are functionally similar have to be envisaged. As a consequence all that products that are based on the same technology will be included in this study.

The 'domestic lighting' is not a lighting specifiers market, this means that the technical lighting requirements (e.g. illuminance levels) are not specified by the consumer before installation according to technical standards. Therefore the approach is different from the previous EuP studies for office and street lighting. In this study, a lamp technology based approach is proposed. This means a focus on the lighting technology that is most commonly used in the domestic market. The advantage of this approach is that the Prodcom classification according to lamp technology can directly be adopted and possible implementing measures can easily be followed up.

Luminaires are considered as being part of the system environment. Therefore it is proposed to not consider the complete luminaire as such but to consider only the impact of the following specific functional elements incorporated in the luminaire or sold together as one unit:

- sockets,
- built-in light source control gear,
- external light source control gear (non-mounted),
- dimming control,
- optical reflector.

The supporting structure (boxes, bars etc.) of a luminaire will only be taken into account if necessary for the assessment of an improvement, and even then with the bare minimum elements of the most simple luminaire in each category, as it is impossible to analyse all decorative elements found in domestic luminaries on the market (gold plating, crystal, ..).

For the eco-reports and the LCA's, the data from former EuP-studies will be used if available: for halogen transformers the study on power supplies (Lot 7), for ballasts and dimming control the studies on public street lighting and office lighting (Lot 8 and 9).

External mounted dimmers (wall mounted) are considered as part of the external system. Only requirements for compatibility will be discussed.

Also functional properties will be considered that enable energy efficient light sources or light use (lamp compartment properties, ..). For the found system-related improvement options (if any) environmental impact assessment and LCC impact assessment will be made in task 8 at product level.

Additional definitions for LED-applications:

A 'retrofit LED lamp' in this study has been defined as a self-ballasted lamp, incorporating a LED light source and any additional elements necessary for a stable operation of the light source; it is provided with a lamp cap conform IEC 60061-1, which cannot be dismantled without permanent damage (see EN 62560: *'Safety Requirements for Self-ballasted LED lamps'* and IEC/PAS 62612 Ed.1: *'Performance requirements for Self-ballasted LED-lamps for general lighting services > 50 V'*).

A 'LED-luminaire' is a luminaire incorporating one or more LED light sources and all additional elements necessary for stable operation of the light sources and in which no LED light source or other element can be replaced or changed by the consumer. The luminaire can be installed as a whole, just like a normal luminaire.

A 'LED-module' is a combination of two (or more) seperate parts i.e. a LED light source and a part containing all additional elements necessary for a stable operation of the accompanying LED light source. This LED module is not intended to be sold as such to an end consumer but only to luminaire manufacturers and specialized installers.

1.1.2 Classification of domestic lamps and luminaires

Please note that in Eurostat's product-specific statistics for trade and production (the so-called Europroms[108]-Prodcom[109] statistics) domestic lighting can be reported in two manners:

3. According to lamp technology.
4. According to function of the luminaire.

Prodcom is a valuable source of information in total number of sales and average price. This level of aggregation is rather raw. For the purpose of the eco-design analysis extra sub-categories will be therefore added.

1.1.2.1 Lamps applicable in domestic lighting

The PRODCOM segmentation for lamps related to domestic lighting is displayed in Table 1-1.

Table 1-1: Prodcom segmentation for lamps related to domestic lighting

31.50.12.93	Tungsten halogen filament lamps, for a voltage > 100V Excluding: - ultraviolet and infra-red lamps - for motorcycles and motor vehicles

[108] Europroms is the name given to published Prodcom data. It differs from Prodcom in that it combines production data from Prodcom with import and export data from the Foreign Trade database.

[109] Prodcom originates from the French "PRODuction COMmunautaire"

31.50.12.95	Tungsten halogen filament lamps for a voltage ≤ 100V Excluding: - ultraviolet and infrared lamps - for motorcycles and motor vehicles
31.50.13.00	Filament lamps of a power ≤ 200W and for a voltage > 100V Including: - reflector lamps Excluding: - ultraviolet and infrared lamps - tungsten halogen filament lamps - sealed beam lamp units
31.50.15.10	Fluorescent hot cathode discharge lamps, with double ended cap Excluding: - ultraviolet lamps
31.50.15.30	Fluorescent hot cathode discharge lamps Excluding: - ultraviolet lamps - lamps with double ended cap
31.50.15.53	Mercury vapour discharge lamps Excluding: - ultraviolet lamps - dual lamps (Including : metal halide lamps)

As mentioned before, for the purpose of the eco-design analysis, extra sub- categories will be added; the complete list of lamp types is included in Table 1-2.

In this study directional light sources (DLS) or directional lamps (e.g. reflector lamps) and non-directional light sources (NDLS) or non-directional lamps will be discriminated, because the performance data provided by manufacturers are different for both lamp types and it allows to execute the study in two phases. Within directional light sources, further discrimination can be made according to light distribution or beam angle.

The base line proposal for defining these directional and non-directional light sources is based on the light distribution per solid angle. The unit for a solid angle is the steradian [sr]; a complete solid angle can e.g. be visualized as a sphere and counts 4π sr (see Figure 1-1).

Figure 1-1: Visualization of a complete solid angle.

According to the definition in part 1 of the study and Commission Regulation (EC) No 244/2009 of 18 March 2009 implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to ecodesign requirements for non-directional household lamps, discrimination of light sources is made in the following categories:

- ‘Directional Light Source’ or DLS means a light source having at least 80% light output within a solid angle of π sr (corresponding to a cone with angle of 120°). A DLS uses a reflector or an optical component (e.g. lens for LED) to align the luminous flux.
- 'Non-Directional Light Source' or NDLS means a light source that is not a directional light source.

As a consequence, although they are ‘reflector’ lamps, there currently are probably no CFLi-R with small diameter on the market that meet this definition of directional light source; they only can be found in the wider diameters. In this part 2 of the study, two categories of CFLi-R will be discriminated namely CFLi-R-NDLS and CFLi-R-DLS. CFLi-R-NDLS have to fulfil the requirements of the non-directional light sources that are entered in Commission Regulation (EC) 244/2009.

Table 1-2: Overview of directional lamp types to be discussed in this study

PRODCOM Code	Definition Prodcom	Voltage [V]	Wattage [W]	Low luminance Frosted High luminance Clear	Directional / Non-Directional Llight Source	Socket type	Application	Other names	Acronym in this study
31.50.13.00 	Filament lamps of a power ≤ 200W and for a voltage > 100V Including: -reflector lamps Excluding: -ultraviolet and infrared lamps -tungsten halogen filament lamps -sealed beam lamp units .	230 - 240	≤200		DLS	E14 E27 B15d B22d		Incandescent reflector lamp or General Lighting Service reflector lamp	GLS-R
31.50.13.00 31.50.14.93 	Filament lamps for a voltage > 100V Excluding: -ultraviolet and infrared lamps -tungsten halogen	230 - 240	>200		DLS	E40	Floodlighting In general, not used for domestic lighting	Incandescent reflector lamp or General Lighting Service reflector lamp High Wattage	GLS-R-HW

PRODCOM Code	Definition Prodcom	Voltage [V]	Wattage [W]	Low luminance Frosted High luminance Clear	Directional / Non-Directional Llight Source	Socket type	Application	Other names	Acronym in this study
31.50.14.93  	filament lamps -those of a power ≤ 200W -for motorcycles and motor vehicles -sealed beam lamp units		300		DLS	MP GX16d	Traffic signalling flash lamp In general, not used for domestic lighting		GLS-R-special
31.50.12.95  	Tungsten halogen filament lamps for a voltage ≤100V Excluding: -ultraviolet and infrared lamps -for motorcycles and motor vehicles	12	12 - 100		DLS	GU4 GU5,3 G53 GY4		Halogen reflector lamp	HL-LV-R
						B15 Ba15d	In general, not used for domestic lighting		
31.50.12.93  	Tungsten halogen filament lamps, for a voltage > 100V Excluding: - ultraviolet and infra-red lamps - for motorcycles and motor vehicles	230	20 - 100		DLS	GU10 GZ10 E14 E27 G9		Halogen reflector lamp	HL-MV-R HL-MV-R-HW

PRODCOM Code	Definition Prodcom	Voltage [V]	Wattage [W]	Low luminance Frosted High luminance Clear	Directional / Non-Directional Llight Source	Socket type	Application	Other names	Acronym in this study
31.50.15.30  	Fluorescent hot cathode discharge lamps Excluding: -ultraviolet lamps -with double ended cap	230	9 - 23		DLS	E14 E27 GU10	Domestic, hotel and general lighting retrofit for incandescent or halogen reflector lamp	Compact Fluorescent Reflector Lamp with integrated ballast Note: these lamps can be either DLS or NLDS (part 1 of the study).	CFLi-R, CFLi-R-DLS, CFLi-R-NDLS
(31.50.15.59 ?) 	Discharge lamps Excluding: -fluorescent hot cathode lamps -dual lamps -mercury or sodium vapour lamps -ultraviolet lamps	230	23		DLS	E27 B22d	Domestic (etc.) retrofit for incandescent and halogen reflector lamp	Electrodeless induction reflector lamp with integrated ballast.	
31.50.15.53  	Mercury vapour discharge lamps Excluding: -ultraviolet lamps -dual lamps *(Including: metalhalide lamps)*		20 - 150 20 35 70	High Clear	DLS	GX8.5 GX10 E27 B22d	Tertiary lighting	Metalhalide reflector lamp	MH-R

PRODCOM Code	Definition Prodcom	Voltage [V]	Wattage [W]	Low luminance Frosted High luminance Clear	Directional / Non-Directional Llight Source	Socket type	Application	Other names	Acronym in this study
31.50.15.53 	Mercury vapour discharge lamps Excluding: -ultraviolet lamps -dual lamps *(Including: metalhalide lamps)*	230	20	High Clear	DLS	E27 B22d	Domestic, hotel and general lighting retrofit for incandescent or halogen reflector lamp	Metal halide reflector lamp with integrated ballast.	MHi-R
No specific code (to be confirmed)   	White, Light Emitting Diode Retrofit Directional lamp	230	0,01 - 100		DLS	GU10 E27 /B22d etc.	Domestic, hotel and general lighting retrofit for incandescent or halogen reflector lamp	WLED Retrofit Directional Lamp with integrated power supply White Light Solid State Retrofit Directional r Lamp with integrated power supply	WLEDi-DLS
No specific code (to be confirmed) 	White, Light Emitting Diode Retrofit Directional lamp	12V	0.01 - 100		DLS	G4 GU5,3 etc.	Domestic, hotel and general lighting retrofit for low voltage halogen reflector lamp	WLED Retrofit Directional Lamp White Light Solid State Retrofit Directional Lamp	WLED-LV-DLS
No specific code (to be confirmed) 		misc	?		DLS	No cap	General lighting	WLED module	

PRODCOM Code	Definition Prodcom	Voltage [V]	Wattage [W]	Low luminance Frosted High luminance Clear	Directional / Non-Directional Llight Source	Socket type	Application	Other names	Acronym in this study
No specific code (to be confirmed)	?	230	1 - ??		DLS NDLS	No cap	Residential and general lighting	Integrated LED-luminaire	

detail: 

Remarks:

- The following lamps were also part of the previous EuP studies on Office and Street Lighting:
  - linear fluorescent lamps
  - CFLni (compact fluorescent lamps with non integrated ballast
  - HID lamps.

  Although they are not again part of all tasks in this study, they will be considered as BAT in task 6.
- HID lamps with high colour rendering index, especially MH-lamps, will be included in this study (task 6) because they form an energy efficient alternative for halogen lamps. MH-lamps are nowadays rarely or not used in domestic lighting; they are mainly used in professional lighting applications (shops, sport fields, etc.). However they will be considered as BNAT or BAT (task 6) because of their potential to replace halogen lamps. Please also note that the Prodcom code 31.50.15.53 covers the complete group of mercury vapour discharge lamps. The Prodcom data are therefore not relevant for this study.
- Normal HPM lamps, included in the same Prodcom code 31.50.15.53 are not used in domestic lighting applications and phasing out was already proposed in the EuP preparatory study on street lighting.

1.1.2.2 Luminaires applicable in domestic lighting

Prodcom segmentation for domestic luminaires is represented in Table 1-3.

Table 1-3: Prodcom segmentation for domestic luminaires.

31.50.22.00	Electric table, desk, bedside or floor standing lamps
31.50.22.03	Domestic and residentials luminaires (excl. spots): for incandescent lamps
31.50.22.05	Domestic and residentials luminaires (excl. spots): for discharge lamps
31.50.22.09	Domestic and residentials luminaires (excl. spots): for other lamps
31.50.25.30	Chandeliers and other electric ceiling or wall lighting fittings (excl. those used for lighting public open spaces or thoroughfares)
31.50.25.31	Luminaires for domestic and residential (excl. spots): for incandescent lamps
31.50.25.32	Luminaires for domestic and residential (excl. spots): for halogen lamps
31.50.25.33	Luminaires for domestic and residential (excl. spots): for compact fluorescent lamps
31.50.25.34	Luminaires for domestic and residential (excl. spots): for other lamps
31.50.25.47	Spots, display lighting: for incandescent lamps
31.50.25.48	Spots, display lighting: for other lamps
31.50.25.79	Other lighting fixtures: luminaires (interior), n.e.c.
31.50.34.30	Electric lamps and lighting fittings, of plastic and other materials, of a kind used for filament lamps and tubular fluorescent lamps
31.50.34.35	Exterior luminaires for houses and gardens : for incandescent lamps
31.50.34.37	Exterior luminaires for houses and gardens : for other lamps
31.50.42.50	Parts (excl. of glass or plastics) of lamps and lighting fittings, etc.

It can be stated that this segmentation is not very suitable for the technical analysis in this study.

On the one hand, the categories 'for incandescent lamps' should include all lamps that can be directly operated on the 230V with E14/E27 and B15d/B22d caps as there are: CFLi, WLEDi and certain HL-MV.

On the other hand, the categories for discharge lamps include all fluorescent lamps (LFL and CFLni) as well as HID lamps.
Also the statement 'for other lamps' is not identical for all categories of luminaires: sometimes there is a special category for halogen lamps and sometimes they are included in the category 'other lamps'.

Table 1-4 gives an overview of the domestic luminaire categories as they will be used in this study, this table was agreed with the sector organisation(CELMA)[110]. This categorisation is therefore in line with the terminology used in the sector and linked to technical parameters.

Remark: Luminaires with ballast, suitable for HID-lamps are rarely used for domestic applications. Moreover, they were already partly discussed in the EuP-study on public street lighting and included in Commission Regulation 245/2009; they will not be discussed again in this study.

Table 1-4: Overview of luminaire categories according to commercial terminology (catalogues, websites)

Luminaire category	Mounting method	Electrical connection	Light distribution	Ingress protection
Downlights (recessed mounted)	ceiling integrated	fixed (wired)	Directional light distribution	≥IP2X
Suspension (chandeliers)	ceiling suspended	fixed (wired)	Any	≥IP2X
wall&ceiling	surface mounted	fixed (wired)	Any (excluding Narrow beam spotlights)	≥IP2X
Desk	free surface standing	plug	Directional light distribution	≥IP2X
Table	free surface standing	plug	Non directional light distribution	≥IP2X
Floor	free surface standing	plug	Any	≥IP2X
Spotlights	surface mounted	fixed (wired)	Narrow beam directional light distribution	≥IP2X
Outdoor	surface mounted/floor standing	fixed (wired)	Directional light distribution(often) or non(rare)	≥IP44

1.1.3 General lamp and luminaire performance specification parameters

1.1.3.1 General lamp performance specification parameters

Each lamp has its own specific characteristics; the important performance assessment parameters are (EN 12665(2002))[111]:

- a "rated value" is the value of a quantity used for specification purposes, established for a specified set of operating conditions of a product. Unless stated otherwise, all requirements are set in rated values;
- a "nominal value" is the value of a quantity used to designate and identify a product;
- rated luminous flux Φ [lm]: quantity value of the initial luminous flux of the lamp, for specified operating conditions. The value and conditions are specified in the relevant standard, corresponding unit: lumen [lm];
- nominal luminous flux Φ [lm]: a suitable approximate quantity value of the initial luminous flux of the lamp, corresponding unit: lumen [lm];

[110] www.celma.org
[111] The definitions of 'nominal' and 'rated' value are not mentioned in this standard but in several other standards such as EN 60081 and EN 50294.

- “Switching cycle” is the sequence of switching on and switching off the lamp with defined intervals;
- "Premature failure" is when a lamp reaches its end of life after a period in operation which is less than the rated life time stated in the technical documentation;
- “Lamp cap” means that part of a lamp which provides connection to the electrical supply by means of a socket or lamp connector and, in most cases, also serves to retain the lamp in the holder;
- “Lamp holder” or “socket” means a device which holds the lamp in position, usually by having the cap inserted in it, in which case it also provides the means of connecting the lamp to the electric supply;
- "Light source control gear" means one or more components between the supply and one or more light sources which may serve to transform the supply voltage, limit the current of the lamp(s) to the required value, provide starting voltage and preheating current, prevent cold starting, correct power factor or reduce radio interference. Ballasts, halogen convertors and transformers and Light Emitting Diode (LED) drivers are examples of light source control gears;
- an electrical switch is a device that switches off the electrical supply, it can be electronic or mechanical and can also include dimming functions, presence detection etc.;
- Luminous Intensity (I) of a source in a given direction: quotient of the luminous flux dΦ leaving the source and propagated in the element of solid angle dΩ

  $I = \frac{d\Phi}{d\Omega}$, corresponding unit: candela [cd] , cd = lm . sr^{-1} ;
- Rated lamp power (Plamp [W]): quantity value of the power consumed by the lamp for specified operating conditions. The value and conditions are specified in the relevant standard, corresponding unit: Watt [W];
- Nominal lamp power (Plamp [W]): a suitable approximate quantity value of the power consumed by the lamp, corresponding unit: Watt [W];
- Lamp Survival Factor (LSF): fraction of the total number of lamps which continue to operate at a given time under defined conditions and switching frequency;
- Lamp Lumen Maintenance Factor (LLMF): ratio of the luminous flux emitted by the lamp at a given time in its life to the initial luminous flux;
- Operational lifetime (a combination of LSF and LLMF newly introduced in some draft standards e.g. draft EN 62612): length of time during wich a lamp provides more than xx% of the original, rated luminous flux (e.g. LLMF ≥ 0,70 or ≥ 0,50 indicated as L_{70} or L_{50}) and the maximum failure rate[112] is still lower than yy% (e.g. LSF ≥ 0,5 or ≥ 0,9 indicated as F_{50} or F_{10});
- Luminous efficacy of a NDLS-lamp (ηlamp): quotient luminous flux emitted by the power consumed by the source, unit lumen per Watt [lm/W];
- Luminous efficacy of a DLS-lamp (ηlamp): quotient of the luminous flux emitted in a solid angle of 0.6π or a cone with an angle of 90°, by the power consumed by the source, unit lumen per Watt [lm/W];
- Colour Rendering: the effect of an illuminant on the colour appearance of objects by conscious or subconscious comparison with their colour appearance under a reference illuminant.

[112] Failure rate F_x is the percentage of a number of tested lamps that have reached the end of their individual lifes; $F_x = 100\ (1 – LSF)$.

- CIE general colour rendering index CRI [R_a]: mean of the CIE special colour rendering indices for a specific set of eight (a = 8) test colour samples. (If the colour rendering index is based on more colour samples, 'a' must be specified, e.g. R_{14} or R_{20}.) For a source like a low-pressure sodium vapour lamp, which is monochromatic, the R_a is nearly zero, but for a source like an incandescent light bulb, which emits essentially black body radiation, R_a is assumed to be one hundred. (see also CIE 13.3). *Remark:* It must be stated that the R_a value of any lamp is referred to the Planckian black body radiator with the identical colour temperature. As mentioned before, the colour rendering of the incandescent lamp is assumed to be 100. In fact, real colour rendering should be based on the illumination of the sun. Compared to the sun, the light spectrum of an incandescent lamp contains much more red components and therefore some scientists have doubts on these R_a values. Also for LED's, this definition of CRI is not suitable and a working group in CIE 177 is working on a new proposal.
- Chromaticity coordinates (x, y): these are coordinates which characterise a colour stimulus (e.g. a lamp) by a ratio of each set of tristimulus values to their sum. Tristimulus values means the amounts of the three reference colour stimuli required to match the colour of the stimulus considered (e.g. a lamp). As the sum of three chromaticity coordinates equals 1, two of them are sufficient to define a chromaticity. The CIE defined different colour spaces with its own coordinates, for light sources the most common system is 'CIE xy' also known as 'CIE 1931 colour space'. The gamut of all visible chromaticities on the CIE plot is tongue-shaped or horseshoe-shaped shown in colour in Figure 1-2. In more general terms, a distance on the xy chromaticity diagram does not correspond to the 'degree' of 'perceived' difference between two colours. Other colour spaces (CIELuv and CIELab in particular) have been designed to reduce this problem but there is currently no single solution. Light with a flat energy spectrum (white) corresponds to the point (x,y) = (0.33 ,0.33).

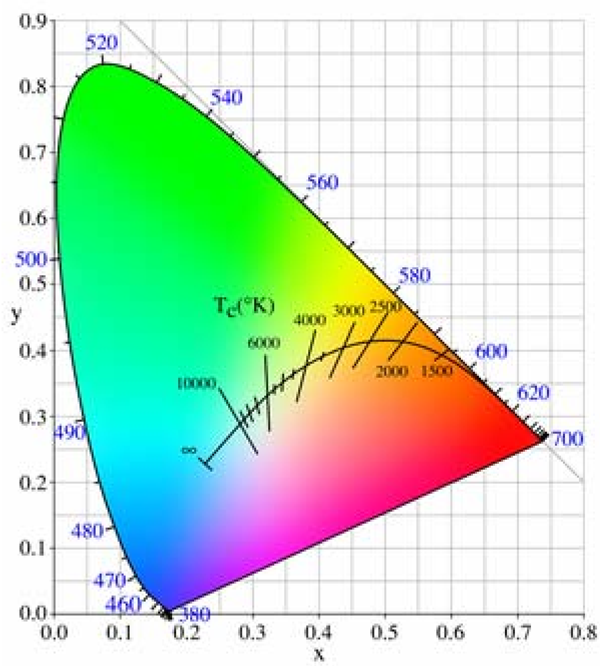

Figure 1-2 The CIE 1931 x,y chromaticity space, also showing the chromaticities of black-body light sources of various colour temperatures (Tc), and lines of constant correlated colour temperature (Tcp).

- Colour temperature Tc: temperature of a Planckian radiator whose radiation has the same chromaticity as that of a given stimulus, unit [K].
- Correlated colour temperature (Tcp [K]): temperature of a Planckian (black body) radiator whose perceived colour most closely resembles that of a given stimulus at the same brightness and under specified viewing conditions. The recommended method for calculation is included in CIE publication 15[113]. Please note that a black body absorbs all electromagnetic radiation that falls onto it and the amount and wavelength (colour) of electromagnetic radiation they emit is directly related to their temperature (see also Figure 1-2). Incandescent lamps (non coloured) are Planckian (black body) radiators and are located exactly on the black body locus (see Figure 1-2). Other light sources can have coordinates that are not exactly located on the black body locus, therefore they have a 'correlated' colour temperature. Please note also that the chromaticity of these light sources (e.g. CFL) is therefore not identified by a single parameter such as correlated colour temperature, this means that for example CFL lamps can appear with different colour but have the same correlated colour temperature[114].
- MacAdam Ellipses: MacAdam ellipse is the region on a chromaticity diagram which contains all colours which are indistinguishable, to the average human eye, from the colour at the centre of the ellipse. MacAdam ellipses are described as having 'steps' which really means 'standard deviations'. If a large sample of the population were used and if a trained observer could reliably repeat his observations, then the steps would translate to probabilities for the general population as follows:1 sd = 68.26 % of the general, colour-normal population 2 sd = 95.44 % “3 sd = 99.44 %. Any point on the

[113] CIE 15: 2004 Colorimetry, 3rd ed.

[114] Rensselaer (2003), 'Increasing market acceptance of compact fluorescent lamps (CFLs)',Mariana Figueiro et al., Project Report of Lighting Research Center, Rensselaer Polytechnic Institute, September 30, 2003.

boundary of a '1-step' ellipse, drawn around a target, represents 1 standard deviation from the target. For a '3-step'ellipse, the boundary represents 3 standard deviations from the target, and so on. These MacAdam Ellipses are included in the standards for fluorescent lamps for describing acceptable colour deviation (EN 60901, EN 60081). Please note that LED lamps don't use these MacAdam Ellipses but defined zones of product groups in the CIE 1931 x,y chromaticity diagram. LEDs are binned for chromaticity in the manufacturing process. These bins, when superimposed on the CIE 1931 Chromaticity Diagram, take the form of quadrangles, as opposed to ellipses (standardisation work in IEC and also in USA[115] is under progress).

Other performance parameters addressed in this study:

- dimmability;
- starting time: time needed for the lamp to start fully and remain alight, after the supply voltage is switched on;
- warm-up time: time needed for the lamp to reach 80% of its full luminous flux, after the supply voltage is switched on (in the ongoing revision of standard EN 60969 a change to limit the warm-up time to 60% is proposed);
- hot restrike capabilities (i.e. start-up after a short switch off time);
- power quality (power factor and harmonic currents e.g. third harmonic line current (%), fifth harmonic line current, current crest factor) see standard EN 61000-3-2;
- unit purchase cost;
- ”Clear lamp” is a lamp (excluding compact fluorescent lamps) with a luminance above 25000 cd/m² for lamps having a luminous flux below 2000 lm and above 100000 cd/m² for lamps having more luminous flux, equipped with only transparent envelopes in which the light producing filament, LED or discharge tube is clearly visible (see part 1, Annex 11.1.1);
- “Non-clear lamp” is a lamp that does not comply with the specifications under the preceding point, including compact fluorescent lamps;
- “Second lamp envelope” is a second outer lamp envelope which is not required for the production of light, such as an external sleeve for preventing mercury and glass release into the environment in case of lamp breakage (see second lamp envelope criterion in part 1, Annex 11.1.5);
- the lamp dimensions and sockets, especially for more energy efficient lamp retrofit solutions.
- the light distribution, especially for more energy efficient lamp retrofit solutions and directional light sources; this distribution can be given in different forms (flux code, polar intensity curve, Cartesian diagram or illuminance cone diagram) but should at least be available as CEN / CIE flux code.

  The CEN (or CIE) flux code (source EN 13032-2) represents the optical characteristics of the luminaire (see Figure 1-3) and consists of 9 whole numbers separated by spaces defined as:
  FCL1/FCL4, FCL2/FCL4, FCL3/FCL4, DFF, LOR, FCU1/FCU4, FCU2/FCU4, FCU3/FCU4, UFF equal to respectively:
  N1, N2, N3, N4, N5, N6, N7, N8, N9.
  UFF is upward flux fraction (= ULOR/LOR= 1-DFF)

[115] Energystar (2007), 'ENERGY STAR® Program Requirements for Solid State Lighting Luminaires Eligibility Criteria – Version 1.0 DRAFT' April 9, 2007.

DFF is downward flux fraction (=DLOR/LOR)
LOR is light output ratio.
FCL1-4 are accumulated luminous fluxes in lower hemisphere for the four zones from 0° to 41.4° (FCL1), 60° (FCL2), 75.5° (FCL3) and 90° (FCL4).
FCU1-4 are accumulated luminous fluxes in upper hemisphere for the four zones from 180° to 138.6° (FCU1), 120° (FCU2), 104.5° (FCU3) and 90° (FCU4).

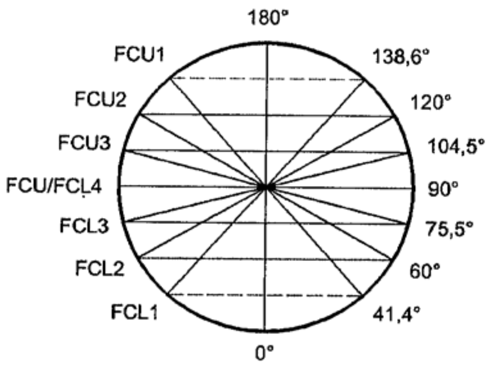

Figure 1-3: Zones for the calculation of accumulated luminous fluxes according to the CEN flux-code.

A polar intensity curve (see Figure 1-4) illustrates the distribution of luminous intensity, in cd/1000 lm, for diffrent axial planes of the luminaire. The curve provides a visual guide to the type of distribution expected from the luminaire e.g. wide, narrow, direct, indirect etc, in addition to intensity. For a DLS, the distribution is normally symmetric in all planes. This is illustrated in Figure 1-4 where the planes C0-C180 and C90-C270 are covering each other.

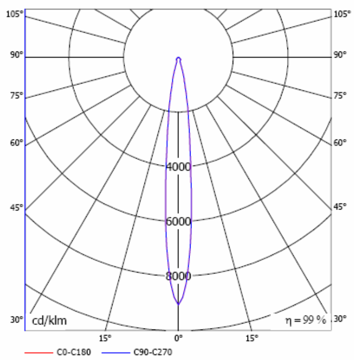

Figure 1-4: Example of a polar intensity curve.

Generally a Cartesian diagram is used for floodlights (see Figure 1-5); this also indicates the distribution of luminous intensity, in cd/1000 lm, for different axial planes of the luminaire and provides a visual guide to the type of distribution expected from the luminaire e.g. narrow or wide beam etc, in addition to intensity.
On this curve the beam angle can easily be defined.

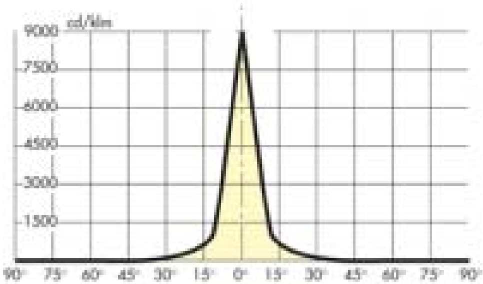

Figure 1-5: Example of a Cartesian light distribution diagram.

An illuminance cone diagram (see Figure 1-6) is usually used for spotlights or lamps with reflectors; the diagram indicates the maximum illuminance, Elux, at different distances, plus the beam angle of the lamp over which the luminous intensity drops to 50%. The beam diameter at 50% peak intensity, relative to distance away, is also shown.

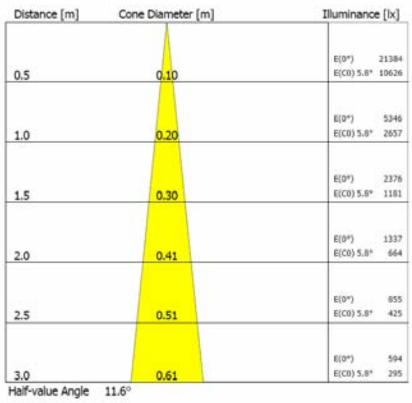

Figure 1-6: Example of an illuminance cone diagram.

- beam angle: the angle between those points on opposite sides of the beam axis where the intensity drops to 50% of the maximum (mostly specified on the Cartesian light distribution diagram);
- the beam can also be defined by a solid angle; the mathematical relationship between the solid angle (Ω) of the beam and the beam angle (θ) in ° is:
  $$\Omega \text{ [sr]} = 2\pi * (1 - \cos \theta/2)$$
- peak intensity in candela [cd]: the maximum luminous intensity (normally in the centre of the beam angle) see standard EN 61341.

1.1.3.2 Definition of a "white light source":

A white light source gives a natural appearance to all different colours. Visible light is the electromagnetic radiation with a wavelength between 380 nm (upper limit of UV) and 780 nm (lower limit of infrared) and all combinations of these wavelengths).

Currently there is no scientific definition nor for a white, neither for a coloured light source. Therefore a definition of a ‘white light source’ was developed for this study. This definition can be found in Annex 11.1.1 of part 1.

It must be noted that this white light definition is only used in this study to limit the scope of the lamps that will be considered because coloured lamps are excluded. It can never be used as a quality parameter for lamps.

1.1.3.3 General luminaire performance specification parameters:

The important performance assessment parameters for luminaires are (EN 12665(2002)):

- *light output ratio(LOR)*: ratio of the total flux of the luminaire, measured under specified practical conditions with its own lamps and equipment, to the sum of the individual luminous fluxes of the same lamps when operated outside of the luminaire with the same equipment, under specified conditions;
- *light output ratio working (LORw):* ratio of the total flux of the luminaire, measured under specified practical conditions with its own lamps and equipment, to the sum of the individual luminous fluxes of the same lamps when operated outside of the luminaire with a reference ballast, under reference conditions.

Note that great care should be given not to interpret LOR as solely ‘the optical efficiency of a luminaire’:

- As explained in the lot 8 office lighting study (p.184) the LOR can account in part for an efficacy increase in the lamp when lamp efficacy is influenced by temperature (e.g. with T5 fluorescent lamps and some CFLi’s). Double counting should be avoided.
- Some ballasts could drift to a higher power consumption compared to the specified standard conditions for lamp lumen measurement when installed in a luminaire and therefore influence LOR positive or negative.
- There is no input power measurement (P_{in}) done during LOR measurement, however a complementary measurement could be sufficient to calculate a correction factor for temperature sensitive light sources ($C_{LOR} = P_{in}$ lamp/P_{in} lum). P_{in} lamp is measured when measuring the lamp outside the luminaire and P_{in} lum is measured when measuring the luminaire.
- In most cases when lamps have a stable input power, independent of the lamp temperature, $C_{LOR} = 1$.

Additional performance parameters for luminaires considered in this study:

- *Luminaire Efficiency Rating (LER*): is the Light Output Ratio of the luminaire multiplied with the ballast efficiency and the lamp efficacy.

  $$LER = LOR \times \eta ballast \times \eta lamp \times C_{LOR}$$

  with LOR in luminaire standard working conditions (ambient temperature 25°) and ηlamp at 25°C .

  Note: for luminaires with integrated lamps and ballasts, e.g. some LED luminaires, only LER data is available or needed. The individual data of LOR or power supply loss is unknow and cannot always be measured.;
- *Ballast efficiency (*ηballast): means the ratio between the lamp power (ballast output) and the input power of the lamp-ballast circuit with possible sensors, network connections and other auxiliary loads disconnected
- *Stand-by losses;*

- *Cable losses:* (might be significant for low voltage luminaries (12 V).

1.1.4 Functional unit for domestic lighting

Knowing the functional product used in this study we now further explain what is called the "functional unit" for domestic lighting. In standard 14040 on life cycle assessment (LCA) the functional unit is defined as "the quantified performance of a product system for use as a reference unit in life cycle assessment study". The primary purpose of the functional unit in this study is to provide a calculation reference to which environmental impacts (such as energy use), costs, etc. can be related and to allow for comparison between functionally equal domestic lighting products with and without options for improvement. Please note that further product segmentations will be introduced in this study in order to allow appropriate equal comparison.

The proposed functional parameter (FP) for non-directional lamps (NDLS) in this study is:

"1 lumen provided by a lamp during 1 hour of operation in any direction".

(As defined in the applicable standards, the measurement of the lumen output shall be performed after the lamp has burned for the defined hours, mostly 100 hours.)

The proposed functional parameter (FP) for DLS (GLS-R, HL-MV-R, HL-LV-R, MHi-R, CFLi-R, halogen reflector retrofit LED lamps) in this study is:

"1 lumen provided by a spot lamp during 1 hour of operation in the functional solid angle of 0,6π or cone of 90°".

The proposed functional parameter (FP) for DLS (i.e. luminaires with integrated lamps e.g. LED-downlighters, LED modules, CFLi-R not sold for retrofitting reflector lamps) in this study is:

"1 lumen provided by a lamp during 1 hour of operation in the functional solid angle of π.".

1.1.5 Rationale and comparison of the functional unit for domestic lighting in part 1 and part 2 and for street lighting and office lighting

The following Table 1-5 gives a comparison of the different functional units that were used in the preparatory studies on lighting: lot 8 (office), lot 9 (street), lot 19 (domestic).

Table 1-5: Comparison of different functional units used in the preparatory studies on lighting

Lighting study	Product boundary	System	Functional unit	Functional lumen

Domestic (lot 19) Part 1	Lamp (NDLS)	Luminaire, room, wiring	**Lumen*h** (luminous flux in one hour)	All lumen (4π sr)
Domestic (lot 19) Part 2	Lamp (DLS)	Luminaire, room, wiring	**Lumen*h** (luminous flux in one hour)	Directed lumen (0.59π s, π sr)
Tertiary (lot 8&9) Street&office	Luminaire+lamp	Room, task area, wiring	**Lumen*h/m² = lx*h** (illuminance in one hour)	Lumen in task area

In the studies on tertiary lighting, the chosen functional unit was the '*provided illuminance in one hour operation'* or in particular cases of street lighting the *'provided luminance illuminance in one hour operation'*. This matched well with the practice of professional lighting design found in those sectors. In professional design, those units are primary parameters (besides glare reduction, uniformity, etc.). This approach and many of the conclusions of those studies can be used in the tertiary lighting sector, they will not be repeated here.

On the other hand, this approach is rarely applied in domestic lighting and only for the so-called architectural lighting, based on a virtual simulation of the interior, where professional designers are involved. Because the use of lamps is not limited to one sector, conclusions of both studies can overlap.

Moreover an illuminance based approach is not useful to evaluate the function to create a visual ambience with lighting, hereafter also referred to as "ambient lighting". In the case of ambient lighting the focus is not to provide illumination in a task area but to provide the proper luminance of a variety of elements in the interior including the luminaire itself. The luminance then depends on the reflection properties of the objects. Nevertheless, the luminance approach was possible in street lighting (fast traffic) where the purpose is to see the road. The road surface properties and orientation is easy to quantify. In ambient interior lighting, due to the very different nature of interior objects and their orientation, it is difficult to quantify and there is no general rule or base case. The same often applies to Horeca and shop lighting. Also on those applications the number of tasks, their time duration and their area can vary strongly which would make a meaningful quantification difficult.

Finally, part of the light generated within a luminaire is used to provide luminance on the decorative ornaments of the luminaire itself which is hard to quantify, as such it cannot be considered as waisted light.

Therefore in this study on domestic lighting, the *'functional lumen'* was preferred because this is very close to the holistic approach found in domestic lighting. As stated before, here no illuminance calculations are made and the light is mostly not intended to illuminate only a task area but it is generally used for ambient lighting and decorative purposes.

For general, domestic illumination, non-directional light sources (NDLS) are most suitable and all emitted lumens are functional. For directional light sources (DLS) that are intended for accent lighting, only the lumens that are emitted in a certain cone are functional. The cone of 90° was chosen for defining the DLS functional lumens (see Figure 1-7) because this fits particular well with the current reflector lamps. This will be demonstrated in chapter 4 where data of a cone of 120° (π sr) are compared to a 90° (0.59π sr) cone. Another benefit of a 90° compared to a 120° cone is the lower cost for market surveillance because it can reduce the lumens to be measured with a goniometer.

In theory the cone of 82,8° (π/2 sr) could be interesting because it is included in the CEN flux code (EN 13032-2) of standard photometric files. Nevertheless after consulting stakeholders with measurement data this narrower cone would reject useful lumens and was therefore not used.

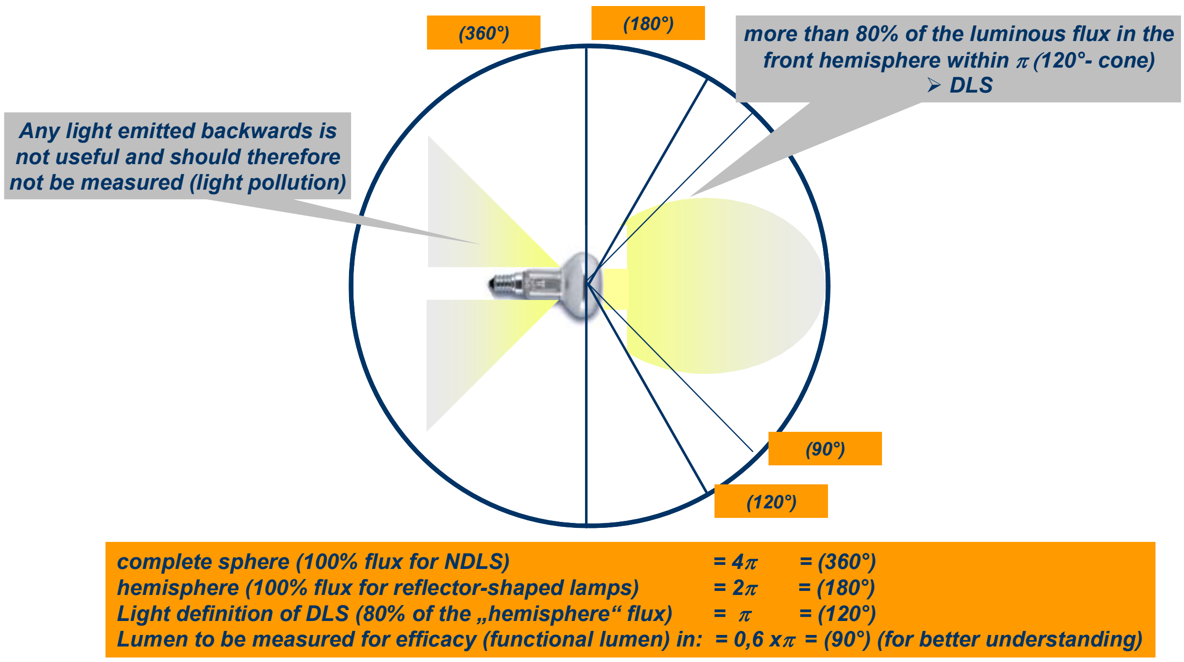

Figure 1-7 Definition of the functional lumen for DLS reflector lamps

1.1.6 How to deal with the 'Light Output Ratio' (LOR) and 'Light Output Function'(LOF) for decorative luminaires with lamps used in domestic and service sector lighting

Luminaires that are used for functional lighting in the tertiary sector (e.g. office and street lighting) have photometric data that include the LOR. In that case the LOR is a dominant parameter related to the luminaire efficiency.
Nevertheless, this approach to quantify the luminaire efficiency by its LOR cannot be applied one to one on decorative luminaires used for lamps within the scope of this study.
The main reason is explained in section 1.1.5, i.e. part of the light transmitted through the luminaire shield is used to provide luminance on the decorative ornaments (of different transmittance) of the luminaire itself (another part of the light is absorbed in the luminaire and lost as heat).
It is also not common practice to provide LOR data for those luminaires (CELMA communication in 2009), only very few manufacturers do so and mainly for the purpose of application in photometric simulation tools with high end architectural luminaires.
Moreover the reproduction and reliability of LOR data of decorative luminaire that rely on hand crafted parts (painting, glass, ..) will be very unreliable.
Finally LOR might also rely on the used lamp type.
For luminaires with DLS lamps (e.g. reflector lamps) there is normally no lumen loss within the luminaire compared to the defined functional unit for DLS lamps, because those lamps are normally not shielded.
For decorative luminaires with NDLS lamps the 'Light Output Function' (LOF) of a luminaire could be seen as the lumen output from the luminaire characterised by its LOR together with the luminance of the decorative ornaments. The LOF is hard to quantify in

absolute terms and is connected to lumens that are wasted by excessive light absorption on invisible reflective parts or visible transparent parts.

As a conclusion we will further talk about the 'Light Output Function' (LOF) knowing that the absolute performance of the whole picture of EU27 installed and sold luminaires is impossible to quantify.
This LOF and its potential improvement is only relevant for the impact scenarios calculated in part 1, because it is related to the installed base of NDLS lamps. Hence it could only result in a correction factor applicable to the part 1 scenarios and their improvement options (if any). These improvement options(if any) will be considered for luminaires having equal 'Light Output Function' and only the ratio on saved power consumption will be assessed.
Nevertheless, the LOR value of domestic NDLS luminaires is useful in quantifying how much light is actually going into illuminating the room (disregarding the light spent on illuminating the decorative ornaments of the luminaire itself). Taken on its own, LOR could for example be used to establish minimum criteria for luminaires that manufacturers want to claim as particularly efficient.

1.2 Lighting test standards or guidelines

This paragraph identifies and shortly describes the 'test standards or guidelines' that are related to the functional unit, resource use (energy, materials, ..), safety and other lighting product specific standards.
A "test standard or guideline" is defined in the context of this study as a standard or guideline that sets out a test method, but that does not indicate what result is required when performing that test. Therefore, strictly speaking, a test standard can be different from a "technical standard". Especially 'technical standards' that are a specification against which all others may be measured are not discussed hereafter(e.g. the measurement of power, luminous flux, ..). In addition to "official" test standards, there are other sector specific procedures for product testing that are compiled by industry associations or other stakeholders for specific purposes included in this section. Also ongoing work for the development of new standards or guidelines is discussed together with recommendations for new ones.

The following references are made to:
- EN, European standard ratified by either CEN (European Committee for Standardization) or CENELEC (European Committee for Electro-technical Standardization),
- IEC, International Electro-technical Commission,
- CIE, International Commission on Illumination.

Identified gap: None of the EN or IEC standards relate specifically to reflector lamps.

1.2.1 Standards and guidelines related to the functional unit

- *EN 60064:* '*Tungsten filament lamps for domestic and similar general lighting purposes - Performance requirements*'.

Scope:

This standard applies to tungsten filament incandescent lamps for general lighting services (GLS) which comply with the safety requirements in EN 60432-1.

- *EN 60357:* '*Tungsten halogen lamps (non-vehicle) - Performance specifications*'.

Scope:

This standard specifies the performance requirements for single-capped and double-capped tungsten halogen lamps, having rated voltages of up to 250 V, used for the following applications:

- projection (including cinematograph and still projection)
- photographic (including studio)
- floodlighting
- special purpose
- general purpose
- stage lighting.

This third edition cancels and replaces the second edition published in 1982 and amendments.

- *EN 60969 : 'Self-ballasted lamps for general lighting services - Performance requirements'.*

Scope:

This Standard specifies the performance requirements, together with the test methods and conditions, required to show compliance of tubular fluorescent and other gas-discharge lamps with integral means for controlling starting and stable operation (self-ballasted lamps) intended for domestic and similar general lighting purposes.

- *EN 60081 : 'Double-capped fluorescent lamps - Performance specifications'.*

Scope:

This International Standard specifies the performance requirements for double-capped fluorescent lamps for general lighting service.

The requirements of this standard relate only to type testing. Conditions of compliance, including methods of statistical assessment, are under consideration.

The following lamp types and modes of operation are included:

a) lamps having preheated cathodes, designed for operation on a.c. mains frequencies with the use of a starter, and additionally operating on high frequency;

b) lamps having preheated high-resistance cathodes, designed for operation on a.c. mains frequencies without the use of a starter (starter less), and additionally operating on high frequency;

c) lamps having preheated low-resistance cathodes, designed for operation on a.c. mains frequencies without the use of a starter (starter less), and additionally operating on high frequency;
d) lamps having preheated cathodes, designed for operation on high frequency;
e) lamps having non-preheated cathodes, designed for operation on a.c. mains frequencies;
f) lamps having non-preheated cathodes, designed for operation on high frequency.

For some of the requirements given in this standard, reference is made to "the relevant lamp data sheet". For some lamps these data sheets are contained in this standard. For other lamps, falling under the scope of this standard, the relevant data are supplied by the lamp manufacturer or responsible vendor.

- *EN 60901:* '*Single-capped fluorescent lamps – Performance specifications*'.

Scope:

This International Standard specifies the performance requirements for single-capped fluorescent lamps for general lighting service.
The requirements of this standard relate only to type testing. Conditions of compliance, including methods of statistical assessment, are under consideration.

The following lamp types and modes of operation with external ballasts are included:
a) lamps operated with an internal means of starting, having preheated cathodes, for operation on a.c. mains frequencies;
b) lamps operated with an external means of starting, having preheated cathodes, for operation on a.c. mains frequencies with the use of a starter, and additionally operating on high frequency;
c) lamps operated with an external means of starting, having preheated cathodes, for operation on a.c. mains frequencies without the use of a starter (starter less), and additionally operating on high frequency;
d) lamps operated with an external means of starting, having preheated cathodes, for operation on high frequency;
e) lamps operated with an external means of starting, having non-preheated cathodes, for operation on high frequency.

- *EN 50285: 'Energy efficiency of electric lamps for household use – Measurement methods'.*

Scope:

Specifies the test conditions and method of measurement of luminous flux, lamp wattage and lamp life as given on a label on the lamp packaging, together with a procedure for verification of the declared values. Only those parameters that are specific to Directive 92/75/EEC are included in this standard, all other parameters are defined in the relevant lamp performance standards.

- *EN 13032-1 (2004), Lighting applications — Measurement and presentation of photometric data of lamps and luminaires — Part 1: Measurement and file format*

Scope:

This European Standard establishes general principles for the measurement of basic photometric data for lighting application purposes. It establishes the measurement criteria needed for the standardisation of basic photometric data and details of the CEN file format for electronic data transfer. This is part 1 of a multi part standard. Part 1 deals with the basic photometric measurement and file format. Other parts deal with lamps and luminaires data depending on the applications.

Status:

Recently adopted; manufacturers do not yet have data available according to this format.

Identified gaps:

In practice the sector often uses a sector specific file format (EULUMDAT, IES, ..).
For a luminaire that can house different lamp types, it is dependent on the characteristics of the lamp, as well optical as thermal.
LOR measurement without Power (P) measurement of the luminaire (see section 1.1.3.3).

- *EN 13032-2(2004): Light and lighting. Measurement and presentation of photometric data of lamps and luminaires. Part 2: Presentation of data for indoor and outdoor work places*

Scope:

This document specifies the required data for lamps and luminaires for the verification of conformity to the requirements of EN 12464-1 and prEN 12464-2. It also specifies data that are commonly used for lighting of indoor and outdoor work places. When these data are provided, they should conform to this document

- *EN 60921:* '*Ballasts for tubular fluorescent lamps – Performance requirements*'.

Scope:

This standard specifies performance requirements for ballasts, excluding resistance types, for use on a.c. supplies up to 1 000 V at 50 Hz or 60 Hz, associated with tubular fluorescent lamps with pre-heated cathodes operated with or without a starter or starting device and having rated wattages, dimensions and characteristics as specified in IEC 60081 and 60901. It applies to complete ballasts and their component parts such as resistors, transformers and capacitors. (It only applies to ferromagnetic ballasts; electronic ballasts are covered under IEC60929.)

- *EN 60929 :* '*AC-supplied electronic ballasts for tubular fluorescent lamps – Performance requirements*'.

Scope :

This International Standard specifies performance requirements for electronic ballasts for use on a.c. supplies up to 1 000 V at 50 Hz or 60 Hz with operating frequencies deviating from the supply frequency, associated with tubular fluorescent lamps as specified in IEC 60081 and IEC 60901 and other tubular fluorescent lamps for high frequency operation. (It only applies to electronic ballasts; ferromagnetic ballasts are covered under IEC60921.)

- *CIE 127 (2007) : 'Measurement of LED's' (2^nd^ ed.)*

Scope :

There are significant differences between LEDs and other light sources which made it necessary for the CIE to introduce new quantities for their characterization with precisely defined measurement conditions. New quantities introduced here are "Averaged LED Intensity" and "Partial LED Flux".
The report describes in detail the measurement conditions for ALI (Averaged LED Intensity), Total and Partial LED Flux and Spectral Power Distribution. It is shown that measurements by substitution method using LED standards can be simpler; however it is important to compare similar coloured LEDs or use colour correction on the measurement results. The standard LEDs need to be calibrated by National Metrology Laboratories or a laboratory traceable to National Metrology Laboratories.

- *Draft EN 62612 (IEC/PAS 62612) :* '*Self-ballasted LED-lamps for general lighting services >50V – Performance requirements*'.

Scope :

This draft International Standard, already in the stadium of a publicly available specification (PAS), specifies the performance requirements for self-ballasted LED lamps with a supply voltage up to 250V, together with the test methods and conditions, required to show compliance with this standard, intended for domestic and similar general lighting purposes, having:
– a rated wattage up to 60 W;
– a rated voltage of up to 250V AC or DC;
– a lamp cap according to IEC 62560 1)
The requirements of this standard relate to type testing.
This standard does not cover self-ballasted LED lamps that intentionally produce tinted or coloured light neither does it cover OLEDs.
Recommendations for whole product testing or batch testing are under consideration.
These performance requirements are additional to the requirements in the draft standard IEC 62560: safety standard for self-ballasted LED lamps.

Remark:

In this draft standard, the definition for the lifetime of a lamp is in accordance with the definition ”operational lifetime” as introduced in this study in part 1.1.3.1.

- *Australian and New Zealand standard proposal AS/NZS 4847.1:200X :* ‘Test method Energy performance *for Self-ballasted lamps for general lighting services*’.

Scope :

The objective of this part of the Interim Standard is to specify test methods for key performance attributes of self-ballasted compact fluorescent lamps (CFLs) that have integrated means for starting, controlling and stable operation. Part 2 of this Interim Standard is intended to cover Minimum Energy Performance Standards requirements with compliance values or limits.

This Interim Standard is structured to be suitable for reference in minimum performance Standards legislation.

- *Australian and New Zealand standard proposal AS/NZS 4934.1(Int):2008 :* ‘Test method Energy performance *for Incandescent lamps for general lighting service*.

Scope :

This Interim Standard specifies test methods for energy performance of tungsten filament and tungsten halogen lamps used in general lighting services.

This Interim Standard applies to both non-reflector and reflector lamps of all voltages.

“Incandescent lamps” in this standard proposal include also halogen lamps.

Identified gaps:

The proposed measurement method for directional light sources in an Ulrich-sphere is not easy for taking into account the functional solid angle. If screens are used to measure the light output in these solid angles, a precise positioning of the optical centre of the lamp is needed.

1.2.2 Other test standards and guidelines not related to the functional unit

3. EN 12665 (2002): ‘Light and lighting - Basic terms and criteria for specifying lighting requirements’

Scope:

This standard defines basic terms for use in all lighting applications; specialist terms with limited applications are given in individual standards. This standard also sets out a framework for the specification of lighting requirements, giving details of aspects which shall be considered when setting those requirements.

- *EN 60968 : ‘Self-ballasted lamps for general lighting services - Safety requirements’.*

Scope:

This Standard specifies the safety and interchangeability requirements, together with the test methods and conditions, required to show compliance of tubular fluorescent and other gas-discharge lamps with integrated means for controlling starting and stable operation (self-ballasted lamps), intended for domestic and similar general lighting purposes, having: -a rated wattage up to 60 W; -a rated voltage of 100 V to 250 V; -Edison screw or bayonet caps.

- *EN 60630 : 'Maximum lamp outlines for incandescent lamps'.*

Scope:

This Standard specifies the maximum outlines for GLS-lamps in different shapes, with different caps etc.

- *EN 60061 : 'Lamp caps and holders together with gauges for the control of interchangeability and safety'*

Scope:

This Standard specifies the dimensions of all kind of standardized lamp caps and holders together with the control gauges. for GLS-lamps in different shapes, with different caps etc.

Status:

Continuously enlarged because *'creativity'* of lamp designers seems to be unlimited.

- *EN 60669-2-1 : 'Electronic switches for households and similar use'.*

Scope :

Applies to electronic switches and to associated electronic extension units for household and similar fixed electrial installations either indoors or outdoors.

- *EN 61047 : 'D.C. or A.C. supplied electronic step-down converters for filament lamps. Performance requirements'.*

Scope :

Specifies performance requirements for electronic step-down convertors for use on d.c. supplies up to 250 V and a.c. supplies up to 1000 V at 50 Hz or 60 Hz with operating frequencies deviating from the supply frequency, associated with tungsten halogen lamps as specified in IEC 60357 and other filament lamps.

- *EN 50294 : 'Measurement Method of Total Input Power of Ballast-Lamp Circuits'.*

Scope:

This Standard gives the measurement method of the total input power for ballast-lamp circuits when operating with their associated fluorescent lamp(s). This standard applies to electrical ballast-lamp circuits comprised solely of the ballast and of the lamp(s). NOTE: Requirements for testing individual ballasts during production are not included. It specifies the measurement method for the total input power for all ballasts sold for domestic and normal commercial purposes operating with the following fluorescent lamps: linear lamps with power equal to or greater than 15 W; single ended (compact) lamps with power equal to or greater than 18 W; other general purpose lamps. This standard does not apply to: ballasts which form an integral part of the lamp; ballast-lamp circuits with capacitors connected in series; controllable wire-wound magnetic ballasts; luminaires which rely on additional optical performance aspects.

The standard mandates that a ballast lumen factor be declared by the manufacturer - this has to be in the range 0.925 to 1.0 for magnetic ballasts and between 0.925 and 1.075 for electronic ballasts.

The test method for ferromagnetic and electronic ballasts is quite different and each is described below:
For magnetic ballasts, the test ballast is operated with a reference lamp. In addition the reference lamp is operated with a reference ballast. The total input power and the lamp power are measured for each circuit in parallel. Finally, the total input power for the test ballast/lamp circuit is corrected for the ballast lumen factor (BLF), this correction is done by measurement of the lamp power compared to the reference lamp. Please note that for the reference ballast a normalized ballast lumen factor of 0.95 has been chosen (this suggests that manufacturers tend to under-run lamps on average on magnetic ballasts). A similar method exists for electronic ballasts, in this case a reference ballast lumen factor of 1 is chosen. The total input power for the test ballast/lamp circuit is corrected for the ballast lumen factor (BLF), this correction is done by measurement of the lamp luminous flux compared to the reference lamp. Please note that for T5 fluorescent lamps no magnetic reference ballast exists, therefore an electronic reference ballast with known BLF needs to be obtained (Klinger (2006)), e.g. from a lamp manufacturer.
It is important to realize that in this approach the losses of the lamp filament preheating are accounted as ballast losses, because magnetic ballasts have switch-off lamp filament preheating enforced by the principle and also the most advanced T5 ballasts that are used as reference ballast do so.

- *EN 60927: 'Specification for auxiliaries for lamps. Starting devices (other than glow starters). Performance requirements'.*

Scope:

Specifies performance requirements for starting devices (starters and igniters) for tubular fluorescent and other discharge lamps for use on a.c. supplies up to 1 000 V at 50 Hz or 60 Hz which produce starting pulses not greater than 5 kV. Should be read in conjunction with IEC 60926.

- *EN 61048 : 'Auxiliaries for Lamps - Capacitors for Use in Tubular Fluorescent and Other Discharge Lamp Circuits - General and Safety Requirements'.*

Scope :

This International Standard states the requirements for both self-healing and non-self-healing continuously rated a.c. capacitors of up to and including 2,5 kVAr, and not less than 0,1 μF, having a rated voltage not exceeding 1 000 V, which are intended for use in discharge lamp circuits operating at 50 Hz or 60 Hz and at altitudes up to 3000m.

- *EN 61049 : 'Capacitors for Use in Tubular Fluorescent and Other Discharge Lamp Circuits Performance Requirements'.*

Scope :

Specifies the requirements for both self-healing and non-self-healing continuously rated a.c. capacitors of up to and including 2,5 kVAr, and not less than 0,1 F, having a rated voltage not exceeding 1 000 V, which are intended for use in discharge lamp circuits operating at 50 Hz or 60 Hz and at altitudes up to 3 000 m. Does not cover radio-interference suppressor capacitors, the requirements for which are given in IEC 60384-14. This publication supersedes IEC 60566.

- *EN 60598-1 : 'Luminaires Part 1 : General requirements and tests'.*

Scope:

This Part 1 specifies general requirements for luminaires, incorporating electric light sources for operation from supply voltages up to 1000 V. The requirements and related tests of this standard cover: classification, marking, mechanical construction and electrical construction.

Important remark:

This standard demands a.o. that on every luminaire, the number, the type and the maximum wattage of all the suitable lamps must be indicated. For safety reasons, no other lamps or no higher wattages may be installed.

- *EN 60598-2: 'Luminaires - Part 2: Particular requirements - Chapter 1: Fixed general purpose luminaires'.*

Scope:

This chapter of Part 2 of IEC Publication 598 specifies requirements for fixed general purpose luminaires for use with tungsten filament, tubular fluorescent and other discharge lamps on supply voltages not exceeding 1000 V. It is to be read in conjunction with those chapters of Part 1 to which reference is made.

- *EN 60598-2: 'Luminaires - Part 2: Particular requirements - Chapter 2: Recessed luminaires'.*

Scope:

Specifies requirements for recessed luminaires for use with tungsten filament, tubular fluorescent and other discharge lamps on supply voltages not exceeding 1000 V. This chapter does not cover air-handling luminaires.

- *EN 60598-2: 'Luminaires - Part 2: Particular requirements – Chapter 6: Luminaires with built-in transformers for tungsten filament lamps'.*

Scope:

Specifies requirements for luminaires with built-in transformers for use with all tungsten filament lamps, halogen lamps included.

- *CIE 089 (1989) : 'Measurement of luminous flux' (technical report)*

Scope :

This technical report defines the terminology required for luminous flux measurements. It then deals with the principles of luminous flux measurements and describes methods for the evaluation of the illuminance distribution, the measurement of luminous flux by means of an integrating sphere photometer and the determination of luminous flux via luminance, luminous intensity and luminance measurements.

- *EN 60013-2 (CIE 13.3) : 'Method of Measuring and Specifying Colour Rendering Properties of Light Sources'*

Scope :

This standard establishes the recommended method of measuring and specifying colour rendering properties of light sources based on resultant colour shifts of test objects, referred to as the "Test-colour Method". It is the fundamental method for appraisal of colour rendering properties of light sources, and is recommended for type testing as well as for testing individual lamps.

This specification applies to most general purpose illuminants (e.g. tungsten filament lamps, tubular fluorescent lamps, and all other kinds of gaseous discharge electrical lamps except sources of predominantly monochromatic radiation such as low pressure sodium, etc.). This method may also be applied to modified daylight.

The rating consists of a General Colour Rendering Index which may be supplemented by a set of Special Colour Rendering Indices. The derivation of the Special Colour Rendering Indices is based on a general comparison of the length of colour difference vectors in the CIE 1964 Uniform Space.

To apply the recommended Test-Colour Method the resultant colour shifts for suitably chosen test-colour samples must be calculated. A set of eight test-colour samples is specified by their spectral radiance factors for calculating the General Colour Rendering Index. These samples cover the hue circle, are moderate in saturation, and are approximately the same in lightness. Data for six additional test-colour samples representing a strong red, yellow, green and blue as well as complexion and foliage colours are also supplied. From the colour shifts, Colour Rendering Indices may be found.

- *CIE 177 (2007) : 'Colour Rendering of White LED Light Sources')*

Scope :

The Committee recommends the development of a new colour rendering index (or a set of new colour rendering indices) by a Division 1 Technical Committee. This index (or these indices) shall not replace the current CIE colour rendering index immediately. The usage of the new index or indices should provide information supplementary to the current CIE CRI, and replacement of CRI will be considered after successful integration of the new index. The new supplementary colour rendering index (or set of supplementary colour rendering indices) should be applicable to all types of light sources and not only to white LED light sources. Possibilities for an improved description of colour rendering are summarized in the Appendix of this Technical Report. (This work is still under consideration!)

- *IEC/TS 61231 : 'International lamp coding system (ILCOS)'.*

Scope :

This technical specification gives the rules for the international lamp coding system and covers all lamp categories, excluding vehicle lamps. Coding for the main lamp types is specified and, for the others, will follow by amendments to this technical specification as appropriate.

The object of the international lamp coding system is:

- to improve communication about the different types of lamps;
- to help in discussions concerning interchangeability and compatibility of products;
- to create a closer relationship between international standards and manufacturers' literature (for example the code could be given in future in the relevant parts of a standard);
- to enable correct replacements of lamps;
- to be used as a complementary marking on the luminaire;
- to replace national and regional coding systems.

- *EN 62471 (2008) : 'Photobiological safety of lamps and lamp systems'.*

Scope :

This international Standard gives guidance for evaluating the photobiological safety of lamps and lamp systems including luminaires. Specifically it specifies the exposure limits, reference measurement technique and classification scheme for the evaluation and control of photobiological hazards from all electrically powered incoherent broadband sources of optical radiation, including LED's but excluding lasers, in the wavelength range from 200 nm through 3000 nm.

1.3 Existing legislation

1.3.1 Legislation and Agreements at European Community level

1.3.1.1 Regulations

- *Commission Regulation (EC) No 244/2009* of 18 March 2009 implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to ecodesign requirements for non-directional household lamps.
- *Commission Regulation (EC) No 245/2009* of 18 March 2009 implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to ecodesign requirements for fluorescent lamps without integrated ballast, for high intensity discharge lamps, and for ballasts and luminaires able to operate such lamps, and repealing Directive 2000/55/EC of the European Parliament and of the Council.

1.3.1.2 Environmental Directives (RoHS, WEEE)

- *Directive 2002/95/EC on Restriction of the use of certain Hazardous Substances in electrical and electronic equipment (RoHS)*

Scope:

The RoHS Directive stands for "the restriction of the use of certain hazardous substances in electrical and electronic equipment". This Directive bans the placing on the EU market, from 1 July 2006, of new electrical and electronic equipment containing lead, cadmium, mercury, hexavalent chromium, polybrominated biphenyl (PBB) and polybrominated diphenyl ether (PBDE) flame retardants.

Exemptions:

In annex, the exemptions from this requirements (a.o. for lamps) are listed:

- mercury in compact fluorescent lamps not exceeding 5mg per lamp
- mercury in straight fluorescent lamps for general purposes not exceeding

halophosphate	10mg
triphosphate with normal lifetime	5mg
triphosphate with long lifetime	8mg

- mercury in straight fluorescent lamps for special purposes
- mercury in other lamps not specifically mentioned in this annex
- lead in glass of fluorescent tubes.

There are no exemptions for luminaires and ballasts.

- *Directive 2002/96/EC on waste electrical and electronic equipment (WEEE)*

Scope:

The WEEE Directive aims to:

- reduce waste arising from electrical and electronic equipment (EEE);
- make producers of EEE responsible for the environmental impact of their products, especially when they become waste.

- encourage separate collection and subsequent treatment, reuse, recovery, recycling and sound environmental disposal of EEE .
- improve the environmental performance of all those involved during the lifecycle of EEE.

Exemptions:

In annex I A, all general categories of electric and electronic equipment concerned are mentioned; in annex I B, the subcategories with the exemptions are listed. In the subcategory of luminaires for fluorescent lamps, an exception is made for luminaires in households. Also filament bulbs (incandescent and halogen lamps) are exempted from this directive.

1.3.1.3 Efficiency Directives

- *Directive 2000/55/EC on energy efficiency requirements for ballasts for fluorescent lighting*

Scope:

The purpose of this Directive is to improve the efficiency of the systems by limiting the ballast losses. For this purpose, CELMA developed a classification system that takes both parts of the system into account, the lamp and the ballast and that is compliant with the directive. It constitutes an implementing measure within the meaning of article 15 of Directive 2005/32/EC.

- *Directive 98/11/EC of 27 January 1998 implementing Council Directive 92/75/EEC with regard to energy labelling of household lamps*

Scope:

This Directive, which was published on 10th March 1998, applies the energy labelling requirements for household electric lamps supplied directly from the mains (filament and integral compact fluorescent lamps) and to household fluorescent lamps (including linear and non-integral compact fluorescent lamps), even when marketed for non-household use.

In Annex I of the Directive, the design and content of the label is setted out, as well as the colours that may be used.

The label must include the following information:

• the energy efficiency class of the lamp;
• the luminous flux of the lamp in lumens;
• the input power (wattage) of the lamp;
• the average rated life of the lamp in hours.

The label shall be chosen from the following illustrations in Figure 1-3. Where the label is not printed on the packaging but a separate label is placed on or attached to the packaging, the colour version shall be used. If the ‘black on white’version of the label is used, the printing and background may be in any colours that preserve the legibility of the label.

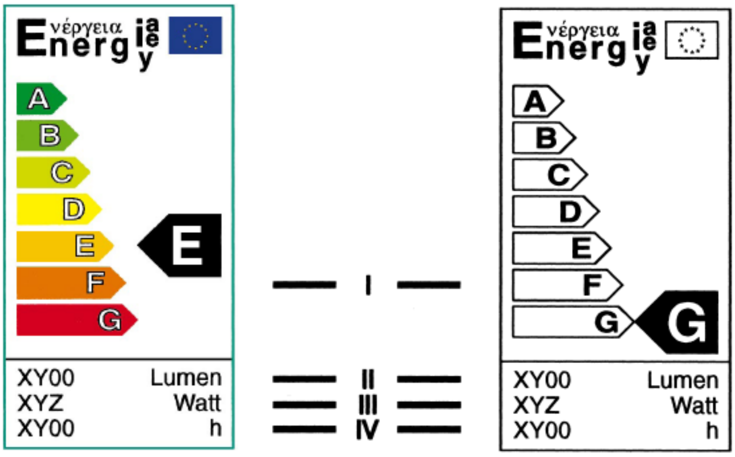

Figure 1-8: Energy efficiency label

The following notes define the information to be included:

V. The energy efficiency class of the lamp, determined in accordance with Annex IV. This indicator letter shall be placed at the same level as the relevant arrow.

VI. The luminous flux of the lamp in lumens, measured in accordance with the test procedures of the harmonised standards referred to in Article 1(4).

VII. The input power (wattage) of the lamp, measured in accordance with the test procedures of the harmonised standards.

VIII. The average rated life of the lamp in hours, measured in accordance with the test procedures of the harmonised standards. Where no other information on the life of the lamp is included on the packaging, this may be omitted.

Where the information specified in II, III and, where applicable, IV is included elsewhereon the packaging of the lamp, it may omitted from from the label, as may the box that contains it.

Annex IV of the Directive specifies the calculation to determine the energy efficiency class of a lamp.

Identified gaps:

- The mention of the average rated life of the lamp is not strictly imposed.
- The origin of the formulas in Annex IV is not clear.
- Some much used lamps are excluded from the labelling e.g. reflector lamps (DLS) and lamps with an inut power of less than 4W (e.g. LED's).
- Also all lamps that are not directly supplied from the mains, e.g. the widespread low voltage halogen lamps (HL-LV) are not included in this Directive.

- *Commission Decision of 9 September 2002 establishing revised ecological criteria for the award of the Community eco-label to light bulbs and amending Decision 1999/568/EC*

Scope:

This Decision amends the Decision 1999/568/EC for the award of the Community eco-label. It sets specific criteria for light bulbs that aim in particular at promoting:

- the reduction of environmental damage or risks related to the use of energy (global warming, acidification, depletion of non-renewable resources) by reducing energy consumption,
- the reduction of environmental damage or risks related to the use of resources in both the manufacture and treatment/disposal of a light bulb by increasing its average lifetime,
- the reduction of environmental damage or risks related to the use of mercury by reducing the total emissions of mercury during the lifetime of a light bulb. to become this Community eco-label.

In annex also the test method is described to measure the mercury content.

1.3.1.4 Other product related directives

- *Directive 2006/25/EC of 5 April 2006 on the minimum health and safety requirements regarding the exposure of workers to risks arising from physical agents (artificial optical radiation.*

Scope:

The Council Directive 2006/25/EC of 5 April 2006 introduces measures to protect workers from the risks associated with optical radiation, owing to its effects on the health and safety of workers, in particular damage to the eyes and to the skin.

- *Electromagnetic Compatibility (EMC) Directive 2004/108/EEC*

Scope:

The Council Directive *2004/108/EEC* of 15 December 2004 on the approximation of the laws of the Member States relating to electromagnetic compatibility (EMC Directive) governs on the one hand the electromagnetic emissions of this equipment in order to ensure that, in its intended use, such equipment does not disturb radio and telecommunication as well as other equipment. In the other the Directive also governs the immunity of such equipment to interference and seeks to ensure that this equipment is not disturbed by radio emissions normally present used as intended.

- *Low Voltage Directive (LVD) 73/23/EEC*

Scope:

The Low Voltage Directive (LVD) 73/23/EEC seeks to ensure that electrical equipment within certain voltage limits both provides a high level of protection for European citizens and enjoys a Single Market in the European Union. The Directive covers electrical equipment designed for use with a voltage rating of between 50 and 1000 V for alternating current and between 75 and 1500 V for direct current. It should be noted that these voltage ratings refer to the voltage of the electrical input or output, not to voltages that may appear inside the equipment. For most electrical equipment, the health aspects of emissions of Electromagnetic Fields are also under the domain of the Low Voltage Directive.

1.3.1.5 Quality charters and voluntary agreements from industry on EU-level

- *There is a ' European Compact Fluorescent Lamps QUALITY CHARTER' see ' http://re.jrc.cec.eu.int/energyefficiency/CFL/ '*

Scope:

This charter, that is in revision at this moment, is an initiative promoted by the European Commission in co-operation with the following organisations: EURELECTRIC, ELC, ADEME (France), NOVEM (The Netherlands), THE DANISH ELECTRICITY SAVING TRUST (Denmark) and THE UK ENERGY SAVING TRUST (UK).

The aim of the European CFL Quality Charter is to offer a high quality standard to be used by utilities and other bodies in their promotion and procurement campaigns. The ultimate goal of the European Quality Charter for CFL is to increase consumer confidence in this environmentally friendly technology, which save money and the environment. To achieve this, the charter promotes the manufacturing, marketing and sales of high quality CFLs in the European Union in order to offer residential customers a satisfying product from an energy, comfort and economic point of view.

The requirements that are imposed by this charter are related to safety, performance, information, guarantee and information:

- Safety: standards EN 60968, EN 61199 and EN 60598 and comply with CE-marking legislation;
- Performance: luminous efficacy following energy label A (with a derating factor for lamps with an external casing 'bulb form') see Figure 1-4, lumen maintenance, running up time, number of ignitions (> lifetime in hr) and colour rendering (Ra≥80), with a written conformity certificate from an approved 'Notified Body[116]';

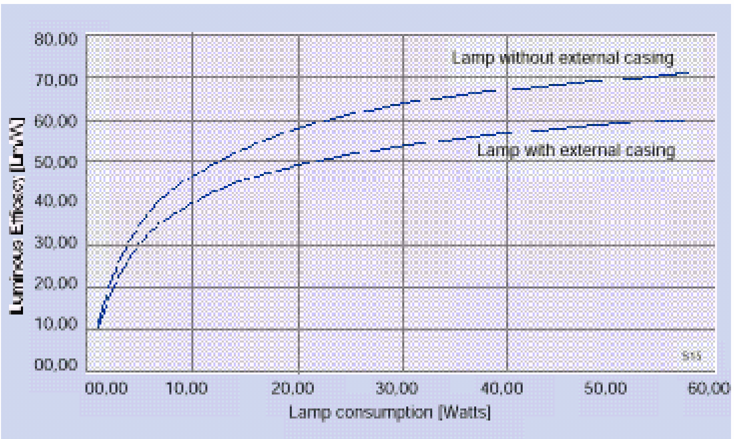

Figure 1-9: Luminous Efficacy limits for Integral Compact Fluorescent lamps

- Lifetime (LSF=0.5): minimum 6000hr and for 'Long Life' lamps minimum 12000hr;

[116] Notified bodies as defined in the Annex to 93/465/EEC: Council Decision of 22 July 1993 concerning the modules for the various phases of the conformity assessment procedures and the rules for the affixing and use of the CE conformity marking, which are intended to be used in the technical harmonization directives.

- Information: lifetime and energy label A must be shown on the individual package of each lamp, mentioned equivalence with GLS filament lamp must comply with defined lumen output;
- Guarantee: 2 years on lamp failure;
- Quality of production: manufactured under a Quality Assurance System EN ISO 9002 or equivalent.

It is important to note that the charter is a voluntary set of criteria established by the European Commission in collaboration with the organisations mentioned above.

- *The European Lamp Companies federation (ELC) has elaborated eco-design levels for certain lamp types the so-called ELC Eco-Profiles.*

  The following ecoprofiles can be found on their website http://www.elcfed.org/2_resource_publications.html :

  - *Eco-Profile for Self-ballasted Fluorescent Lamps*
  - *Eco-Profile for Fluorescent Lamps*
  - *Eco-Profile for Compact Fluorescent Lamps non-integrated*
  - *Eco-Profile for HID Lamps.*

1.3.2 Legislation and Agreements at Member State level

There are member states (a.o. in the UK by the Energy Saving Trust, in Sweden by the Swedish Energy Agency) that are preparing minimum performance specifications for (domestic) lamps. The specifications aim to enhance energy efficiency but also envisage colour rendering, colour temperature, lifetime, lumen maintenance, starting time, warm-up time, number of ignitions and guarantee period.

1.3.3 Third Country Legislation and Agreements

This section again deals with the subjects as above, but now for legislation and measures in Third Countries (extra-EU); some of them were indicated by stakeholders (NGO's, industry, consumers) as being relevant for the product group.

There are various minimum standards and labelling programs applied worldwide for compact fluorescent lamps (CFL) but only 4 countries have MEPS programmes that prohibit the sale of low efficiency CFL's[117]:

- China
- Mexico
- South Korea
- Japan.

[117] Source : Report No :2005/12 from the (Australian) National Appliance and Equipment Energy Efficiency Program : Minimum Energy Performance Standards - Compact Fluorescent Lamps.

Efficient Lighting Initiative (ELI) is an international program that develops voluntary technical specifications to identify lighting products that save energy and meet consumer expectations for quality and performance; see www.efficientlighting.net .

There is also the US governmental ‘Energy Star’ sensitization campaign for saving energy a.o. on lighting (see http://www.energystar.gov/index.cfm?c=lighting.pr_lighting).
For light bulbs (see http://www.energystar.gov/index.cfm?c=cfls.pr_cfls) people can consult a buyers guide and learn how to handle the mercury problem.
Also for luminaires (see http://www.energystar.gov/index.cfm?c=fixtures.pr_fixtures) comparisons between different fixtures can be found a.o. on LED-lighting in domestic sectors (see http://www.energystar.gov/index.cfm?c=ssl.pr_residential) and in commercial sectors (see http://www.energystar.gov/index.cfm?c=ssl.pr_commercial).
The ‘Energy Star’ programm is only a voluntary initiative. Manufacturers that fulfil those voluntary requirements can become partners and can obtain an ‘Energy Star Label’ for their products. The US have only legislation with MEPS for Fluorescent Lamps (not for CFL’s), for Incandescent Reflector Lamps and for Under-Cabinet Luminaires[118].

Australia and New Zealand are preparing standards for MEPS and testing methods for compact fluorescent lamps and also for halogen (reflector) lamps [119].

Japan has a ‘Top Runner Programme’ for the efficiency of Energy using Products. For lighting, this programme imposes burdens for fluorescent lighting (see: http://www.eccj.or.jp/top_runner/).

On the website www.apec-esis.org existing MEPS and labelling programmes worldwide at the moment of this study can be found. Due to accelerated efforts of several governments, the accuracy of this source can not be guaranteed.

In Annex 9.4, some current MEPS and quality parameters for CFLi’s worldwide can be found.

[118] Source : Appliance – Efficiency Regulations, December 2006, CEC-400-2006-002-REV2, California
[119] http://www.energyrating.gov.au/library/details200718-phaseout-incandescent-lamps.html.

2 ECONOMIC AND MARKET ANALYSIS

The aims of the economic and market analysis are:

- to place the product group "domestic lighting" within the total of EU industry and trade policy (see 2.1),
- to provide market and cost inputs for the assessment of EU-27 environmental impact of the product group (see 2.2),
- to provide insight into the latest market trends so as to indicate the place of possible eco-design measures in the context of the market-structures and ongoing trends in product design (see 2.3), and
- to provide a practical data set of prices and rates for the Life Cycle Cost calculation (LCC) (see 2.4).

2.1 Generic economic data

2.1.1 Definition of 'Generic economic data' and data sourcing

"Generic economic data" gives an overview of production and trade data as reported in the official EU statistics. It places domestic lighting products within the total of EU industry and trade and also enables to check whether the product complies with the eligibility criterion of Art. 15., par. 2, sub a, of the EuP Directive:

> "*The EuP [to be covered by an implementing measure] shall represent a significant volume of sales and trade, indicatively more than 200,000 units a year within the Community according to more recently available figures.*"

To investigate the volume of sales and trade of a product group, it makes sense to rely on Eurostat's product-specific statistics. For trade and production figures, these are the so-called Europroms[120]-Prodcom statistics.

Although the aim is to take into account the specific attributes of the Member States' national lighting markets, much of the analysis could only be performed at the level of the EU total lighting market or regions of EU, as data were only available for few years and only in an aggregated form. The comparisons of imports, exports, production and apparent consumption[121] give an impression

[120] Europroms is the name given to published Prodcom data. It differs from Prodcom in that it combines production data from Prodcom with import and export data from the Foreign Trade database.

[121] "Apparent consumption" is the estimation of the yearly consumption for each product based on the amount produced plus the amount imported minus the amount exported. This is the rationale for combining Prodcom and Foreign Trade data in Europroms (Eurostat Data Shop Handbook, part 6.4.2 Europroms-Prodcom data, version 29/08/2003).

of the relative scales within the total lighting market but for numerous reasons[122] the comparisons must be considered only as approximations. The required data for all lamps (in both physical volume and in money units) is expressed by:

Apparent EU-27 consumption = Production + Imports – Exports

2.1.2 Generic data on lamp sales

At present, the main relevant domestic lamp types[123] are: GLS lamps, halogen lamps, linear fluorescent and compact fluorescent lamps. New lamp types like LED (Light Emitting Diode, at present with no Prodcom code available) and metal halide are relevant as new technologies and are treated as improvement options in the study (see chapter 7). Table 2-1 shows the relevant DLS categories in Eurostat.

Table 2-1: Prodcom segmentation for domestic Lamps

PRODCOM Code	DESCRIPTION
31.50.12.93	Halogen lamps : HL-MV, HL-MV-R
31.50.12.95	Halogen lamps : HL-LV, HL-LV-R
31.50.13.00	GLS lamps : GLS-F, GLS-C, GLS-R
31.50.15.30	Compact fluorescent lamps: CFLi + CFLi-R and nearly not domestic used CFLni + CFLni-R

The market data in physical volume and monetary units were retrieved for these product categories from the Eurostat[124] for EU-27 trade[125] and production for the years 2003-2007. Results including the calculated apparent consumption are presented in Figure 2-1.

Figure 2-1 shows that for EU-27:

- Over the past two years, the apparent consumption of GLS lamps has fluctuated (the production data for 2007 in Prodcom seems to be an estimate which is assumed to be around 250 million too high)..
- Apparent consumption of HL-MV and HL-LV was both around 300 million/year. A substantial part of these lamps is sold in the commercial sector. Table 2-5 shows a large increase in ELC sales from 2004-2008 for HL-LV and even more for HL-MV. Several countries also report that their domestic stock of HL has considerably increased during the past few years, e.g. Denmark where the halogen part of the stock increased from 15% in 2000 to 29% in 2006. For 2006, the contribution of halogen lamps increased to 31% of the stock in Germany and 24% for EU-27. Eurostat data do not seem to include all halogen sales, maybe because sales of multiple packs (2, 3 or even 8 lamps per pack) are counted as 1 lamp and lamp sales along with luminaires are missing.
- There has been a 434% increase in the apparent consumption of CFL (CFLi+CFLi-R+ +CFLni+CFLni-R) from 145 million in 2003, 177 million in 2004, 241 million in 2005, a dramatic increase to 426 million in 2006 and finally 630 million in 2007 (confirmed update by Nov. 2008 which was mentioned in the text of the report for part 1 of the study). A

[122] The general advantages, flaws and limitations of these official EU statistics are extensively discussed in i) the MEEUP Methodology Report and ii) the Eurostat data shop Handbook (part 6.4.2.) Europroms-Prodcom data, version 29/08/2003.
[123] See chapter 1 for an overview of lamp types, names and codes.
[124] http://epp.eurostat.ec.europa.eu (Theme "Industry, trade and services", last consulted 06/08/2008)
[125] In this study the focus is trade leaving and entering the EU-27 - Eurostat also includes data per EU country.

considerable part of these lamps are CFLi used in the domestic sector (see details in the end of 2.2.2).

- EU-27 net-export GLS and LFL and net-import of HL and CFL (CFLi+CFLni).

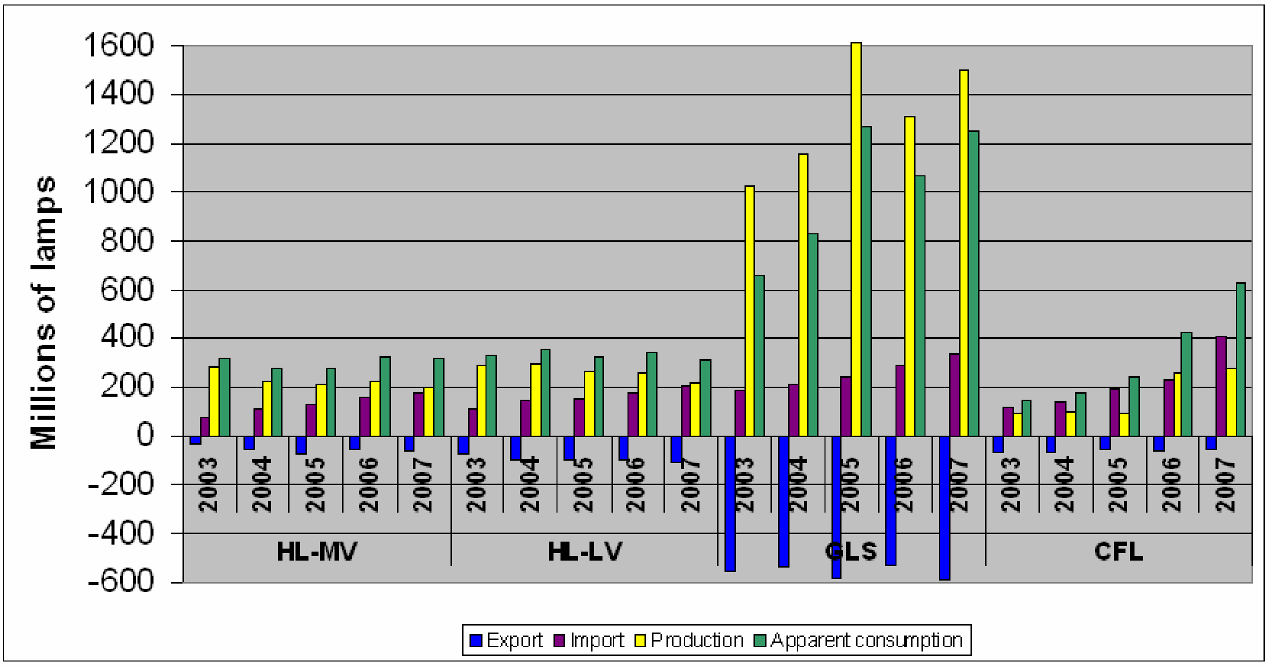

Figure 2-1: Volume of production, trade and sales of lamps for EU-27

The above Eurostat data include lamps in all sectors and thus not only domestic lighting application. In section 2.2, the use of different lamps in lighting is examined in more detail.

The Eurostat data might not include all lamps because:

- Some lamps are often sold in multipacks that could have been counted as 'one' unit in Eurostat. This could be the case for reflector lamps like HL-MV with G9, GU10 or R7s caps.
- Many luminaires for domestic lighting are sold with lamps that might not be counted in.

Product trends can also influence the data, such as the recent shift toward "double life" incandescent lamps, which have a lifetime 2000 hours. Unit sales will decline as the installed base extends its operating hours.

For a comparison of the economical value of export and production as well as import and apparent consumption please see part 1 of this study.

2.1.3 Generic data on luminaire sales

Table 2-2 shows the relevant luminaire categories in Prodcom (Eurostat).

Table 2-2: Prodcom segmentation for domestic luminaires

PRODCOM Code	DESCRIPTION
31502200	Electric table, desk, bedside or floor standing lamps
31502203	Domestic and residential luminaires (excl. spots): for incandescent lamps
31502205	Domestic and residential luminaires (excl. spots): for discharge lamps
31502209	Domestic and residential luminaires (excl. spots): for other lamps
31502530	Chandeliers and other electric ceiling or wall lighting fittings (excl. those used for lighting public open spaces or thoroughfares)
31502531	Luminaires for domestic and residential (excl. spots): for incandescent lamps
31502532	Luminaires for domestic and residential (excl. spots): for halogen lamps
31502533	Luminaires for domestic and residential (excl. spots): for compact fluorescent lamps
31502534	Luminaires for domestic and residential (excl. spots): for other lamps
31502547	Spots, display lighting: for incandescent lamps
31502548	Spots, display lighting: for other lamps
31502579	Other lighting fixtures: luminaires (interior), n.e.c.
31503430	Electric lamps and lighting fittings, of plastic and other materials, of a kind used for filament lamps and tubular fluorescent lamps
31503435	Exterior luminaires for houses and gardens : for incandescent lamps
31503437	Exterior luminaires for houses and gardens : for other lamps
31504250	Parts (excl. of glass or plastics) of lamps and lighting fittings, etc.

The categorisation in Table 2-2 is quite differentiated but the current luminaire data available in Eurostat are very limited as shown in Table 2-3.

Table 2-3: Prodcom luminaire production data available

PRODCOM Code	2004	2005	2006	2007
31502200 Table, desk, bedside or floor-standing lamps	26,000,000	19,971,309	21,936,702	22,004,961
31502530 Chandeliers + other ceiling or wall fittings	337,368,722	616,858,778	318,001,780	324,058,556
31503430 Lamps+fittings (filament+tubular fluorescent)	81,857,235	71,742,161	66,428,725	78,804,115
Total	445,225,957	708,572,248	406,367,207	424,867,632
Sales/household in case all production was sold in EU27 ')	2.1	3.4	1.9	2.0

‘) There are also sales in non-domestic settings but this assumed to be compensated by the imports that are missing

Remarks on Eurostat luminaire sales:

- All data in the table only include production, as export and import are not available;
- Data in the red fields with red shading is evaluated to be wrong probably because the sales in the category 31502530 are doubled;
- Only three categories include data and only production data – there are no export and import data. On the assumption that import from outside EU27 (mainly from China) equals EU27 export, those figures reflect the EU27 consumption;
- Communication with CELMA[7] gives the impression that there are sales in the other PRODCOM categories but that these sales are statistically regrouped into the three categories with data in Eurostat;
- Similar luminaires are used in non-domestic lighting, e.g. Horeca;
- Luminaires for fluorescent lamps and for street lighting are not included (see EuP studies on street and office lighting).

Concluding assumption on domestic and non-domestic luminaire sales:

[7] Federation of National Manufacturers Associations for Luminaires and Electro technical Components for Luminaires in the European Union. CELMA represents 16 national associations.

- Discussions with a central member of CELMA concluded that an average sales of 2 luminaires per household per year is a realistic value.
- The above Prodcom production data also includes production from the non-domestic sector. However, the luminaire sales in the non-domestic sectors are assumed to be 1.5-2 times the sales amount for the domestic sector and the non-domestic sales are assumed to be the difference between import of luminaires from China and the EU27 export of luminaires (as mentioned above is Eurostat at present only including production data and neither import nor export data).

2.2 Market and stock data

The purpose of this section is to provide market data for the identification of the most representative products in the European market and for the EU-wide environmental impact assessment of the product group ‘domestic lighting’ (chapters 5 and 8) as defined in section 1.1. Another purpose is to provide market inputs for scenario analysis up to 2020 (chapter 8).

Market and stock data are required for the following time periods:

- 1990 (Kyoto reference) or 1995;
- 2003-2007 (most recent real data);
- 2010-2012 (forecast, end of Kyoto phase 1) in a BAU (Business as Usual) scenario;
- 2020-2025 (forecast, year in which all – or at least a substantial share of - new ecodesigns of today will be absorbed by the market) in a BAU scenario.

Please note that it is not the purpose of chapter 2 to forecast the effect of future policy options related to domestic lighting (this is handled in chapter 8). Future policy options and their estimated impacts are discussed in chapter 8.

In order to assess the environmental impact, according to the MEEuP methodology, 'primary MEEuP market parameters' that will be used for impact modelling in chapters 5, 7 and 8 are identified (see Table 2-2). These parameters should reflect:

- Installed lamps (stock) in domestic lighting according to the product categories defined in section 1.1 most recently (2003-2007) and in the past (1990 or 1995 estimation) per EU-27 country;
- Lamp and luminaire sales growth (% or physical units) according to the product categories defined in section 1.1 to forecast the impact in Business as Usual for 2011 and 2020 for a BAU scenario;
- Average Product Life (in years) for lamps and for luminaires;

From the above data, the following dedicated MEEuP parameters will be derived:

- Total sales of lamps according to the product categories defined in section 1.1 versus generic data, (also in €, when available);
- Total lamp sales estimated when purchasing a new luminaire versus replacement lamp sales for existing luminaires (derived, if available);

- Total sales of luminaires according to the product categories defined in section 1.1 versus generic data, (also in €, when available);

In this section 'additional MEEuP model parameters' are defined when the 'Primary MEEuP market parameters' are not available.

The lamp life in years can be deduced, based on the average operational hours and the operational lifetime in hours. Operational lifetime data are included in chapter 4.

For non-ballasted lamp technologies, luminaires have no limitation on life time due to operational hours, while there is a limit due to the ballast for technologies as CFL and LED.DLS are primary non-ballasted and for this luminaire life in years seems to depend primarily on rebuilding the home and on changes in fashion. The luminaire life time is calculated based on total sales of luminaires in relation to the domestic stock of luminaires.

Table 2-2 gives an overview of the market parameters that are chosen to be included in the MEEuP model for EU-27. Regarding the parameters, it is important to note that:

- 1, 2, 3, 6, and 8: available data per EU-27 Member State are used, which are then aggregated to generate total EU-27 data.
- 1, 2, 5, 6, 7, and 8: data change over the concerned time frame 1990-2020 (forecast trends), but these data do not vary between different scenarios.
- 3 and 4 data change over the concerned time frame 1990-2020 (forecast trends), and these data also vary depending on the scenario that is applied: business as usual, least life cycle cost, best available technology etc.

Table 2-4: Input data included in the MEEuP Model totals for EU-27

Ref.	**Table. inputs for EU-27 Totals**	**Unit**	**Primary MEEuP market parameter**	**Additional MEEuP market Parameter**
1	Number of households per country and total	Households		X
2	Increase in number of households (per 5 years)	%		X
3	Number of different types of lamps and luminaires per household	Lamps Luminaires		X
4	Per lamp types % division on NDLS and DLS lamps	%	x	
5	Forecast of increase in number of lamps (per 5 years)	%	x	
6	Weighted average Wattage per lamp type	W	x	
7	Lamp life time per lamp type	Hours		X
8	Average operational hours per lamp type	Hours/year	x	
9	Luminaire life time for different categories	Years		x

Ballasts for LFL and CFL in the domestic sector are included in the luminaire that customers buy. As a consequence, they are not handled as a separate parameter in this study on domestic lighting. For details on ballasts, please refer to the preparatory study on Office lighting (Lot 8)[126].

[126] Preparatory Studies for Eco-design Requirements of EuPs, Lot 8: Office lighting, Final Report (April 2007).

For details on power supplies for low voltage halogen lamps, please see the study on external power supplies (Lot 7)[127]; the sales volume is included in luminaire sales for HL-LV. LED power supplies are low in sales and were neglected in chapters 2-6, but they will be used as BAT from chapter 6 on.

Luminaires for the domestic sector include a huge amount of different products with a very large price range. They are sold by thousands of luminaire manufacturers organised in CELMA. Mainly decorative elements can increase the price of domestic luminaires. This study does not aim to assess those decorative elements (see scope and the related system approach in chapter 1). Therefore neither average nor maximum domestic luminaires prices are evaluated. Luminaire related prices will be limited to the minimum price increase when applicable (see chapter 4 and 6).

Section 2.2.6 summarizes the market and stock data that will be used in the other chapters of the study.

2.2.1 Data retrieval

The following 4 approaches for retrieving market data (complementary to Eurostat data in section 2.1) were explored:

Literature research and EU R&D project data: various studies have been conducted on the energy use of domestic lighting for EU R&D programmes and several Member States have delivered useful data on the number of installed lamps and their related energy consumption. The most recent overview of the global trade in lamps and lighting products, and the global market value and trends can be found in the recently published IEA Light's Labour's Lost (IEA, 2006).

Consultation of ELC[128], major retailers, and CELMA: a request for lamp and luminaire sales data and any other relevant information for part 2 was launched at the meetings with ELC and CELMA (Oct. 2008 and Jan. 2009). In March 2009, ELC provided aggregated sales data for 2007 and 2008 for reflector lamps. CELMA was unable to give data but a CELMA member agreed with the conclusion in 2.1.3 related to generic luminaire sales volumes.

Expert-inquiry: in spring 2007, DG JRC (Joint Research Centre) of the European Commission sent a 10-question-survey about installed lamps to experts in different Member States and to other lighting related organisations. Experts from nearly all EU-27 filled in the questionnaire and the responses provided useful data on number of lamps per household and numbers and use of energy efficient lamps for the different Member States. These data are used along with new and more detailed lamp information collected in the EU R&D project REMODECE[129]. This project includes the results from the 12 cooperating countries plus some national research projects in other EU countries. Data for the remaining countries are estimated based on the above data.

Unfortunately, REMODECE did not specify if the lamps were reflector lamps. To compensate for this, a reflector lamp expert survey was performed among participants in the EU R&D projects

[127] Preparatory Studies for Eco-design Requirements of EuPs, Lot 7: External power supplies and battery chargers (January 2007).

[128] European Lamp Companies federation including 8 members

[129] Residential Monitoring to Decrease Energy Use and Carbon Emissions in Europe

REMODECE and ENERLIN. Many replies were received, but the experts underlined that their answers were rather uncertain.

Calculated estimations based on the number of households in EU-27 and stock data for some member countries measured from EU R&D projects: Data on the number of households per Member State can be found in Eurostat. The EU-27 total installed base of domestic lamps can be derived by combining this with the lamps-per-household data available for a number of EU countries along with the average measured and/or estimated lifetime of different lamp types. Forecast on population, number of households, number of luminaires and lamps can be used to make projections regarding the future installed base and annual sales of domestic lighting products (up to 2020).

Enquiry for all stakeholders: a lamp questionnaire for sales data and other relevant market information was addressed directly to ELC, 2 major European lamp retailers, and The China Chamber of Commerce. All other stakeholders were also invited to contribute; the questionnaire can be downloaded by registered stakeholders on the project website (www.eup4light.net). Only ELC replied.

2.2.2 Annual lamp and luminaires sales

The objective of this section is to determine the current sales as reliably as possible for the domestic lighting lamp types as defined in section 1.1 for the latest full year for which data are available.

Analysis of lamp data received from ELC

In December 2007, ELC answered the questionnaire, as far as possible, for the period 2004-2006. ELC data were split up in 4 regions of the EU: Central & Eastern, Middle, Northern and Southern. The available data include sales in all sectors in the society and unfortunately no data are available on the division of these sales between different sectors. In March 2009, ELC provided aggregated reflector lamp data for 2007 and 2008.

The sales figures for application in domestic lighting can only be estimated using information from research, lamp industry experts and assumptions. At present, the most used lamps in the domestic sector are GLS and halogen lamps, a small amount of linear fluorescent lamps (LFL's) and an increasing amount of CFL's with integrated ballast.

Table 2-3 shows the annual ELC sales and shows for 2006 (last year with both NDLS + DLS sales):

- DLS (reflector lamps) represents 12% of the total sales volume.
- GLS-R contributes with 11% of the GLS sales.
- HL-LV-R contributes with 55% of the total HL-LV sales.
- HL-MV-R contributes with 42% of the total HL-MV sales (growing faster than HL-LV).

Table 2-5: Volume of ELC (only including ELC members) reflector lamp sales in EU-27, 2004-2008

Lamp type	*2004*	*2005*	*2006*	*2007*	*2008*	*Change 2004 - 2008*	*DLS part of NDLS+DLS*
GLS-R	*163,822,491*	*144,513,034*	*138,360,572*	*162,390,388*	*150,870,523*	*-8%*	*11% (2006)*
HL-LV-R	*66,915,971*	*71,422,261*	*73,181,823*	*68,185,164*	*81,048,849*	*+21%*	*55% (2006)*
HL-MV-R	*28,753,170*	*29,758,531*	*31,705,477*	*46,302,947*	*62,965,941*	*+118 %*	*42% (2006)*
CFLi-R				*1,086,647*	*2,687,760*	*+147 %*	*1% (2007 estimate)*
Total	*251,491,632*	*245,693,826*	*243,247,872*	*277,965,146*	*297,573,073*	*+7%*	*12% (2006)*

Concerning GLS and HL sales, the annual percentage distribution of the sales on wattages and regions is not changing much in the period 2004-2006, so to get a picture of the distribution on wattages it is enough to look at the last year with available data (2006).

For GLS reflector lamps, Table 2-5 shows that:

- GLS-R lamps sales are distributed as 55% 40W, 27% 60W, 9% ≤ 25W and finally the last 9% includes the wattages 75W, 100W and 150-200W (around 12,300,000/year),
- In general, the sale of GLS reflector lamps is decreasing especially for the high wattages 75W, 100W and 150-200W,
- The weighted average wattage is 51W in 2006.

Table 2-6: GLS-R % distribution of ELC sales in EU-27, 2006

% ELC sales 2006	***EU Region***				
GLS-R Wattage	*Central & Eastern*	*Middle*	*Northern*	*Southern*	***Total***
≤25W	2.0	5.0	1.4	0.6	**9.0**
40W	10.1	37.7	2.4	4.9	**55.2**
60W	5.0	18.1	0.4	3.4	**26.9**
75W	0.2	1.6	0.0	0.6	**2.4**
100W	0.2	2.4	0.0	0.8	**3.5**
150-200W	0.3	2.3	0.0	0.4	**3.0**
Total	**17.7**	**67.1**	**4.3**	**10.8**	**100**

Wattage	**2004**	**2005**	**2006**	**Decrease in sales (%)**
<=25W	13,930,960	12,785,155	12,424,272	**-11%**
40W	88,641,372	79,042,894	76,388,608	**-14%**
60W	43,959,116	38,481,869	37,224,249	**-15%**
75W	4,682,156	3,912,891	3,307,753	**-29%**
100W	6,412,696	5,557,390	4,840,024	**-25%**
150-200W	6,196,190	4,732,834	4,175,666	**-33%**
Total	**163,822,491**	**144,513,034**	**138,360,572**	**-16%**

For halogen low voltage lamps, Table 2-6 shows that:

- HL-LV-R is one third ≤ 20W and two third >20W,
- The largest sales increase is seen for HL-LV-R ≤ 20W,
- Assuming average wattage >20W is 35W and that there are one third 10W hidden in the ≤ 20W category, the weighted average is 29W.

Table 2-7: HL-LV EU-27 % distribution of ELC sales in 2006 and 2004-6 sales increase

% ELC sales 2006	***EU Region***				
Wattage	*Central & Eastern*	*Middle*	*Northern*	*Southern*	***Total***
HL-LV-R <=20W	2.2	20.1	2.0	9.8	**34.2**
HL-LV-R >20W	3.8	37.3	2.7	21.9	**65.8**
H-LV-R total	**6.0**	**57.4**	**4.8**	**31.7**	**100**
Wattage	**2004**	**2005**	**2006**	**Increase in sales (%)**	
HL-LV-R <=20W	19,466,508	24,142,385	25,010,136	**28%**	
HL-LV-R >20W	47,449,463	47,279,876	48,171,687	**2%**	
Total	**66,915,971**	**71,422,261**	**73,181,823**	**9%**	

HL-LV-R 15W is included by ELC in the general category because of lack of answers

For halogen mains voltage lamps, Table 2-7 shows that:

- Sales of HL-MV-R are distributed as follows: 42% >60W, 35% 60W and 23% ≤ 40W.
- Sales of HL-MV-R ≤ 40W are increasing very fast with a 44% sales growth between 2004 and 2006,
- Assuming the average wattage >60W is 75W and the average wattage <=40W is 35W, the weighted average is 60W but since the sales increase very fast for wattage <=40W, it is for the near future considered more appropriate to select 50W as an average.

Table 2-8: HL-MV EU-27 % distribution of ELC sales in 2006 and 2004-2006 sales increase

% ELC sales 2006	***EU Region***				
Wattage	*Central & Eastern*	*Middle*	*Northern*	*Southern*	***Total***
HL-MV-R <=40W	2.3	15.8	2.0	3.2	**23.2**
HL-MV-R 60W	1.8	23.3	3.4	6.7	**35.2**
HL-MV-R >60W	1.5	30.0	3.1	7.0	**41.6**
HL-MV-R total	**5.6**	**69.0**	**8.6**	**16.8**	**100**

Wattage	2004	2005	2006	Increase in sales (%)
HL-MV-R <=40W	5,103,999	5,863,506	7,369,583	**44%**
HL-MV-R 60W	10,176,305	10,513,726	11,151,501	**10%**
HL-MV-R >60W	13,472,866	13,381,299	13,184,393	**-2%**
Total	**28,753,170**	**29,758,531**	**31,705,477**	**10%**

Analysis of total EU-27 lamp sales (including companies outside ELC)

Table 2-9 summarizes sales data for the year 2006:

- The total for GLS is adjusted to 1350 million (from 1067 million in Eurostat, see Figure 2-1) as Eurostat data are lower than the sum of the sales data from the manufacturers – maybe because some sales of packages of two bulbs sometimes go into statistics as sales of one bulb. Reasons for significant differences between sales data and apparent consumption from official statistics are extensively discussed in the MEEuP report (VHK, 2005).
- ELC data are summarized data from Table 2.5.
- 2 major European lamp retailers have informed of the rough size of their 2006/2007 sales of own-brand lamps.
- Other sales are sales from other manufactures assumed to be the residual sales to meet the total Eurostat sales.
- ELC provided their 2006 CFLni sales, i.e. 170 million.

Table 2-9: Volume of EU-27 sales (millions/year) for all sectors in 2006

Lamp type	Total (Euro-stat)	ELC Sales	2 major European lamp retailers Sales	Other Sales (residual)	Non Direct and Direct Lamps %
GLS	1350	1096	62	44	NDLS 89%
GLS-R		138	10		DLS 11%
HL-LV	300	60	26	120	NDLS 45%
HL-LV-R		73	21		DLS 55%
HL-MV-LW	330	20[130]	10	193	NDLS 58%
HL-MV-HW		24	1		
HL-MV-R-LW		19	46		DLS 42%
HL-MV-R-HW		13	4		
CFLi	426	97	60 (3% DLS)	159	NDLS 99%
CFLni		90 ¤	0	20	-
CFLi-R		1 (2007)	5 (estimate for 2007)		DLS 1%

¤ Value estimated from EuP lot 8 information and informal data about ELC CFLni sales in 2007

Table 2-9 shows that ELC is covering nearly all GLS and LFL sales but less than half of the HL and CFL sales. The NDLS/DLS distribution for halogen lamps is derived from new data received in 2008 and the distribution is a bit different from the earlier developed MEEuP model (see section 2.2.6) based on 2006 data. A sensitivity analysis was executed in relation to chapter 8 in part 1 of the study. It did show that the influence of using the new NDLS/DLS distributions would only

[130] ELC HL-MV sales 44 million and HL-R-MV sales 32 million is divided on LW (≥75W) and HW (>75W) by own judgement

result in a small difference of about 2-3% in energy savings with no influence on the outcome of comparison and ranking of the scenarios.

Analysis of total EU-27 luminaires sales

CELMA regrets that they are unable to provide any luminaire data or estimates of sales within different types of luminaires.

The only available luminaire sales data come from Eurostat. Table 2.2 shows yearly sales of 2 luminaires per household divided up into three categories:

- 5% Table, desk, bedside and floor-standing lamps
- 76% Chandeliers and other ceiling and wall fittings
- 19% Lamps and fittings (filament and tubular fittings)

Unfortunately, the division is not very specific because only three of the sixteen Eurostat categories seem to be in use as a kind of "sum-up" categories.

2.2.3 Stock of different installed lamps and luminaire types per household

Stock of installed lamps

Stock data in part 1 of the study were provided in response to an end-user survey in the EU R&D project REMODECE including 500 consumers per country for 11 countries. Besides this, Sweden and UK have provided data from large national surveys performed in 2007. They include data from a JRC questionnaire to national experts [Bertoldi and Atanasiu, 2007] and it was estimated that the mentioned 13 countries use 76% of the total EU-27 stock. The detailed data for the 13 countries were finally rescaled to four EU regions and summed for EU-27. The results (included in the MEEuPs model as shown in section 2.2.6) were:

- The EU-27 average is 24.3 installed lamps/household in 2006 (variation: 10-40 installed lamps/country),
- The average share of GLS lamps is 13.15 GLS/households equal to 54% of the lamps,
- The average share of HL-LV is 4.46 equal to 18% of the lamps,
- The average share of HL-MV is 1.32 equal to 5% of the lamps,
- The average share of LFL is 1.83 equal to 8% of the lamps,
- The average share of CFLi is 3.58 equal to 15% of the lamps.

Unfortunately, nearly all the above data is not split up in non-reflector and reflector lamps. As shown in Table 2.8, sales of halogen reflector lamps have increased rapidly the last years. By the end of 2008, the participants in the EU R&D projects REMODECE and Enerlin were asked about their estimate of the current stock of reflector lamps. The answer is shown in table 2.10.

Table 2-10: Survey including estimates of the stock of reflector lamps by the end of 2008

REFLECTOR LAMPS				Estimates - no measured or surveyed data							
				GLS-R	HL-LV-R		HL-MV-R		CFLi-R		
EU region	Country	Number of house holds in millions		E27, E14	GU4 GU5.3	G53	E14, E27, B14d, B22d	GU10, GZ10	E14, E27, B14d, B22d	GU10, GZ10	Lamps in total
		Total	included	no/HH	no/HH		no/HH		no/HH	no/HH	no/HH
Central and Eastern EU	BG	3.7	1	1	1	0	0	0	0	0	2.0
	CZ	4.4	1	1	2	0	0	0.1	0.01	0	3.1
	CY	0.3									
	EE	0.6									
	HU	4.1									
	LV	1.0	1	3.5	2	0	1	2	0.5	0	9.0
	LT	1.3									
	MT	0.1									
	PL	13.3	1	2	3	0	0.1	0.5	0	0	5.6
	RO	8.1	1	1.5	0.5	0.1	0.3	0.6	0.0	0.0	3.0
	SK	2.1									
	SI	0.7									
Middle EU	AT	3.3									
	BE	4.3	1	1	4	0	0.5	0.4	0	0	5.9
	FR	32.2	1	0	3.6	0,0	0	0.7	0	0	4.3
	DE	39.1	1	1	5	0	0	1	1	0	8.0
	EI	1.4									
	LU	0.2									
	NL	7.0									
	UK	26.2									
Northern EU	DK	2.5	1	0.5	7	0	0.2	2	0.1	0	9.8
	FIN	2.5									
	SE	4.5									
Southern EU	GR	3.7	1	0.7	1.2	0	0.2	0	0.1	0	2.2
	IT	22.5	1	1.5	6.9	0	2.1	0	0	0	10.5
	PT	4.2	1	2	4	0	0.5	0.5	0	0	7.0
	ES	17.2									

EU region	Number of Cap		GLS-R	HL-LV-R		HL-MV-R		CFLi-R	
			E27, E14	GU4 GU5.3	G53	E14, E27, B14d,	GU10, GZ10	E14, E27, B14d,	GU10, GZ10
	Total	Included	no/HH	no/HH	no/HH	no/HH	no/HH	no/HH	no/HH
Central+Eastern EU	39.7	0	1.6	1.9	0	0.2	0.5	0	0
Middle EU	113.7	0	0.6	4.3	0	0	0.8	0.5	0
Northern EU	9.5	0	0.5	7.0	0	0.2	2.0	0.1	0
Southern EU	47.6	0	1.5	5.8	0	1.6	0.1	0	0
EU 27	210.6	0	1.0	4.3	0	0.4	0.6	0.3	0

Compared to the BAU forecast in section 2.2.7 (see Figure 2.2) GLS-R and HL-MV-R are in line with our BAU forecast while we consider the estimates of HL-LV-R and CFLi-R to be higher than the actual EU-27 stock mainly due to many countries are missing in the above survey.

In part 1, the EU-27 stock of lamps for 1995 was estimated although the EU did not include that many countries at that time. This calculation showed an average of 21.3 lighting points/household (variation: 6-36 points/country) including 18.0 GLS (85%), 0.9 HL-LV, 0 HL-MV, 1.4 LFL and 1.0 CFLi. We estimate that the 21.3 lighting points/household in 1995 included 1.5 GLS-R and 0.5 HL-LV-R (we don't have 1995 reflector lamp data so it is our best guess).

<u>Stock of installed luminaires</u>

As explained in chapter 1, in this study the luminaires are treated as belonging to the system environment of the lamp or light source. There is an enormous market of different luminaire types for domestic lighting.

Unfortunately, no direct EU27 luminaire stock data are available. However with 24.3 installed lamps / household in EU27, we assume that every household uses 20.7 luminaires (85% of 24.3 lamps/home) including a few luminaires per home that contain more than one lamp (the assumption is based on impressions from the audit in the REMODECE project – unfortunately the number of luminaires was not counted in REMODECE) The total number of luminaires is thus assumed to be 85% of the total number of lamps which is equal to around 4300 million luminaires used in the domestic sector for the year 2006 (see the MEEuP's model in section 2.2.6) of which 770 million luminaires are for DLS.

CELMA[131] proposed to define luminaires according to their market share in categories shown in Table 2-11 also containing characterisation by different technical parameters.

Table 2-11: Luminaire categories according to commercial terminology (catalogues, websites)

Luminaire category	Mounting method	Electrical connection	Light distribution	Ingress protection
Downlights (recessed mounted)	ceiling integrated	fixed (wired)	Directional light distribution	≥IP2X
Suspension (chandeliers)	ceiling suspended	fixed (wired)	Any	≥IP2X
wall&ceiling	surface mounted	fixed (wired)	Any (excluding Narrow beam spotlights)	≥IP2X
Desk	free surface standing	plug	Directional light distribution	≥IP2X
Table	free surface standing	plug	Non directional light distribution	≥IP2X
Floor	free surface standing	plug	Any	≥IP2X
Spotlights	surface mounted	fixed (wired)	Narrow beam directional light distribution	≥IP2X
Outdoor	surface mounted/floor standing	fixed (wired)	Directional light distribution(often) or non(rare)	≥IP44

Table 2-12 shows guessed estimates of the market share of the different luminaire categories provided by CELMA which are average values of data collected from some large members of CELMA in June 2009.

Table 2-12: CELMA guess estimates of luminaire category market distribution, percentages with cap lock in effect and control properties

Luminaires categories	Market share in %	Percentage with GU9, GU10 or R7S cap	Percentage of dimmers	Presence Detectors	Daylight control	Range of wattage
Downlights (recessed mounted)	11%	70%	0%	no	no	2-100
Spotlights	18%	45%	10%	no	no	2-100
Suspension	19%	25%	5%	no	no	20-300
Wall & ceiling	22%	20%	5%	no	no	20-300
Desk	5%	15%	5%	no	no	5-60
Table	4%	5%	15%	no	no	20-100
Floor	5%	35%	25%	no	no	20-300
Outdoor	16%	35%	1%	**yes**	**yes**	20-300

CEPAPI members in Belgium has delivered 2008 sales data for **wall swiches** used to operate domestic luminaires:

- 91% traditional mechanical control switches
- 4% electronic control switches (timers, PIR detectors) with electromagnetic relay

[131] www.celma.org

- 5% electronic control switches with electronic control (FET, IGBT, Triac,..) e.g. solid state relay or phase controlled dimmers.

The above data could serve to estimate the energy saving on luminaires having equal Light Output Function (LOF) as defined in chapter 1.

Nowadays, spot lights and down lights mainly use DLS lamps. As explained later in chapter 3, there is no optical improvement potential for spotlights using DLS lamps because those lamps are generally not shielded and there is thus no loss of functional lumen.

The other categories of luminaires mainly use the NDLS lamps. The above luminaire data are thus also relevant for the impact scenarios calculated in part 1 with the installed base of NDLS lamps. The analysis can be handled by a correction factor applicable to the part 1 scenarios and their improvement options (if any). For those luminaires only the ratio or percentage on saved power consumption will be assessed and not the absolute LOF.

For the calculation of potential energy savings, it is also important to know the amount of up-lighter luminaires, equipped with high wattage, linear halogen lamps. A large UK lighting study performed in 2007, found that there could be installed up to 6 million halogen up-lighters in total for all sectors in the UK. Assuming that half of these luminaires are used in the domestic sector, it means that 1 out of 8 households has an up-lighter luminaire which for EU27 is equal to 26 million households. This is assumed to be representative for Western European countries while it might be too high for Eastern European countries. Based on the UK usage, the usage for all sectors in EU27 is roughly estimated to be 40 million up-lighters.

Table 2.12 includes an estimate of 5% floor lamps where 35% are estimated to include R/S cap. The total is thus equal to 210 million households * 20.7 luminaires/hh * 5% * 35% = 76 million uplighters alone for the household sector. Compared to the UK numbers above, the estimated share for R7S cap in Table 2.12 is considered to be too high. A total use of 40 million up-lighters for all sectors in EU27 is still our best estimate.

Concerning lighting control information contained in Table 2.12, the relative savings (if any) related to dimmers, presence detectors and daylight controls will be assessed in chapter 6.

Please note some of the luminaires for lamps within the scope of this study are also used in Horeca sector and shop lighting.

Average lamp wattages for different lamp types

In part 1, selection of average lamp wattages was based on the studies: EURECO (1999-2000), “Eclairage 100" (1999), UK lighting market transformation survey (2007) and the Podo project (2005-2006). Unfortunately, nearly none of these studies include details about reflector lamps. Therefore, estimates of the average wattages are based on the weighted average of wattage sales data and trends in section 2.2.2 although the wattage sales distribution might not be the same as the wattage stock distribution.

Based on the above information, the following average lamp wattages were chosen for reflector lamps:

- 50W for GLS

- 50W for HL-MV. In Part 2 there is no division on HL-MV-LW and HL-MV-HW as there is not a large variation in wattage size for DLS as there was for NDLS in part 1.
- 35W for HL-LV.
- 12 W for CFLi-R. At present, no wattage information is available from ELC. 12W is chosen as base-case because the lumen output is comparable to the wattages for the other lamp types.

2.2.4 Average operational hours per lamp type

The average operational hours per lamp type is an important parameter necessary for estimating the total stock of lamps along with the technical lamp lifetime and lamp sales.

The average operational hours for lamps depend on the user behaviour and on the environment; these topics are discussed in chapter 3 and also include presence of household members, activities, lighting control e.g. by clock, burglar protection, outdoor lighting level and/or presence detection. For part 1 of this study, measured data were used from different EU R&D activities/projects. Unfortunately, none of these studies includes detailed information on distribution in DLS and NDLS.

- GLS-R 400 hours/year
- HL-MV-R 450 hours/year
- HL-LV-R 500 hours/year
- CFLi-R 800 hours/year.

Some stakeholders claim that DLS lamps may have larger operating hours compared to NDLS because are not used in cellars and similar places. On the other hand, some of the DLS lamps are placed as down lighers in staircases, corridor and hall with a low level of use . As the measured data is not divided on NDLS and DLS, it is decided to use the same operational hours for DLS as for NDLS.

The impact analysis also includes the use of the lamps in the non-domestic sector, so the weighted average operational hours for all sectors used in the calculation are actually higher than the above values as shown in section 2.2.6.

Finally, it has to be stressed that the impact assessment calculations use **lumen / hour** as the functional unit. As a consequence, differences in operational hours will have a low impact (only for the economic assessment) on the calculations in chapter 7 (improvement options) and 8 (scenarios). Chapter 8 will contain a sensitivity analysis in order to find the uncertainty of the results related to the size of the operational hours.

2.2.5 Summary of MEEuP market parameters

Table 2-13 summarizes the data to be used in the EcoReport calculations in the next chapters of the study. Comments on this table are:

- 2006 stock of installed lamps/household (from section 2.2.3); these data are to be considered as bottom line data because a luminaire with two lamps might have counted as one and some sockets might have been forgotten.
- The division on %NDLS and %DLS is based on sales data in section 2.2.2.
- Weighted wattages (see section 2.2.4)
- Average operational hours (see section 2.2.5)
- Lamp lifetimes (found in chapter 4 by studying the manufacturer's catalogues).
- Forecast of the stock of installed lamps for 2011 and 2020 (estimates). Alternatively, it was considered to perform a trend analysis based on the UNECE database[132] but this was refused due to large changes between lighting sources within the last few years.
- Any yearly forecast of the stock = Yearly replacement sales + Yearly change in stock.
- Yearly lamp replacement sales = Stock of lamps in 2006 * operational hours per year/lamp lifetime.
- Yearly change in sales of lamps is calculated from a forecast of the stock of different lamps as explained in part 2.2.7 and 2.3.
- Number of homes (not available in Eurostat) is collected from a comparative study of UNECE House statistics (old data from 2002), House Statistics in EU (2004) other studies and national statistics. The actual number of homes (dwellings) in EU-27 is found to be 210 million homes.
- The growth rates are related to trends and are explained in section 2.3.1.
- The yearly sales of luminaires divided on categories are based on Eurostat data as explained in section 2.2.2.
- Estimation of the stock of installed luminaires/household is primarily based on the found stock of lamps/household and the estimated average lamps/luminaire (see section 2.2.3).
- Life time for luminaires is calculated based on the forecasted stock of lamps in Table 2-13:
    - 'New sales' = (31.0-24.34) lamps*0.85 lamps/luminaires/(2020-2006) = 0.40
    - 'Replacement sales' = 2.0 – 0.40 = 1.6 luminaires
    - Luminaires lifetime (average) = 24.34 lamps * 0.85 lamps/luminaire/1.6 luminaires = 13 years

[132] The database model of the Statistical Division (UNECE/STAT) maintained by the Environment and Human Settlements Division contains data with specific reference to data on housing and building. Data are collected for the ECE Bulletin of Housing and Building Statistics and through the Country Profiles on the Housing Sector from a number of both national and international sources.

Table 2-13: MEEuP lighting model with Business as Usual (BAU) forecast

Scenario: BAU

MEEuP Lighting Model for EU27

Capita	477,000,000
Homes	210,000,000
Capita/home	2.27
Input data	
Calculated	

Domestic sector	GLS-F	GLS-C	HL-MV LV	HL-MV HV	HL-LV	LFL	CFLi	Total
Stock of lamps (NDLS+DLS) per home 2006	9.20	3.95	0.61	0.71	4.46	1.83	3.58	24.34
% NDLS	99	66	55	55	49	100	99	
% DLS	1	34	45	45	51	0	1	
Stock of lamps	1932000000	829500000	128100000	149100000	936600000	384300000	751800000	5111400000
Stock of NDLS lamps	1912680000	547470000	70455000	82005000	458934000	384300000	744282000	4200126000
Stock of DLS lamps	19320000	282030000	57645000	67095000	477666000	0	7518000	911274000
Lamp life time (hours)	1000	1000	1500	1500	3000	12000	6000	
Average operational hours (hours/year)	400	400	450	450	500	700	800	
Replacement Sales per year	772800000	331800000	38430000	44730000	156100000	22417500	100240000	1466517500
Forecast of stock (NDLS+DLS) in 2011	4.9	2.5	3.0	2.0	5.1	2.0	8.1	27.6
Stock of lamps	1022700000	525000000	630000000	420000000	1071000000	420000000	1701000000	5789700000
Stock of NDLS lamps	1012473000	346500000	346500000	231000000	524790000	420000000	1683990000	4565253000
Stock of DLS lamps	10227000	178500000	283500000	189000000	546210000	0	17010000	1224447000
Forecasted change in sales in 2007	-181860000	-60900000	100380000	54180000	26880000	7140000	252760000	198580000
Total sales 2007	590940000	270900000	138810000	98910000	182980000	29557500	353000000	1665097500
NDLS sales 2007	585030600	178794000	76345500	54400500	89660200	29557500	349470000	1363258300
DLS sales 2007	5909400	92106000	62464500	44509500	93319800	0	3530000	301839200
Forecast of stock (NDLS+DLS) 2020	3.5	2.3	4.7	2.5	5.9	2.0	10.1	31.0
Wattage weighted average (W)	54	54	40	300	30	38	13	
Lamp Wattage Factor	1	1	1	1	1.11	1.05	1.05	
Electricity consumption in 2006, TWh (total)	41.73	17.92	2.31	20.13	15.59	10.73	8.21	
Electricity consumption in 2006, TWh (NDLS)	41.31	11.83	1.27	11.07	7.64	10.73	8.13	
Electricity consumption, %	35.8	15.4	2.0	17.3	13.4	9.2	7.0	

Data control for 2007	GLS-F	GLS-C	HL-MV LV	HL-MV HV	HL-LV	LFL	CFLi+CFLni
Eurostat Apparant consumption, EU27, 2007	811626000	347000000	318000000		310460000	388072000	630000000
Domestic 2007 Sales/Apparant consumption 2007	0.7	0.8	0.4	0.3	0.6	0.1	0.6
Eurostat includes both domestic and commercial customers.							
Apparent EU27 consumption = Production in EU27 + Imports - Exports							

Non-domestic sector	GLS-F	GLS-C	HL-MV LV	HL-MV HV	HL-LV	LFL	CFLi+CFLni
2007 sales in the non-domestic sector	220686000	76100000	80280000		127480000	358514500	277000000
Sales for the non-domestic sector is calculated as the residual.							

Table 2-13 does't include LEDi-R since the size of LED sales in the domestic sector are actually minor and no data are available in the sales statistics. Besides that, the performance and quality of LED lamps/luminaires are actually often low. The very high prices of LED lamps sets a barrier for intrusion. Anyway, LEDi-R will most likely come into use in the period until 2020 but the speed of intrusion is very unsure. Therefore, it is decided to handle the use of LEDi-R as an improvement option in Task 7.

Figure 2-2 shows the BAU (Business As Usual) forecast of the yearly DLS stock, for the domestic sector, of GLS-R, HL-MV-R, HL-LV-R and CFLi-R. The number of GLS-R is decreasing while the use of halogen lamps is increasing, especially the HL-MV-R. The use of CFLi-R is in an up-start phase and assumed to grow slowly because of a high price barrier and lock in effects (see chapter 3). The growth rates are related to trends explained in section 2.3.1. The forecast is also in line with the trends in sales for the last years shown in the section 2.2.2.

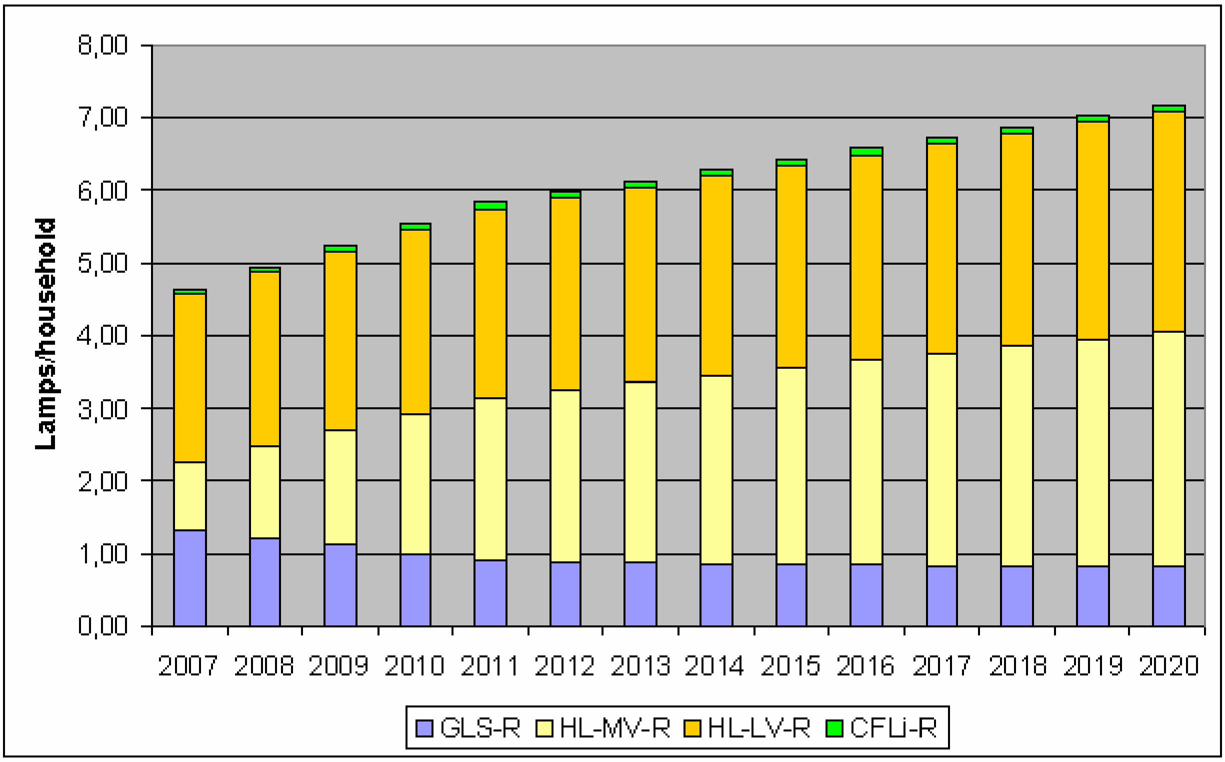

Figure 2-2: BAU (Business as Usual) forecast of the domestic DLS stock

Table 2-14 summarizes the domestic MEEuP data that are used to develop MEEuP data for all sectors.

Table 2-14: Lamp data and domestic stock for 2006 used in section 2.2.6

Lamp type	Stock of Domestic DLS lamps	Lamp life	Average operation per year	Base case wattages
	millions	Hours	Hours	Watt
GLS-R	320	1000	400	50
HL-MV-R	125	1500	450	50
HL-LV-R	478	3000	500	35
CFLi-R	6 (2007)	6000	800	12

2.2.6 Stock and sales MEEuP data for all sectors

The DLS base-cases (see section 2.2.4 and chapter 5) are used in order to investigate environmental and economic results for the domestic sector as well as “Other sectors” (non-domestic) with the assumption that lamp life, the average wattage, the lamp price and the shares of DLS lamps are the same as in the domestic sector.

The same CFLi-R’s are assumed to be used both in the domestic and non-domestic sector as there don’t appear to be any CFLni-R at the market.

In the calculations, it is assumed that the share of replacement sales (see definition in section 2.2.6) for the domestic sector can also be used for the non-domestic sector as we don’t have detailed information about this. The domestic replacement shares are: 131% for GLS-R-F, 122% for GLS-R-C, 35% for HL-MV-R, 85% for HL-LV-R and 28% for CFLi-R.

It is assumed that all base-cases in the non-domestic sector operate 1800 hours per year (250 working days/year with around 7 operating hours per day) for both NDLS and DLS lamps. The annual burning hours for all sectors are calculated in Table 2-27 based on a weighted average in 2006:

$$Operation\ hours_{All} = (Operation\ hours_{Dom} \times Stock_{Dom} + Operation\ hours_{Other} \times Stock_{Other}) / Stock_{All}$$

Table 2-15: Calculation of average operation hours per year for all sectors

	GLS-R-F	*GLS-R-C*	*HL-MV-R*	*HL-LV-R*	*CFLi-R*
Domestic sector	400	400	450	500	800
Non-Domestic	1800	1800	1800	1800	1800
All sectors	507	482	555	695	1056

The stock of lamps for "Other sectors" (non-domestic sectors) are calculated as:

Total Stock = (Lamp life /Operation hours) x Share of Replacement Sales x Total Sales

The stock in 2007 is calculated based on survey data from 2006 as well as 2007 Eurostat data.

Based on the above assumptions, formula and the market trends described in section 2.3, the BAU (Business as Usual) forecast shown in Table 2-16 is produced. This BAU forecast will be used in scenario calculations in chapter 8. The data for 1995 is estimates based on data in Table 2.12 in part 1 of this study.

Table 2-16: BAU (Business as Usual) forecast of the DLS stock including all sectors

STOCK	GLS-R	HL-MV-R	HL-LV-R	CFLi-R	TOTAL
1995	495,000,000	6,000,000	78,000,000	0	**932,000,000**
2006	320,492,926	135,276,750	562,212,950	10,103,333	**1,028,085,959**
2007	291,591,919	228,310,650	584,873,780	12,350,493	**1,117,126,843**
2008	268,863,050	299,335,970	599,377,647	14,977,744	**1,182,554,412**
2009	246,134,181	370,361,291	613,881,514	17,604,995	**1,247,981,981**
2010	223,405,311	441,386,611	628,385,381	20,232,246	**1,313,409,550**
2011	200,676,442	512,411,932	642,889,248	22,859,497	**1,378,837,119**
2012	198,644,874	537,463,182	654,094,289	23,486,644	**1,413,688,989**
2013	196,613,306	562,514,432	665,299,330	24,113,791	**1,448,540,859**
2014	194,581,739	587,565,682	676,504,372	24,740,937	**1,483,392,730**
2015	192,550,171	612,616,932	687,709,413	25,368,084	**1,518,244,600**
2016	190,518,603	637,668,182	698,914,455	25,995,231	**1,553,096,470**
2017	188,487,035	662,719,432	710,119,496	26,622,377	**1,587,948,340**
2018	186,455,467	687,770,682	721,324,537	27,249,524	**1,622,800,211**
2019	184,423,900	712,821,932	732,529,579	27,876,671	**1,657,652,081**
2020	182,392,331	737,873,182	743,734,620	28,503,818	**1,692,503,951**

Figure 2-4 shows the forecasted stocks of GLS-R, HL-MV-R, HL-LV-R and CFLi-R. The growth rates are related to trends explained in section 2.3.1.

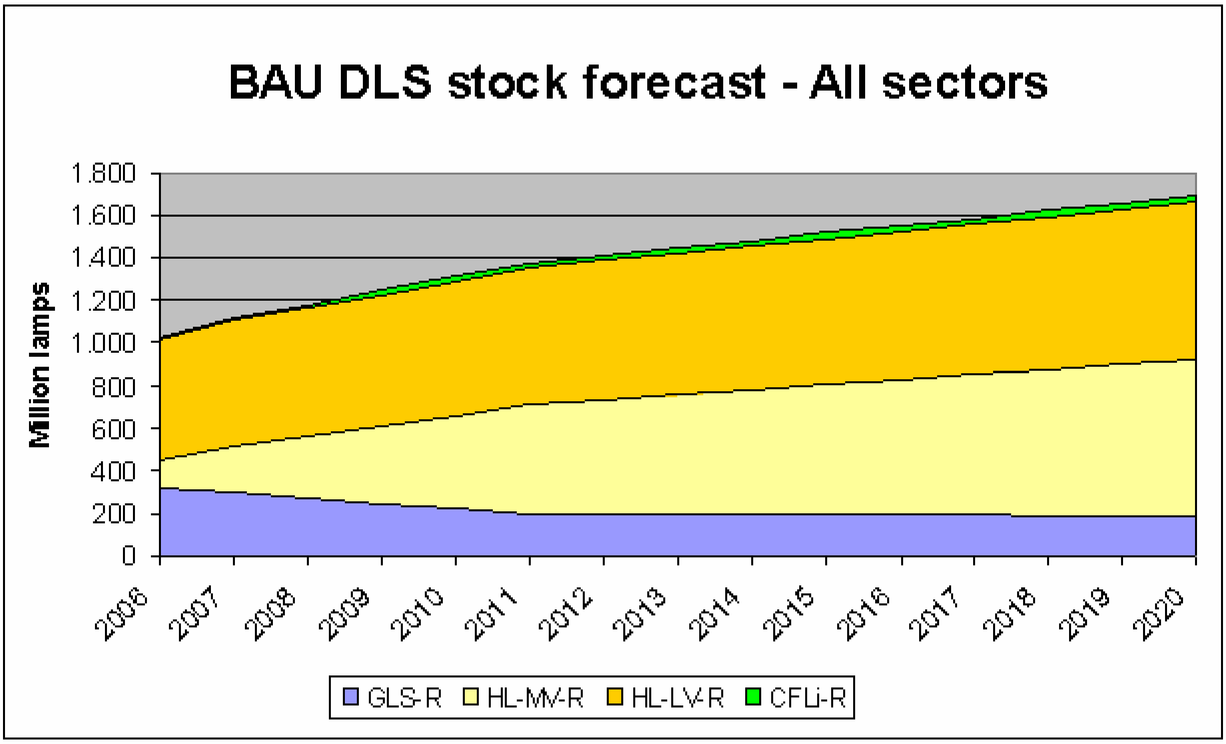

Figure 2-3: Business as Usual (BAU) forecast of the DLS stock including all sectors

Figure 2-4 shows that even without any legislation, the market share and the stock of GLS-R are relatively small and decreasing, falling from 31% in 2006 to 11% in 2020. The potential for energy efficiency primarily concerns the market share of halogen reflector lamps.

Following the assumption in section 2.2.3, the forecast of stock of luminaires is estimated to be 85% of the total number of lamps (NDLS+DLS). The amount of luminaire sales in the non-domestic sectors is assumed to be between 1.5 - 2 times the sales in the domestic sector (see section 2.1.3).

2.3 Market trends

2.3.1 General product design trends and features from marketing point of view

The number of lamps and luminaires are growing because of:

- Installation of more light sources (trend) along with the growing welfare;
- Central & Eastern EU expand their use of lighting most likely to a level similar to the rest of EU;
- Increasing living space per capita because of a growing number of people living alone;
- Shift to reflector halogen down-lighting typically includes a shift from one or two lamps to line(s) of lighting points.

One could fear that there is no natural limitation on this growth rate because the eye is able to adapt to a broad luminance range and daylight levels are by far not yet reached in domestic lighting.

Complaints about glare and/or overheating of the room due to the use of some of these new halogen reflector lamps might slow down this growth rate. These problems are already experienced in shop lighting, hotel receptions and new glossy kitchens with reflector lamps – they have sometimes . resulted in the installation of additional air conditioning. The overheating could also be reduced by using a cold mirror coating design for the reflector in order to transmit the IR radiation back towards the reflector[133].

The halogen market is expected to saturate in the future with a shift to energy efficient solutions by LED-R or CFLi-R, which are currently more expensive lamps and/or with lower performance (the beam angle performance for the CFLi-R is low) compared to the halogen lamps. Improvement of the performance plus the rate of price reduction will determine the development in the shift.

Within the halogen market, there is a trend of a market shift from HL-LV (12 V) to HL-MV (230 V), mainly because the installation work is easier without a transformer. This is documented by ELC sales in Table 2-5 and Table 2-6 showing a larger increase in low wattage HL-MV sales. Domestic customers in Belgium, Italy and UK already have a high stock of HL-MV-R lamps.

[133] Comment by Auer Lighting.

The above BAU forecast includes therefore increases in halogen lamp sales of 9.3%/year for HL-MV and 1.4%/year for HL-LV for the period 2007-2020.

The Light&Building 2008 fair in Frankfurt, newsletters and other exhibitions show that both European and Asian manufacturers are very inventive at a very high speed concerning LED-R and CFLi-R.

The number of luminaires is growing as the number of lamps is growing. Besides this trend, the use life time of the luminaires seems primarily to depend on changes in fashion. Technically there is nearly no limitation on the life time of a luminaire; they can even be found in antique shops.

Domestic lighting purchase process by the DIY customers

The current domestic lighting purchase process mainly takes place in the retail market. The customer buys luminaires and lighting sources in lamp shops, furniture stores (e.g. IKEA), building market/do-it-yourself shops and supermarkets. A questionnaire concerning the availability of reflector lamps in different shops was sent to the partners in the EU R&D projects Enerlin and REMODECE. The answers are shown in
Table 2-17.

Table 2-17: Where can the user buy reflector lamps?

			GLS				Halogen reflector Low Volt.								Halogen reflector MV								CFLi reflector lamps							
EU region	Country	Number of house	GLS Reflector				GU4 + GU5.3				G53				E14, E27, B14d, B22d				GU10, GZ10				E14, E27, B14d, B22d				GU10, GZ10			
		millions	LS	IK	BM	SM	LS	IK	BM	SM	LS	IK	BM	SM	LS	IK	BM	SM	LS	IK	BM	SM	LS	IK	BM	SM	LS	IK	BM	SM
Central and Eastern EU	BG	3,7	1				1				1				1				1				1	0	0	0	1	0	0	0
	CZ	4,40	1	1	1	1	1	0	1	1	1	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0
	CY	0,32																												
	EE	0,60																												
	HU	4,10																												
	LV	0,97	1	1	1	1	1	0	1	1	1	0	0	0	1	0	1	0	1	1	1	0	1	0	1	0	1	0	1	0
	LT	1,30																												
	MT	0,13																												
	PL	13,30	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	0	1	1	1	1	1	0	1	0	1	1	1	1
	RO	8,13	1	1	1	1	1	1	1	1	1	0	0	0	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0
	SK	2,10																												
	SI	0,69																												
Middle EU	AT	3,30																												
	BE	4,30	1			0	1	1	1	1					1			0	1		1	0	1			0	1		0	0
	FR	32,20																												
	DE	39,10	1	1	1	1	1	1	1	1	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1	0	1	0	1	0
	EI	1,44																												
	LU	0,20																												
	NL	7,00																												
	UK	26,20																												
Northern EU	DK	2,50	1	0	1	0	1	1	1	1	1	0	0	0	1	0	1	0	1	1	1	1	1	1	0	0	1	0	0	0
	FIN	2,50																												
	SE	4,50																												
Southern EU	GR	3,70	1	1	1	1	1	1	1	1					1	1	1	1					1			0	1	0	0	0
	IT	22,50	1	1	1	1	1	1	1	1	1	0	0	0	1	1	1	1	1	0	0	0	1	0	0	0	1	0	0	0
	PT	4,20	1	1	0	0	1	1	0	1	1	1	0	1	1	1	0	1	1	1	0	1	1	1	0	1	1	1	0	1
	ES	17,20																												
TOTAL			11	8	8	7	11	8	9	10	9	2	1	1	11	6	7	5	10	6	6	5	10	3	3	1	9	2	3	2
			LS = lamp Shop																											
			IK = IKEA or similar																											
			BM = Building Market																											
			SM = Supermarkets																											

Table 2-17 shows:

- Nearly all reflector lamps are available in lamp shops,
- GLS-R is available in most shops,
- HL-LV-R (GU4 and GU5.3 cap type) is available in most shops,
- HL-MV-R is available in 50% of the shops,
- CFLi-R is currently only available in 25% of the shops.

LED-R was not included in the questionnaire since the product is not yet available in many consumer shops. Concerning the future shift to more energy efficient lighting, it is important that CFLi-R and LED-R solutions become available in all shops along with awareness campaigns.

The consumer seems to buy his luminaires primarily in DIY shops and installs the luminaires himself. In cases where light distribution matters and consumers rely on DIY shops they simply purchase luminaires for reflector lamps that can be oriented (these statements are impressions from discussion of these topics with people involved in this business).

Domestic lighting purchase process by professionals

A smaller amount of luminaires (in some countries like Italy a larger amount) is bought from architectural lighting manufacturers and is installed by professionals upon the specification of a lighting designer or architect. Some manufacturers of architectural lighting provide the photometric data that can be used in software simulation tools (see lot 8 and 9).

With growing welfare, many people are installing new kitchens, bathrooms or are adding verandas to their home. In this process, the designers, home decorators, installers or qualified electricians have a large influence by including lighting solutions in their projects. Many furniture and appliance manufacturers are even including lighting in their products, and this market seems to be dominated by halogen, down lighting reflector lamps. From 1995 until 2007, this has caused a shift from few GLS to a multitude of halogen lamps as can be seen in section 2.2.2 and Table 2-12. It has become fashionable to use a number of halogen reflector lamps in down lights for general illumination of kitchen, bathroom, corridor, hall, bed room and even living room. Typically 35W or 50W, 24 degree HL-LV or HL-MV are used. In several of these places, the directional light is inadequate to provide enough general lighting and therefore additional lighting might be added. Dimmers are also frequently used to be able to reduce the light output from down lighters that can cause discomfort glare.

The professionals often install ceiling and wall fittings/luminaires as a part of their installation work.

Global lighting production market

The global lighting-product manufacturing industry is made up of many enterprises ranging from large multinational private companies that manufacture a broad range of lighting products to small single-product firms publicly or privately owned. (IEA, 2006).

When viewed as a region, the European Union is the world's largest producer of lighting equipment in terms of value, although China is about to surpass the EU in terms of volume (IEA, 2006). The European lighting manufacturing industry has annual revenues of about EUR 13 billion, of which EUR 5 billion (USD 6.2 billion) originates from lamp manufacturers (ELC, 2005 in IEA, 2006) and EUR 8 billion from luminaires, ballasts and associated electrotechnical equipments (CELMA, 2005 in IEA, 2006).

Lamp manufacturers are represented by the European Lamp Companies Federation (ELC), which includes among its members Philips Lighting, OSRAM, GE Lighting, Aura Lighting Group, BLV, Leuci, Narva and Sylvania Lighting International (SLI). The European activities of these companies employs roughly 50,000 people and produces annual revenues of EUR 5 billion[134] (IEA, 2006). ELC claims to represent 95% of the total European lamp production but their part of the sales is much smaller as a considerable part e.g. of the CFLi sales is covered by retailers that import directly from China.

Manufacturers of luminaires and electrotechnical parts for luminaires are represented by CELMA. The 16 national member associations of CELMA represent some 1,200 companies in 11 European countries. These producers, which include many SMEs, directly employ some 100,000 people and

[134] http://www.elcfed.org/index.php?mode=0

generate EUR 8 billion annually. CELMA claims to supply more than 90% of luminaires and associated electrotechnical parts for the EU market (IEA, 2006).

Market shares and competition

Lamps are a globally traded commodity and there is a high degree of standardisation between international lighting markets. The lamp market is highly concentrated, with a limited amount of players and thus financial power in the marketplace, whereas the luminaire market is very fragmented.

For several decades four major multinational lamp manufacturers have dominated the international lamp market:

- Philips, based in the Netherlands
- OSRAM, based in Germany (also present in the United States as Sylvania)
- General Electric, based in the United States.
- Sylvania, based in Europe, recently renamed Havells Sylvania.

While these companies have a strong presence in almost all global markets, their strength appreciably varies in the different sectors and regions (IEA, 2006).

Shifts to a higher degree of use of CFLi-R and LED-R will result in a large import of lighting products from China.

According to Eurostat data for 2007, the EU-27 Member States with the largest luminaire production market share are:

- Italy 21%
- Germany 11%
- Spain 11%
- UK 7%
- France 5%.

Remark: Not all country data are available at Eurostat because some countries have classified them as confidential while other country data are not available and are estimated by Eurostat.

2.3.2 Duration of redesign cycle and market lifetime of the EuP

For these aspects, domestic lighting products are discussed as consisting of two essential parts:

- the light source, in some cases including its control gear,
- the luminaire as a holder for lamp and control gear.

Both parts have different redesign cycles and different market lifetimes.

2.3.2.1 Redesign cycle for a light source

The duration of a redesign cycle for a light source depends mainly on technology and it can last from several months to more than 50 years from first idea to functioning technology and working prototype. The redesign cycle will always include the long term reliability testing.

If it is only a question of amelioration of known, patent free technology, the main factor is lifetime testing: the maximum number of possible burning hours per year is about 8.000. A conversion of the production lines with possible investment decisions can extend this period.
Manufacturers are continuously working on ameliorating their products in such a way that the new product can replace the old one, without changing luminaire or control gear.

For example the low voltage, pin based halogen lamp was introduced in the seventies of the previous century and pleased the designers and customers by its bright, small appearance. Infrared reflecting coating in lamp production was already applied in low pressure sodium lamps in the beginning of the years 1980. It took about a decade to introduce this technology in the low voltage halogen lamps production; the results in energy savings are significant (for more information see chapter 6).

A similar example is the compact fluorescent lamp with integrated ballast that was globally introduced in the early 1980's and which is still continuously being ameliorated to replace a (frosted) incandescent lamp. The first lamp was fairly large and heavy with magnetic ballast and low R_a. New lamps are smaller, have lightweight electronic control gear, a colour rendering $80<R_a<90$ and finger, spiral or GLS look-alike forms (see chapter 6).

The LED is an example of an important technology change. The light emitting diode was invented in 1907.Research was discontinued because the light yields were extremely low, but in 1962 a team from GE demonstrated the first LED. 6 years later LEDs were first commercialised and used as red-light indicator lamps and electronic displays. Very bright red, yellow and green LEDs were produced in the 1980s. In the mid-1990s blue LEDs were developed. During the next years this led to development of WLED and its introduction as a 'general' light source[135].

2.3.2.2 Redesign cycle for a luminaire

A luminaire for domestic lighting is mostly intended to hold the light source and its possible control gear and to embellish the 'home environment'. The redesign cycle depends on the technological changes of light sources, fashion, the creativity of the designer and the production cycle. Changing production lines, finishing up available stocks of spare parts and new purchase contracts are the most influencing parameters. This cycle can be short e.g. some months after a decision or after the introduction of a new light source.

2.3.2.3 Market lifetime of a light source

It is not always easy to determine the market lifetime of a light source and its possible control gear.
A clear example of a long market lifetime is the incandescent lamp that was invented in 1879.
After its introduction on the market (almost 130 years ago), various improvements were performed: the carbon wire was replaced by a tungsten wire, the vacuous bulb was first filled with an inert gas such as nitrogen and later in some cases with argon or krypton.

Also the halogen lamp is a special type of incandescent lamp where the filling gas contains halogen or xenon. The first halogen lamps came on the market in the years 1960 in the known form with R7s-cap. It was introduced originally for its improvement in lamp lumen maintenance, and was later recognised for its ability to improve lifetime and efficacy.

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135 The history of LEDs is a short summary of the description in Light's Labour's Lost, IEA, 2006

The smaller size low voltage halogen lamp that was introduced in the years 1970 stays on the market, although a better technology, the infrared coating, is available on the market. The end of the product life of the non-IRC halogen lamps will mainly depend on retail price and sufficient availability on the market; the fact that these new IRC-lamps are more energy-efficient doesn't seem to influence the consumers so much when the price stays high.

For CFLi's, the market lifetime is dependent on the meaning of 'product'. The first generation of compact fluorescent lamps can be considered a different product from the current CFLi's. These first generation lamps have even completely disappeared from the European market due to the better quality, shape and price of the new generation. At this time, the new generation lamps are being continuously ameliorated, but basically the product has not changed. It is very difficult to determine a product's market lifetime as the 'product' itself is not clearly determined.

It might be reasonable to operate with a market lifetime of maximum 20 years for any product.

2.3.2.4 Market lifetime of a luminaire

For the market lifetime of a luminaire (the period during which a luminaire is available for sale), a subdivision has to be made between:

- Classic, highly fashinable or traditional luminaires like crystal luminaires, bronze luminaires etc.
- Design, trendy and low price luminaires.

For the first small category, the market lifetime does not expire; manufacturers will only change details, but the basic model almost lasts for 'eternity'. The second and largest category, that is fashion dependent, has rarely more than a maximum market lifetime of 3 years as lighting designers like to renew their products as frequent as possible to be trendy.

For some special applications such as Christmas lights, the market lifetime can even be only one season, especially nowadays that LED's are entering the market for this purpose.

As a consequence, a uniform lifetime for domestic luminaires can hardly be given. A weighted average market lifetime of a luminaire of 3-4 years can be assumed.

2.4 Consumer expenditure data

2.4.1 Product prices

Eurostat data are not suitable for estimating product prices (luminaires, lamps, ballasts, other replacement parts). For product prices, we therefore used manufacturers' catalogues. Taking into account that the prices displayed in these catalogues are for retail trade, realistic assumptions for the prices of different lighting parts were made based on the experience of the market, e.g. consultation of small and large retailers, advertising brochures etc.

Chapter 4 gives specific retail prices for domestically used DLS lamps are; that prices can also be found in Table 2-31.

Table 2-18: Typical EU-27 retail prices for DLS lamps for domestic use

Lamp type	Lamp specification and cap	Price in €
GLS-R	R63, E27 (B22d)	1.3
HL-MV-R	R63, E27 (B22d), xenon	3
	PAR20, E27 (B22d)	13
	PAR20, E27 (B22d), IRC+TRAFO	26
	MR16, GU10	3
	MR16, GU10, xenon	7.5
HL-LV-R	MR16, 12V, GU5,3	1.5
	MR16, 12V, GU5,3, IRC	7
	R111, 12V, G53	9
	R111, 12V, G53, IRC	12
CFLi-R	R50, GU10	8
	R63, E27 (B22d)	8

Product prices for lamps can also include taxes or recycling contributions that can differ from country to country, some examples are included hereafter.

Denmark has taxation on lighting sources added to the sales price:

- CFLi no tax
- GLS 3.75 DKK (= 0.5 Euro)
- Fluorescent tube 7.5 DKK (= 1 Euro)
- Halogen low voltage 0.75 DKK (0.1 Euro)
- Halogen 230V 3.75 DKK (= 0.5 Euro)
- Metal halogen 7.5 DKK (= 1 Euro)
- Emission lamp 7.5 DKK (= 1 Euro)

The Danish taxation is basically a tax to collect state income but also an energy efficiency effort since there is no tax on CFLi's - nevertheless there is a tax for fluorescent tubes and metal halide lamps although these lamps are very energy efficient.

According to a decree-law of April 12, 2007 *Portugal* has such an added cost or 'tax' for low energy efficiency lamps to compensate for environmental influence from this type of lighting. The tax is calculated based on the following parameters: electric power and life cycle of the lamp compared to energy efficient lamps and the average value of CO_2 emission factor and cost for Portugal. The tax income will feed the Portuguese Fund for Carbon (80%) and the Energy Efficiency Fund (20%).

Several countries have an added 'disposal/recycling' contribution that is included in the sales price. For example *Belgium* has a WEEE directive specifying that a cost is added to the sales price for recycling. It is not a tax since it is not raised by the government but a contribution to take care of the recycling. The cost per lamp is at present € 0.30 and is added for CFL, LFL and other discharge lamps while there is no cost for GLS and HL. For more information on recycling schemes and costs in other EU-27 countries please consult www.weee-forum.org.

For luminaires, production costs and used materials vary greatly and are almost only dependent on decorative aspects. The luminaire market price variation is from 4 to 2000 €. For more information about luminaire prices please see chapter 4. In line with the system approach explained in chapter 1 only the minimum extra cost (if any) will be taken into account in this study.

2.4.2 Electricity rates

Electricity costs account for an important part in the domestic lighting costs: according to IEA[136] lighting amounts up to 79% of the total cost. Electricity rates (euro/kWh) are subject to fluctuations due to recent market liberalisation.

Eurostat regularly reports on electricity prices for domestic household consumers are shown in Table 2-19 below.

[136] Source: IEA, 2006

Table 2-19: Electricity prices for domestic customers137

EU region	Country	Number of households	Electricity price for hh customers using 3500 kWh/year
		millions	€/kWh by 1/1 2007
Central and Eastern EU	Bulgaria (BL)	3.7	0.0658
	Czech Republic (CZ)	4.4	0.1067
	Cyprus (CY)	0.3	0.0796
	Estonia (EE)	0.6	0.075
	Hungary (HU)	4.1	0.1222
	Latvia (LV)	1.0	0.0686
	Lithuania (LT)	1.3	0.0777
	Malta (MT)	0.1	0.0895
	Poland (PL)	13.3	0.1184
	Rumania (RO)	8.1	0.1018
	Slovenia (SK)	2.1	0.1537
	Slovakia (SI)	0.7	0.1064
Middle EU	Austria (AT)	3.3	0.1545
	Belgium (BE)	4.3	0.1581
	France (FR)	32.2	0.1211
	Germany (DE)	39.1	0.1949
	Ireland (IE)	1.4	0.1662
	Luxembourg (LU)	0.2	0.1684
	The Netherlands (NL)	7.0	0.218
	United Kingdom (UK)	26.2	0.1323
Northern EU	Denmark (DK)	2.5	0.258
	Finland (FI)	2.5	0.116
	Sweden (SE)	4.5	0.1714
Southern EU	Greece (EL)	3.7	0.072
	Italy (IT)	22.5	0.2329
	Portugal (PT)	4.2	0.15
	Spain (ES)	17.2	0.1225
EU27 average (weighted by hh)		**210.6**	**0.1529**

2.4.3 Repair, maintenance and installation costs

Lamps are currently considered as replacement parts for luminaires because lamp lifetime is typically shorter than the luminaire lifetime. LED's lamps that last as long as the luminaire change this point. The LED technology is considered in chapter 6.

Domestic customers are typically doing installation, maintenance and shift of lamps and luminaries themselves but are often not able to do maintenance/shift of more complicated outdoor or ceiling luminaries installed by professionals when building or rebuilding the home.

Many people are installing new kitchens, bathrooms or are adding verandas where installation of new luminaries is an integral part of the rebuilding. In this case, it is not necessary to include installation costs as the customer is doing this rebuilding anyway and it is part of a total package.

[137] Eurostat collects regularly data for 5 categories of domestic consumption, ranging between annual consumption 600 kWh to 20,000 kWh. Here is used "medium size household" (3,500 kWh/year)

Replacement of lamps is mostly done by the domestic user and hence no labor cost will be taken into account. Repair, maintenance of replacement of luminaires, are typically also done by the domestic user but for some ceiling and outdoor luminaires installed during the construction, the replacement might be so difficult that the customer needs to hire a professional to do this; in that case the cost might be very high and is thus unpredictable.

The replacement of luminaires is sometimes done by a professional installer, frequently in combination with other construction or renovation work (e.g. new kitchen installation). A UK market research report on domestic lighting[138] showed that 39% of the domestic luminaires (especially ceiling mounted and outdoor) were installed by qualified electricians. Hence in some cases installation costs for luminaires should be taken into account.

For improvement options in later chapters no installation or maintenance costs were taken into consideration when the luminaires are not supposed to be replaced before their end of life.
For improvement options where a professional installer is absolutely required to replace a luminaire, the average hourly labour cost of €21.22, representative for EU25 (source Eurostat, data for 2004). As this cost is five years old, an updated average hourly labour cost of €25 is used.

- Hourly labour cost = €25

2.4.4 Interest and inflation rate

EU-27 averages for interest rate and inflation rate are published by ECB and Eurostat:

- Interest rate = 3.9 % (source ECB[139])
- The Inflation rate was 2.1 % (source Eurostat[140]) in 2007 at the start of this study. Since then, the inflation rate has risen up to 4 % and returned back down to 2 %. Under the present circumstances, it is very hard to forecast the inflation rate.

Please note that these values can vary on a monthly basis and are related to currency (Euro-zone and outside Euro-zone member states).

[138] Domestic Lighting Report, Lighting Association, UK, 2008.
[139] ECB long-term interest rate; 10-year government bond yields, secondary market. Annual average (%), 2005
[140] EU-27 Annual Inflation (%) in Dec 2005 Eurostat "Euro-Indicators", 7/2006 - 19 January 2006.

3 CONSUMER BEHAVIOUR AND LOCAL INFRASTRUCTURE

Consumer behaviour can -in part- be influenced by product-design but overall it is a very relevant input for the assessment of the environmental impact and the Life Cycle Cost of a product. The scope of this chapter is to identify barriers and restrictions to possible eco-design measures, due to social, cultural or infra-structural factors. A second aim is to quantify relevant user-parameters that influence the environmental impact during product-life and that are different from the Standard test conditions as described in section 1.2.

3.1 Definition of the Consumer and context

For domestic lighting it is important to discriminate between the two types of customers who purchase lamps and luminaires:

4. The person responsible for the putting into service of a new house/flat or renovation of parts of the home, e.g. interior designers, property developers, kitchen and bathroom designers and installers, hereafter called the *'service providers'*. Please note also that more and more appliances are including lighting, e.g. extractor fans in the kitchen in which case a service provider is also involved. Interior designers and/or lighting architects are thus having a growing influence and some decisions are taken in the same as in some parts of the tertiary sector.
5. The consumer who lives in the home and makes use of the lighting equipment, hereafter called the *' user'*.

In the domestic lighting market the 'service provider' and 'user' can be the same, especially when Do-It-Yourself (DIY) equipment is bought and put into service by the user as a DIY consumer.

Nevertheless, the ’service providers’ is often not the user. They have a growing influence on energy used in the domestic homes because with growing welfare, many people install new kitchens, bathrooms, corridor, adding a veranda etc. In this process, the designers, home decorators, installers or qualified electrician have a large influence by including lighting solutions that are typically outdoors, installations in the ceiling, and sometimes even more. Some of those furniture and appliance manufacturers include lighting in their products, and this market is dominated by a multitude of down lighting by reflector lamps actually mainly of the halogen type. The lighting is an integral subcomponent of the design and installation process where the customer buys “the whole package” including lighting. In this case both service providers and the consumers take decisions that affect the quality, cost and efficiency of lighting in the home. In case service providers tender and win jobs on having low costs while not having to pay any future operating costs there is a ‘split incentive’: there is no incentive for service providers to purchase high efficiency lighting because it usually has a higher first cost and may mean they aren't awarded the contract.

It should be noted that the lamps and luminaries within the scope of this study are also used in lighting for the tertiary sector (e.g. Horeca sector, shops). In this sector, service providers are typically involved and often also lighting designers performing calculations. The process is similar to what is described in the preparatory study concerning office lighting (Lot 8). Please see this study[141] for description of this service approach – in contrary to domestic circumstances photometric data for 'architectural lighting luminaires' for offices is available for the service provider and lighting designer. In general, the tertiary sector is more conscious of full life-cycle costs and thus manufacturers tend to enter that market first with higher first-cost products with lower overall operating costs. The products then migrate to the domestic sector, as manufacturers perfect their designs and technology and lower the production costs.

3.2 Real Life Efficiency and quantification of relevant parameters

3.2.1 Background info on lighting design criteria

The concept of energy-efficient lighting is meaningless unless the lighting system provides the conditions necessary to perform the task. The goal in designing a lighting system is to provide a suitable visual environment that provides "right light at the right time at the right place".

The main objectives for installing electric lighting systems are:

- Facilitating the performance of visual tasks
- Promoting safety and security
- Attractively revealing the environment – create atmosphere
- Participating in the interior design of the household by attractive design of lamp or luminaire.

The priority of the above objectives in the design process depends on the specific situation and the preference of the user. Moreover, if the object is three-dimensional or coloured, the direction of the incident light or its colour rendering properties becomes important determinants of visibility.

In the domestic sector all the design is up to the consumer in contrast to the commercial sector using lighting codes and standards for satisfactory visual performance.

[141] VITO EuP Lot 8, Office Lighting, Final Report, April 2007.

Considering usefulness and effectiveness of DLS, it is essential to choose the correct beam angle and field angle for cover of a kitchen work surface or highlight a painting on their wall.

3.2.2 Lumen losses within luminaries

For *luminaires with DLS lamps* nearly all luminaires found on the market do not obstruct the functional lumen output from the lamp as defined in Task 1 (functional unit) (see Figure 3-1). Hence for these luminaires there is simply no improvement potential related to lumen losses. Please note that this might to some extent explain the popularity of those DLS lamps (see chapter 2). The LOR (Light Output Ratio) of those luminaires is 1.

Figure 3-1 DLS luminaires have most often LOR=1

For luminaires with NDLS lamps there is a broad spread on lumen losses within luminaires (LOR) (see Figure 3-2). The LOR for these luminaires can vary from below <0.1 up till 1 (bare lamp holder).

Figure 3-2 Domestic luminaire for NDLS: left with LOR <0.1, middle[142] *LOR > 0.5, right >0.99*

Notes on luminaire LOR (Light Output Ratio):

- Both the visual appearance and the lumen losses within luminaires are optimal when the luminaire is designed for the lamp type used in the luminaire. It is therefore important that luminaire manufacturers bring luminaires on the market that are dedicated to the lamp type so the customer is aware of combining luminaire and lamp in the best way. Hence LOR can vary in real life if another lamp type or shape is used in the luminaire.
- The right energy efficient luminaire will balance: maximum light output ratio, glare control, light distribution and amount of decorative ornaments that absorb light.
- It should be noted that the LOR improvement potential for functional luminaires that are used in the tertiary lighting sector were assessed in preparatory studies on office and street lighting (lot 8 and 9). All those luminaires have an optical system to control the light distribution. This information and approach will not be repeated in this study.
- Lumen losses can be compensated with a coating material combination with high reflectivity itself and a specified coating design for the reflector. Typical efficiency of the reflector (DLS) within the light field varies between 60% and 80%, depends on the reflector type, coating and light source.[143]
- In case of LED luminaires with integrated lamps, only LER can be used (see chapter 1 for definition of LER).
- The main parts (e.g. lamp cap) that influence LOR and light distribution are often sold separately (see Figure 3-3).

[142] Lesslamp by Jordi Canudas (b. 1975 Barcelona, Spain): The Less Lamp is a sealed lamp shade that needs to be broken in order to release the light trapped within. The shell is cracked using a specially designed hammer. The user decides the appearance and position of the hole depending on how much light is required and where it is to be directed.

[143] Information provided by Auer Lighting.

Figure 3-3 Domestic NDLS luminaire (LOR=1) that optionally can be equipped with a lampshade (LOR<1). The lampshade prevents glare and influences light distribution.

3.2.3 Illumination losses in the task area by lack of lighting design

For performing a visual task, maintaining a minimum illumination level in the task area is essential, moreover glare should be prevented and the uniformity should be kept within acceptable limits. This is the typical approach for a professional lighting design within the tertiary sector as explained in the preparatory study on office lighting (lot 8). Domestic lighting is typically not related to measurable lighting levels, so it is primarily up to the consumer's requirements of functionality and creating atmosphere. Luminaire efficiency has thus no impact on selection choice for the vast majority of users. For domestic luminaries used over a long period, the appropriate lamp choice will change according to the location and use of the luminaire, as well as when the user grows older and requires more light for the same task. Fashion lighting is replaced according to personal choice. In neither situation will there be a single lamp rating that will be "correct" unless it forms a physical part of the appearance or operation of the luminaire.

Increased domestic use of DLS with dimmers instead of NDLS create the ability to control light with distinct variations between light and dark that might allow screen based entertainment with better viewing conditions. This increases the number of lamps but not necessarily the electricity consumption depending on the behaviour of the consumer. In this case, simultaneous use of all the lighting sources will likely produce unpleasing lighting conditions.

Nevertheless, professional lighting designers are seldom involved in domestic lighting and many common practices found in domestic lighting cause a loss of illumination[144]. Following are two examples of how reflector lamps are used in domestic sector that illustrate the opportunity for improvement in this area.

Example 1 Poor application for reflector lamp – DLS used as NDLS:

[144] PLDA agrees that there is a lot of thoughtless application of multiple down-lights in new build and refurbishment and this needs to be controlled - they see this as a design issue not a technology issue.

Many reflector lamps are used for general lighting (as NDLS) without making use of the lighting that is limited to a specific beam angle. On the contrary, there might be areas not lit properly where the users thus install extra lighting.

Example 2 Optimum use of reflector lamps (DLS):

In this case a series of spot lamps with adjustable lamp holders are installed in the ceiling. This allows the user to control and fine tune the light in the desired direction e.g. towards the wall behind the sofa or at the table and away from the TV set. The "optimum" installation might also be dimmable so that the user can adjust lighting levels optimally for changing needs in the living room (e.g., watching TV vs. reading). This is a very common practice in the modern living room and is part of the explanation for the growth in use of DLS (see chapter 2).

3.2.4 Room surface reflection

The room surface reflection can have a significant influence on the illumination level in the task area, for more information see the preparatory study on office lighting (Lot 8)[1]. The improvement potential (e.g. using white painted walls) is outside the product scope of this study.

3.2.5 Lamp efficacy and sensitivity of the human eye

Please see chapter 3 in the final report for part 1 of the study and the new mandatory regulation 244/2009.

3.2.6 User influence on switching schemes (annual operating time)

Please see chapter 3 in the final report for part 1 of the study.

3.2.7 Lamp dimming

Please see chapter 3 in the final report for part 1 of the study.

3.2.8 Influence of the power factor and harmonic currents of a light source

Please see chapter 3 in the final report for part 1 of the study.

3.2.9 Influence of voltage change

Please see chapter 3 in the final report for part 1 of the study.

1

3.2.10 Decrease in lamp efficacy in real life operation compared to standard conditions

The lamp efficacy that is announced by manufacturers is measured after an ageing period of a number of hours burning in standard conditions as defined in the specific European standard on performance requirements for the lamp type (see chapter 1).

Due to normal ageing and deviation from lamp specification conditions when placed in a luminaire, the efficacy might be influenced – this is certainly the case for a LED luminaire.

3.2.10.1 Lumen depreciation over the life time

For all lamps except LED please see chapter 3 in the final report for part 1 of the study.

WLED retrofit lamp

For most light sources, the lamp fails before significant lumen depreciation occurs while LEDs continue to operate also at very low light levels. Therefore LED lifetime is usually defined as lumen depreciation to a certain level e.g. 70% of initial lumens (abbreviated as L70 or L_{70}) together with a particular failure rate e.g. B50 (also known as F50) (50% failure rate, see also chapter 1 and figure 3.7).

The LED industry group ASSIST[145] (Alliance for Solid-State Illumination Systems and Technologies); stated that 70% lumen maintenance is close to the threshold at which the human eye can detect a reduction in light output. LED manufacturers publish lumen depreciation curves based on testing of their products, extrapolating lumen depreciation to the 70% level because it takes too long to measure. For LEDs, this threshold might be too low because people will age by more than ten years within the long LED lifetime and people lose sensitivity of their eye with age.

Depending on the application, other depreciation levels may be appropriate as end of life limits, such as L_{50} or L_{80}.

The standard IESNA LM-80-08 – Approved Method for Measuring Lumen Maintenance of LED Light Sources (released 2008) applies to LED arrays, packages and module but **not** luminaires. It includes a test method for $L_{70,}$ including photometric measurements at three temperatures 55°C, 85°C and XX°C (the manufacturers own choice) and a test duration of minimum 6,000 hours with measurements at 1,000 hour intervals. This standard does **not** provide guidance regarding predictive estimations or extrapolation. IES TM-21-xx which is currently under development will address this topic.

Figure 3.4 shows an example of a LED **predicted** lumen maintenance curve for a warm white LED[146] in operation at drive current 700 mA with junction temperature at or below 120°C where the lumen depreciation starts right from the start and 80% depreciation occurs already around 1100 hours and 70% occurs around 25,000 hours.

[145] Details about ASSIST can be found at www.lrc.rpi.edu/programs/solidstate/assist/index.asp
[146] Atlas Lamina Series LED Light Engines, FM-0167, rev. 02.14.2007.

ELC informs[147] that especially in LED retrofits, driver components experience high temperatures as they are hidden inside or next to the heat sink. Thus, lifetime can be limited by a sudden driver failure when components like capacitors reach their end-of life. This must be taken into account when defining lifetime. Concerning lifetime stated on the package, ELC claim that manufacturers should be obliged to provide lifetime estimations or elevated-temperature measurements that predict a driver lifetime.

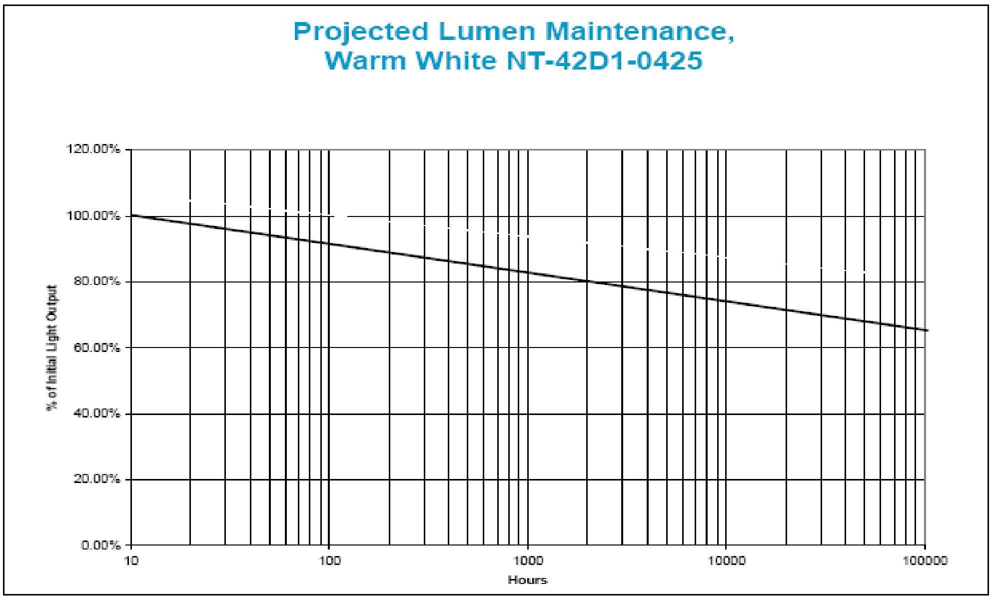

Figure 3-4: Predicted LED lumen maintenance curve for a warm white LED Source of a relatively lower quality: Atlas LED Light Engines, www.laminalighting.com

Figure 3-5 shows a **measured** LED lumen maintenance curve for the first 6000 hours provided by one of the large manufacturers[148] where 92% depreciation occurs at 6000 hours

[147] ELC comments to the first draft of the chapter.

[148] PHILIPS Technology White paper: Understanding power LED life analysis, *www.philipslumileds.com/pdfs/WP12.pdf*

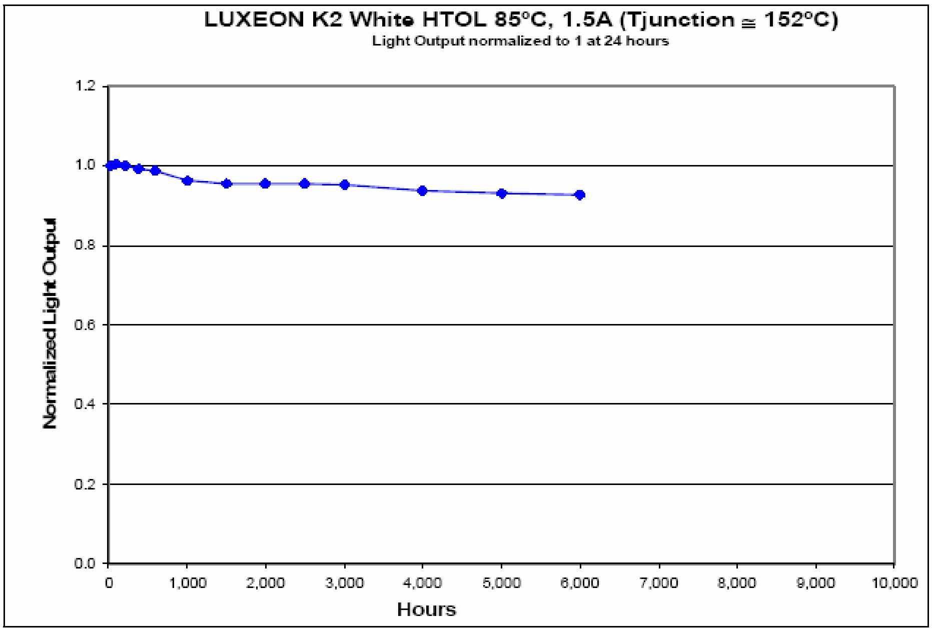

Figure 3-5: LED lumen maintenance curve for Philips Lumileds K2 LED (high quality)

The LED depreciation varies a lot depending on the quality of the product.

Conclusion

The LED chip has a lifetime of at least 50,000 hours in most application situations but as informed by ELC[149] the lamp lumen maintenance depends primarily on the materials surrounding the chip: epoxy coatings will typically not survive 10,000 hours and plastics materials in the housing tend to show browning of materials in the light path (epoxy, silicone) that will gradually decreasing light output and often with an avalanche-type browning that may lead to almost complete shadowing e.g. after 7,000 hours. In the end, only qualified lifetime data on all the components included can give a clear indication of predicted lifetime.

For the LED, a depreciation factor of 0.95 for the first 6,000 hours and 0.85 for the first 25,000 hours is good quality. For the LED lamp, the factor might be much lower depending on the use of materials besides the LED chip.

Integrated LED luminaires

This section is based on the large amount of American data available publicly and some rather new data European data provided in relation to stakeholder meeting or presented at recent conferences. The main purpose of chapter 3 is to present the quality issues from a consumer perspective. Quantitative European LED lamp data used in our calculations (see chapter 7 and 8) are shown in chapter 4 and 6.

Rated output for LED chips and LED lamps is often quoted at a temperature of 25°C which is very different from operation in a LED luminaire where the junction temperature typically

[149] ELC comments to first draft of this chapter.

will be in the interval 60-150°C. A LED manufacturer[150] informs that high thermal impedance (poor thermal conductivity) from the LED chip to the heat sink will lead to elevated junction temperatures and this will have a profound effect on lifetime and ageing characteristic of the LED. They inform that thermal resistance of a properly designed dedicated LED luminaire might be in the range 0.5 to 1°C per watt and it is possible to operate luminaires with LEDs that self-heat to only a little above ambient temperature and nowhere near the junction temperatures quoted above. Test specifications and procedures must relate to continuous operation in still air conditions e.g. a recessed downlighter would be designed to be installed in a ceiling and maybe covered with insulating material.

A European business manager[151] reports that good thermal management is the key for successful LED lighting design as both lifetime, light-output, efficiency and colour stability are directly linked to the temperature. They report the rule of thumb that every 10°C temperature rise will half the lifetime.

The DOE CALiPER program[152] began reliability testing on LED luminaires in August 2007. Figure 3-6 summarize lumen depreciation interim testing results for 13 LED products. The lumen depreciation testing is not completed for these samples, but these interim results already provide insight. The two white lines in the plot are provided as reference curves: the horizontal white line indicates 70% of the initial output, and the descending white curve represents a typical logarithmic decay that would reach L70 at 50,000 hours.

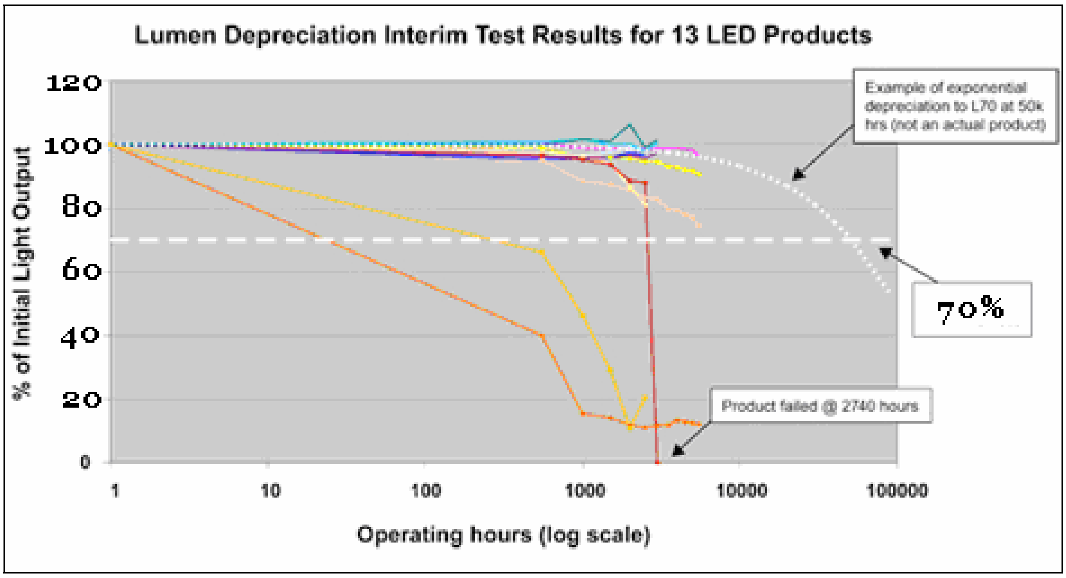

Figure 3-6: Interim results from CALIPER lumen depreciation testing. May 2008, source: CALIPER Round 5 Summary Report

Some luminaires in Figure 3-6 maintain output levels over the first 6,000 hours of operation (7 of 13 products are producing over 96% of their initial output). Others exhibit rapid lumen depreciation within the first 1,000 to 2,000 hours, and some products exhibit significant

150 Information provided to the study by PhotonStar LED Ltd, UK, Robin Morris

151 "Good Thermal Management is the key for Successful LED LIghtikng Design", Michael Stoll, The Bergquist Company GmbH, CIE Light and Lighting Conference, 25-27 May 2009.

152 U.S. Department of Energy - Energy Efficiency and Renewable Energy, Solid-State Lighting, http://www1.eere.energy.gov/buildings/ssl/reliability_points.html

colour shift over the first 6,000 hours of operation. No general patterns can be observed yet (please observe these results are from 2007/2008 and LED applications are improved with a very high speed but the variation in quality at the market is huge).

The 13 products in Figure 3-6 cover a range of LED configurations, including task lamps, replacement lamps, retrofit lamps, and outdoor area luminaires. At this point of testing, and given the small sample size, one cannot draw conclusions about the lumen depreciation performance of any particular category of products (based on size or application).

A Technology institute in Korea[153] reports that LED luminaire manufacturers often claim a lifetime of 50,000 hours but this is typically only based on the LED used and do not account for other components as thermal resistance between LED chip and air, plastic encapsulation, semiconductor defects, etc. The institute performed accelerated life test using ambient temperature stress conditions for samples of 3 products and found a lifetime at room temperature as low as 5500 hours.

In June 2008, the DOE reports, there is not a standard reporting format for LED lifetime or lumen depreciation curves. A test procedure currently is in development by the Illuminating Engineering Society of North America (designated LM-80, IESNA Approved Method for Measuring Lumen Maintenance of LED Light Sources). The US Lighting Research Centre also reports[154] that their preliminary test results indicate significant performance variations among different manufacturer's products and they mention that researchers are developing alternate lifetime prediction methods to avoid long-term product testing.

The EPA Residential Light Fixture program is under development and has expanded it scope to include decorative LED fixtures[155].

3.2.10.2 Decrease in lumen output and lifetime due to temperature

Concerning, CFLi/CFLi-R please see chapter 3 in the final report for part 1 of the study.

As mentioned above, the rated output and nominal output for an LED is often quoted at a temperature lower than the junction temperature in an LED fitting or luminaire, in which the light output and efficiency will be significantly less. It is therefore necessary to test LEDs in a complete system.

The LED lumen maintenance is dependent on drive current and junction temperature. Figure 3-7 shows published lifetime curves from a large manufacturer for their K2 LED package. According to this graph the lifetime decreases with higher junction temperature and the junction temperature has to be decreased in case the drive current is increased, e.g. to obtain a lifetime of 60,000 hours the junction temperatures has to be lower than 140^{o}C with at drive current 700 mA where it could be up to 160^{o}C with a drive current at 350 mA.

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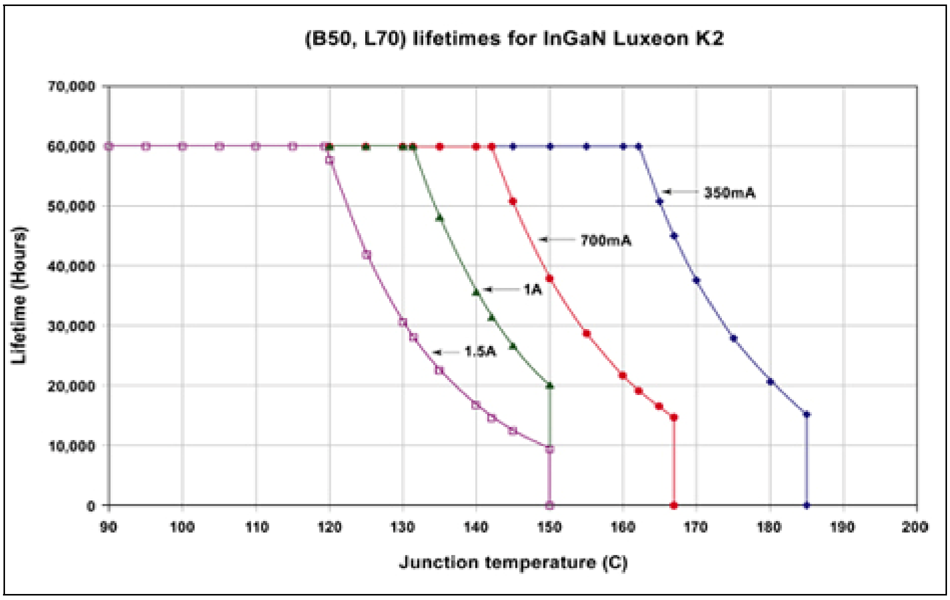
153 "LED Reliability Test for General Lighting", Seung Hyun Park and others, Korea Photonics Technology Institute, Korea, DIE Liht and Lighting Conference, 25-27 May 2009.

154 http://www.lrc.rpi.edu/programs/solidstate/cr_highfluxleds.asp

155 http://www.energystar.gov/index.cfm?c=revisions.fixtures_spec



B50, L70 means 50% of the products have at least 70% lumen maintenance for the projected number of operating hours.

Figure 3-7: Expected LED lifetime as a function of drive current indicated by each coloured line and target LED junction temperatures. Source: Philips Lumileds

Accurate measurements of the LED junction temperature in a fitting or luminaire will help in designing optimal thermal management of lumen output, energy efficiency and lifetime, and at the same time it will reduce the number of LEDs needed to obtain a specific lumen output. However, there are conflicting requirements as use of a larger number of LEDs improves the energy efficiency and lifetime by driving the LEDs less hard in order to obtain the same light output as for a smaller number of LEDs using more power. However, this is at the cost of using more LED chips.

Some new standards are under development by the CIE to address test methods that evaluate the junction temperature and as well IESNA standards concerning approved methods for electrical and photometric measurements of high-power LED's (please see chapter 1 for the actual status of the standards).

With high-power LEDs it is essential to remove heat from the LED through efficient thermal management by use of materials with high thermal conductivity. Unfortunately, some high thermal conductivity materials are relatively expensive, and there is a trade/off between cost, performance, manufacturability and other factors. As the efficacy of LEDs increase, a greater share of the input wattage will be converted into photons and less waste heat will be generated. Thus, heat sinks for LED luminaires will be smaller as the technology improves, and a decrease in size means luminaire size and cost will also reduce because less heat-sink is necessary.

3.2.10.3 Interactive effects of the light source on heating/cooling of the house

Please see chapter 3 in the final report for part 1 of the study.

3.2.10.4 Conclusion on correction factors used for real life lamp efficacy

Please see chapter 3 in the final report for part 1 of the study.

3.2.10.5 Luminaire maintenance factor (LMF)

This factor takes into account the soiling of luminaire surfaces and associated light depreciation. For more information about this topic please see the preparatory study on office lighting (lot 8)[1]. Luminaires in commercial installations are supposed to get dirty faster because they have higher density of people traffic, longer use-hours per day and associated dust levels. The cleaning might also be more frequent in the home. Household luminaires are used in a higher variety of circumstances than office luminaires. In the household, table, wall-mounted, floor-standing and furniture-integrated (e.g. kitchen) luminaires are likely to get dirty faster but also to be cleaned more frequent than lamp in the ceiling.

Concerning the use of reflector lamps (DLS), luminaire pollution is normally not considered to be a problem, because the complete optic system is within the lamp and replaced with the lamp. Cleaning of domestic luminaires is a common practice and in many cases straightforward. This raises LMF.

With reference to the discussion above and the office lighting study (lot 8) mentioned above, the conclusion is:

- For luminaires with DLS lamps LMF will not be used (LMF=1).
- For luminaires with NDLS the benchmark value of office lighting can be used (LMF =0.95).

3.2.11 Homogenity of the light field in sight of contrast[156]

An homogenous impression of a light field of a luminary leads to relaxed and pleasing atmosphere for the consumer. If any distortions/shadows within the light field the consumer might be try to compensate it with further luminaries in order to overlap the distortions/shadows. It might be sense to evaluate a kind of homogeneity within the light field. Independent of the adaption phase of the human eye and environment illumination, the variation of the illumination level along the initial curve should not exceed ± 5 %. Details are shown in Figure 3-8.

[156] The content of this section is provided by Auer Lighting

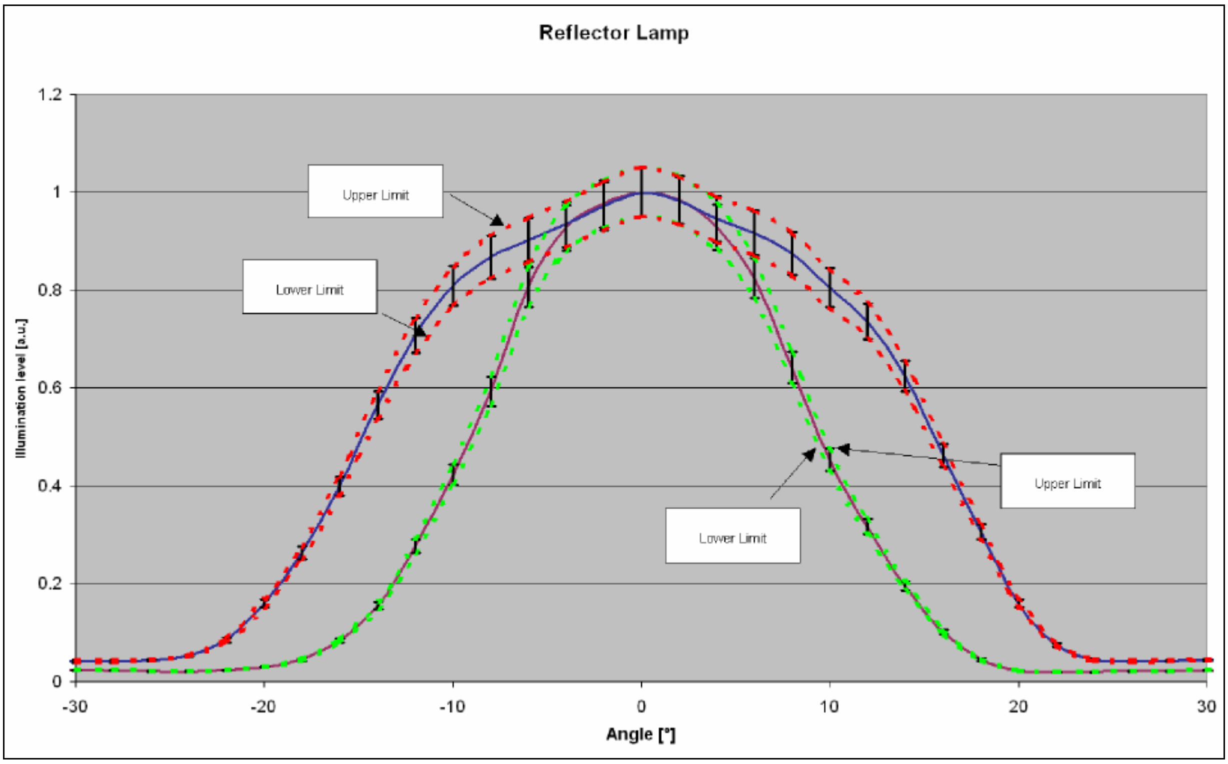


Figure 3-8: Variation of the illumination level along the initial curve should not exceed ± 5
Source: Auer Lighting

Typical light distribution curves for different types of reflector lamps are stipulated in:

- Figure 3-9 for a 50 mm Reflector lamp in combination with a halogen light source.
- Figure 3-10 for PAR 38 Reflector in combination with a halogen light source.
- Figure 3-11 for a 50 mm Reflector in combination with a discharge lamp.

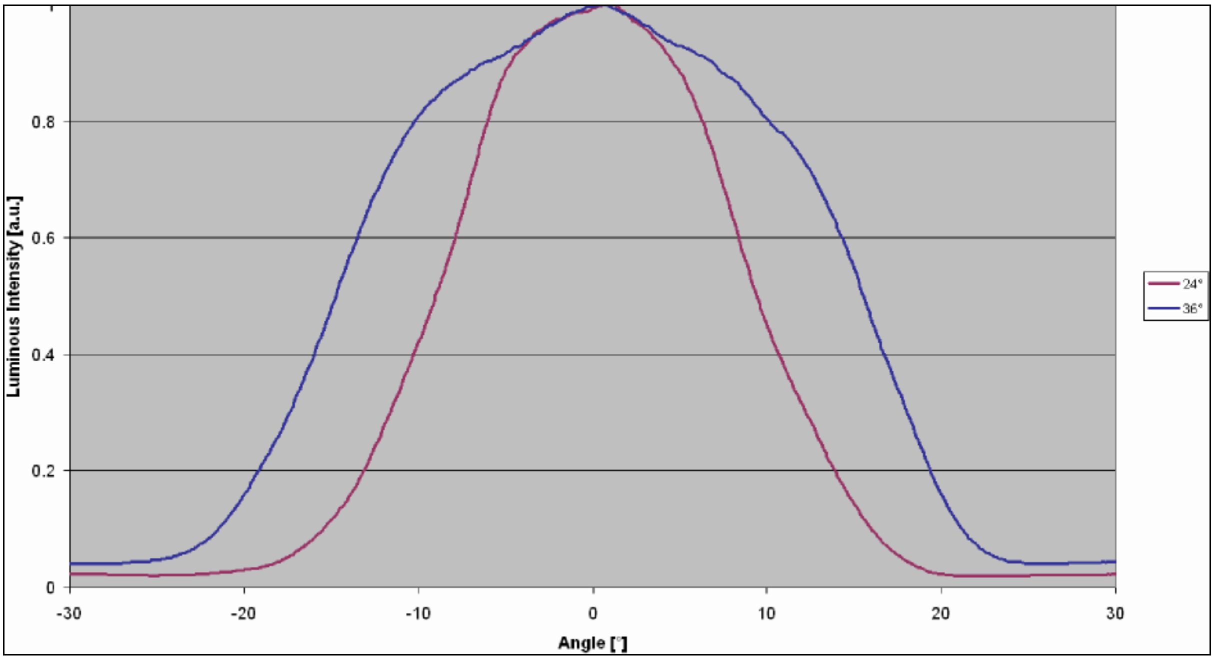


Figure 3-9: Sketch of typical light distribution curve for a 50 mm reflector lamp in combination with a halogen light source Source: Auer Lighting

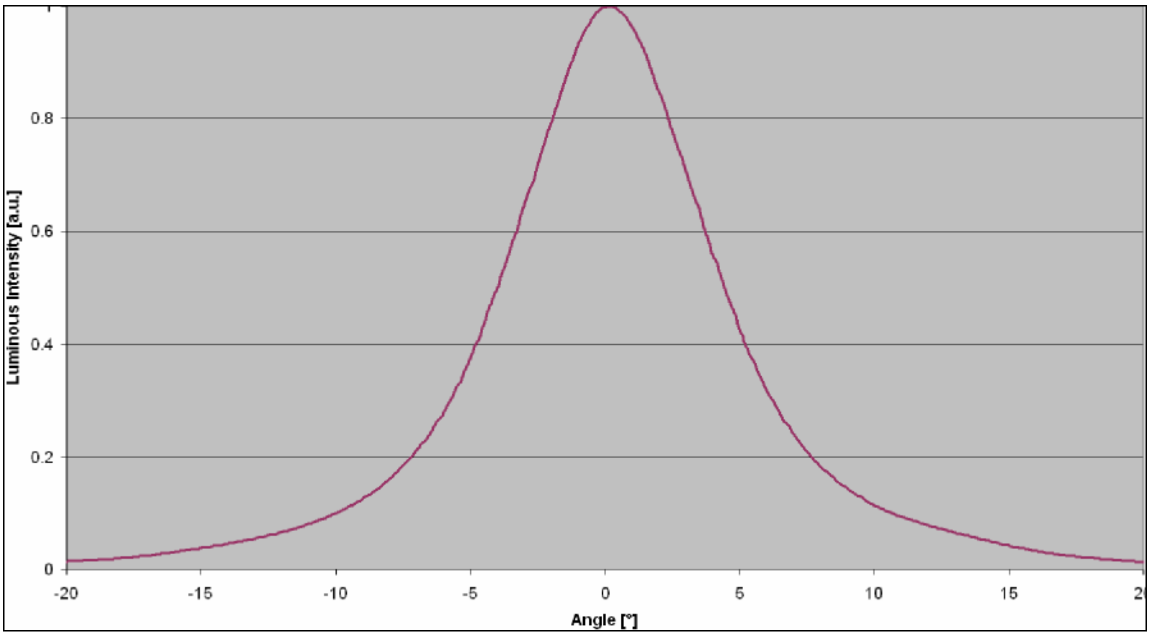


Figure 3-10: Sketch of a typical light distribution curve for a PAR38 reflector lamp in combination with a halogen light source Source: Auer Lighting

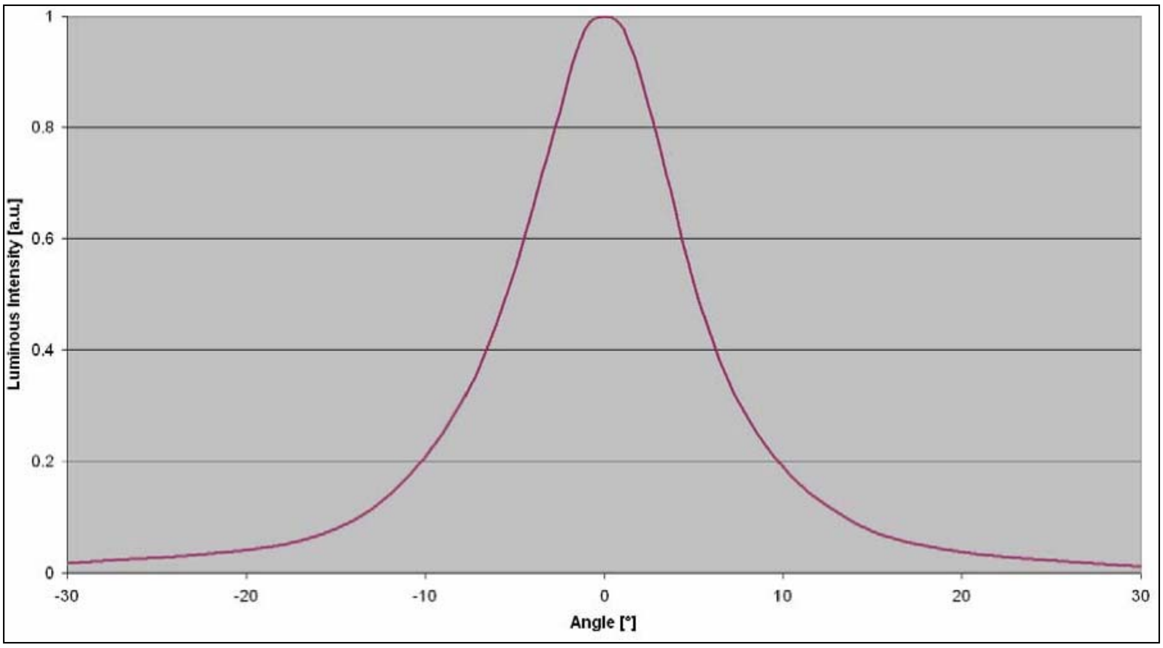


Figure 3-11: Sketch of a typical light distribution curve for a 50 mm reflector lamp in combination with a discharge lamp Source: Auer Lighting

3.2.12 Homogenity of the light field of colour impression[14]

A homogenous colour impression in the light field of the reflector lamps leads to a pleasing atmosphere as well. In order to describe the colour inhomogenity further light technical measurements were done. The maximum difference of the colour coordinates within the complete light field up to the tenth beam angle was measured for different types of reflector and light source combination. Detailed results are shown in Table 3-1.

Table 3-1: Test results: Colour coordinates within the complete light field, Source: Auer Lighting

Reflector Type	Half beam angle in [°]	Light Source	dx	dy
50 mm	10	Halogen	0.002	0.002
	24	Halogen	0.004	0.002
	36	Halogen	0.011	0.005
50 mm	24	Discharge	0.012	0.012
	36	Discharge	0.012	0.006
PAR	36	Halogen	0.004	0.002
50 mm	32	LED	0.06	0.09

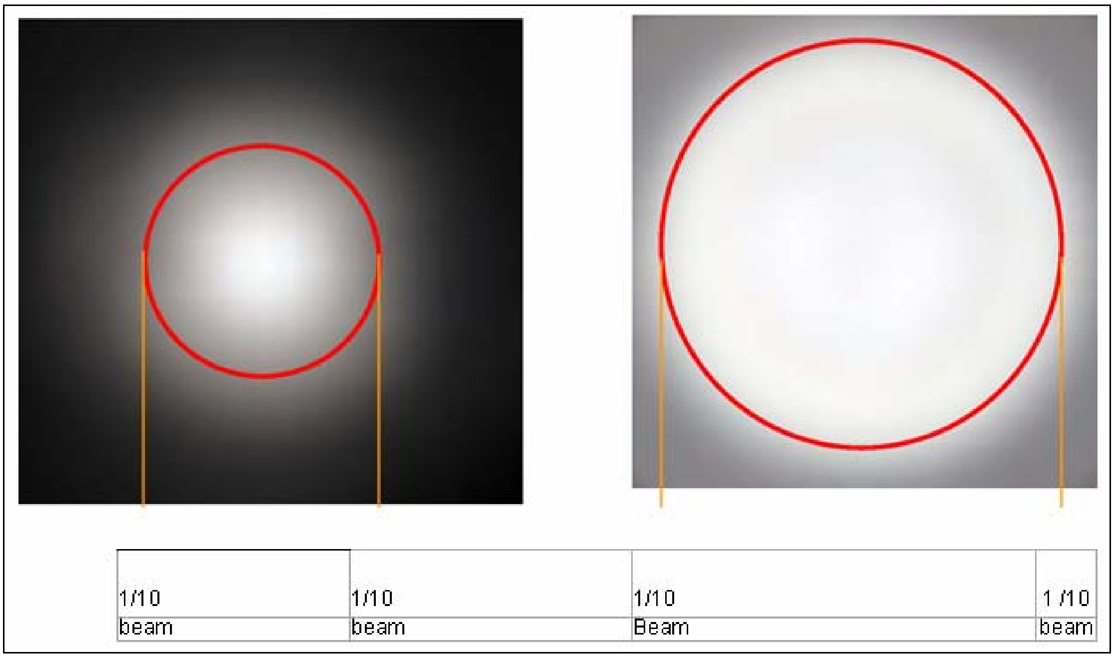


Figure 3-12: Sketch of the light field and the measurement area for the colour coordinates. Source: Auer Lighting

3.3 End of Life behaviour related to consumers

Please see chapter 3 in the final report for part 1 of the study.

3.4 Influence of local infra-structure and facilities

3.4.1 Influence of the physical room infrastructure

Please see chapter 3 in the final report for part 1 of the study.

3.4.2 Lack of skilled and informed users

A very broad range of DLS lamps for domestic application is available on the market (see chapter 1). A one to one comparison of lamp types is not always straightforward and could create a user barrier as will be discussed in more detail in 3.5. The new lamp types often have very different selection parameters that, when applied correctly, could offer more comfort and user satisfaction. For example, CFLi-R and LED might be bought in a broader product range of colour temperatures, light distribution patterns or product lifetime compared to GLS or halogen lamps. Concerning beam angles, HL-LV lamps are offered with all kind of beam angles while CFLi-R are at present only available for broad angles (down to 70 degrees) due to information from a leading market manufacturer.

The well known GLS-products might be replace by a large variety of products, but often the single store has only a few products, little knowledge and little experience. This gives a high risk of buying dissatisfying products. In this situation, cheap products with a short lifetime also seem to be important, besides the expensive long lifetime products justifying a fairly high price. Users should therefore be clearly informed about correct lamp selection parameters (start up time, light colour, light distribution, beam angle, light output, dimming method, life time, temperature sensitivity...) It is also recommended that users are informed in a timely manner about the proper energy efficient retrofit solution in case certain products become obsolete.

Designers and their organisation note that great many reflector lamps are being used inappropriately in the domestic settings when a number of down-light reflector lamps are used for general illumination of kitchen, bathroom, corridor, hall, bed rooms and even living room although reflector lamps are not made for this purpose.. In many circumstances, directional lighting typically with 24 degree beam angle might provide inadequate lighting and therefore additional lamps with more distributive characteristics are added resulting in the total electrical lighting consumption becomes unreasonable. Frequently dimmers are used to be able to reduce the light output from the down lighters that often cause discomfort glare. Use of a multitude of halogen down lighters in the kitchen often also causes thermal discomfort[157] by emitting heat. It appears as there is a large potential for energy efficient lighting.

The down lighters cause discomfort glare because of the brightness of halogen, LED and some CFLi-R lamps without an outer envelope and that the eye look up directly at the lamps without any kind of shielding – the higher wattage, the larger discomfort glare. Disability glare might also occur and might cause increased lighting consumption when an increase in the background luminance contributes to an increase in veiling luminance. Consequently, a higher luminance for the object to be perceived could be needed.

The brightness of the lamps might be adjusted with appropriate fixtures and dimmers. However, the colour temperature of the lighting from GLS and halogen lamps changes significantly when the lamp is dimmed which is undesirable when the lighting supplements daylighting.

Problems with glare might be reduced by buying lamps with smooth reflectors (with a mirror finish) as they should create a sharper fall-off to the illuminated area.

In many cases, consumers choose to install luminaires that provides functional illumination and an attractive decoration. However the knowledge to provide sufficient illumination often fails and often the selection is only made from a “decorative” point of view. In that case the consumer might end up by overcompensating a stronger lamp or with more luminaires. More

[157] ELC informs that dichroitic mirrors might be used in the DLS to avoid thermal discomfort.

information on the optical efficiency of the luminaire and its standard performance along with a recommendation of lamps at the moment of purchase could support the consumer.

3.4.3 Lack of skilled service providers

This is especially important for furniture-integrated luminaires (e.g. kitchens, bathrooms...) as sales people could have a strong influence on the selection and the amount of installed luminaires in modern houses. Service providers do in many cases also install reflector lamps in down-lights for general illumination. The user often experiences that the directional light provided is inadequate to make the room feel "lit", install additional lamps and increase the electricity consumption. The cases have not occurred if the right beam angle for the DLS or a NDLS has been used.

Service providers installing domestic lighting are not likely to use software to design their illumination strategy for a room. Rather, they would tend to over-illuminate a space and install a dimmer, so the end-user can adjust the room according to their taste and they cannot be criticised for low light levels.

Some energy retrofit solutions, e.g. replacing a dimmable GLS or halogen lamp by a CFLi-R or LED can benefit from professional advice in order to reduce trial and error by users and possible negative consumer experiences.

As discussed in part 3.1, there might be a 'split incentive' with no incentive for service providers to purchase high efficiency lighting because it usually has a higher first cost and operating costs are not considered as a part of their business - although it could be considered.

3.4.4 Luminaire socket and space lock-in effect

Compared to NDLS, DLS include a much greater range of caps/bases and lamp sizes and, typically, luminaires are designed to closely house the reflector lamps. When considering smaller form factor lamps such as MR16 and AR111, the lamp itself can be a structural part of the fitting.
There are possibly the majority of small reflector lamp fittings that cannot operate with lamp types other than that for which they were originally designed.

Additionally the beam and field angle of the reflector lamp are key operating factors so replacement lamps have to have identical beam characteristics to the lamp they are replacing.

3.4.5 Electrical wiring lock-in effect

Consideration has to be given to internal wiring in luminaries and systems with external transformers, both wire wound and electronic[158].

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[158] The content of this section is provided by PLDA (Professional Lighting Designers Association), May 2009.

To a significant extent the output voltage of transformers for lighting is governed by the resistance applied across the secondary wiring. In the case of wire wound transformers the voltage increases as the resistance is reduced. Replacing lamps with significantly lower wattage types will cause over voltage and premature lamp failure for conventional lamps. For LED or CFLi reflector lamps with integrated electronics instant failure or fire risk are also potential results.

For many low price electronic transformers failure to provide adequate resistive load results in a flashing output as the voltage builds and cuts off. The output of electronic transformers is not sine wave and is also at high frequency, this can also cause problems for downstream electronics such as ballasts in CFLi and LED replacement lamps.

3.5 Potential barriers to possible eco-design measures

This section, dealing with the lighting source, shall be seen as complementary to the earlier sections. Particularly, the CFLi-R and the LED is in the focus with regard to quality and raised questions. Anyhow, there should also be attention paid to quality tests of halogen lamps, e.g. the performance and lumen maintenance for halogen lamps is low in a new test of 26 halogen lamps[159].

It seems reasonable not to set higher quality requirements to LED lamps than to CFLi-R in order not to discriminate.

It is very important to distinguish between LED lamps and LED luminaires.

3.5.1 CFLi-R quality

Please see chapter 3 in the final report for part 1 of the study.

3.5.2 HL-R quality

HL-MV-R and HL-LV-R reflector lamps are nowadays characterized by beam angle and peak intensity (candela). The beam angle is important for the user to assure that the light is directed to the target as intended. The peak intensity allows the user easily to calculate the centre illuminance at the target by the simple formula:

$$E = I/d^2$$

where d is the distance in meter
I is luminous intensity in candela
E is the illuminance in lux perpendicular to the lamp

[159] Warentest 2/2009 Test of halogenlamps

Concerning beam angle, PLDA refers to the American system where reflector lamps are divided in groups as around 10°, around 24°, around 36° and from 36° to 60° beam angle.

Quality problems with reflector halogen lamps might arise and are due to lower lamp efficacy, wrong peak intensity, deviate beam angle or reduced life time.

Recent test of halogen lamps[19] shows this is also very important for the consumer economy especially for HL-MV-R lamps. The test includes 6 lamps with GU10 socket: 1 lamp with xenon gas (labeled as Energy Saver) where both the energy efficiency and the economy is equal to use of GLS lamps while the consumer spend more money for the remaining 5 HL-MV-R and spend from 10% to 55% more energy (VITO has found that the calculation methode should be adjusted and that the results are even worth). The same is the case for testing of two HL-MV-R with G9 socket. The test also includes 5 HL-LV-R with GU5.3 socket where the consumer obtains a good economy plus energy saving around 30% energy saving for "normal" lamps and 44% for lamps with IRC coating (labeled as Energy Saver).

The above results are also due to that the test shows a huge difference in lifetimes and often very different from what is claimed on the package – for HL-LV-R the lifetime is often higher than claimed (typically 2000-2200 hours) but there is also a Energy Saver lamp case where the claim is 5500 hours lifetime but the test shows 3450 hours. For HL-MV-R the claim is rather low with three lamps with only 1000-1100 hours, one lamp with 1500 hours and three lamps with 2000-2200 hours (one package without this imformation). The measured lifetimes are on average a little higher than those claimed but case by case the difference is large and goes in both directions (positive and negative).

Concerning the colour of the halogen reflector lamps the recent investigation shows:

- Due to information at the package, the correlated colour temperature (CCT) is low for HL-MV-R with 2600-2750K (too warm for many people) and higher (and closer to what most consumers seems to prefer) for HL-LV-R with 2750-3200K.
- The colour rendering index (CRI) is by definition 100 for filament lamps (see also discussion in chapter 1), nevertheless very warm lamps (2600 K) are very yellowish and it can be discussed if it is the right colour (depending on the reference).

In conclusion, it is very important that the packaging includes correct information about beam angle, efficacy, peak intensity, lifetime and colour. ELC informs[160] they are preparing an ecoreport including requirements to minimum lumen level per lamp type and performance variation for 7 beam categories.

3.5.3 LED quality

The performance of WLED products (White LED called LED further on) available at the market varies within a very wide range and actually new more efficient LEDs comes on the

[160] Comment at the stakeholder meeting 26 May 2009.

market every six months. Some testing programs[161] have also found that the performance within individual batches of identical sources varied as much as 40%. That indicates that the actual manufacturer has not performed a proper binning. This may be caused by downward pressure on pricing increase the temptation for manufacturers to "cut corners".

Both the correlated colour temperature (CCT) and the colour rendering index (CRI) vary within large intervals. A new study of colour rendering of LED sources[162] with a paired comparison of halogen and fluorescent to 7 different clusters of LED at 3000K (CCT). They found, that in general, that the colour rendering was found more attractive with some of the LEDs mixing than with standard light sources. They find that the neither of alternative scales to measure gives the best description of all aspects: attractiveness (Gamut best), naturalness (CRI best) and colour difference (CIECAMO2 best).

There is a high risk of "market-spoiling" if some manufacturers claims overstate their LED performance. Consumers unlucky enough to purchase a low performing LED (not performing as claimed by the manufacturer) can be very dissatisfied and they may reject the technology, and the overall reputation of LED systems could suffer. This has already been experienced when the CFLi product was introduced at the market and it took many years and a lot of work to overcome the barriers created during the first years at the market. It is very important not to repeat this failure when the LED is introduced at the market.

LED luminaires and replacement lamps available today often claim a long lifetime, usually 50,000 hours. These claims are based on the estimated lumen depreciation of the LED used in the product and often do not account for other components or failure modes. Lifetimes claimed by LED luminaire manufacturers should take into account the whole lighting system, not just the LEDs. One of the key lessons learned from early market introduction of CFLi[163] is that long life claims need to be credible and backed-up with appropriate manufacturer warranties.

Another important aspect is that LED's are often integrated permanently into the fixture/luminaire, making their replacement difficult or impossible.

The beam characteristics of LEDs are usually determined by discrete optical elements attached to the LED or LED board. The beam and field characteristics are different from a reflector optic with a single source and this might result in a non circular beam pattern, colour variation across the beam (especially for single LED devices) and failure to achieve good beam definition at beam angles below 24 degrees[164].

Formalisation of product quality and a performance testing process is needed urgently. Independent testing has to start as soon as possible and the results have to reach the key

[161] "The Need for Independent Quality and Performance testing of Emerging Off-grid White-LED Illumination systems for Developing Countries", Evan Mills, LBNL and Arne Jacobsen, Schatz Research Center, Technical report 1, The Lumina project, August 2007, http://light.lbl.gov.

[162] "Colour Rendering of LED sources: Visual experiment on Difference, Fidelity and Preference", Jost-Boissard, Fontoynont and Blanc-Gonnet, Ecole Nationale Travaux Publics de l'Etat,CIE Light and Lighting Conference with emphasis on LED, 27-29 May 2009.

[163] US DOE. "Compact Fluorescent Lighting in America: Lessons Learned on the Way to Market". 2006.

[164] Comment from PLDA, May 2009.

audiences. The availability of standard test procedures can support manufacturers' product development efforts, evaluation of progress towards achieving higher quality (comparison to established benchmarks) and competitive analysis.

On the other hand, it is important to ensure the cost of testing is not overly burdensome to manufacturers. High-cost testing can be less successful than a more moderate approach because small firms might be unable to afford the entry cost to high-cost testing and some manufacturers might avoid markets where quality assurance is required. Another strong argument is that LED products have such long lives that lifetime testing and acquiring of real application data on long-term performance becomes problematic as new versions of products are available before current ones can be fully tested.

An overview of measurements including a number of LED lamps can be found at the Renewable Energy OliNo web site[165] including different kind of fittings. Unfortunately, most of the lamps don't fulfil the quality requirements to either efficacy, CCT and/or CRI.

3.5.3.1 ENERGY STAR Qualified LED lighting

On September 30, 2008, the ENERGY STAR Solid-State Lighting (SSL including LEDs, OLEDs and PLEDs) Criteria program went into effect as an important step towards ensuring the quality of LED lighting.

Manufacturers who are ENERGY STAR partners can begin submitting products for qualification, retailers can begin promoting these qualified products in their stores and showrooms, utilities and energy efficiency organisations can begin implementing incentive programs for these efficient products, and consumers can start looking for the ENERGY STAR on quality products. The ENERGY STAR label on SSL luminaires provides consumers with the confidence that these products meet efficiency and performance criteria established by DOE in collaboration with industry stakeholders.

The rapid pace of the technology advances led DOE to select a two-phase approach:

1. First phase allows for early participation of a limited range of market-ready products
2. Second phase sets out more rigorous performance targets for future products. The criteria are continually updated to keep pace with the technology advances.

The released requirements for obtaining to be ENERGY STAR qualified LED lighting include:

1. **Energy consumption** at least 75% less energy than incandescent (GLS) lighting for the same quantity of lighting (lumens).[166]
2. **Reduces maintenance costs** by lasting 35 - 50 times longer than incandescent (GLS) lighting and about 2 - 5 times longer than fluorescent lighting. No bulb-replacements, no ladders and no ongoing disposal program.
3. **Minimum three-year warranty** which is far beyond the industry standard.

165 http://www.olino.org/

166 ELC mention in their comments to a draft of this report that the luminaire efficacy is for some applications required as ">20 lm/W", which is not a 75% energy reduction compared to use of a GLS-R.

4. **Offers convenient features** by being available with dimming on some indoor models and automatic daylight shut-off plus motion sensors on some outdoor models.
5. **Brightness equal to or greater than existing lighting technologies** (incandescent or fluorescent) and the light must be well distributed over the area lighted by the fixture.
6. **Light output remaining constant over time**, only decreasing towards the end of the rated lifetime (at least 35,000 hours or 12 years based on 8 hours use per day). The L70 criteria suggested in chapter 1 require minimum 25,000 hours for domestic indoor applications and minimum 35,000 hours for other professional and outdoor applications.
7. **Color quality**. The shade of white light must appear clear and consistent over time[167].
8. **Efficiency as good as or better than fluorescent lighting**.
9. **Light coming on instantly** when turned on.
10. **No flicker** when dimmed.

In the DOE Caliper testing program[168] was found power factors within the interval 0.52-0.99 so power factor could also be a quality parameter but this is not included in the list as it is not an issue from a consumer perspective. ELC publiced[169] recently a note "Mains Power-Quality Effect by Electronic Lighting Equipment", that conclude the present IEC 61000-3-2 "Limits for harmonic current emission" are sufficient and there is no need for tightening the requirements.If this is done as suggested by some parties it would lower the lamp performance, and increase the lamp size, the electronic waste and the cost. This is in line with the content of part 1 of our study.

Until a detailed European specification is prepared, it might be worth to adopt these specifications in order to establish the market under a known and trusted mark. Next section gives a proposal of what are the most important qaulity parameters from a European consumer perspective.

3.5.3.2 Most important LED lighting quality parameters for a European consumer

Different sources describe quality requirements of importance for the consumer when buying LED lamps, modules and luminaires:

- ENERGY STAR[10]
- LBNL reports[14]
- IEC/PAS 62612 Ed.1 "Performance requirements for Self-ballasted LED lamps" giving a complete survey of relevant parameters

[167] ELC mention in their comments to a draft of this report that CRI is required to be minimum 75 for indoor applications and that CCT is limited to warm white ANSI bins.

[168] Caliper Summary Report, January 2009, Round 7 of products testing (prepared for DOE), http:apps1.eere.energy.gov/buildings/publications/pdfs/ssl/calliper round 7 summary final.pdf

[169] ELC (www.elcfed.org) (5/2009): 'ELC position paper on Mains Power-Quality Effects by Electronic Lighting Equipment'

- CIE 127:2007 standard addressing individual LEDs.

The most important LED quality parameters from a consumer perspective are evaluated to be:

1. Lumens where the rated output for the LED luminaire is important (not for the LED). Requirements to the manufactures could be measurement of total luminous flux e.g. by use of goniometer in order to characterize the light-distribution pattern.
2. Requirements to minimum lamp efficacy in lumens/W
3. Lifetime in hours for the LED luminaire or lamp (not for the LED chip).
4. Lamp efficacy as a function of time. A high-quality LED can maintain high lighting levels for tens of thousands of hours, while the output of low quality products declines more rapidly. Long-term measurements require 12+ months so it is important to find a short-term approach for measuring.
5. Requirement to how fast the light should come on instantly when turned on.
6. Colour: CCT (Correlated Colour Temperature) and CRI (Colour Rendering Index).
7. Glare: Measurement of the intensity of light from the source itself. This is important given the small size of LED lights and their corresponding brightness, which can cause discomfort glare as well as injury if users look directly into the light. A very recent test [170] reports glare varied by a factor 1.4 and that it was above the acceptable threshold in most cases. Anyhow, glare will not be greater than with "traditional" DLS. Limiting glare (UGR) values are specified for many commercial applications.
8. Information about if the lamp is available with dimming, automatic daylight shut-off and/or motion sensors (especially important for outdoor models).
9. Requirement to stroboscope effect and flicker. Power supplies using pulse-width modulation makes the LED blink/flicker with a certain frequency (typically between 100 and 150 Hz). The flicker frequency is not directly visible but may lead to: a) Stroboscopic effects on rotating objects (making it look like it is not moving or like it rotates at another speed or direction). b) "Cascades" of bright points in the visual field when moving the visual direction rapidly ie. when turning the head.
10. Minimum warranty in years.

3.5.3.3 Integrated LED luminaires

LED luminaire lifetime is not identical to estimated LED lifetime. LED luminaire lifetime is also a function of the power supply, operating temperatures, thermal management, materials, and electrical and material interfaces. DOE[171] reports that definitive lifetime ratings will not

[170] "Measured off-grid lighting system performance", Evan Mills, LBNL and Arne Jacobsen, Schatz Research Center, Technical report 4, The Lumina project, December 2008, http://light.lbl.gov.

[171] http://www1.eere.energy.gov/buildings/ssl/reliability_points.html

be possible until more experience is logged with a wide range of LED luminaires in the field. They recommend looking for:

- High-quality LEDs from manufacturers who publish reliability data.
- Luminaire warranty offered by the manufacturer – should be at least comparable to traditional luminaires used for the application under consideration.
- Luminaire photometric report, based on LM-79-08 test procedure, from an independent testing laboratory.
- Temperature data (for example, board, case, or solder joint temperature) for the LEDs when operated in the luminaire in the intended application; and information about how the measured temperature relates to expected lifetime of the system.
- Any test data available about longer term performance of the LED luminaire, such as DOE CALiPER testing, manufacturer in-house testing, or field tests conducted by DOE, utilities, or other parties.

3.5.4 Luminaire socket and space lock-in effect

For this item, see section 3.4.4.

3.5.5 Electrical wiring and control system lock-in effect

Please see chapter 3 in the final report for part 1 of the study.

3.5.6 Harmonic interference in the low voltage network

Please see chapter 3 in the final report for part 1 of the study.

3.5.7 Alleged negative health effects due to optical and electromagnetic radiation from certain light sources

Please see chapter 3 in the final report for part 1 of the study.

3.5.8 Luminaire photometric data is usually not measured

Few luminaires within the scope of this study are provided with photometric data, the requirement for having a minimum LOR or LER performance or providing data about it could create additional cost and administration. In decorative luminaires such a requirement could limit the amount and light absorption of the ornaments sold with the luminaire. It is important to remember that decorative luminaires are mainly chosen by the consumer to serve an aesthetic function.

As mentioned in section 3.2.3, the efficiency of a domestic luminaire is not a basis for its selection for purchase. It is therefore doubtful if provision of information for the majority of domestic luminaries is useful or worthwhile.

Basic design rules rather than LOR requirements could avoid cost and administration but there are no public known examples so far.

Design rules for luminaries with reflectors could be[172]:

a) Rules of reflectance and allowable absorbance of reflectors
b) Rules of opening area dependant of luminous area of the light source and dependant of directionality as "non directional luminaire", "directional luminaire" or "directional spot luminaire".
c) For closed luminaries rules for transmittance and allowable absorbance of screens.

Exceptions could be made for luminaires marked with a text saying it is not intended for household room illumination (as done for light sources).

[172] Proposal received from the DEA (Danish Energy Agency) developed by their lighting advisor Hansen & Henneberg

4 TECHNICAL ANALYSIS EXISTING PRODUCTS

This chapter is a general technical analysis of current products on the EU-market and provides general inputs for the definition of the Base Case (chapter 5) as well as the identification of part of the improvement potential (chapter 7), i.e. the part that relates to better performing products on the market. Some Best Available Technologies including LEDs will only be introduced in chapter 6.

4.1 Production phase

4.1.1 Selected DLS products

The Table 4-1 below summarizes the types of reflector lamps that are taken into account as most relevant for general domestic lighting. This list is based on the types of lamps that are currently installed in Europe. As mentioned before, Best Available Technology that is nowadays less or rarely used will only be introduced in chapter 6 including LED's.

The catalogues contain a multitude of lamps for various applications, including non-domestic; for reasons of simplification only selected representative products are included in this study. These representative lamps were selected after the analysis of the market data and the current availability in the shops.

Representative lamps are discriminated into four groups:

- the blown reflector GLS-lamps (R63 with E27/B22d cap) and the similar halogen lamps,
- the PAR 38 high wattage GLS and halogen lamps (GLS-R-HW and HL-MV-R-HW),
- the small, mains voltage MR16 halogen lamps with GU10 cap and a GU10 capped compact fluorescent replacement lamp,
- the low voltage MR16 halogen lamps with GY5.3 cap.

In Table 4-1 a selection of reference lamps is made per lamp type, i.e. one typical wattage and for one type, several beam angles in the same wattage.

Blown reflector lamps have the disadvantage that the optimum position of the filament wire or the halogen bulb in the reflector varies a lot and the satination of the outer bulb increases the spill light and reduces the light output and efficacy. As a consequence, light output of different samples can considerably differ. The efficacy data in Table 4-6 try to reflect the average that can be found on the market.

The mains voltage MR16 halogen lamps normally have a reflective layer of evaporated aluminium and the corresponding GU10 cap.

For the low voltage MR16 halogen lamps, the dichroic versions (cool beam) were chosen because the aluminized reflector versions are almost disappeared from the market. A dichroic reflector has several reflective layers, which results in a higher efficacy compared to the aluminized version (reflection coefficient of 0.90-0.95 against 0.85 for evaporated aluminium).

Selected reflector lamps:

Table 4-1: Overview of selected lamps.

Lamp type / **Acronym**	**Wattage** [W]	**Colour Temp** [K]	**Colour rendering** Ra	**Beam Angle** [°]	**ILCOS-code**
Incandescent reflector lamp, R63, E27 (B22d) **GLS-R**	60 (40)	2700	100	30	IRR-60-230-E27-63/30
Halogen reflector lamp, R63, E27 (B22d) **HL-MV-R**	60	2900	100	30	HAGS/UB-60-230 E27-63/30
Incandescent reflector lamp, PAR38, E27 (B22d) **GLS-R**	(80) 120	2700	100	25	IRR-120-230-E27-120/25
Halogen reflector lamp, PAR38, E27 (B22d) **HL-MV-R**	100	2900	100	30	HAGS/UB-100-230 E27-120/30
Halogen reflector lamp, MR16, GU10 **HL-MV-R**	50 (35)	2900	100	40	HAGS/UB-50-230-GU10-51/40
Halogen reflector lamp, MR16, 12V, GU5.3 **HL-LV-R**	50 (35)	3000	100	10/24/36 -38/60	HRGS/UB-50-12-GU5.3-51/36
Compact fluorescent reflector lamp, R50, GU10 **CFLi-R**	7	2700	>80	120	FBR-7/27/1B-230-GU10-51/120
Compact fluorescent reflector lamp, R120, E27 (B22d) **CFLi-R**	20	2700	>80	120	FBR-20/27/1B-230-E27-120/120

For these typical lamps, product data are collected as needed from the VHK model, i.e. the EcoReport tool. The production phase is modelled according to the MEEuP methodology report. Detailed information on environmental impact is included in chapter 5 of this MEEuP methodology report. The method focuses on seven environmental impact parameters (Total Gross Energy Requirement, Electricity, Feedstock energy (for plastics only), Process Water, Cooling Water, Hazardous Solid Waste, Non-Hazardous Waste). This method satisfies the requirement set out in article 15 paragraph 4 (a) of the eco-design directive (2005/32/EC): *'Considering the life cycle of the EuP and all its significant environmental aspects, inter alia energy efficiency, the depth of analysis of environmental aspects and of the feasibility of their improvement shall be proportionate to their significance. The adoption of eco-design requirements on the significant environmental aspects of an EuP shall not be unduly delayed by uncertainties to regarding the other aspects'.* In order to satisfy these requirements, the most relevant products were chosen and sometimes an available similar process or material (based on physical or chemical similarity) is used when it is not directly available in the MEEUP methodology. These requirements often allow to follow a simple and straightforward approach.

In this study, types of lamps were put together within a certain range of weight of components and a range of power.
Incandescent reflector lamps in R63-form in 40 and 60W have the same dimensions and thus an almost equal Bill of Material (BOM). Moreover, in chapter 2 can be seen that these lamps are apparently the most used (>82%) incandescent reflector lamp in EU27. The 60W lamp is choosen as most representative.

This range will also allow the assessment of aberrations caused by differences in the production phase of DLS lamps. But here again, one can expect a very low total environmental impact for lighting by the 'production phase' according to part 1 of this study.
The results serve as input for the assessment of the base case, which is discussed in the next chapter.

If relevant and possible, data sets from different sources are checked on their consistency.
The BOM (Bill Of Materials) is used as input for modelling the production phase in the VHK-model. The input tables are included in the following sections. For the discussion of the end-of-life phase of materials is referred to section 4.5.

4.1.2 Selected luminaires (4) to assess the luminaire socket and space lock-in effect

As explained in chapter 1 the luminaires are treated in this study as belonging to the system environment of the lamp or light source.

In chapter 3 two improvements were identified at system level (luminaire), in this section the focus is on the so-called ‘Luminaire socket and space lock-in effect’ (see chapter 3)
Because of the wide spread of products available and the lack of reliable quantitative data on the performance of stock and sales (see chapter 2&3) this study will deal with the impact on a qualitative basis. The sole purpose is to assess the potential impact of an improvement option at luminaire level in the sensitivity analysis in chapter 8 on a qualitative basis using one or more reference luminaires, this information is not relevant for chapters 5 and 7.

Please also note that ballasts for fluorescent lamps, external transformers and power supplies for low voltage halogen lamps were already discussed in the study on office lighting[173] or on external power supplies[174].

The luminaire market in the domestic sector is very large. The production costs and material used vary significantly, almost exclusively as a function of the decorative aspects. Consistent with the system approach discussed in Chapter 1, luminaires with the minimal parts will be considered in the luminaires studied in this analysis. The section evaluating luminaires for DLS luminaires will compare differences between two selected luminaires, referred to as “reference luminaire cases.

[173] Preparatory Studies for Eco-design Requirements of EuPs, Lot 8: Office lighting, Final Report (April 2007).
[174] Preparatory Studies for Eco-design Requirements of EuPs, Lot 7: External power supplies and battery chargers (January 2007).

Proposed reference luminaire cases for this assessment:

- **Two luminaires for DLS lamps:** GU10 mains voltage luminaire compared to GU5.3 low voltage luminaire, hereafter indicated as '**Case1DLS'**. This case should also be representative for a G9 luminaire compared to GY6.35, the improvement and additional costs are similar.
- **Two uplighter luminaire for NDLS lamps**: an up-lighter with R7s socket for a linear halogen mains voltage lamp compared to another one equipped for a Circular FL(ni), hereafter indicated as'**Case2NDLS**'

4.1.3 Average luminaire wattage to assess energy consumption

This data is included in chapter 2.

4.1.4 DLS lamps production

Data on composition and weight of the lamps that are summarized in Table 4-4 are based on samples. Some data are also collected from producers' catalogues. Note that the substances in the same lamp family that have hazardous characteristics and the substances that have environmental impact are independent from the power [W] of the lamp but only dependent on the technology.
For incandescent reflector lamps, differences could be found in the weight of glass, dependent on the bulb form, and in the weight of metal for the socket, dependent on the socket type E27/B22 versus E15/B15. Howerver, as only the R63 E27/B22d types are chosen as representative for the normal wattages and PAR38 E27/B22d for the high wattages, in the same group no difference is taken into account.

Also for the HL-MV-R GU10 types the BOM for different wattages is nearly the same and the same statement can be made for the different lamp families in HL-LV-R.

Some remarks about the environmental impacts related to this input table are:

- The environmental impacts of the residual rare earth metals are assumed negligible.
- The environmental impact of the noble filling gasses (argon, krypton and xenon) is assumed negligible. A noble gas is chemically inert and therefore not an hazardous gas. Carbon dioxide emission due to production of 1 kg Argon is only 0.295 kg, for 1 kg Krypton only 102 kg and for 1 kg xenon 710 kg[175]. Due to the very small amount of these gasses in halogen bulbs, their environmental impact is far less than for other lamp parts as can be checked after chapter 5.

The potential effects of these assumptions in the environmental impact assessment will be further discussed in chapter 8 in the sensitivity analysis.

The following tables present the input data using the terminology from the VHK model for the environmental assessment (see Table 4-4).

[175] Swiss Centre for Life Cycle Inventories: Ecoinvent database

Table 4-2: Input data for the materials extraction and production of the lamps (expressed in g)

MATERIALS Extraction & Production / *Description of component*	Incandescent reflector lamp, R63, E27 – **40/60W**	Halogen reflector lamp, R63, E27, – **60W**	Incandescent reflector lamp, PAR38, E27 – **80/120W**	Halogen reflector lamp, PAR38, E27, – **100W**	Halogen reflector lamp, MR16, GU10 – **50W**	Halogen reflector lamp, MR16, 12V, GU5.3 – **50W**	Compact fluorescent reflector lamp, R50, GU10 – **7W**	**Category**	**Material or Process MEEUP**
Glass	28	30	361	365	36	29	20	7-Misc.	**54-Glass for lamps**
Aluminium for caps	1.5	1.5						4-Non-ferro	**26-Al sheet/extrusion**
Copper for caps / connector pins			3.5	3.5	1.5	0.3	1.5	4-Non-ferro	**30-CU tube/sheet**
Cement						0,7		7-Misc.	**58-Concrete**
Soldering	0.5	0.5	0.5	0.5					**52-Solder**
Metal Mercury							0.004		
Plastic housing							15		**PBT**[176]
Printed circuit board, assembled							10		**53-PWB assembly**
Total weight	***30***	***32***	***365***	***369***	***37.5***	***30***	**47**		

More than 98% of the total weight is modelled; the remaining materials are expected not to have a major environmental impact. Therefore, only a minor underestimation of the total environmental impact of the lamp is expected.

The inputs that refer to the production (manufacturing processes) of the lamps are directly derived from the input data for the materials extraction and production. There is a significant difference in the production parameters per lamp family: incandescent, halogen or compact fluorescent. Following the VHK case study, it is taken into account that for the production of 1 kg sheet metal for lamps, 1.25 kg sheet metal is needed as input material (20% sheet metal scrap).

176 **PBT** PolyButyleneTerephtalate

4.1.5 Production of luminaires (4) selected to assess the luminaire socket and space lock-in effect

In line with the system approach explained in chapter 1 only the minimum relevant parts will be taken into account for the selected reference luminaires. Only the differences between the two reference luminaires will be compared per luminaire case as defined in section 4.1.2.

Case1DLS: GU10 mains voltage luminaire compared to GU5.3 low voltage luminaire.

Only price and BOM of low voltage transformer 60 VA (lot 7 preparatory study) will be used, see Table 4-3. The estimated average price was € 10.00.

Table 4-3 BOM of low voltage transformer 60 VA lot 7

Pos nr	MATERIALS Extraction & Production Description of component	Weight in g	Category Click &select	Material or Process select Category first !
1	Housing			
2	Upper case	65,6	4-Non-ferro	26-Al sheet/extrusion
3	Bottom case	17,9	1-BlkPlastics	10-ABS
4	Electronic assembly			
5	PVB	17,2	6-Electronics	49-PWB 1/2 lay 3.75kg/m2
6	Big caps & coils (THT)	99,7	6-Electronics	44-big caps & coils
7	Diodes, transistors, varistors	6,9	6-Electronics	47-IC's avg., 1% Si
8	ICs	0,0	6-Electronics	47-IC's avg., 1% Si
9	SMD /LED's (others)	0,0	6-Electronics	48-SMD/ LED's avg.
10	Terminal block	3,3	6-Electronics	45-slots / ext. ports
11	Miscellaneous			
12	Polyester film	4,1	1-BlkPlastics	1-LDPE
13	Packaging			
14	Back paper packaging	5,0	7-Misc.	56-Cardboard
15	Plastic slide pack	8,0	1-BlkPlastics	8-PVC

Case2NDLS: an up-lighter with R7s socket for a linear halogen mains voltage lamp compared to another one equipped for a Circular FL(ni).

Only price and BOM of a fluorescent lamp electronic ballast (lot 8 preparatory study on office lighting) will be used. BOM data is included in Table 4-4. The estimated average price was 29 euros. For the lamp the equivalent BOM of a LFL T5-28W will be used from lot 8 (p. 114), current price is about 4 euro.

Table 4-4 BOM of a typical electronic ballast for fluorescent lamp.

MATERIALS Extraction & Production ***Description of component***	**Electronic ballast for 1xLFL T5-54W (EEI=A2)**	**Category**	**Material or Process**
PCB	25,00	6-Electronics	**49-PWB 1/2 lay 3.75kg/m2**
Housing_Steel sheet	127,50	3-Ferro	**21-St sheet galv.**
PET film	5,00	1-BlkPlastics	**2-HDPE**
solder paste	2,50	6-Electronics	**52-Solder SnAg4Cu0.5**
Coil	70,00	6-Electronics	**44-big caps & coils**
Metal film capacitor_Aluminium	7,50	4-Non-ferro	**26-Al sheet/extrusion**
ELKO component_Aluminium sheet	5,00	6-Electronics	**44-big caps & coils**
luster terminal_PP	3,75	1-BlkPlastics	**4-PP**
luster terminal_steel	3,75	3-Ferro	**22-St tube/profile**
Total weight (g)	***250***		

4.1.6 Production of an average luminaire to assess energy consumption

In line with the system approach explained in chapter 1 only the minimum relevant parts will be taken into account for the selected reference luminaires.
Hence the average luminaire BOM is not relevant for this assessment. If there are significant material differences connected to improvement options (if any), those differences will be included in chapter 6.

4.2 Distribution phase

4.2.1 Distribution phase of reflector lamps

The environmental impact of the distribution of lamps is modelled according to the VHK-model. The input parameters for the lamps are shown in the table below. The main difference can be found in the volume of the packaged final product, which is based on the dimensions of the respective lamps.

Table 4-5: Input data for the environmental assessment of the distribution of the lamps (expressed in dm³)

MATERIALS Extraction & Production ***Description of component***	Incandescent reflector lamp, R63, E27 – **60W**	Halogen reflector lamp, R63, E27 , – **60W**	Incandescent/halogen reflector lamp, PAR38, E27 – **100/120W**	Halogen reflector lamp, MR16, GU10 – **50W**	Halogen reflector lamp, MR16, 12V, GU5.3 – **50W**	Compact fluorescent reflector lamp, R50, GU10 – **7W**	**Category**	**Material or Process MEEUP**
Volume per packaged retail product	0.41	0.41	1.70	0.40	0.40	0.23	7-Misc.	**62-per dm³ retail product**

4.2.2 Distribution phase of luminaires

As stated before the focus is on differences for luminaire cases (two by two). It will be assumed that the identified luminaire cases have identical packed volume, hence no impact difference will be taken into account.

4.3 Use phase (product)

In this section, an overview is included of the calculation of the annual resources consumption and the direct emissions related to the defined performance parameters in chapter 1 and 3 under standard and non-standard conditions. This section also includes a representative overview of the performance parameters found for products on the market year 2008-2009.
The purchase prices of the lamps that are mentioned in Table 4-6 are prices found on the retailer market. They can vary with 50% plus or minus and this will be taken into account in the sensitivity analysis.

In chapter 6, dedicated to the Best Available Technology (BAT) and Best Not Yet Available Technology (BNAT), upcoming products are considered with more improved performance parameters but with a high actual price and/or a low actual trade volume or products that are only in the R&D phase.

4.3.1 Rated annual resources consumption (energy, lamps) during product life according to the test standards defined in chapter 1

4.3.1.1 Annual energy consumption formula

The annual energy consumption (E_y) of a lamp in standard conditions is straightforward related to the lamp power and burning hours per year:

$$E_y\ [kWh] = P_{lamp}\ [kW] \times t_{operating}.$$

where,

- P_{lamp} = lamp power in kW as defined in chapter 1,
- $t_{operating}$ = burning hours per year as defined in chapter 2.

4.3.1.2 Annual lamp consumption formula

The annual consumption of lamps per lighting point in standard conditions is straightforward and related to the lamp lifetime in hours. It is assumed that in domestic lighting, lamps are used until end of life.

$$N_y = t_{operating} / t_{life}$$

where,

- t_{life} of the lamp is usually taken at LSF = 0,5 (LSF is the Lamp Survival Factor see chapter 1).

4.3.1.3 Assessment of relevant lamp types and product performance parameters

For incandescent lamps, the typical declared operational lifetime t_{life} is 1000h and for halogen lamps, operational lifetimes vary from 2000 to 5000h and are declared by manufacturers. For CFLi's, different declared operational lifetimes can be found on the market: e.g. 6000, 8000, 12000 and 15000h.

The colour rendering Ra for incandescent and halogen lamps is accepted to be 100.
For CFLi's, usually the colour rendering Ra and varies between 80 and 90.

Colour temperature T_C for incandescent lamps is in the range from 2400K to 2900K, for mains voltage halogen lamps from 2700K to 2900K and for low voltage halogen lamps T_C is about 3000K. Most currently used CFLi's have T_C = 2700K, but also lamps with a higher T_C are available on the market.

Table 4-6 includes the performance parameters for the selected base-case lamp types that are used further in this study. Lamp lifetime data were retrieved from the data supplied by manufacturers on their products and in their catalogues.

The performance of a reflector lamp in catalogues is mostly expressed in candela (cd) and beam angle (θ). The luminous efficacy (lm/W) of a reflector lamp (η_{lamp}) is in most cases not given in manufacturers catalogues. Measurement data were provided by ELC members. From this data it can be concluded that the real measured peak intensity and beam angle can vary compared to the nominal value, therefore working with functional lumen output is more stable for the purpose of this study. This is also illustrated in Table 4-6 with HL-LV-R lamps with different beam angles; as can be seen there the beam angle has a small influence on efficacy in the same technology.

Please note that most of the sold CFLi reflector lamps are NDLS, e.g. the typical 7 Watt GU10 (MR16) or equivalent E14 (R50) lamp which has only about 68 % lumen (130/190) in a solid angle of π. Therefore these lamps will not be considered as a base case in chapter 5. The few CFLi-R lamps that really are DLS are efficient and have few improvement options, see E27 (R120) compared to others in a simular solid angle. In chapter 6 CFLi-R might be considered as improvement options for HL-LV-R lamps, however as already can be seen the improvement potential is poor. Especially because BAT HL-LV-R lamps are not yet included (see chapter 6).

Please also note that not all lamps are retrofit solutions for each other, hence there is a lock-in effect (see also chapter 3).

Table 4-6: Selected lamp efficacy, cost data and life time

Lamp type / Acronym	Wattage	Average LWFt[177]	Intensity	Beam angle	Luminous flux in a solid angle of 2π	Luminous flux in solid angle π (angular beam 120°)	Functional lumens in an angular beam of 90°	ηlamp(90°) @25 °C (without LWFt)	Life time	Unit price (for end user)
	[W]		[cd]	[°]	[lm]	[lm]	[lm]	[lm/W]	[h]	[€]
Incandescent reflector lamp, R63, E27 (B22d) **GLS-R**	40	1	321	53	296	264	209	5.2	1000	1.3
Incandescent reflector lamp, R63, E27 (B22d) **GLS-R**	60	1	836	29	487	427	328	5.5	1000	1.3
Halogen reflector lamp, R63, E27 (B22d) **HL-MV-R**	40	1	714	23	315	275	213.7	5.3	2000	4.5
Halogen reflector lamp, R63, E27 (B22d) **HL-MV-R**	60	1	1037	29	529	475	379.8	6.3	2000	4.5

[177] LWFt = Total Lamp Wattage Factor = LWFp x LWFe (see section 4.4.1).

Incandescent reflector lamp, PAR38, E27 (B22d) **GLS-R**	80	1	1882	27	699	677	617	7,7	1000	5.4
Incandescent reflector lamp, PAR38, E27 (B22d) **GLS-R**	120	1	3562	25	1230	1176	1131	9,4	1000	5.4
Halogen reflector lamp, PAR38, E27 (B22d) **HL-MV-R**	100	1	2620	30	1251		1081	10.8	2000	13.5
Halogen reflector lamp, MR16, GU10 **HL-MV-R**	35	1	416	36	219	202	175	5.0	2000	4.1
Halogen reflector lamp, MR16, GU10 **HL-MV-R**	50	1	851	31	367	346	313	6.3	1000	3.1
Halogen reflector lamp, MR16, GU10 **HL-MV-R**	50	1	790	34	392	369	329	6.6	2000	4.1
Halogen reflector lamp, MR16, 12V, 38°, GU5.3 **HL-LV-R**	35	1.11	1297	26	392	370	333	9.5	2000	1.5
Halogen reflector lamp, MR16, 12V, GU5.3 **HL-LV-R**	35	1.11	1261	39	537	519	471	13,5	4000	3.3
Halogen reflector lamp, MR16, 12V, 38°, GU5.3 **HL-LV-R**	50	1.11	1290	34	546	521	470	9.4	2000	1.5
Halogen reflector lamp, MR16, 12V, 10°, GU5.3 **HL-LV-R**	50	1.11	8800	10	744	709	640	12.8	4000	3.3
Halogen reflector lamp, MR16, 12V, 24°, GU5.3 **HL-LV-R**	50	1.11	2500	24	763	737	677	13.5	4000	3.3
Halogen reflector lamp, MR16, 12V, 38°, GU5.3 **HL-LV-R**	50	1.11	1500	36	782	765	714	14.3	4000	3.3
Halogen reflector lamp, MR16, 12V, 60°, GU5.3 **HL-LV-R**	50	1.11	1100	60	828	809	750	15.0	4000	3.3
Compact fluorescent reflector lamp, MR16, GU10 **CFLi-R**	7	1.05	60	130	190	130	85	12.1	6000	6
Compact fluorescent reflector lamp, R120, E27 (B22d) **CFLi-R**	20	1,05	265	110	638	440	385	19,3	6000	15.0

Remarks: the xxx highlighted values are not measured but calculated based on the adjacent values,
the CFLi-R do not meet the requirements for a DLS (≠ 80% light output in the 120° cone angle),
all mentioned luminous fluxes are initial luminous fluxes.

4.4 Use phase (system)

This chapter is important to understand the limitations that are imposed on domestic light sources and also aspects related to the 'putting into service of domestic lighting equipment'. This section identifies and describes the functional system to which the product in question belongs and identifies and quantifies, to the extent possible, those product features that can reduce the environmental impact not only of the product but of the system as a whole. Please note that the scope of the system analysis is wider than the scope of the EuP Directive. The question that should be posed during the analysis is whether and how the system performance could be improved leading to environmental benefits with measures that are restricted only to issues that can be influenced by technical features or additional information of the product under investigation as defined in chapter 1. Furthermore, the system analysis serves as an addition to the more traditional product-specific analysis in paragraph 4.3, i.e. to design product specific legislation (if any) in such a way that it would not make system-oriented innovations impossible.

4.4.1 Assessment of energy consumption of the reflector lamps during product life, taking into account the system

4.4.1.1 Influence of the power factor

See for this item also section 3.2.8. For lamps operating on a ballast or electronics, the power factor can go down to 0,50[178]; the lower the power factor, the higher the electrical current that is needed to provide in the same amount of real power. . Use of higher current to compensate for a lower power factor than 1 is assumed to cause 5% more losses in the electrical grid that feeds the lamp. Therefore a correction factor 'Lamp Wattage Factor LWFp' is introduced as shown in Table 4-7.

Table 4-7 Adjustment to correct for Power Factor (LWFp) used in this study

lamp type	LWFp
GLS-R	1
HL-LV-R types	1
CFLi-R	1.05
LED retrofit for HL-MV-R	1.05
LED retrofit for HL-LV-R	1

The formula for the real power becomes:

P_{real} [W] = Plamp x LWFp.

The real annual energy consumption (E_{yreal}) per lamp is related to the standard energy consumption by:

E_{yreal} [kWh] = E_y [kWh] x LWFp.

178 IAEEL newsletter 3-4/95, 'Power Quality for Beginners'

4.4.1.2 Influence of the external power supply or external ballast

The low voltage halogen lamps need an external power supply and CFLni's need an external ballast. Those transformers and ballasts are mostly incorporated in the luminaire. As discussed in other EuP studies[179], this also causes power losses in the system.

Table 4-8: Transformer efficiencies (source BIOIS)

Rated Lamp Load (P) (in watts)	Full load Efficiencies Assumption for EuP preparatory study	
	Magnetic transformers	Electronic transformers
$0 < P \leq 60$	**80 %**	**92.5 %**
$60 < P \leq 105$	**84 %**	
$105 < P \leq 210$	**90 %**	
$210 < P$	**92 %**	

To take into account those losses, a 'Lamp Wattage Factor LWFe' for low voltage halogen lamps is introduced. According to the values in Table 4-1, and a transformer distribution of 70% electronic vs. 30% magnetic, a value LWFe = 1,11 is taken into account; the same value is used for external ballasts on CFLni's.

Table 4-9: Adjustment to correct for Power Supply Losses or external ballast (LWFe)

lamp type	LWFe
GLS-R	1
HL-MV –R types	1
HL-LV –R types	1,11
CFLi-R	1
LED retrofit HL-MV-R	1
LED retrofit HL-LV-R	1.17

The formulas for the real power and the real electricity consumption are the same as for the compensation of the power factor with LWFp replaced by LWFe.

4.4.2 Assessment of the use phase of the luminaires (4) selected to assess the luminaire socket and space lock-in effect when assessing the energy consumption

This will be done based on the energy consumptions of the selected lamp types for comparison. Therefore equivalent BAT lamp types (GU10 vs GU5.3, R7s vs CFLni) will be selected based on chapter 6 data.

[179] Preparatory Studies for Eco-design Requirements of EuPs, Lot 8 & 9: Office lighting & Street lighting and Lot 7: External power supplies and battery chargers.

4.4.3 Other elements of the system environment

Another important element of the system environment are dimming devices that are installed in the electrical grid. Very few CFLi lamps can be operated with a standard dimmer.

Also an external power supply or ballast[180] can be needed for low voltage lamps or CFLni's.

Please note that both elements were already discussed in part 1 of the study.

Finally, also the room itself belongs to the system. Improvement can be obtained by increasing use of day lighting, brighter and more reflective surfaces (wall, ceiling, floor, carpet, furniture, etc.) and the positioning of the light source.

4.5 End-of-life phase

The NDLS lamps are treated equal to DLS lamps, please see part 1 of this study.

For luminaires it will be assumed that identified luminaire cases or improvement options have identical end of life behaviour, hence there are no difference to be taken into account in line with the approach explained in chapter 1.

[180] Preparatory Studies for Eco-design Requirements of EuPs, Lot 8 & 9: Office lighting & Street lighting and Lot 7: External power supplies and battery chargers.

5 DEFINITION OF THE BASE-CASE

Chapter 5 comprises of an assessment of average EU products, the so called "base-cases".

A base-case is "a conscious abstraction of reality". The description of the base-cases is the synthesis of the results of tasks 1 to 4. The environmental and life cycle cost analysis are built on these base-cases throughout the rest of the study and it serves as the point-of-reference for chapter 6 (technical analysis of BAT), chapter 7 (improvement potential), and chapter 8 (policy analysis).

According to the MEEuP methodology, the scope of a preparatory study should be covered by one or two base-cases in chapter 5. Nevertheless, as discussed in chapter 1, a wide range of lamps are available and chapter 2 highlighted that their sales amounts are significant. Therefore, it was decided to analyse a larger number of base-cases to portray the market reality in a comprehensive manner. Detailed analysis of several base-cases will also allow a more realistic assessment of improvement potentials in the subsequent tasks and EU-27 total environmental impact.

From section 2.2.3, 4 base-cases were considered to be representative of the current European market of directional light sources (DLS):

- **Incandescent lamp, reflective (GLS-R): 50 W**
- **Halogen lamp, mains voltage, reflective, high wattage (HL-MV-R-HW): 100 W**
- **Halogen lamp, mains voltage, reflective, low wattage (HL-MV-R-LW): 50 W**
- **Halogen lamp, low voltage, reflective (HL-LV-R): 35 W**

The choice of the wattage of the base-cases was based on the outcomes of primary the EU R&D project EURECO and others (see chapter 2, section 2.2.3) which provided information about the use of lighting sources by wattage groups for several European countries.

The average yearly use times are different for all base-cases and figures presented in chapter 2 for all sectors (see section 2.2.4) are used in this chapter:

- Incandescent lamp, reflective (GLS-R): 400 hours/year
- Halogen lamp, mains voltage, reflective, high wattage (HL-MV-R-HW): 450 hours/year
- Halogen lamp, mains voltage, reflective, low wattage (HL-MV-R-LW): 450 hours/year
- Halogen lamp, low voltage, reflective (HL-LV-R): 500 hours/year

As already mentioned in chapter 4 (section 4.1.3), neither ballasts for CFLi-R, nor transformers and power supplies for low voltage halogen lamps will be discussed in detail in this study as they were already detailed in the study on office lighting[181] and on external power supplies[182].

Please note that CFLi reflector lamps will not be considered as a base-case lamp in part 2 related to DLS lamps. As can be concluded from chapter 4 most of them are NDLS and belong to part 1. Moreover the sales of CFLi reflector lamps are low as presented in chapter 2. Also the current sales of LEDs are low and are therefore not considered as base case lamps in order not to complicate the calculation model. Both LEDs and CFLi-R will be discussed in chapter 6 as improvement options for the base-cases.

Luminaire cases were presented in section 4.1.2 and the environmental assessment will be discussed in qualitative terms in Chapter 8.

The environmental impacts of the base-cases are evaluated with the EuP EcoReport tool as specified in the MEEuP methodology. This allows identifying the significance of the different phases of the life cycle in terms of environmental impacts.

Inputs used in this chapter were defined in previous chapters. Chapter 4 provides the required technical data, Bill of Materials (BOM), packaging and packaged volume, energy consumption during the use phase and considerations regarding the end-of-life of materials for existing products. Economic data (sales and stocks in EU-27, as well as product price and electricity tariff) were established in chapter 2.

For each of the 4 base-cases, the electricity consumption used in chapter 5 is for real life conditions. Thereby, the correction lamp wattage factors for power quality (LWFp) and external ballasts (LWFe) presented in section 4.4.1 have been taken into consideration. Further, the average lamp lumen maintenance factor (LLMF), as discussed in chapter 3 of Part 1, is used to calculate the lamp efficacy of the base-cases.

5.1 Product-specific inputs

5.1.1 Base-case GLS-R (General Lighting Service)

As stated in section 4.4.1, the BOM and packaged volume for 40 W and 60 W GLS are the same. Therefore, an average wattage of 50 W is assumed, and the BOM and packaged volume are taken from the 60 W GLS.

- **Bill of Material**

The BOM of this base-case is derived from the products presented in chapter 4 (section 4.1.2) for the incandescent lamp of 50 W (see Table 5-1).

[181] Preparatory Studies for Eco-design Requirements of EuPs, Lot 8: Office lighting, Final Report (April 2007).
[182] Preparatory Studies for Eco-design Requirements of EuPs, Lot 7: External power supplies and battery chargers, Final Report (January 2007).

Table 5.5-1: EcoReport material input table for base-case GLS-R

Nr	Product name	Date	Author
	Base-Case GLS-R		BIO

Pos nr	MATERIALS Extraction & Production Description of component	Weight in g	Category Click &select	Material or Process select Category first !
1	Glass	28	7-Misc.	54-Glass for lamps
2				
3	Aluminium for caps	1.5	4-Non-ferro	26-Al sheet/extrusion
4				
5	Soldering	0.5	6-Electronics	52-Solder SnAg4Cu0.5

- **Primary scrap production during sheet metal manufacturing**

It was assumed that the production of 1 kg sheet metal for lamps required 1.25 kg sheet metal, which leads to 20 % of sheet metal scrap. **This assumption is valid for the 4 base-cases.**

- **Volume and weight of the package volume**

The weight of the base-case is 30 g and it has a packaged volume of 0.41 dm^3.

- **Annual resource consumption and lamp efficacy**

The power rating of the base case GLS-R is 50 W as the correction factors are equal to 1, with a lamp lifetime of 1000 hours. With a yearly use of 400 hours (taking into consideration the use in all sectors and not only the domestic one), the lifespan of a typical incandescent lamp is 2.5 years.

Luminous efficacy is taken as the average of the measured efficacy in a 60 W and 40 W GLS-R, which results in a luminous efficacy of 5.35 lm/W. Considering a Lamp Lumen Maintenance Factor (LLMF) of 0.965 for GLS lamps, the **average luminous efficacy of base-case GLS-R is 5.16 lm/W** within an opening angle of 90°.

- **Disposal and Recycling**

For incandescent lamps, 100 % of the product is assumed to be disposed in landfills.

5.1.2 Base-case HL-MV-R-HW (Halogen Lamp – Mains Voltage – Reflective – High Wattage (230 V))

Chapter 4 presented various types of HL-MV-R. The 100 W lamp is chosen for the high wattage base-case, as it corresponds with the high power market average as mentioned in chapter 2.

- **Bill of Material**

The BOM of the base-case HL-MV-R-HW presented in Table 5.5-2 is based on the data presented in chapter 4.

Table 5.5-2: EcoReport material input table for base-case HL-MV-R-HW

Nr	Product name	Date	Author
	Base-Case HL-MV-R-HW		BIO

Pos nr	MATERIALS Extraction & Production Description of component	Weight in g	Category Click &select	Material or Process select Category first !
1	Glass	365	7-Misc.	54-Glass for lamps
2				
3	Copper for caps/connector pins	3.5	4-Non-ferro	30-Cu tube/sheet
4				
5	Solderin	0.5	6-Electronics	52-Solder SnAg4Cu0.5
6				

- **Volume and weight of the package volume**

The weight of the base-case HL-MV-R-HW is 369 g and it has a packaged volume of 1.70 dm^3.

- **Annual resource consumption and lamp efficacy**

The electricity consumption of the base-case HL-MV-R-HW is 100 Wh/h, as the total Lamp Wattage Factor (LWFt) is equal to 1 according to chapter 4 (section 4.4.1). The lamp lifetime is 2000 hours with an average use of 450 hours per year (taking into consideration the use in all sectors and not only the domestic one). Therefore, the lifespan of a typical HL-MV-R-HW is 4.44 years.

Based on a measured initial lamp efficacy of 10.8 lm/W and average LLMF of 0.975, the **average luminous efficacy of the base-case HL-MV-R-HW is 10.53 lm/W** within an opening angle of 90°.

- **Disposal and Recycling**

100 % of the HL-MV-R-HW is assumed to be disposed in landfill.

5.1.3 Base-case HL-MV-R-LW (Halogen Lamp – Mains Voltage – Reflective – High Wattage (230 V))

The 50 W lamp is chosen for the low wattage base-case, as it corresponds with the low power market average as mentioned in chapter 2.

- **Bill of Material**

The BOM of the base-case HL-MV-R-LW presented in Table 5.5-3 is based on the data presented in chapter 4.

Table 5.5-3: EcoReport material input table for base-case HL-MV-R-LW

Nr	Product name	Date	Author
	Base-Case HL-MV-R-LW		BIO

Pos nr	MATERIALS Extraction & Production Description of component	Weight in g	Category Click &select	Material or Process select Category first !
1	Glass	36	7-Misc.	54-Glass for lamps
2				
3	Copper for caps/connector pins	1.5	4-Non-ferro	30-Cu tube/sheet
4				

■ **Volume and weight of the package volume**

The weight of the base-case HL-MV-R-LW is 37.5 g and it has a packaged volume of 0.40 dm^3.

■ **Annual resource consumption and lamp efficacy**

The electricity consumption of the base-case HL-MV-R-LW is 50 Wh/h, as the total Lamp Wattage Factor (LWFt) is equal to 1 according to chapter 4 (section 4.4.1). The lamp lifetime is 1500 hours with an average use of 450 hours per year (taking into consideration the use in all sectors and not only the domestic one). Therefore, the lifespan of a typical HL-MV-R-LW is 3.33 years.

Based on a measured initial lamp efficacy of 6.45 lm/W and average LLMF of 0.975, the **average luminous efficacy of the base-case HL-MV-R-LW is 6.29 lm/W** within an opening angle of 90°.

■ **Disposal and Recycling**

100 % of the HL-MV-R-HW is assumed to be disposed in landfill.

5.1.4 Base-case HL-LV-R (Halogen Lamp – Low Voltage – Reflective (12 V))

Using the given product market data, 35 W was chosen as the representative power. The BOM and lamp data is taken from measurements of various 50 W lamps. It assumed that a 35 W and a 50 W lamp have the same characteristics, aside from power and lamp efficacy.

■ **Bill of Material**

The BOM of HL-LV-R is derived from the products presented in chapter 4 (section 4.1.2) for the low voltage halogen lamp of 50 W (see Table 5.5-4).

Table 5.5-4: EcoReport material input table for base-case HL-LV-R

Nr	Product name	Date	Author
	Base-Case HL-LV-R		BIO

Pos nr	MATERIALS Extraction & Production Description of component	Weight in g	Category Click &select	Material or Process select Category first !
1	Glass	29	7-Misc.	54-Glass for lamps
2				
3	Copper for caps	0.3	4-Non-ferro	30-Cu tube/sheet
4				
5	Cement	0.7	7-Misc.	58-Concrete

- **Volume and weight of the package volume**

The weight of the base-case HL-LV-R is 30 g and it has a packaged volume of 0.40 dm^3.

- **Annual resource consumption and lamp efficacy**

The power rating of the base case HL-LV-R is 35 W, however there is a lamp wattage factor (LWFt) of 1.11 (see section 4.4.1). This is due to the inefficiencies in the transformer that steps down the voltage from mains voltage to low voltage. Therefore, the real power consumed is 38.85 W. The lamp lifetime is 3000 hours, with an assumed usage of 500 hours/year (taking into consideration the use in all sectors and not only the domestic one). Thus, the expected lifetime of the lamp is 6 years.

Based on a measured luminous efficacy of 10.34 lm/W and an average LLMF of 0.975, it can be assumed that the **average luminous efficacy of the base-case HL-LV-R is about 10.08 lm/W** within an opening angle of 90°.

- **Disposal and Recycling**

Similar to incandescent lamps, 100% of halogen lamps are assumed to be placed in landfill.

5.2 Base-case Environmental Impact Assessment

5.2.1 Base-case GLS-R

Table 5-6 presents the results of the environmental impact assessment of the base-case GLS-R.

It is clearly visible that for each of the 15 environmental impact indicators, the use phase is the most impacting stage over the whole product life cycle. The total energy consumption for the whole life cycle of the 50 W GLS-R base-case is 580 MJ.

Table 5.5-5: Environmental assessment results from EcoReport (base-case GLS-R)

Table . Life Cycle Impact (per unit) of Base-Case GLS-R

Nr	Life cycle Impact per product:	Date	Author
0	Base-Case GLS-R	0	BIO

Nr	Life Cycle phases --> / Resources Use and Emissions	unit	PRODUCTION Material	PRODUCTION Manuf.	PRODUCTION Total	DISTRI-BUTION	USE	END-OF-LIFE* Disposal	END-OF-LIFE* Recycl.	END-OF-LIFE* Total	TOTAL
	Materials										
1	Bulk Plastics	g			0.0			0.0	0.0	0.0	0.0
2	TecPlastics	g			0.0			0.0	0.0	0.0	0.0
3	Ferro	g			0.0			0.0	0.0	0.0	0.0
4	Non-ferro	g			1.5			1.5	0.0	1.5	0.0
5	Coating	g			0.0			0.0	0.0	0.0	0.0
6	Electronics	g			0.5			0.4	0.1	0.5	0.0
7	Misc.	g			28.0			28.0	0.0	28.0	0.0
	Total weight	g			30.0			29.9	0.1	30.0	0.0
									see note!		
	Other Resources & Waste							debet	credit		
8	Total Energy (GER)	MJ	0.9	0.1	1.0	52.1	525.0	2.1	0.0	2.0	580.1
9	of which, electricity (in primary MJ)	MJ	0.5	0.0	0.5	0.0	525.0	0.0	0.0	0.0	525.5
10	Water (process)	ltr	0.3	0.0	0.3	0.0	35.0	0.0	0.0	0.0	35.3
11	Water (cooling)	ltr	0.0	0.0	0.0	0.0	1400.0	0.0	0.0	0.0	1400.0
12	Waste, non-haz./ landfill	g	6.4	0.2	6.6	51.6	608.8	36.8	0.0	36.7	703.7
13	Waste, hazardous/ incinerated	g	0.0	0.0	0.0	1.0	12.1	0.1	0.0	0.1	13.2
	Emissions (Air)										
14	Greenhouse Gases in GWP100	kg CO2 eq.	0.0	0.0	0.1	4.6	22.9	0.2	0.0	0.2	27.7
15	Ozone Depletion, emissions	mg R-11 eq.				negligible					
16	Acidification, emissions	g SO2 eq.	0.2	0.0	0.2	12.1	135.2	0.3	0.0	0.3	147.8
17	Volatile Organic Compounds (VOC)	g	0.0	0.0	0.0	0.1	0.2	0.0	0.0	0.0	0.3
18	Persistent Organic Pollutants (POP)	ng i-Teq	0.0	0.0	0.0	0.3	3.4	0.3	0.0	0.3	4.0
19	Heavy Metals	mg Ni eq.	0.0	0.0	0.0	2.6	9.0	0.6	0.0	0.6	12.3
	PAHs	mg Ni eq.	0.1	0.0	0.1	2.6	1.0	0.0	0.0	0.0	3.8
20	Particulate Matter (PM, dust)	g	0.0	0.0	0.0	1.7	2.9	2.7	0.0	2.7	7.3
	Emissions (Water)										
21	Heavy Metals	mg Hg/20	0.1	0.0	0.1	0.1	3.4	0.2	0.0	0.2	3.7
22	Eutrophication	g PO4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	Persistent Organic Pollutants (POP)	ng i-Teq				negligible					

Figure 5-1 and Figure 5-2 show the contribution of each of life cycle phases to two main environmental indicators: gross energy requirement (GER) and global warming potential (GWP). The use phase is the highest contributor of these impacts as it represents about 91% of the total energy consumption and about 83% of the GWP over the product's lifetime.

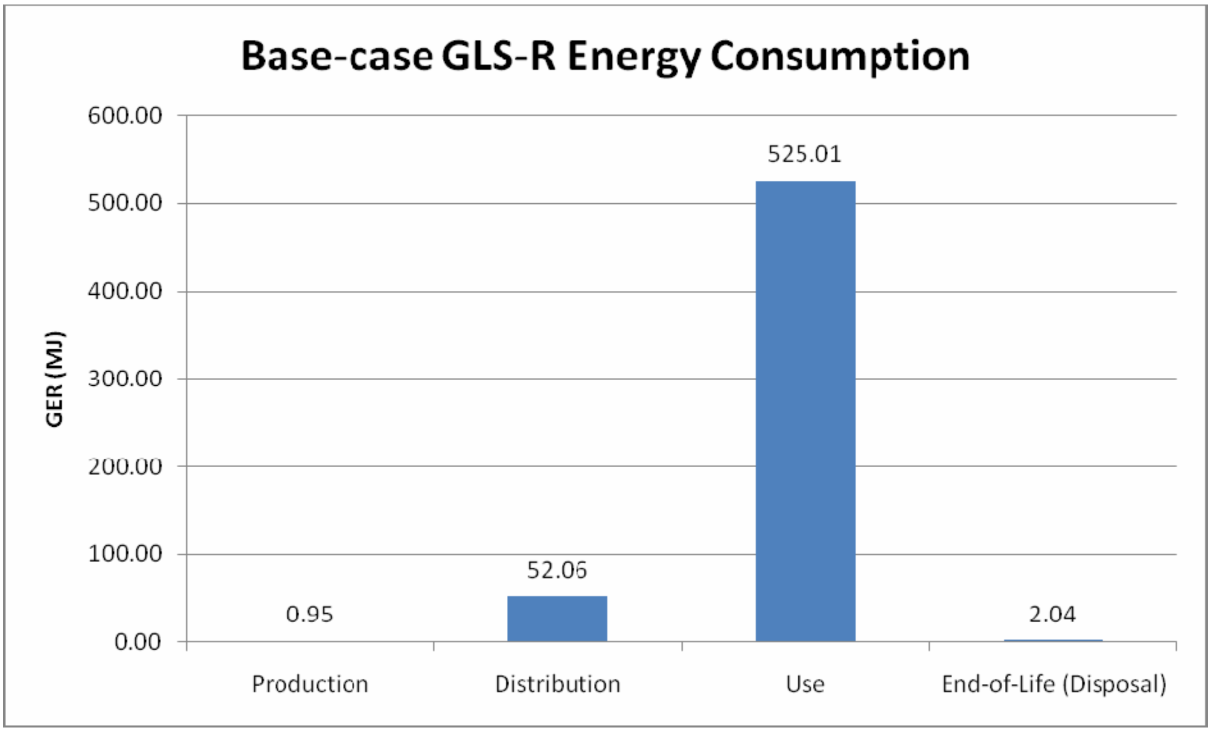

Figure 5-1: Total energy consumption during all life cycle phases

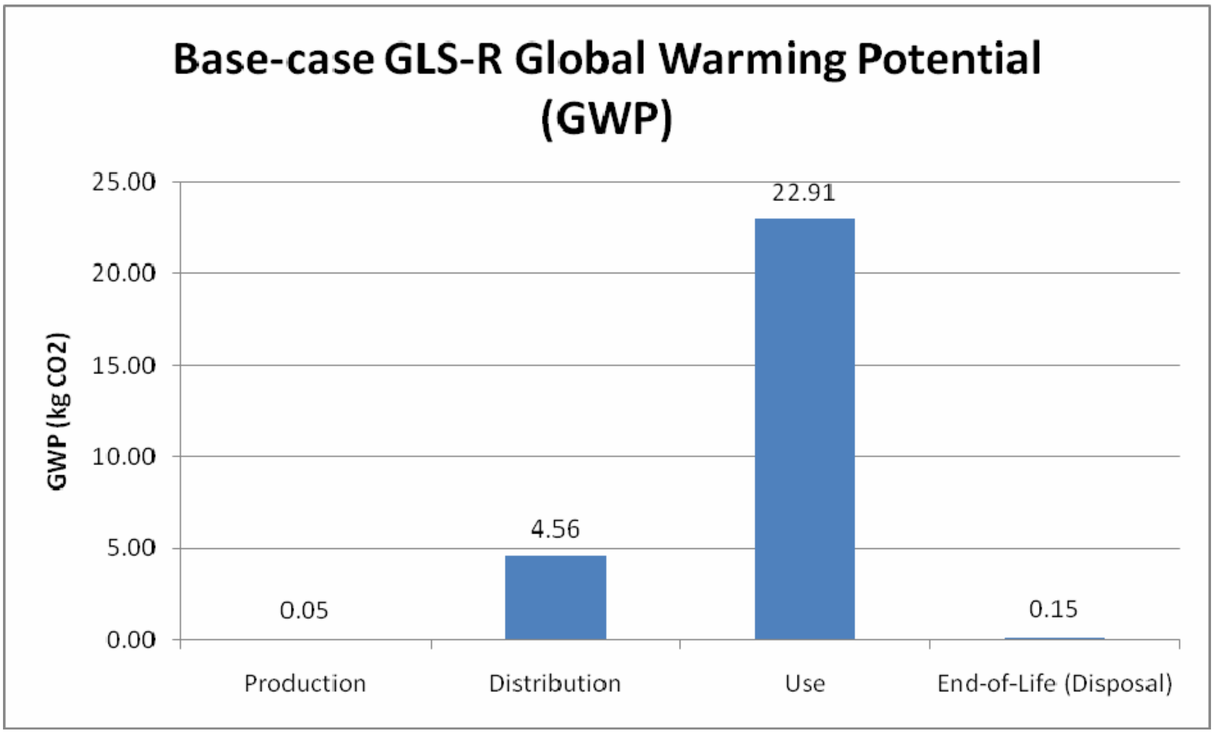

Figure 5-2: Total Global Warming Potential during all life cycle phases

Figure 5-3 presents the contribution of the life cycle phases for each of the 15 environmental impact indicators.

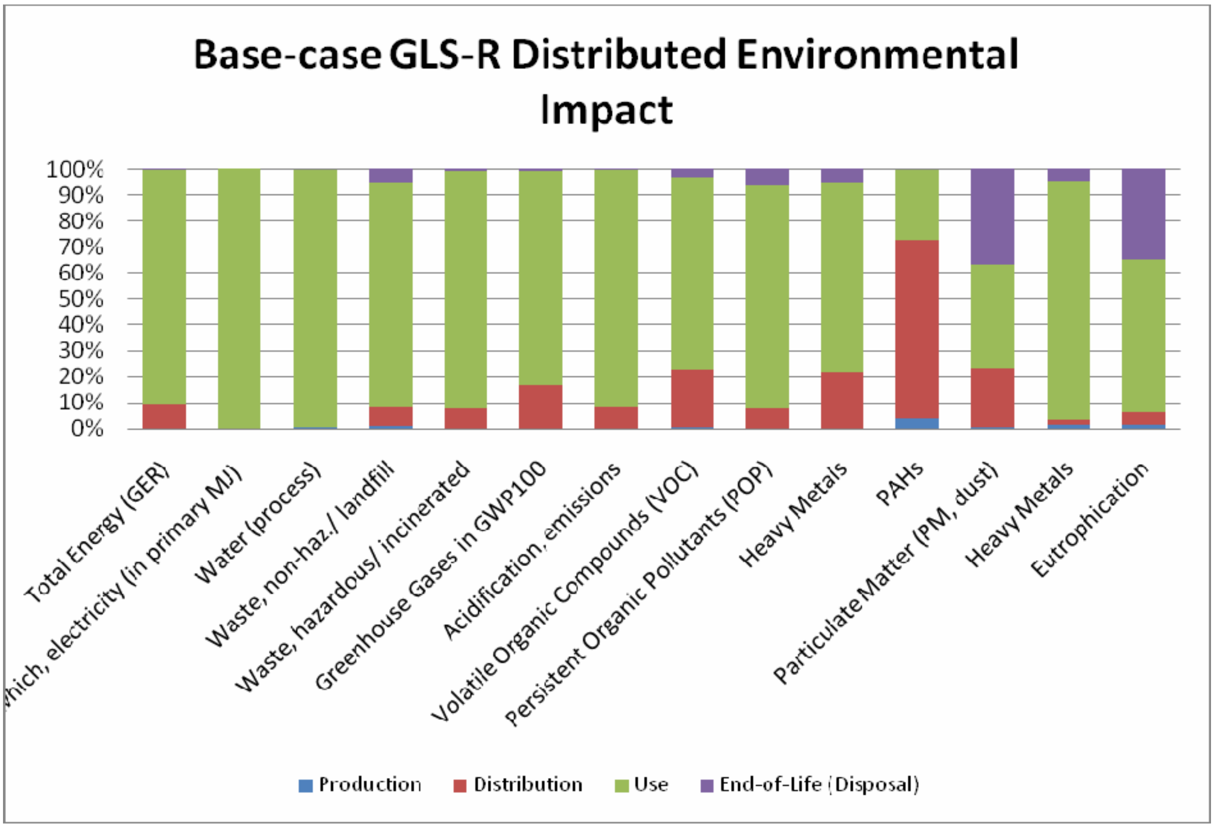

Figure 5-3: Distribution of environmental impacts per life cycle phase

Several observations can be made from this analysis:

- The production phase is negligible for all environmental impact indicators. Its highest contribution is 4% to the emissions of Polycyclic Aromatic Hydrocarbons (PAHs) to air, due to the use of aluminium for the caps of the lamps.
- The distribution phase contributes more than 5% of the life cycle impacts for 11 of the 15 environmental impact indicators. Impacts of this phase are the highest for the emission of PAHs (69%), particulate matter to air (23%), volatile organic compounds (VOC) (22%), and heavy metals (21%). This can be explained by the assumption related to transport in trucks from the retailer's central warehouse to the shop. Nevertheless, although the distribution phase has a high contribution to these indicators, their total values over the life cycle remain low. The EcoReport tool does not allow specifying means of transport and distances between the production place of the lamp and retailer's central warehouse; only the volume of the product is taken into consideration to assess environmental impacts of the transport. Nevertheless, according to the MEEuP methodology (section 5.3.6, page 96), a mix of means of transport (trucking, rail, sea freight and air freight) with assumptions on distances was used for all base-cases. This assumption could be considered as disadvantageous for lamps mainly produced in Europe (e.g. GLS-R) and advantageous for lamps produced in Asia (e.g. CFLi-R). However, as mentioned previously, the contribution of the distribution phase to the environmental impacts is either low in relative terms compared to other life cycle phases (e.g. for energy consumption or GWP), or low in absolute terms as total values over the whole life cycle are not significant compared to other products (e.g. for PAHs or VOC).

- The contribution of the use phase to environmental impact varies between 27% (for the emissions of PAHs to air) and 100% (for the use of cooling water). For 10 environmental impact indicators, the use phase contributes to more than 80%.
- For incandescent lamps, the whole product is disposed of into landfill and no benefit is possible with recycling. The end-of-life phase is significant for the emissions of particulate matter to air (37%) due to the transport to the landfill, and for eutrophication (36%). However, the eutrophication potential due to the life cycle of an incandescent lamp is very low (less than 0.03 g PO_4) compared to, for example a typical 32" LCD TV (about 15 g PO_4)[183].

Power generation based on coal implies emissions of mercury to air. According to the DG Joint Research Centre, **the generation of 1 kWh emits 0.016 mg of mercury to air**, assuming it is produced from an EU fuel mix of 31 % coal, 21 % gas and oil, and 48 % non-fossils fuels (of which 32% of nuclear)[184]. This assumption will be used for all base-cases.

Therefore, the total electricity consumption of the base-cases GLS-R during the use phase over the product lifetime being 50 kWh (50 Wh during 1000 hours), **0.80 mg of mercury is emitted to air over the whole life cycle** (mercury emissions in other phases than the use phase are assumed to be negligible for this lamp type).

5.2.2 Base-case HL-MV-R-HW

The outcomes of the "life cycle assessment" of the base-case HL-MV-R-HW carried out with the EcoReport tool are presented in Table 5-8 below.

[183] Source: EuP Preparatory Study on Television (Lot 5) http://www.ecotelevision.org/docs/Lot%205_T5_Final_Report_02-08-2007.pdf
[184] Source: http://lca.jrc.ec.europa.eu/lcainfohub/datasets/html/processes/Power_grid_mix_UCTE__83c1f02c-f2ef-4ac4-9a57-ac2172c38D15__01.00.001.html

Table 5.5-6: Environmental assessment results from EcoReport (base-case HL-MV-R-HW)

Table . Life Cycle Impact (per unit) of Base-Case HL-MV-R-HW

Nr	Life cycle Impact per product:	Date	Author
0	Base-Case HL-MV-R-HW	0	BIO

Nr	Life Cycle phases -->		PRODUCTION			DISTRI-	USE	END-OF-LIFE*			TOTAL
	Resources Use and Emissions		Material	Manuf.	Total	BUTION		Disposal	Recycl.	Total	
	Materials	**unit**									
1	Bulk Plastics	g			**0.0**			0.0	0.0	**0.0**	**0.0**
2	TecPlastics	g			**0.0**			0.0	0.0	**0.0**	**0.0**
3	Ferro	g			**0.0**			0.0	0.0	**0.0**	**0.0**
4	Non-ferro	g			**3.5**			3.5	0.0	**3.5**	**0.0**
5	Coating	g			**0.0**			0.0	0.0	**0.0**	**0.0**
6	Electronics	g			**0.5**			0.4	0.1	**0.5**	**0.0**
7	Misc.	g			**365.0**			365.0	0.0	**365.0**	**0.0**
	Total weight	g			**369.0**			368.9	0.1	**369.0**	**0.0**
									see note!		
	Other Resources & Waste							debet	credit		
8	Total Energy (GER)	MJ	6.2	0.1	**6.3**	**53.8**	**2100.1**	25.2	0.0	**25.2**	**2185.4**
9	of which, electricity (in primary MJ)	MJ	4.8	0.0	**4.9**	**0.0**	**2100.0**	0.0	0.0	**0.0**	**2104.9**
10	Water (process)	ltr	3.1	0.0	**3.2**	**0.0**	**140.0**	0.0	0.0	**0.0**	**143.2**
11	Water (cooling)	ltr	0.0	0.0	**0.0**	**0.0**	**5600.0**	0.0	0.0	**0.0**	**5600.0**
12	Waste, non-haz./ landfill	g	33.1	0.3	**33.4**	**52.5**	**2435.2**	452.4	0.0	**452.3**	**2973.4**
13	Waste, hazardous/ incinerated	g	0.1	0.0	**0.1**	**1.0**	**48.4**	0.1	0.0	**0.1**	**49.6**
	Emissions (Air)										
14	Greenhouse Gases in GWP100	kg CO2 eq.	0.3	0.0	**0.3**	**4.7**	**91.6**	19	0.0	**1.9**	**98.5**
15	Ozone Depletion, emissions	mg R-11 eq.				negligible					
16	Acidification, emissions	g SO2 eq.	13	0.0	**1.4**	**12.4**	**540.8**	3.7	0.0	**3.7**	**558.3**
17	Volatile Organic Compounds (VOC)	g	0.0	0.0	**0.0**	**0.1**	**0.8**	0.1	0.0	**0.1**	**1.0**
18	Persistent Organic Pollutants (POP)	ng i-Teq	0.1	0.0	**0.1**	**0.3**	**13.8**	3.1	0.0	**3.1**	**17.2**
19	Heavy Metals	mg Ni eq.	0.2	0.0	**0.2**	**2.7**	**36.0**	7.4	0.0	**7.4**	**46.3**
	PAHs	mg Ni eq.	0.0	0.0	**0.0**	**2.7**	**4.1**	0.0	0.0	**0.0**	**6.9**
20	Particulate Matter (PM, dust)	g	0.0	0.0	**0.0**	**6.1**	**11.6**	32.8	0.0	**32.8**	**50.5**
	Emissions (Water)										
21	Heavy Metals	mg Hg/20	0.1	0.0	**0.1**	**0.1**	**13.5**	2.1	0.0	**2.1**	**15.9**
22	Eutrophication	g PO4	0.0	0.0	**0.0**	**0.0**	**0.1**	0.1	0.0	**0.1**	**0.2**
23	Persistent Organic Pollutants (POP)	ng i-Teq				negligible					

The total energy consumption (GER) and the Global Warming Potential (GWP) of the base-case HL-MV-R-HW are presented in Figure 5-7 and Figure 5-8 for each stage of the entire life cycle of the product. It is clearly visible that the use phase is predominant for both environmental indicators. The use phase represents about 96% of the total energy required by a typical HL-MV-R-HW 100 W over its whole life cycle and about 93% of its global warming potential.

The distribution phase (assumed transport by trucks) is most significant for the emission of PAHs to air (40%) and does not exceed 15% for the other environmental impacts.

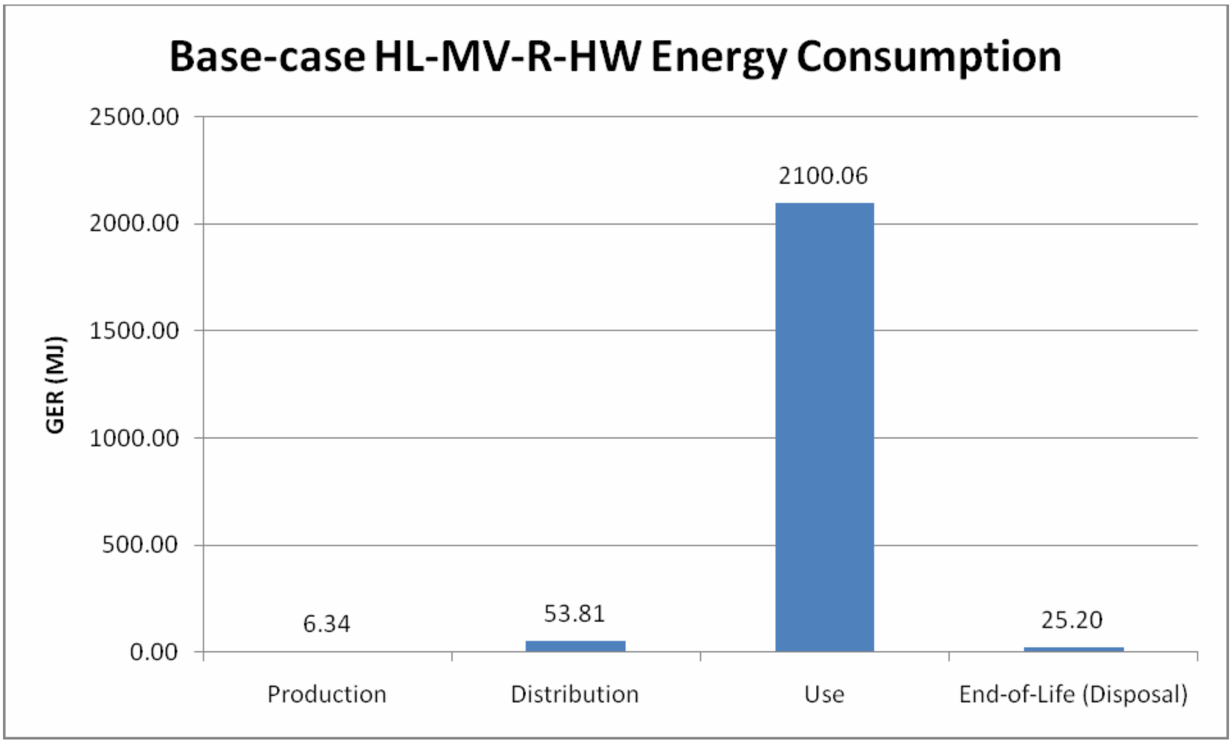

Figure 5-4: Total energy consumption during all life cycle phases

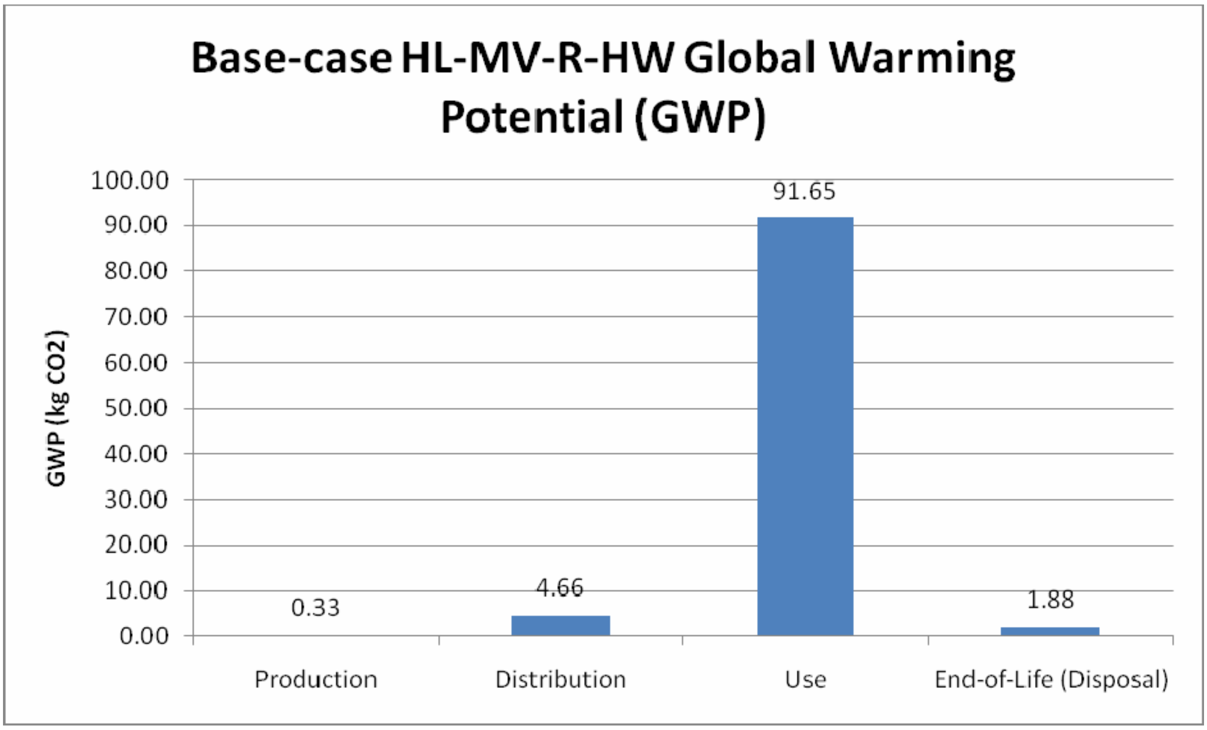

Figure 5-5: Total Global Warming Potential during all life cycle phases

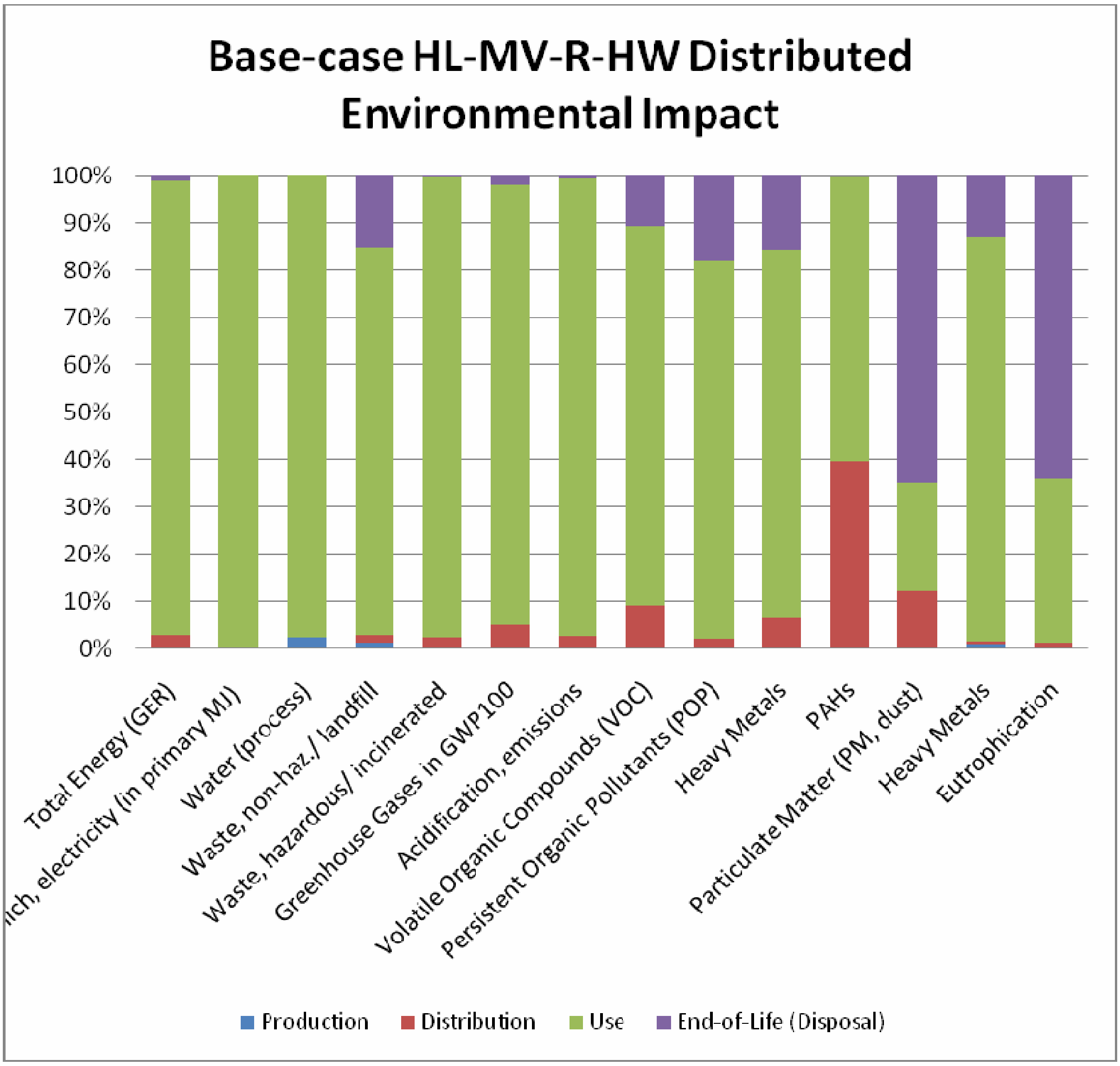

Figure 5-6: Distribution of environmental impacts per life cycle phase

Over its entire life cycle (2000 hours), the base-case HL-MV-R-HW (100 W) emits 3.2 mg of mercury to air, due to electricity generation. Mercury emissions in other phases than the use phase are assumed to be negligible for this lamp type.

5.2.3 Base-case HL-MV-R-LW

The results of the EcoReport for base-case HL-MV-R-LW are presented in Table 5.5-7 below.

Table 5.5-7: Environmental assessment results from EcoReport (base-case HL-MV-R)

Table . Life Cycle Impact (per unit) of Base-Case HL-MV-R-LW

Nr	Life cycle Impact per product:	Date	Author
0	Base-Case HL-MV-R-LW	0	BIO

Nr	Life Cycle phases -->		PRODUCTION			DISTRI-	USE	END-OF-LIFE*			TOTAL
	Resources Use and Emissions		Material	Manuf.	Total	BUTION		Disposal	Recycl.	Total	
	Materials	**unit**									
1	Bulk Plastics	g			**0.0**			0.0	0.0	**0.0**	**0.0**
2	TecPlastics	g			**0.0**			0.0	0.0	**0.0**	**0.0**
3	Ferro	g			**0.0**			0.0	0.0	**0.0**	**0.0**
4	Non-ferro	g			**1.5**			1.5	0.0	**1.5**	**0.0**
5	Coating	g			**0.0**			0.0	0.0	**0.0**	**0.0**
6	Electronics	g			**0.0**			0.0	0.0	**0.0**	**0.0**
7	Misc.	g			**36.0**			36.0	0.0	**36.0**	**0.0**
	Total weight	g			**37.5**			37.5	0.0	**37.5**	**0.0**
									see note!		
	Other Resources & Waste							debet	credit		
8	Total Energy (GER)	MJ	0.7	0.0	**0.7**	**52.0**	**787.5**	2.6	0.0	**2.6**	**842.8**
9	of which, electricity (in primary MJ)	MJ	0.5	0.0	**0.5**	**0.0**	**787.5**	0.0	0.0	**0.0**	**788.0**
10	Water (process)	ltr	0.3	0.0	**0.3**	**0.0**	**52.5**	0.0	0.0	**0.0**	**52.8**
11	Water (cooling)	ltr	0.0	0.0	**0.0**	**0.0**	**2100.0**	0.0	0.0	**0.0**	**2100.0**
12	Waste, non-haz./ landfill	g	12.5	0.1	**12.6**	**51.6**	**913.2**	46.0	0.0	**46.0**	**1023.4**
13	Waste, hazardous/ incinerated	g	0.0	0.0	**0.0**	**1.0**	**18.1**	0.0	0.0	**0.0**	**19.2**
	Emissions (Air)										
14	Greenhouse Gases in GWP100	kg CO2 eq.	0.0	0.0	**0.0**	**4.6**	**34.4**	0.2	0.0	**0.2**	**39.1**
15	Ozone Depletion, emissions	mg R-11 eq.				negligible					
16	Acidification, emissions	g SO2 eq.	0.2	0.0	**0.2**	**12.1**	**202.8**	0.4	0.0	**0.4**	**215.5**
17	Volatile Organic Compounds (VOC)	g	0.0	0.0	**0.0**	**0.1**	**0.3**	0.0	0.0	**0.0**	**0.4**
18	Persistent Organic Pollutants (POP)	ng i-Teq	0.0	0.0	**0.0**	**0.3**	**5.2**	0.3	0.0	**0.3**	**5.8**
19	Heavy Metals	mg Ni eq.	0.1	0.0	**0.1**	**2.6**	**13.5**	0.8	0.0	**0.8**	**17.0**
	PAHs	mg Ni eq.	0.0	0.0	**0.0**	**2.6**	**1.6**	0.0	0.0	**0.0**	**4.2**
20	Particulate Matter (PM, dust)	g	0.0	0.0	**0.0**	**1.6**	**4.3**	3.3	0.0	**3.3**	**9.3**
	Emissions (Water)										
21	Heavy Metals	mg Hg/20	0.1	0.0	**0.1**	**0.1**	**5.1**	0.2	0.0	**0.2**	**5.4**
22	Eutrophication	g PO4	0.0	0.0	**0.0**	**0.0**	**0.0**	0.0	0.0	**0.0**	**0.0**
23	Persistent Organic Pollutants (POP)	ng i-Teq				negligible					

The energy consumption and global warming potential are shown in Figure 5-7 and Figure 5-8, respectively. As with the other base-cases, the use phase has the greatest impact on both energy consumption (93% of total) and global warming potential (88% of total).

The use phase dominates the other environmental impacts as well, as shown in Figure 5-9. The distribution phase contributes a significant amount of PAHs with about 62%.

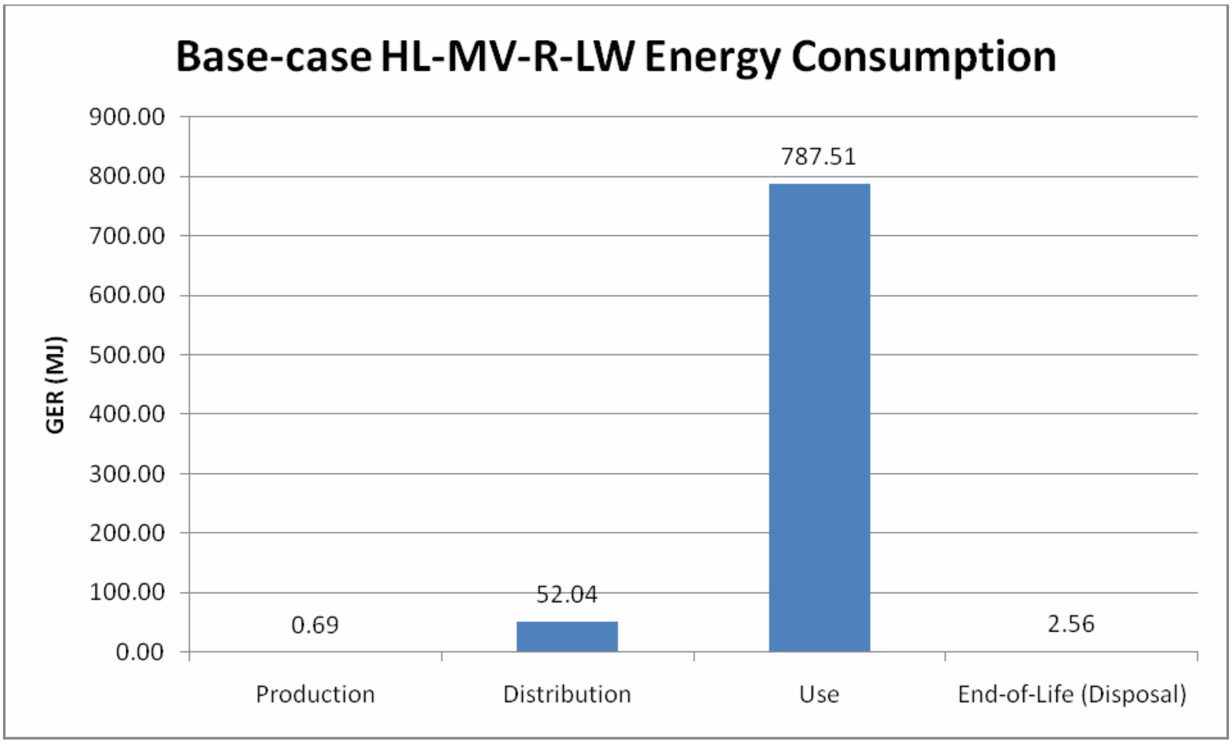

Figure 5-7: Total energy consumption during all life cycle phases

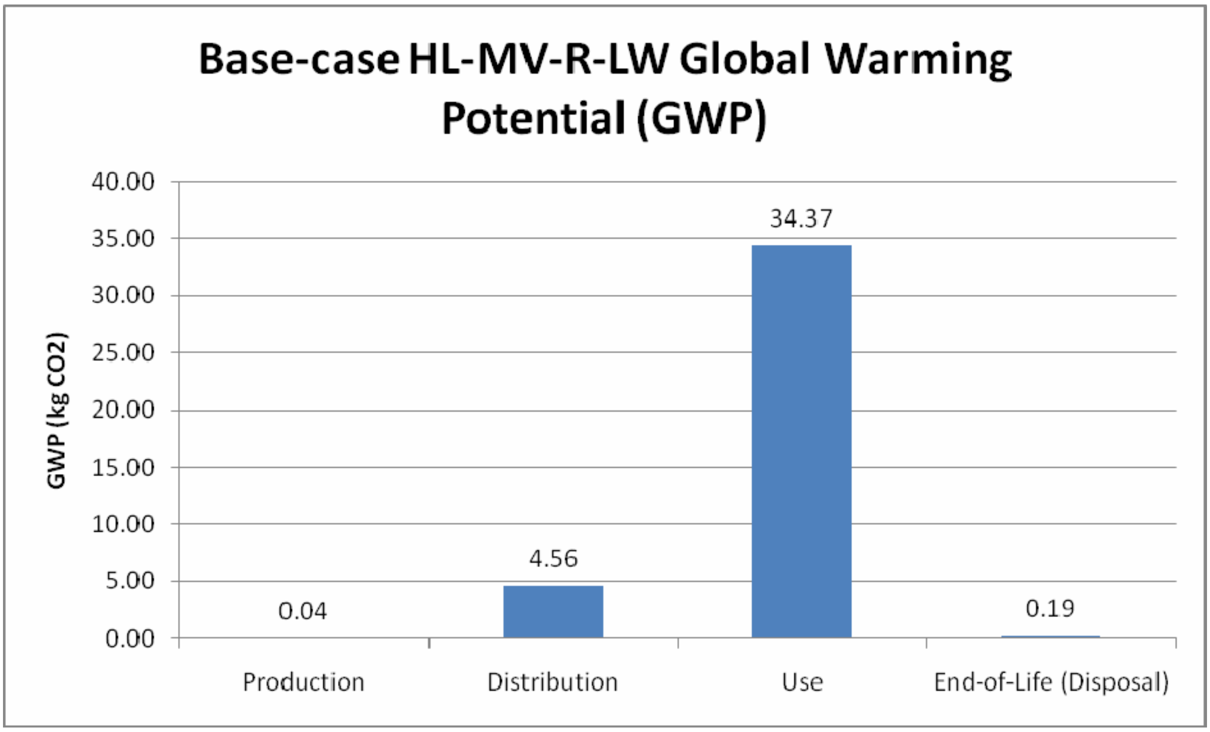

Figure 5-8: Total Global Warming Potential during all life cycle phases

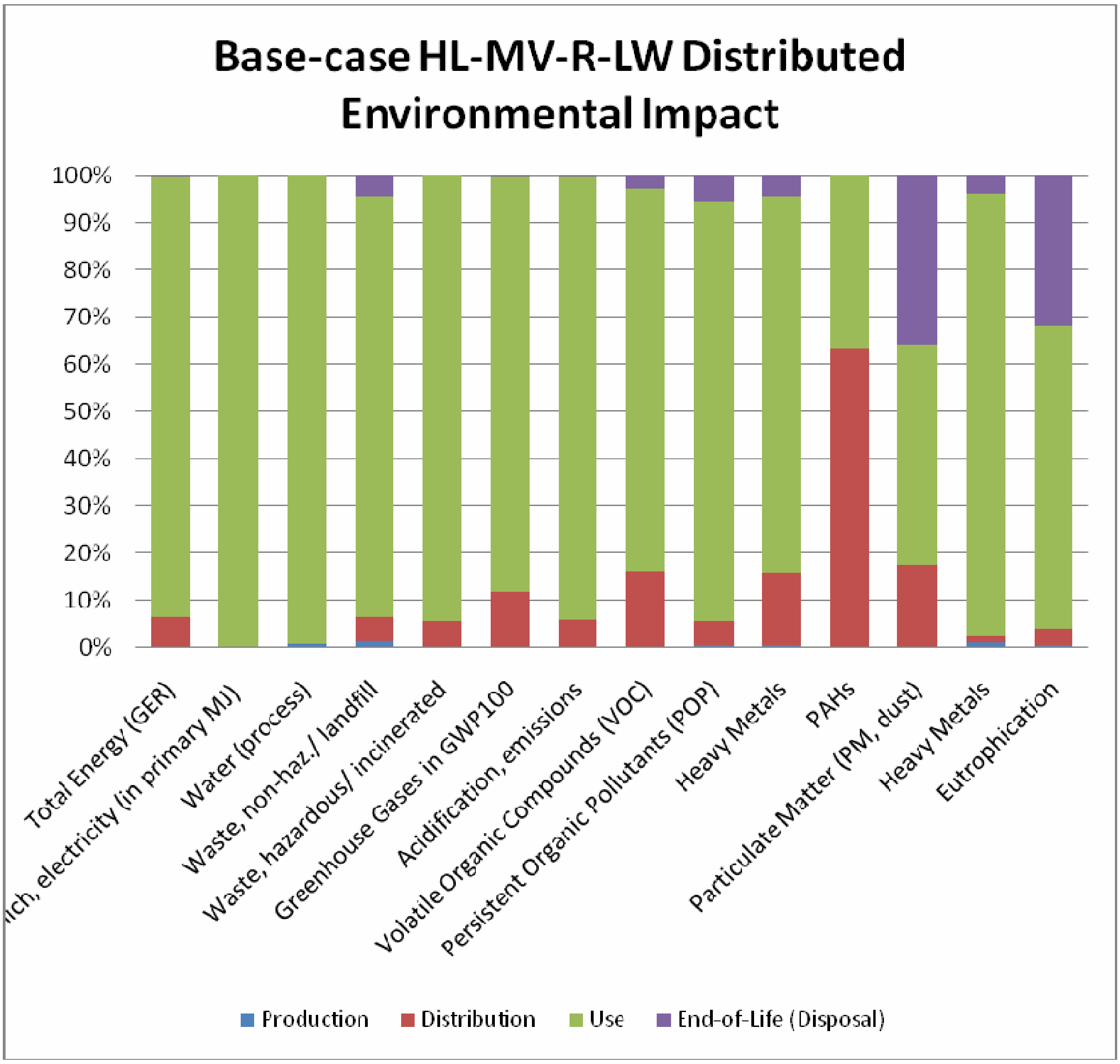

Figure 5-9: Distribution of environmental impacts per life cycle phase

Over its entire life cycle (1500 hours), the base-case HL-MV-R-LW (50 W) emits 1.2 mg of mercury to air, due to electricity generation. Mercury emissions in other phases than the use phase are assumed to be negligible for this lamp type.

5.2.4 Base-case HL-LV-R

Table 5.5-8 presents the outcomes of the "life cycle assessment" of the base-case HL-LV-R using the EcoReport tool.

Table 5.5-8: Environmental assessment results from EcoReport (base-case HL-LV-R)

Table . Life Cycle Impact (per unit) of Base-Case HL-LV-R

Nr	Life cycle Impact per product:	Date	Author
0	Base-Case HL-LV-R	0	BIO

Nr	Life Cycle phases -->		PRODUCTION			DISTRI-	USE	END-OF-LIFE*			TOTAL
	Resources Use and Emissions		Material	Manuf.	Total	BUTION		Disposal	Recycl.	Total	
	Materials	**unit**									
1	Bulk Plastics	g			**0.0**			0.0	0.0	**0.0**	**0.0**
2	TecPlastics	g			**0.0**			0.0	0.0	**0.0**	**0.0**
3	Ferro	g			**0.0**			0.0	0.0	**0.0**	**0.0**
4	Non-ferro	g			**0.3**			0.3	0.0	**0.3**	**0.0**
5	Coating	g			**0.0**			0.0	0.0	**0.0**	**0.0**
6	Electronics	g			**0.0**			0.0	0.0	**0.0**	**0.0**
7	Misc.	g			**29.7**			29.7	0.0	**29.7**	**0.0**
	Total weight	g			**30.0**			30.0	0.0	**30.0**	**0.0**
									see note!		
	Other Resources & Waste							debet	credit		
8	Total Energy (GER)	MJ	0.5	0.0	**0.5**	**52.0**	**1223.8**	2.0	0.0	**2.0**	**1278.4**
9	of which, electricity (in primary MJ)	MJ	0.4	0.0	**0.4**	**0.0**	**1223.8**	0.0	0.0	**0.0**	**1224.2**
10	Water (process)	ltr	0.2	0.0	**0.2**	**0.0**	**81.6**	0.0	0.0	**0.0**	**81.8**
11	Water (cooling)	ltr	0.0	0.0	**0.0**	**0.0**	**3263.4**	0.0	0.0	**0.0**	**3263.4**
12	Waste, non-haz./ landfill	g	2.8	0.0	**2.8**	**51.6**	**1418.9**	36.8	0.0	**36.8**	**1510.1**
13	Waste, hazardous/ incinerated	g	0.0	0.0	**0.0**	**1.0**	**28.2**	0.0	0.0	**0.0**	**29.2**
	Emissions (Air)										
14	Greenhouse Gases in GWP100	kg CO2 eq.	0.0	0.0	**0.0**	**4.6**	**53.4**	0.2	0.0	**0.2**	**58.1**
15	Ozone Depletion, emissions	mg R-11 eq.	negligible								
16	Acidification, emissions	g SO2 eq.	0.1	0.0	**0.1**	**12.1**	**315.1**	0.3	0.0	**0.3**	**327.6**
17	Volatile Organic Compounds (VOC)	g	0.0	0.0	**0.0**	**0.1**	**0.5**	0.0	0.0	**0.0**	**0.5**
18	Persistent Organic Pollutants (POP)	ng i-Teq	0.0	0.0	**0.0**	**0.3**	**8.0**	0.3	0.0	**0.3**	**8.6**
19	Heavy Metals	mg Ni eq.	0.0	0.0	**0.0**	**2.6**	**21.0**	0.6	0.0	**0.6**	**24.2**
	PAHs	mg Ni eq.	0.0	0.0	**0.0**	**2.6**	**2.4**	0.0	0.0	**0.0**	**5.0**
20	Particulate Matter (PM, dust)	g	0.0	0.0	**0.0**	**1.6**	**6.7**	2.7	0.0	**2.7**	**11.0**
	Emissions (Water)										
21	Heavy Metals	mg Hg/20	0.0	0.0	**0.0**	**0.1**	**7.9**	0.2	0.0	**0.2**	**8.2**
22	Eutrophication	g PO4	0.0	0.0	**0.0**	**0.0**	**0.0**	0.0	0.0	**0.0**	**0.0**
23	Persistent Organic Pollutants (POP)	ng i-Teq	negligible								

Figure 5-10 and Figure 5-11 highlight the importance of the use phase for two main environmental impact indicators (total energy consumption and global warming potential). Also, Figure 5-12 shows the relative importance of the use phase compared to the other often negligible phases. The use phase represents about 96% of the total energy required by a typical HL-LV-R 35 W over its whole life cycle (GER), and about 92% of its global warming potential (GWP).

Regarding the distribution phase, its contribution to the environmental impacts does not surpass 14% except for the emission of PAHs to air (52%), which is, as for incandescent lamps, due to the assumed transport by trucks.

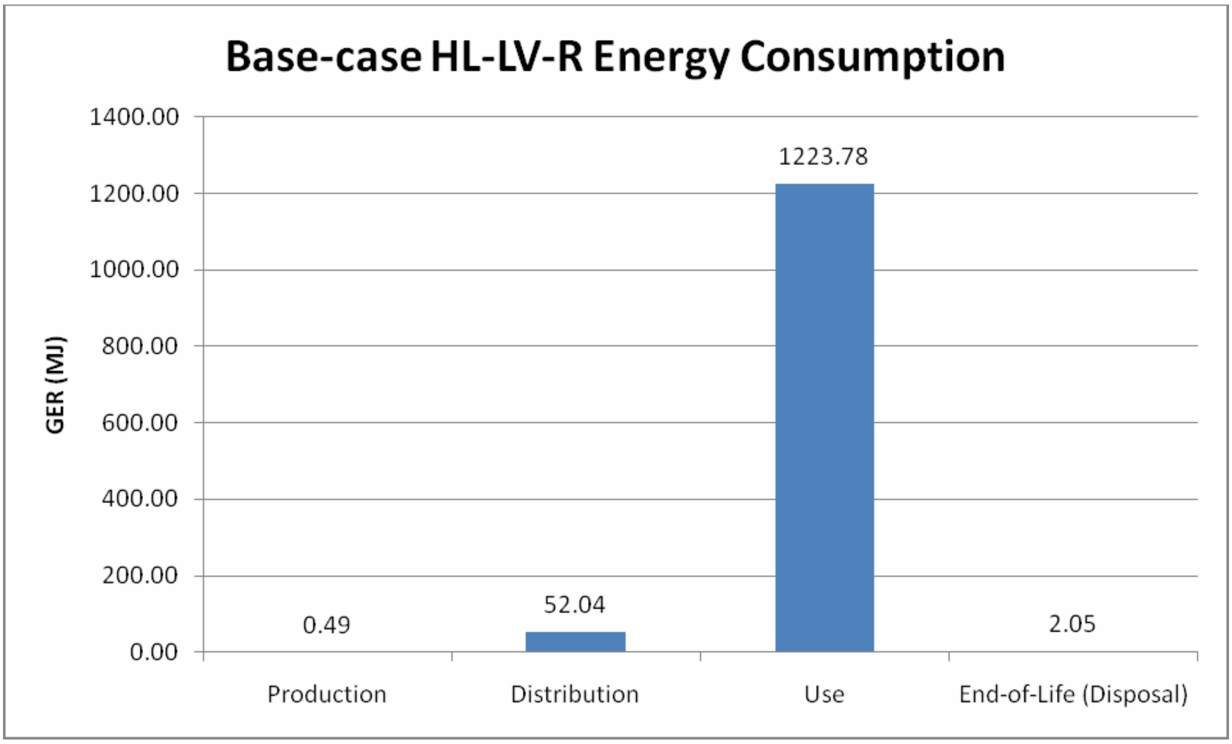

Figure 5-10: Total energy consumption during all life cycle phases

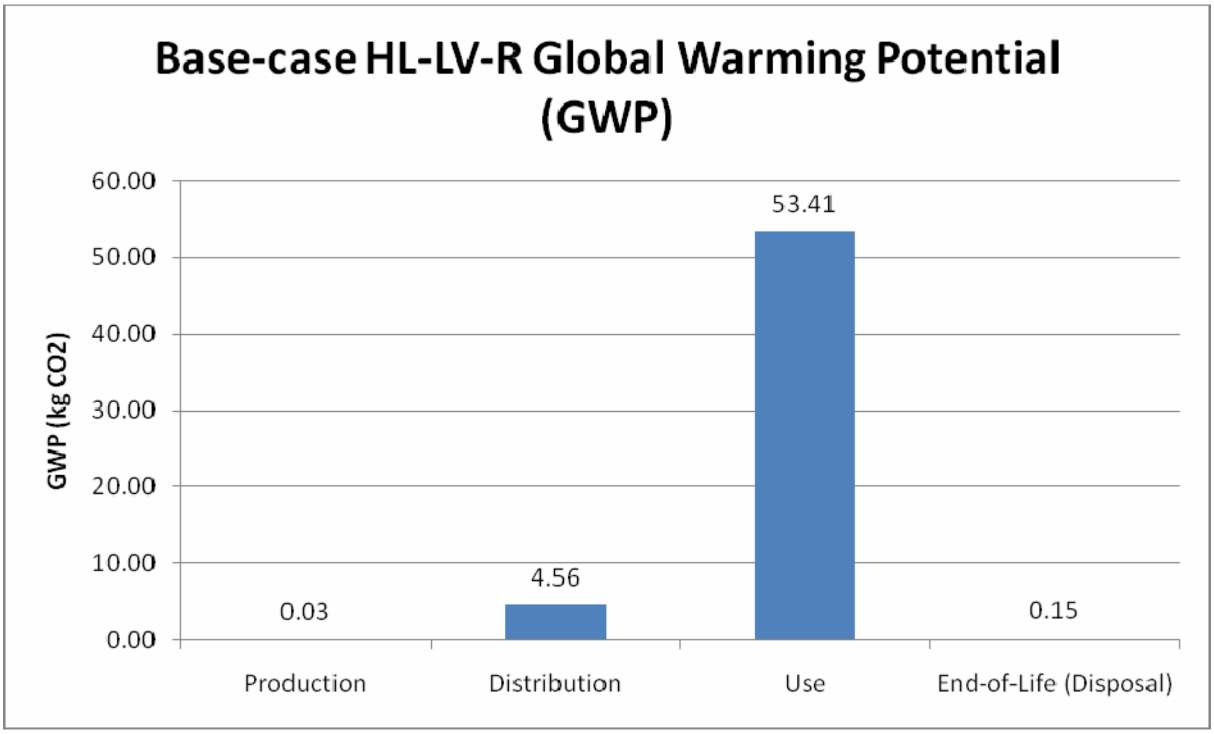

Figure 5-11: Total Global Warming Potential during all life cycle phases

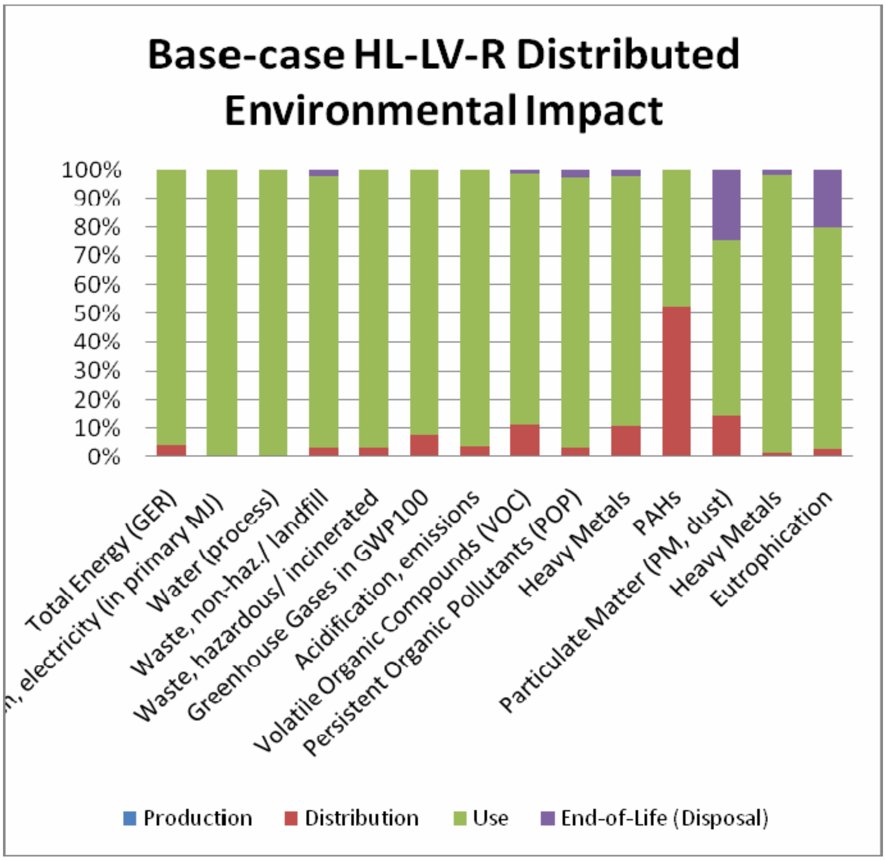

Figure 5-12: Distribution of environmental impacts per life cycle phase

As expected, the three previous figures confirm that the use phase is predominant with at least 80% of the environmental impacts (except for the emissions of PAHs and of Particulate Matter).

Over its entire life cycle (3000 hours), the base-case HL-LV-R (real power consumption 38.85 W) emits 1.86 mg of mercury to air, due to electricity generation. Mercury emissions in other phases than the use phase are assumed to be negligible for this lamp type.

5.3 Base-case Life Cycle Costs

Economic data used for the calculation of the Life Cycle Costs (LCC) were elaborated in chapters 2 and 4. Table 5-11 presents the summary of the LCC input data and results for the 4 base-cases. Electricity tariff, discount rate, and overall improvement ratio are common inputs for all base-cases, of which the parameter "overall improvement ratio" equal to 1 reflects the fact that there have not been improvements related to energy efficiency of the average European lamp types in the recent years (i.e. the average products in 2004/2005 and in 2007 are quite similar in terms of energy efficiency).

Table 5.5-9: Inputs and outcomes of the calculation of the LCC

	GLS-R	**HL-MV-R-HW**	**HL-MV-R-LW**	**HL-LV-R**
Lamp lifespan (years)	2	4.44	3.33	6
Lamp wattage (W)	50	100	50	35
Average functional lumen output within opening angle of 90° (lm)	258.14	1053.98	314.50	391.60
Electricity tariff (€/kWh)	0.1528			
Discount rate	1.8%			
Overall improvement ratio	1.00			
Product price	1.30 €	13.50	3.60 €	2.40 €
Electricity	7.41 €	29.12	11.03 €	16.74 €
Life Cycle Cost	**8.71 €**	**42.62**	**14.63 €**	**19.14 €**

One has to keep in mind that lifespan, lamp wattage and lumen output vary for different lamp types, thus a straightforward comparison with the outcomes of Table 5-11 has to be made with caution. The comparison of the LCC of the 4 base-cases is provided in section 5.6.

5.4 EU Totals for all sectors

This section provides the environmental assessment of the base-cases at the EU-27 level using stock and market data from chapter 2, considering their use in all sectors. The reference year for the EU totals is 2007 for environmental impacts. The term 'EU' is synonymous to 'EU-27'. The total impacts cover:

- The life cycle environmental impact of the new products designed in 2007 (this relates to a period of 2007 up to 2007 + product life) (i.e. impacts of the sales).
- The annual (2007) impact of production, use and (estimated) disposal of the product group, assuming post-RoHS and post-WEEE conditions and the total LCC (i.e. impact and LCC of the stock).

■ Market data for all sectors

In order to carry out the environmental and economic assessment with the EcoReport tool of the base-cases at the EU-27 level for all sectors, it is required to have sales data, stock data as well as annual burning hours. They are presented in Table 5-15.

Table 5.5-10: Market and technical data for all sectors in 2007

	GLS-R	HL-MV-R-HW	HL-MV-R-LW	HL-LV-R
Stock DLS (mln)	292	107	121	584.9
Sales DLS (mln)	126.1	59	84	153
Average wattage (W)	50	100	50	35
Lifetime (h)	1000	2000	1500	3000
Annual burning hours (h)	400	450	450	500

■ **Environmental impacts of the stock in 2007 for all sectors**

Table 5-17 shows the total environmental impact of all products in operation in EU-27 in 2007, assuming that all the products have the same impacts as the base-case of their category. These figures come from the EcoReport tool by multiplying the individual environmental impacts of a base-case with the stock of this base-case in 2007 for all sectors.

Table 5.5-11: Environmental impacts of the EU stock in 2007 for all sectors

		GLS-R	***HL-MV-R-HW***	***HL-MV-R-LW***	***HL-LV-R***	***TOTAL***
main environmental indicators	**unit**	**Value**	**value**	**value**	**value**	**value**
Total Energy (GER)	PJ	68.262	55.655	33.206	127.643	**284.767**
of which, electricity	TWh	5.846	4.851	2.722	11.367	**24.785**
Water (process)	mln.m3	4.122	3.561	1.929	7.991	**17.603**
Waste, non-haz./ landfill*	kton	83.073	90.277	42.397	152.271	**368.019**
Waste, hazardous/ incinerated*	kton	1.558	1.241	0.745	2.907	**6.450**
Emissions (Air)						
Greenhouse Gases in GWP100	mt CO2eq.	3.276	2.613	1.649	5.930	**13.469**
Acidifying agents (AP)	kt SO2eq.	17.384	14.068	8.419	32.631	**72.503**
Volatile Org. Compounds (VOC)	kt	0.032	0.030	0.017	0.055	**0.134**
Persistent Org. Pollutants (POP)	g i-Teq.	0.472	0.536	0.240	0.866	**2.115**
Heavy Metals (HM)	ton Ni eq.	1.462	1.470	0.780	2.544	**6.256**
PAHs	ton Ni eq.	0.472	0.259	0.279	0.639	**1.648**
Particulate Matter (PM, dust)	kt	0.889	2.561	0.576	1.313	**5.339**
Emissions (Water)						
Heavy Metals (HM)	ton Hg/20	0.433	0.462	0.214	0.809	**1.918**
Eutrophication (EP)	kt PO4	0.003	0.009	0.002	0.005	**0.019**

Summary of environmental impacts of base-cases as a percentage of total impact for these lamp types, are presented in Figure 5-18. As the figure shows, low voltage halogen lamps have the greatest impacts within the sector. However, it is very important to note that these lamps also constitute 53% of all lamps in the sector in terms of quantity. The figures stay relatively constant, varying from 41 – 46% of all impacts except particulate matter, which is resulting mostly from the use phase of HL-MV-R-HW.

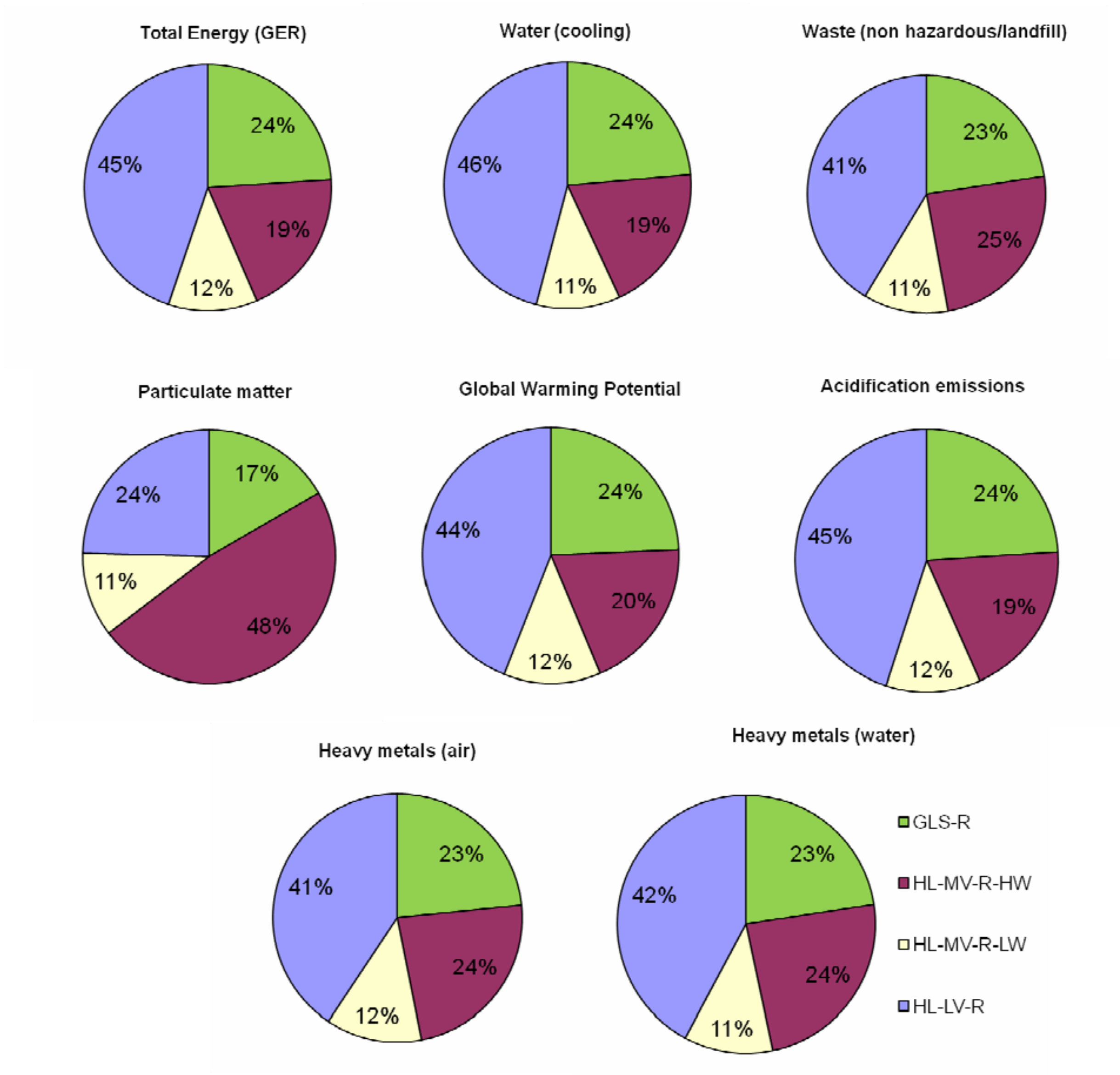

Figure 5-13: Base-cases' share of the environmental impacts of the 2007 stock for all sectors

Table 5-18 summarises the total electricity consumption (during the use phase) of each base-case, assuming that the whole stock is composed of base-cases. Therefore, the total electricity consumption in 2007 of directional lighting sources which are in the scope of this study and used in all sectors is about 24.785 TWh. This represents about 0.88% of the EU-27 total electricity consumption[185].

[185]Source Eurostat: EU-27 electricity consumption in 2006 = 242 million toe = 2,815 TWh

Table 5.5-12: Total electricity consumption for the year 2007 for all sectors

Base-case	EU 27 stock electricity consumption in 2007 for all sectors (TWh)	Share of the total electricity consumption of the 3 lamp types
Base-case GLS-R	5.846	23.58%
Base-case HL-MV-R-HW	4.851	19.57%
Base-case HL-MV-R-LW	2.722	10.98%
Base-case HL-LV-R	11.367	45.86%
TOTAL	**24.785**	**100.00%**

- **Total consumer expenditure in 2007**

Regarding the total consumer expenditure in 2007 related to the 4 base-cases, about 69.9% of the 5.41 billion Euros is due to electricity costs. The distribution per base-case is given in Figure 5-19, and details on consumer expenditure are presented in Table 5-19.

Table 5.5-13: Comparison of total consumer expenditure (EU-27) in 2007 for all sectors

	GLS-R	HL-MV-R-HW	HL-MV-R-LW	HL-LV-R	TOTAL
Lumen output per lamp (lm)	258.14	1053.98	314.50	391.60	n/a
EU 27 sales (mln unit)	126.1	59	84	153	422
Share of the EU 27 sales	29.87%	13.98%	19.90%	36.25%	100.00%
Product price (mln €)	163.9	796.5	302.4	367.2	1630.0
Electricity (mln €)	892.4	737.1	415.3	1736.0	3780.7
Total (mln €)	**1056.3**	**1533.6**	**717.7**	**2103.2**	**5410.8**

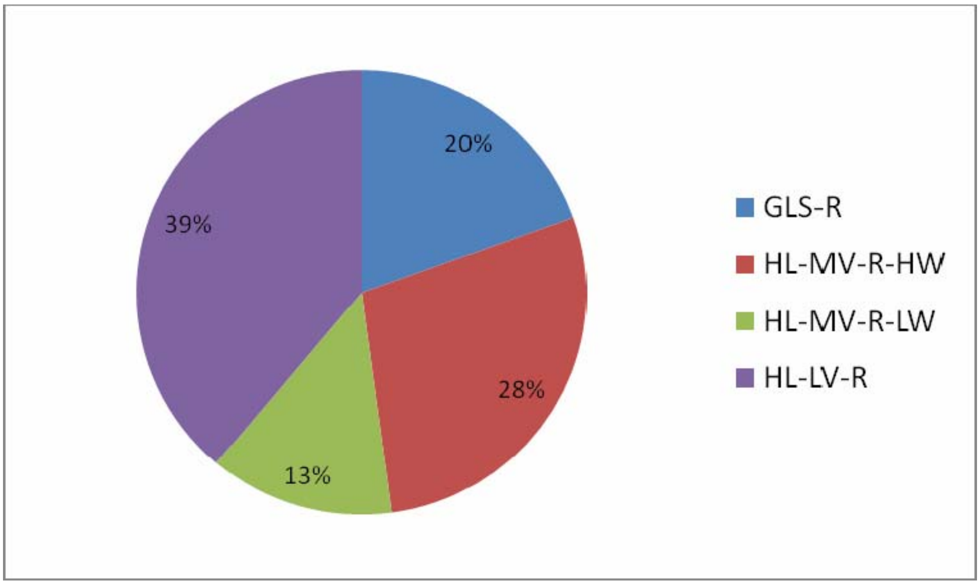

Figure 5-14: Base-cases' share of the total consumer expenditure in 2007 for all sectors

Total consumer expenditure in 2007 related to low-voltage halogen lamps represents 39% of the total, with the next highest being HL-MV-R-HW with 28%. Total consumer expenditure includes product and electricity costs over the product lifetime.

5.5 "Comparison" of the base-cases

As the luminous efficacy of the 4 base-cases defined in this chapter differs, as well as the lifetime, it is interesting and relevant to compare their environmental impacts as well as their life cycle cost taking into account this difference. Therefore, Table 5.5-14, Table 5-21 and Table 5-22 present data per lumen and per hour. In Table 5.5-14, for each environmental indicator, variations with reference to the base-case GLS-R are also given.

Table 5.5-14: Environmental impacts per lumen and per hour

main environmental indicators	unit	***GLS-R*** value per lumen per hour	***HL-MV-R-HW*** value per lumen per hour	***HL-MV-R-LW*** value per lumen per hour	***HL-LV-R*** value per lumen per hour
Total Energy (GER)	J	**2247.06**	**1036.74**	**1786.54**	**1088.15**
	variation with GLS-R	***0.00%***	***-53.86%***	***-20.49%***	***-51.57%***
of which, electricity	J	**2035.59**	**998.54**	**1670.35**	**1042.01**
	variation with GLS-R	***0.00%***	***-50.95%***	***-17.94%***	***-48.81%***
Water (process)	µltr	**136.63**	**67.92**	**83.96**	**69.66**
	variation with GLS-R	***0.00%***	***-50.29%***	***-38.55%***	***-49.02%***
Waste, non-haz./ landfill*	µg	**2726.00**	**1410.56**	**2169.40**	**1285.45**
	variation with GLS-R	***0.00%***	***-48.26%***	***-20.42%***	***-52.84%***
Waste, hazardous/ incinerated*	µg	**51.31**	**23.55**	**40.66**	**24.88**
	variation with GLS-R	***0.00%***	***-54.10%***	***-20.75%***	***-51.50%***
Emissions (Air)					
Greenhouse Gases in GWP100	mg CO2 eq.	**107.20**	**46.73**	**82.99**	**49.49**
	variation with GLS-R	***0.00%***	***-56.40%***	***-22.58%***	***-53.83%***
Acidifying agents (AP)	µg SO2 eq.	**572.67**	**264.83**	**456.74**	**278.88**
	variation with GLS-R	***0.00%***	***-53.76%***	***-20.24%***	***-51.30%***
Volatile Org. Compounds (VOC)	ng	**1035.22**	**466.88**	**776.85**	**449.97**
	variation with GLS-R	***0.00%***	***-54.90%***	***-24.96%***	***-56.53%***
Persistent Org. Pollutants (POP)	10^{-3} pg i-Teq	**15.49**	**8.18**	**12.28**	**7.30**
	variation with GLS-R	***0.00%***	***-47.20%***	***-20.76%***	***-52.91%***
Heavy Metals (HM)	ng Ni eq.	**47.49**	**21.96**	**35.94**	**20.64**
	variation with GLS-R	***0.00%***	***-53.77%***	***-24.32%***	***-56.55%***
PAHs	ng Ni eq.	**14.79**	**3.25**	**8.89**	**4.30**
	variation with GLS-R	***0.00%***	***-78.03%***	***-39.86%***	***-70.94%***
Particulate Matter (PM, dust)	µg	**28.13**	**23.95**	**19.71**	**9.39**
	variation with GLS-R	***0.00%***	***-14.85%***	***-29.94%***	***-66.63%***
Emissions (Water)					
Heavy Metals (HM)	ng Hg/20	**14.27**	**7.52**	**33.61**	**6.94**
	variation with GLS-R	***0.00%***	***-47.27%***	***135.61%***	***-51.35%***
Eutrophication (EP)	ng PO4	**106.76**	**88.42**	**395.09**	**41.51**
	variation with GLS-R	***0.00%***	***-17.18%***	***270.07%***	***-61.12%***

Table 5.5-14 highlights that a typical incandescent lamp represents generally highest environmental impacts over its life cycle compared to the others lamp types. This can be explained by two factors:

- the use phase is the most significant stage of the life cycle for any type of lamp, and

- the base-case GLS-R has the lowest lumen efficacy (5.16 lm/W).

It should be noted the HL-MV-R-LW has increase of 135% of heavy metals into water and 270% eutrophication over the base-case GLS-R.

Also interesting is that on a per lumen per hour basis, the HL-MV-R-HW has the least environmental impact of all options of -78.03% from the GLS-R. This is despite the results shown in Figure 5.13.

As the lamps HL-MW-R-HW and HL-LV-R have a much higher luminous efficacy than the other two base cases (10.53 lm/W and 10.08 lm/W respectively), the environmental impacts are significantly lower.

For two main environmental impact indicators (GER and GWP), Figure 5-20 and Figure 5-21 show the results per lumen per hour for the 4 base-cases with reference to the base-case GLS-R. As expected, incandescent lamps, being the least energy efficient, have the highest magnitude of impacts.

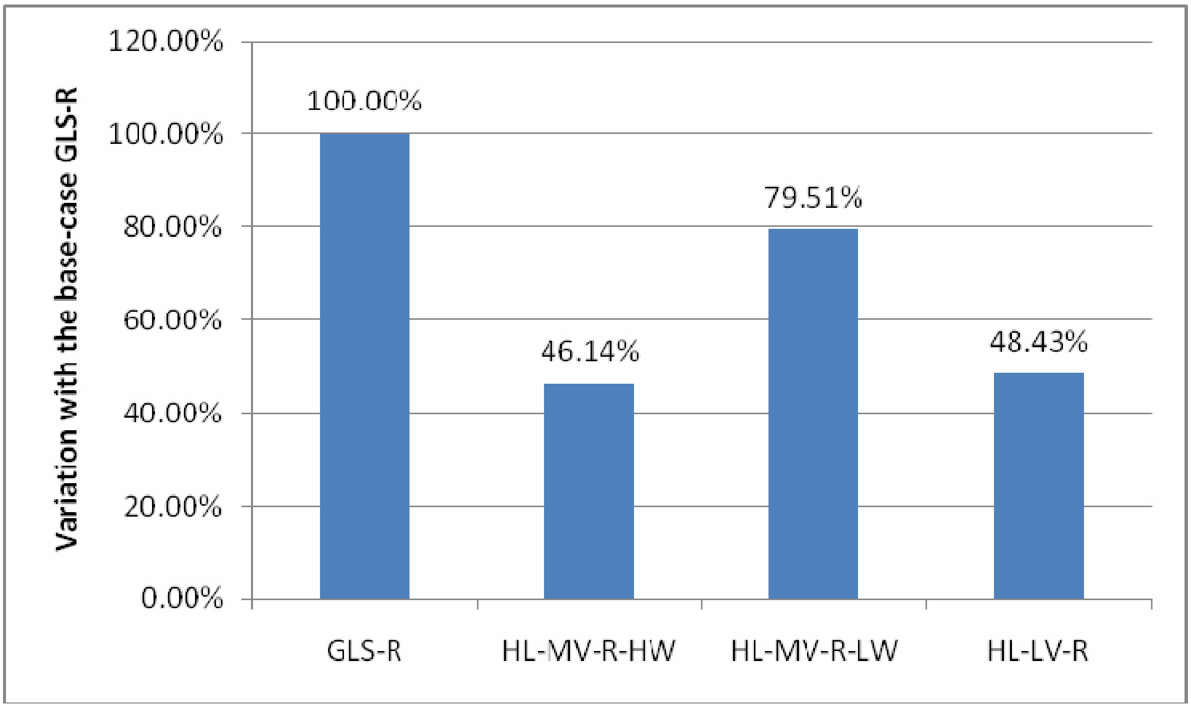

Figure 5-15: Comparison of the base-cases for the GER indicator

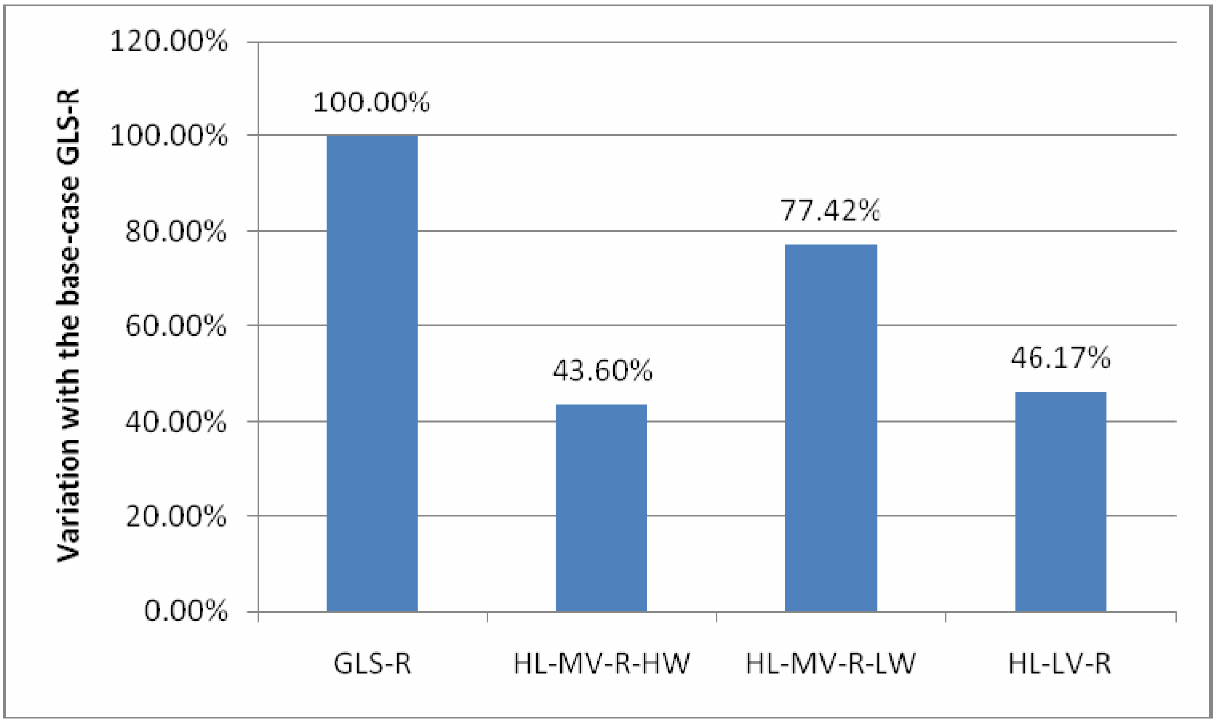

Figure 5-16: Comparison of the base-cases for the GWP indicator

Regarding mercury emissions, Table 5-21 compares values per lumen per hour for the 3 base-cases.

Table 5.5-15: Mercury emissions to air for each base-case per lumen and per hour

	GLS-R	HL-MV-R-HW	HL-MV-R-LW	HL-LV-R
Product life time (hours)	1000	2000	1500	3000
Lumen output per lamp (lm)	258.14	1053.98	314.50	391.60
Mercury emitted to air for the production of 1 kWh (mg)	0.016			
Mercury emitted during the use phase (mg)	0.80	3.20	1.20	1.86
Mercury emitted during the end-of-life (mg)	0	0	0	0
Mercury emitted over lifetime per lumen per hour (ng)	3.10	0.76	2.54	1.59
Difference with the base-case GLS-R	0.00%	-51.02%	-17.92%	-48.78%

As it is assumed that none of the base-cases contain mercury, mercury emissions are only a result from the energy consumed during the use phase. Therefore, as the HL-MV-R-HW has the highest luminous efficacy, it also has the lowest mercury emissions per lumen per hour as well. As shown in Figure 5-22, the base-case HL-MV-R-HW is slightly better than HL-LV-R when focusing on mercury emissions.

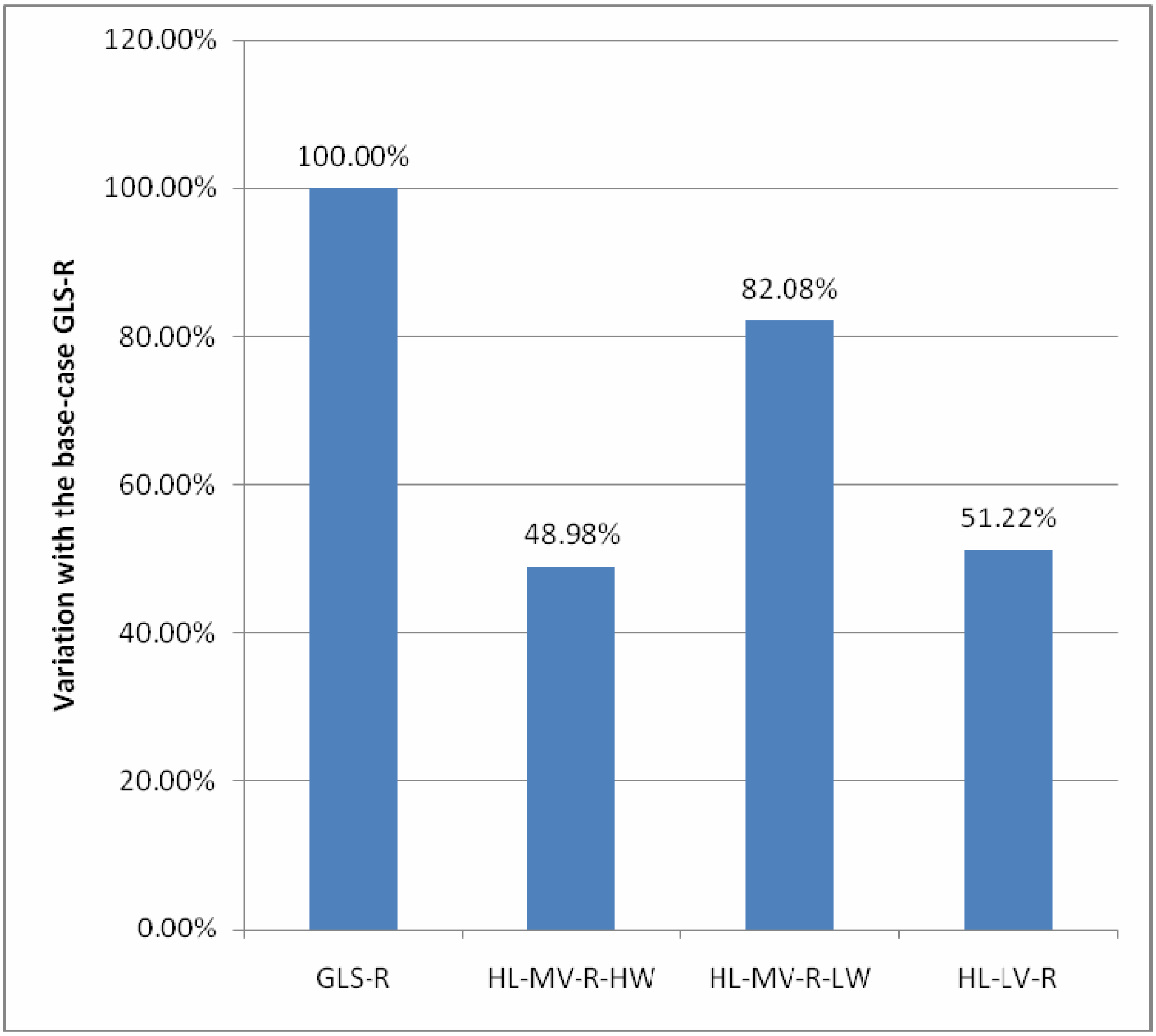

Figure 5-17: Comparison of the base-cases for mercury emissions over lifetime

The life cycle cost per lumen and per hour for each base-case is highlighted in Figure 5-23. It is clearly visible that the use of the base-case GLS-R implies the highest cost over lifetime (product price + electricity cost): 33.72×10^{-6} €/lm/h. This is due to its high cost in electricity per lumen per hour ($28.69\text{x}10^{-6}$ €/lm/h). On the contrary, the base-case HL-LV-R presents a significant reduction compared to the base-case GLS-R (-51.7%) due to its low product price and low electricity consumption.

Table 5.5-16: Economic data per lumen and per hour

	GLS-R	HL-MV-R-HW	HL-MV-R-LW	HL-LV-R
Product life time (hours)	1000	2000	1500	3000
Lumen output per lamp (lm)	258.14	1053.98	314.50	391.60
Product price per lumen per hour (10^{-6} €)	5.04	6.40	7.63	2.04
Electricity per lumen per hour (10^{-6} €)	28.69	13.81	23.37	14.25
LCC per lumen per hour (10^{-6} €)	**33.72**	**20.22**	**31.01**	**16.29**
Difference with the LCC of the base-case GLS-F	0.00%	-40.05%	-8.06%	-51.69%

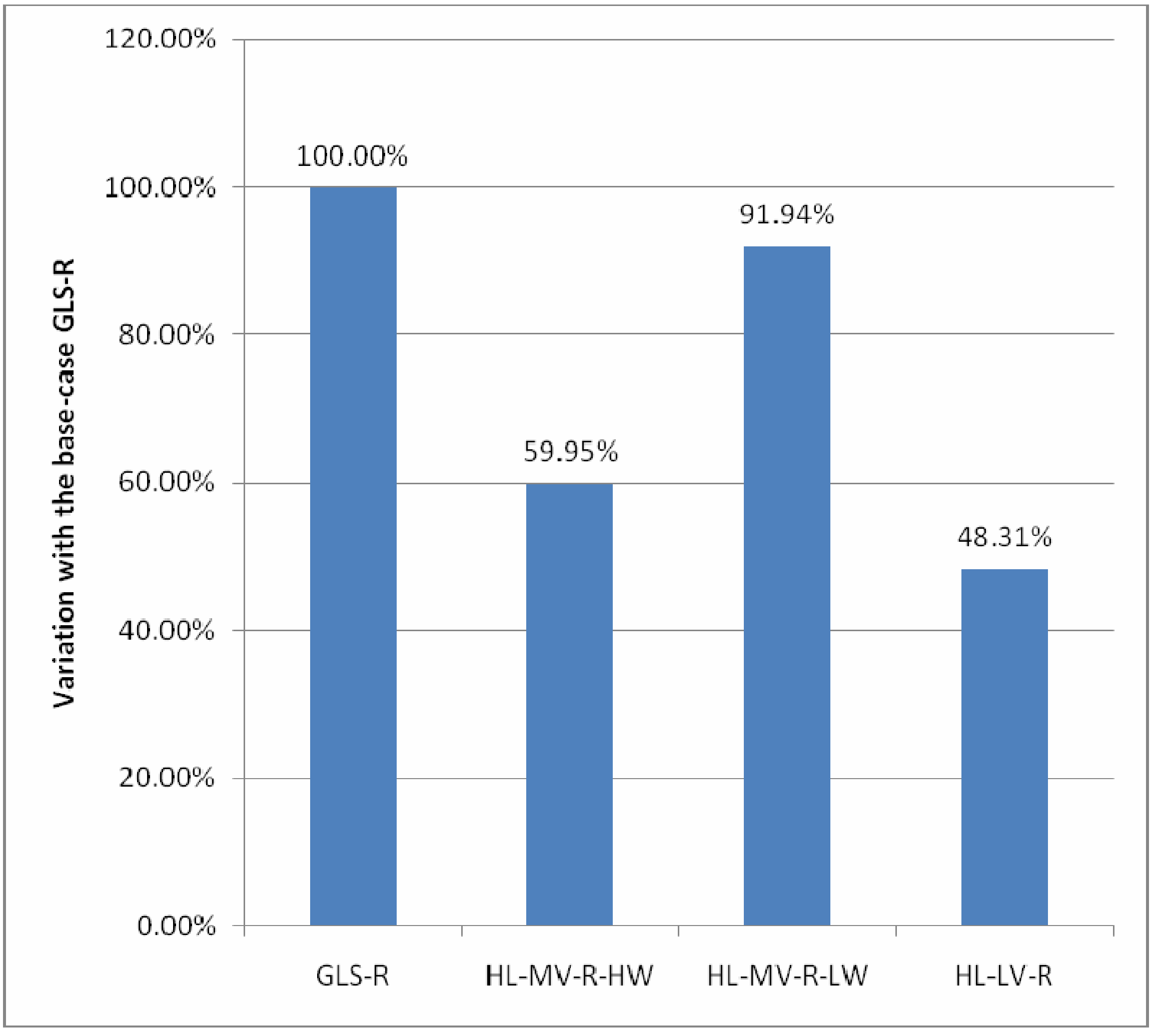

Figure 5-18: Comparison of the base-cases Life Cycle Cost per lumen and per hour

The economical analysis of the 4 base-cases shows that the HL-LV-R is the “best choice” in terms of LCC.

5.6 Conclusions

The environmental impact assessment carried out with the EcoReport tool for each base-case shows that the use phase is, not surprisingly, the most significant stage of the life cycle in terms of energy and resource consumption as well as for environmental impacts. Therefore, the analysis of the improvement potential in chapter 7 will primarily focus on technologies that reduce the electricity consumption, for instance by increasing the lamp efficacy. Regarding environmental impacts, the HL-MV-R-HW and HL-LV-R are the best lamp choices and incandescent lamps the worst choice among the base-cases examined in this chapter. Further improvement options will be examined in chapter 6.

Regarding the Life Cycle Cost of the 4 base-cases, compared per lumen and per hour, the base-case HL-LV-R appears as the least-cost alternative among the 4 base-cases due to its low electricity consumption and low purchase price.

Chapter 6 will examine other DLS lamp types considered as best available technology, such as CFLi-R, LED, and halogen with xenon or infrared coating. It is important to note that the lamps presented in chapter 5 were only base-cases, and chapter 6 will study other lamp types in an attempt to improve upon the base-cases.

6 TECHNICAL ANALYSIS BAT AND BNAT

Scope: This entails a technical analysis and description of the Best Available Technology (BAT) and Best Not yet Available Technology (BNAT) that can be implemented on product or component level. The described BAT is in many cases already available on the market, but is less frequently or not yet used because of the purchase price. It partly provides the input for the identification of part of the improvement potential (task 7), i.e. especially the part that relates to the best available technology. In chapter 7, also cost, intellectual property and availability are taken into account for the selection of options. This is not the case in this chapter and many of the presented technologies are intellectual property or linked to individual companies. The input of this chapter is partially the result of an organised visit to the Light and Building trade fare in Frankfurt 2008 (see also chapter 9 stakeholder consultation). Additional information was collected by consulting manufacturer's catalogues, technical publications and the information that was provided by stakeholders as a comment on the draft published chapters. Much research is ongoing and information is not always publicly available, therefore this chapter can never claim to be complete but aims to give a general overview. For commercial reasons brand names are avoided in the text as far as possible.

This chapter also focusses on technical data[186] that influence the use phase i.e. the energy consumption. As demonstrated in the eco-reports in chapter 5, this phase is much more important than the production phase. For the BOMs, no significant differences with the base case lamps can be noticed. The production phase (including the BOM's) will be examined only for LEDs; the eco-reports for these light sources will be calculated in chapter 7.

6.1 BAT State-of the art

Because the sockets in the installed luminaires (existing stock) have a big influence on possible improvement options for lamps, the BAT and BNAT options are listed in accordance to the cap type.

6.1.1 Mains voltage halogen lamps with Edison (E27/E14) or Swan (B22d/B15d) cap

Improvements for the efficacy of blown reflector halogen lamps type R50, R63, R80 etc. can be classified in:

- improvement of the reflector by changing to a PAR reflector,
- improvement of the reflector by changing to a dichroic or silver coated parabolic reflector,
- improvement of the efficacy by xenon gas filling,

[186] Technical data in this chapter were collected from different sources e.g. www.olino.org , ELC-members, stakeholders, etc.

- improvement of the efficacy by optimized filament wire design,
- improvement of the light output by using anti-reflective coating on the cover glas,
- Incorporating a transformer in a parabolic reflector lamp and using IRC low voltage halogen bulb.

Figure 6-1: Blown reflector R63, PAR20 and PAR20i lamp.

6.1.1.1 Halogen lamps with PAR reflector

Compared to the blown reflector base case lamps R63, GLS-R as well as HL-MV-R, the efficacy of halogen PAR20 reflector lamps is much higher. The reason for this is the poor optical matching of a MV halogen bulb in the blown reflector. PAR reflectors are aluminium coated pressed glass reflectors, optimally made of borosilicate glass, and have the following advantages compared to blown reflectors:

- better beam control by the facetted reflector,
- no use of satinated front cover and therefore a higher % of the luminous flux in the 90° cone,
- much less (spilled) light backward.

In most fittings, blown reflector lamps R63 can easily be replaced by PAR20 halogen lamps without changing the luminaire.
These lamps have an excellent colour rendering (CRI=100) and can easily be dimmed as long as the wattage is above the minimum required wattage of the dimmer.

The technical data for these lamps are shown in Table 6-1.

6.1.1.2 Halogen reflector lamps with xenon gas filling

As already explained in part 1 of the study, efficacy of halogen lamps can be improved by replacing the normal halogen gas filling of the bulb by xenon gas. This is of course also the case for halogen reflector lamps.
These improved lamps are already available on the market for the blown reflector base case lamps and even for the PAR lamps.
These lamps have the same properties as all halogen lamps: excellent colour rendering and normal dimmability.

The technical data for these lamps are shown in Table 6-1.

Important remark:
It must be stated that the improvement due to xenon can not be concluded from the measurements that were performed on market samples for R63 halogen lamps. This mainly confirms the earlier statement that the optimal position of the halogen bulb in a blown reflector lamp can not be guaranteed in normal, continuous production.

6.1.1.3 Halogen parabolic reflector lamps with dichroic or silver coated reflector

Dichroic coating is a multilayer coating which selectively transmits portions of the spectrum[187] (in this case IR); the technology is based on interference filters. High efficiency in visible light can be obtained. Similar multilayer technology is used for 'infrared coated lamps', see also 6.1.3.
The evaporated aluminium coating of the PAR reflector can be replaced by this dichroic multi-layer coating as it is already common practice for low voltage halogen reflector lamps. This dichroic reflector causes an improved reflection[188] for visible light compared to a normal aluminized reflector and gives also a cool beam. A cool beam means that it contains less infra-red radiation or heat. These dichroic reflectors that are common practice for low voltage halogen reflector lamps are also on the market for mains voltage halogen reflector lamps but with a GZ10 cap that differs from the normal GU10 cap. Because the IR-radiation is evacuated on the backside (cap-side) of the lamp, the luminaire has to be suitable to resist this heat. As a consequence a one-to-one replacement from a GU10 capped lamp by a GZ10 capped lamp is not always allowed.
A silver coating on the reflector can have the same result with regard to optical efficacy and avoids the evacuation of heat backwards, of course without providing a cool beam. Silver coating is also more expensive than dichroic coating.
In the range of parabolic reflector lamps with Edison or Swan cap, the dichroic (or silver) coated reflectors are B(N)AT.
A possible problem with dichroic reflectors on Edison or Swan capped lamps could also be the heat problem as mentioned for the GZ10 capped lamps. If the existing luminaire is not designed for this changed heat transfer, these lamps could cause damage and maybe fire risk.
To solve this problem the dichroic coating could be applied on an aluminized reflector or a silver coating can be used.

All the common properties from halogen lamps are maintained.

The technical data for these lamps are shown in Table 6-1.

6.1.1.4 Mains voltage halogen reflector lamps with optimized filament wire design

The design of the filament wire has a strong influence on the light output and light distribution of a mains voltage halogen reflector lamp. The more compact the filament is, the more homogeneous and better the light output of a reflector lamp is.
Compared to a low voltage halogen lamp, the filament of a mains voltage halogen lamp is much longer and focussing this wire in a reflector is not easy. By optimizing the design of the filament, an improved efficacy can be obtained.
All the properties from halogen lamps are maintained.

The technical data for these lamps are shown in Table 6-1.

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[187] (IESNA(1993)): 'Lighting handbook' (ISBN 0-87995-102-8).
[188] In literature, values of 5 till 10% are given.

6.1.1.5 Mains voltage halogen reflector lamps with anti-reflective coating on the front cover glass of the lamp

Glass not only transmits light but also reflects it, especially when the ray of light is not perpendicularly entering the glas. In a reflector lamp, this reflected light is reflected again by the reflector, but as this reflection does not have an efficiency of 100%, the efficacy of the lamp drops with every reflection. An anti-reflective coating on the cover glass avoids reflection and as a consequence, efficacy of the lamp raises. Measurements on coated cover glasses show an improvement in the 180° and 120° cone of 3% for one-sided coating and 5% for both-sided coating; this improvement even amounts to 6% in the 90° cone for both-sided coated cover glass.

The technical data for these lamps are shown in Table 6-1.

6.1.1.6 Mains voltage halogen reflector lamps PAR20 with dichroic or silver coated reflector, anti-reflective coating on the front cover glass and an integrated electronic transformer, using a IRC low voltage halogen bulb

These lamps use the same technology that was explained in part 1 of the study. A low voltage halogen bulb is mounted in the housing of an halogen PAR 20 lamp where also an electronic transformer is incorporated. The E27/B22d cap allows a one to one retrofit with a similar incandescent lamp and the energy consumption reduces to about half of it.
If the low voltage halogen bulb should be coated with an IRC reflective layer, and the reflector should be dichroic or silver coated and the front cover glass anti-reflective coated, efficacy could still rise. Altough IRC technology and dichroic reflectors are common practice in different lamp applications, the application for this specific lamp is not yet available on the market but could be introduced very soon because all technologies are available B(N)AT.

The technical data for these lamps are shown in Table 6-1.

6.1.1.7 Summary of technical data for Edison or Swan capped mains voltage halogen lamps

Table 6-1 summarizes the main improvement data for Edison or Swan capped reflector lamps.

As already written in part 1 of the study, it must be taken into account that efficacy of lamps in the same family rises with the wattage i.e. a lamp of 50W will have a higher efficacy than his family member of 35W with the same technology. It must be noted that some lamps are available with different life times and as mentioned in part 1 there is a trade off between lamp life and lamp efficacy[189].
The relation between lifetime and efficacy is shown in Figure 6-2.

Some lamps are indicated as B(N)AT, they are not yet on the market due to current low market demand however their production is technically obvious and feasable.

[189] (IESNA(1993)): 'Lighting handbook' (ISBN 0-87995-102-8) p. 186

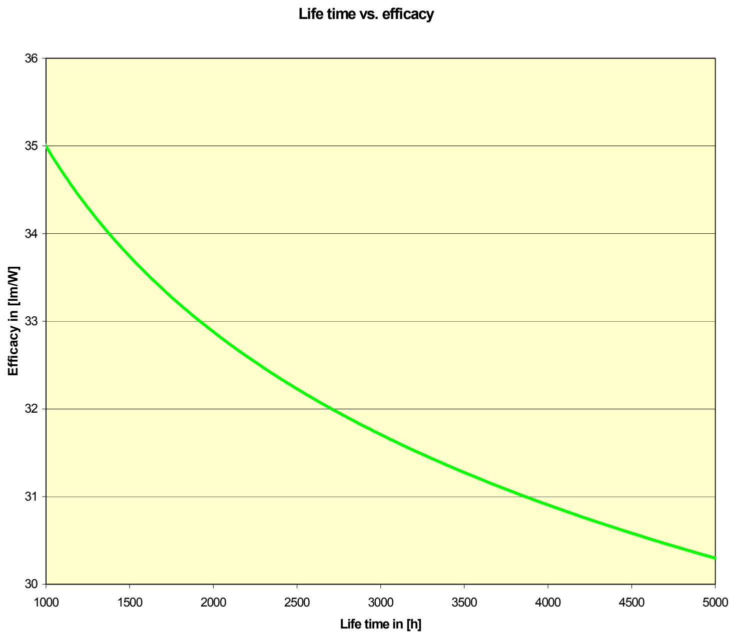

Figure 6-2: Lifetime of lamps versus efficacy[190]

Table 6-1: Data for lamp efficacy, cost and life time of Edison or Swan capped halogen lamps (source: ELC members and other stakeholders)

Lamp type / Acronym	Wattage	LWFt[191]	Beam angle	Intensity	Luminous flux in a solid angle of 2π	Luminous flux in solid angle π (angular beam 120°)	Functional lumens in an angular beam of 90°	ηlamp(90°) @25 °C	Life time	Unit price (for end user)
	[W]		[°]	[cd]	[lm]	[lm]	[lm]	[lm/W]	[h]	[€]
Halogen reflector lamp, PAR20, E27 (B22d) **HL-MV-R**	50	1	25	1056	405	391	353	7.1	2000	12
Halogen reflector lamp, R63, E27 (B22d), xenon **HL-MV-R**	42	1	30	629	384	323	247	5.9	2000	3.0
Halogen reflector lamp, PAR20, E27 (B22d), xenon **HL-MV-R**	50	1	30	1161	446	420	388	7.8	2000	11.0
Halogen reflector lamp, PAR20, E27 (B22d), xenon +optimized filament wire design **HL-MV-R**	40	1	30	1043	340	319	296	7.4	2000	11.0
Halogen reflector lamp, PAR20, E27 (B22d) transfo inc **HL-MV-R**	20	1	25	1200			270	13.5	5000	22.0

[190] Received as a comment and discussed at the 3rd stakeholder meeting
[191] LWFt = Total Lamp Wattage Factor = LWFp x LWFe (see section 4.4.1).

B(N)AT[192] Halogen reflector lamp, PAR20, E27 (B22d), xenon +optimized filament wire design + dichroic **HL-MV-R**	40	1	30	1126	367	345	320	8.0	2000	13.0
B(N)AT[193] Halogen reflector lamp, PAR20, E27 (B22d), xenon +optimized filament wire design + silver **HL-MV-R**	40	1	30	1126			320	8.0	2000	14.5
B(N)AT[194] Halogen reflector lamp, PAR20, E27 (B22d), xenon +optimized filament wire design + dichroic/silver + anti-reflective **HL-MV-R**	40	1	30	1183	386	362	339	8.5	2000	15
B(N)AT Halogen reflector lamp, PAR20, E27 (B22d) transfo inc + IRC **HL-MV-R**	20	1	25	1300			303	15.1	5000	24
B(N)AT Halogen reflector lamp, PAR20, E27 (B22d) transfo inc + IRC + dich/silv **HL-MV-R**	20	1	25	1400			327	16.4	5000	27

*The **B(N)AT** values are calculated.*

6.1.2 Mains voltage halogen reflector lamps with GU10 cap

Four similar improvements as for Edison or Swan capped lamps can be considered for GU10 capped lamps (GU10 capped halogen lamps already use PAR/MR reflectors):

- xenon gas filling,
- improved filament wire design,
- dichroic reflector,
- anti-reflective coating of the front cover glass.

The description of these improvements were already given in the preceding section.

Important remark for dichroic reflector lamps (see also 6.1.1.3):
Because a dichroic reflector evacuates the heat backward, this lamp has a specially adapted cap, the GZ10 cap. Interchangeability with a GU10 cap in the same luminaire is not always possible. If the luminaire has a GZ10 holder, a GU10 capped as well as a GZ10 capped lamp can be placed but if the luminaire is fitted with a GU10 holder, no GZ10 capped lamp can be placed. By this measure, the risk for damage and fire is eliminated.

All properties of halogen lamps are also maintained for these lamps.

The technical data for these lamps are shown in Table 6-2.
It must be noted that nearly all lamps have a relative short life time of 2000 h. Lamps with longer lifetime are rarely found on the market due to the negative impact on lamp efficacy[195].

[192] Intensity, functional lumen and efficacy are only calculated, based on estimated improvement as mentioned.
[193] Intensity, functional lumen and efficacy are only calculated, based on estimated improvement as mentioned.
[194] Intensity, functional lumen and efficacy are only calculated, based on estimated improvement as mentioned.
[195] See Figure 6-2 and (IESNA(1993)): ‘Lighting handbook’ (ISBN 0-87995-102-8) p. 186 relation between lamp efficacy and life time

Some lamps are indicated as B(N)AT, they are not yet on the market due to current low market demand however their production is technical obvious and feasable.

It is important to note that infra-red coating (IRC) on mains voltage halogen lamps, working on the European standard voltage of 230V, has no improvement potential on the efficacy of these lamps. If such improvement claims are found in literature, they are based on American mains voltage lamps, working on 130V.

Table 6-2: Data for lamp efficacy, cost and life time of GU10/GZ10 capped halogen lamps

Lamp type / Acronym	Wattage	LWFt[196]	Beam angle	Intensity	Luminous flux in a solid angle of 2π	Luminous flux in solid angle π (angular beam 120°)	Functional lumens in an angular beam of 90°	ηlamp(90°) @25 °C	Life time	Unit price (for end user)
	[W]		[°]	[cd]	[lm]	[lm]	[lm]	[lm/W]	[h]	[€]
Halogen reflector lamp, MR16, GU10, xenon **HL-MV-R**	42	1	30	826	340	319	285	6.8	2000	7.0
Halogen reflector lamp, MR16, GU10, xenon + optimized filament wire design **HL-MV-R**	40	1	25	1571	386	367	348	8.7	2000	7.0
B(N)AT[197] Halogen reflector lamp, MR16, GU10, xenon + optimized filament wire design + silver **HL-MV-R**	40	1	25	1697	417	396	376	9.4	2000	7.7
B(N)AT[198] Halogen reflector lamp, MR16, GU10, xenon + optimized filament wire design + silver + Anti-Reflect **HL-MV-R**	40	1	25	1782	438	416	398	10.0	2000	8.1

*The **B(N)AT** values are calculated.*

6.1.3 Low voltage halogen reflector lamps

For these lamps, there are two improvement options that are currently on the market:

- xenon gas filling of the bulb,
- xenon gas filling and applying an infra-red coating on the bulb.

These are again improvement options that were explained in part 1 of the study, but now implemented on low voltage halogen reflector lamps.

A third improvement option is the anti-reflective coating of the front cover glass as explained in 6.1.1.5; lamps with this technology are currently not yet available on the market but the technology exists and can easily be applied. The improvement for low voltage lamps however

[196] LWFt = Total Lamp Wattage Factor = LWFp x LWFe (see section 4.4.1).
[197] Intensity, functional lumen and efficacy are only calculated, based on an improvement of 8%.
[198] Intensity, functional lumen and efficacy are only calculated, based on an improvement of 5 or 6%.

is lower than for mains voltage lamps because the filament wire is much more compact in a LV lamp than in a MV lamp. As a consequence the rays of light are much more concentrated and are reaching the front cover glass already more perpendicularly; the measured improvement of an anti-reflective coating on HL-LV-R was only 3%.

It is important to note again that efficacy of low voltage halogen lamps can also be improved by shortening the lifetime as already explained in 6.1.1.7.
Currently lamp manufacturers are bringing low voltage halogen reflector lamps on the market with only xenon filling and almost the same efficacy of the ones with xenon and IRC, however with lifetimes of 2000h instead of 5000h.

All these lamps only differ from the normal low voltage halogen reflector lamps by the form of the halogen bulb, the thin layer of the infra-red reflecting coating and the filling gas.
There are no differences with the base case lamps neither regarding the reflector that is already a multi-facetted dichroic reflector nor regarding the filament wire that has the same compact dimensions that optimally fits in a reflector.
As a consequence the BOM's will not noticeably change compared to the BOM's showed in chapter 4.

Price and efficacy data about these lamps are included in Table 6-2 hereafter. These data will also be used for the improvement options assessment in chapter 7.

Table 6-3: Data for lamp efficacy, cost and life time of HL-LV-R improvements

Lamp type **Acronym**	**Wattage**	**LWFt**[199]	**Beam angle**	**Intensity**	**Luminous flux in a solid angle of 2π**	**Luminous flux in solid angle π (angular beam 120°)**	**Functional lumens in an angular beam of 90°**	**ηlamp(90°) @25 °C (LWFt not incl)**	**Life time**	**Unit price (for end user)**
	[W]		**[°]**	**[cd]**	**[lm]**	**[lm]**	**[lm]**	**[lm/W]**	**[h]**	**[€]**
Halogen reflector lamp, MR16, 12V, GU5.3, xenon **HL-LV-R**	25	1.06	36	862	421	398	367	14.7	2000	6.8
Halogen reflector lamp, MR16, 12V, GU5.3, xenon **HL-LV-R**	35	1.06	36	1992	584	558	524	15.0	2000	6.8
Halogen reflector lamp, MR16, 12V, GU5.3, IRC + xenon **HL-LV-R**	20	1.06	36	1110	418	374	321	16.1	5000	7.0
Halogen reflector lamp, MR16, 12V, GU5.3, IRC + xenon **HL-LV-R**	25	1.06	36	862	421	398	367	14.7	5000	7.0
Halogen reflector lamp, MR16, 12V, GU5.3, IRC + xenon **HL-LV-R**	30	1.06	36	1486	605	588	533	17.8	5000	7.0
Halogen reflector lamp, MR16, 12V, GU5.3, IRC + xenon **HL-LV-R**	35	1.06	36	1898	655	631	565	16.1	5000	7.0

[199] LWFt = Total Lamp Wattage Factor = LWFp x LWFe (see section 4.4.1).

Halogen reflector lamp, MR16, 12V, GU5.3, IRC + xenon **HL-LV-R**	45	1.06	36	2530	991	949	853	19.0	5000	7.0
B(N)AT Halogen reflector lamp, MR16, 36°, 12V, GU5.3, IRC + silver/dichroic **HL-LV-R**	20	1.06	36	1166	439	393	337	16.9	5000	7.5
B(N)AT Halogen reflector lamp, MR16, 36°, 12V, GU5.3, IRC + silver/dichroic + Anti-Refl **HL-LV-R**	20	1.06	36	1200	452	404	347	17.4	5000	8.0
B(N)AT Halogen reflector lamp, MR16, 36°, 12V, GU5.3, IRC + silver/dichroic + Anti-Refl **HL-LV-R**	20	1.06	36	1284	484	434	371	18.6	2000	8.0
B(N)AT Halogen reflector lamp, MR16, 36°, 12V, GU5.3, IRC + silver/dichroic **HL-LV-R**	35	1.06	36	1993	688	663	593	16.9	5000	7.5
B(N)AT Halogen reflector lamp, MR16, 36°, 12V, GU5.3, IRC + silver/dichroic + Anti-Refl **HL-LV-R**	35	1.06	36	2053	708	682	611	17.5	5000	8.0
B(N)AT Halogen reflector lamp, MR16, 36°, 12V, GU5.3, IRC + silver/dichroic + Anti-Refl **HL-LV-R**	35	1.06	36	2196	758	730	654	18.7	2000	8.0
B(N)AT Halogen reflector lamp, MR16, 36°, 12V, GU5.3, IRC + silver/dichroic **HL-LV-R**	45	1.06	36	2657	1040	988	896	19.9	5000	7.5
B(N)AT Halogen reflector lamp, MR16, 36°, 12V, GU5.3, IRC + silver/dichroic + Anti-Refl **HL-LV-R**	45	1.06	36	2736	1071	1018	923	20.5	5000	8.0
B(N)AT Halogen reflector lamp, MR16, 36°, 12V, GU5.3, IRC + silver/dichroic + Anti-Refl **HL-LV-R**	45	1.06	36	2928	1146	1089	987	21.9	2000	8.0
B(N)AT Halogen reflector lamp, MR16, 36°, 12V, GU5.3, IRC + silver/dichroic + Anti-Refl **HL-LV-R**	45	1.06	36	3119	1221	1160	1052	23.4	1000	8.0

Remarks: The LFWt for the improvement options takes into account that the EuP study on External power supplies proposes a (BAT) value of 1.06.
*The **B(N)AT** values are calculated.*

6.1.4 LED retrofit lamps for replacing incandescent and halogen reflector lamps

White-light emitting diode (WLED) solid state lighting (SSL) lamps have been recently becoming available on the market with increasing efficacy (up to 94 lumen/W for an LED die

((Härle (2007)) and increasing life time as a result of decades of semiconductor research and progress. WLEDs that currently could serve as retrofit solutions in this study have much lower efficacy but the rate of improvements is very high, the lower performance can in part be explained by power supply losses, additional optical losses and temperature effects.
Also applications where coloured light is required benefit from LED's, e.g. traffic and other signs (applications with a low power density). LED's can be dimmed easily if the power supply is adapted for this function. WLED's are available in a wide range of lamp efficacies from the same manufacturing production line, these LEDs were sorted during manufacture by their actual efficacy. This efficacy sorting is also called 'efficacy binning'.
WLED's that are nowadays on the market are mainly Solid State Lighting (SSL) devices, that rely on semiconductor material. For this SSL technology, efficacy and life time rapidly decrease with ambient temperature, therefore no high power densities or compact light sources can be obtained. SSLs are therefore primarily produced as discrete devices they are mainly available in low wattages (typical 1 to 5 Watt) and the main market products nowadays are mobile appliances (48 % in 2006, Steele (2007)). They are also sold as LED replacement lamps for existing reflector lamps.
Dr. Shuji Nakamura is the inventor of the white LED which took a composite YAG phosphor coating on top of a blue LED and converted it to white light. This technique is nowadays nearly used by all WLED manufacturers. A theoretical limit in efficacy can be expected in the range of 135-150 lm/W with lens and without power supply losses (Härle (2007). The spectrum of some white LEDs differs significantly from incandescent light. There is a strong dependency of maximum efficacy on colour temperature colour coordinate (up to 20% increase) (Härle (2007)). The most efficient WLEDs appear blue (e.g. CT 6000 K) and do not meet the CRI > 80 colour rendering requirement for office lighting (EN 12464-1). It must be noted that there are also UV based WLEDs on the market. The light spectrum and solid state physics follows the laws of quantum mechanics. Generally, quantum mechanics does not assign definite values to observables. Instead, it makes predictions using probability distributions. As a consequence, UV will never be totally absent for any white light source, it is only a matter of more or less. Moreover, the total absence of UV cannot be measured according to the the Heisenberg uncertainty principle.
The SSL dependence on solid state semiconductor material could keep the price relatively high for these sources and the environmental impact of the production should be followed up in the near future. WLED semi-conductors are crystals comprised of combinations of typically two or tree inorganic elements, such as gallium phosphide (GaP), gallium nitride (GaN), gallium indium nitride (GaInN) or gallium indium phosphide (GaInP). It should be noted that LEDs in general, thus not only WLED, are included in the environmental impact unit indicators in the MEEUP methodology report (table 29 material 48) and herein the production energy requirement or GWP per kg is very high compared to other materials. This can be explained by the high energy (GWP) and environmental impact that is typical for the production of semiconductor material, see also material 47 (ICs SMD) in table 29 in the MEEUP methodology report. The WLEDs in particular make use of the rare raw materials gallium and indium that are used in many other high tech applications (PV panels, monitors, LCD displays with coatings of indium tin oxide) ('Only united are we strong: supply problems await areas other than silicon', Photon International, July 2006). The world annual indium production was estimated(2005) at 455 ton at 650 €/kg with about 6000 ton global reserves only(US Geological Survey, Mineral Commodity Summaries, January 2006). The indium price did rise with a factor 8 from 2002 to 2005. The world annual gallium production is estimated in 2005 at 208 tons at 410 €:kg and the global reserve is more difficult to estimate. Gallium occurs in very small concentrations in ores of other metals and is produced as a

byproduct (e.g. bauxite). Based on the world resource of bauxite the reserve exceeds 1 million ton but probably only a small percentage of this metal is economically recoverable (US Geological Survey, Mineral Commodity Summaries, January 2006). The required energy (GWP) and material for the particular high efficacy WLEDs can only be modelled very approximate nowadays because it is unclear how many % of the production reach the high efficacy rating and there are many different and new production processes involved from which no data is made available due to intellectual property concerns. In this study the environmental impact will be modelled with the unit indicator (material 48 'SMD/LED's Avg per kg') from the MEEUP methodology (table 29). It must be noted that also GaAs and AlGaAs semiconductor is used for LEDs (Schurbert (2003), pp.4-7)[200], the are mainly used for red or infrared LEDs. Arsenic is a well known toxic material. For visible red/orange light currently AlGaInP/GaP is used (Schurbert (2003), p. 213)[201], Infrared LEDs can still rely on these materials however they are not used for products in the focus of this study. Due to the high rate of innovation it cannot be excluded that arsenic compounds will reappear in LEDs for general lighting. It is also clear from the unit indicator in the MEEUP methodology that environmental impact from the production may not be neglected in future assessments.

The rate of innovation is still very high and results in a significant amount of intellectual property (IP). A query for 'LED' in the European patent database[202] results in 1320 filed European patent claims and 9 patent claims were filed in the first trimester of 2009.

More details about LED quality are included in chapter 3. The values included in this section were the best found on the market (5/2009). It should be noted that many products had a lower efficacy and it was reported that many of them do not fulfil their package claims[203].

Even though this part of the study does not look in detail into retrofit LED NDLS lamps that appeared as replacement lamps for NDLS incandescent bulbs since the completion of part 1 of the study, these statements relating to the efficacy, quality and BOM of retrofit LED DLS lamps as compared to other DLS lamp technologies are also largely valid for retrofit LED NDLS lamps compared to other NDLS lamp technologies.

In this chapter, three retrofit lamp types are studied:

- a LED-retrofit lamp for the R63-E27 5B22d) incandescent and halogen reflector lamps
- a LED-retrofit lamp for the MR16-GU10 halogen mains voltage reflector lamps
- a LED-retrofit lamp for the MR16-GU5.3 halogen low voltage lamps.

Price and efficacy data can be found in Table 6-4 and de BOM data in Table 6-5.

Lamps with a correlated colour temperature (CCT) of 2700 K were chosen because this is similar to incadescent lamps, 2700 K is also referred as 'warm white'. Nevertheless it should be noted that most 4000 K LEDs are about 50 % more efficient compared to 2700 K LEDs, as can be concluded from manufacturers catalogue data. This efficacy difference is mainly for

[200] Schubert (2003): 'Light-Emitting Diodes', second edition, ISBN-13 978-0-51-86538-8
[201] Schubert (2003): 'Light-Emitting Diodes', second edition, ISBN-13 978-0-51-86538-8
[202] http://be.espacenet.com/
[203] Dutch Metrology Institute (2009): 'OpgeLED Minder opbrengst dan verwacht' (Be careful for LED performance is less than expected), available at www.vsl.nl

manufacturers that use phosphor to convert blue into white light, colour mixing LEDs might overcome this difference (as reported on the stakeholder meeting).

Figure 6-3: Some examples of LED retrofit lamps

Table 6-4: Data for lamp efficacy, cost and life time of LED retrofit reflector lamps (data source: Olino[204] and ELC members)

Lamp type / **Acronym**	**Wattage**	**LWFt[205]**	**Beam angle**	**Intensity**	**Luminous flux in a solid angle of 2π**	**Luminous flux in solid angle π (angular beam 120°)**	**Functional lumens in an angular beam of 90°**	**ηlamp(90°) @25 °C**	**Life time**	**Unit price (for end user)**
	[W]		**[°]**	**[cd]**	**[lm]**	**[lm]**	**[lm]**	**[lm/W]**	**[h]**	**[€]**
LED retrofit reflector lamp, R63, E27 (CCT 2700 K) **LEDi-R**	7.4	1.05	45	360			247	33.4	30000	40
LED retrofit reflector lamp, R63, E27 (CCT 4200 K) **LEDi-R**	6.4	1.05	26	788	275	249	226	35.3	45000	40
LED retrofit reflector lamp, MR16, GU10 (CCT 2700 K) **LEDi-R**	4.7	1.05	32	382			170	36.1	30000	35
LED retrofit reflector lamp, MR16, GU10 (CCT 3000 K) **LEDi-R**	3.8	1.05	24	657	181	160	143	38.2	15000	35
LED retrofit reflector lamp, MR16, GU10 (CCT 3000 K) **LEDi-R**	3.9	1.05	21	310	137	115	96	24.3	15000	35
LED retrofit reflector lamp, MR16, GU10 (CCT 4200 K) ** **LEDi-R**	3.3	1.05	11	963	75	57	49	14.8	35000	40
LED retrofit reflector lamp, MR16, GU5.3 (CCT 2700 K) **LEDi-R**	4.4	1.17	29	405			136	31	30000	30

*** not complete retrofit for GU10 halogen (lamp is much longer)*

[204] www.olino.org

[205] LWFt = Total Lamp Wattage Factor = LWFp x LWFe (see chapter 4).

Table 6-5: Input data for the materials extraction and production of the lamps (expressed in g)

MATERIALS Extraction & Production	LED retrofit reflector lamp, R63, E27 – **7.5W**		LED retrofit reflector lamp, MR16, GU10 – **4W**		LED retrofit reflector lamp, MR16, 12V, GU5.3 – **4W**	**Category**	**Material or Process MEEUP**
Description of component							
Lens	10.1		10.1		10.1	7-Misc.	**13-PMMA**
Aluminium body for cooling	140		27.3		27.3	4-Non-ferro	**27-Alu die-cast**
Aluminium for caps	1.5					4-Non-ferro	**26-Al sheet/extrusion**
Copper for caps / connector pins			1.5		1.5	4-Non-ferro	**30-CU tube/sheet**
LED	1		0.7		0.7		**48-SMD/LED's avg**
Copper plate (heat transfer)	10		9		9		**30-CU tube/sheet**
Plastic insulation plate	10		2.2		10		**8-PVC**
Porcelain housing			16				
Printed circuit board, assembled	10		7.5		7.5		**53-PWB assembly**
Total weight							

6.1.5 Compact fluorescent reflector lamps (CFLi-R) with integrated electronic ballast

As can be concluded from the technical analysis and the data in chapter 4, most CFLi-R on the market can not be considered as a DLS. Only in the range of lamps with big dimensions, some lamps match the definition of a DLS. Moreover, their efficacy is very low, compared to non directional CFLi. The reason for this lower efficacy and the non conformity with the DLS criterion is caused by the dimensions of the light emitting discharge tube which makes it necessary to lay the folded tube in layers. The upper layer of the folded tube shields the light from the underlying. As a consequence, there is no optical control in small size reflectors.
Nevertheless, a stakeholder reported improved lamps with small dimensions that fulfil the requirements of a DLS. Although these lamps are not yet available on the market, his figures are listed in Table 6-6.
This table also includes data for lamps with big dimensions that are rarely used in domestic lighting but that could be used as a downlighter e.g. in corridors.

It is important to note that even if those lamps fulfil the requirements of a DLS and their efficacy is higher than the efficacy of the comparable lamps (GLS-R or HL-MV-R), the intensity of their beam angle will always be very much lower. Many consumers will be disappointed if they buy these lamps. Their benefit can only be found if they are used as a downlighter.

Table 6-6: Data for lamp efficacy, cost and life time of CFLi-R[206]

Lamp type / **Acronym**	**Wattage**	**LWFt[207]**	**Beam angle**	**Intensity**	**Luminous flux in a solid angle of 2π**	**Luminous flux in solid angle π (angular beam 120°)**	**Functional lumens in an angular beam of 90°**	**ηlamp(120°) @25 °C (without LWFt)**	**ηlamp(90°) @25 °C (without LWFt)**	**Life time**	**Unit price (for end user)**	**% face lumen output in solid angle π (angular beam 120°)**
	[W]		**[°]**	**[cd]**	**[lm]**	**[lm]**	**[lm]**	**[lm/W]**	**[lm/W]**	**[h]**	**[€]**	
B(N)AT Compact fluorescent reflector lamp, R50, E14(B15d) **CFLi-R**	7	1.05	115	68	164	140	98	20.0	14.0	10000	15.0	85
B(N)AT Compact fluorescent reflector lamp, R63, E27 (B22d) **CFLi-R**	11	1,05	125	111	240	206	145	18.7	13.2	10000	15.0	86
B(N)AT Compact fluorescent reflector lamp, R63, E27 (B22d) **CFLi-R**	11	1,05	117	124	240	203	149	18.5	13.5	15000	20.0	85
B(N)AT Compact fluorescent reflector lamp, R50, GU10 **CFLi-R**	11	1,05	99	119	220	182	134	16.5	11.7	15000	18.0	83
B(N)AT Compact fluorescent reflector lamp, PAR30(R100), E27 **CFLi-R**	15	1.05	90	290	600	501	376	33.4	25.1	15000	26.0	84
B(N)AT Compact fluorescent reflector lamp, PAR38(R120), E27 *dimmable* **CFLi-R**	15	1,05	70	450	680	604	492	40.3	32.8	15000	30.0	89
B(N)AT Compact fluorescent reflector lamp, PAR38(R120), E27 **CFLi-R**	23	1.05	110	450	1200	980	711	42.6	30.9	10000	27.0	83

- Lamp 1 could be seen as a replacement (?) for the E14 capped 40W blown reflector incandescent lamp R50 that is not a base case lamp for us.
- Lamp 2 and 3 could be seen as improvement (?) options for the E27 capped 40/60W blown reflector lamps, incandescent as well as halogen (improved lamps with xenon filling 28 and 42W included).

206 Data provided by a stakeholder (Megaman)

207 LWFt = Total Lamp Wattage Factor = LWFp x LWFe (see chapter 4).

- Lamp 4 with a GU10 cap is in fact not a real replacement lamp for the GU10 capped HL-MV-R because the dimensions are different. It can of course also be made with a E14 cap and then it is a similar lamp to lamp 1 (replacing R50 blown reflector lamps)
- Lamps 5, 6 and 7 are replacement (?) lamps for the GLS-R-HW and HL-MV-R-HW.

6.1.6 Cold Cathode Compact Fluorescent Reflector Lamps (CCFLi-R) with integrated electronic ballast

Cold cathodes fluorescent lamps (CCFL) are fluorescent lamps that do not employ a cathode heater. Nowadays, miniature CCFL's are extensively used as backlights for computer liquid crystal displays or flat screen television sets. More recently reflector lamps for general illumination appeared on the market. Their manufacturers claim a longer life time, dimmability and improved light distribution. Compared to a normal CFLi-R it can be said that the smaller light emitting discharge tube could have as a consequence that the light output is higher in the 90° cone angle. It must also be stated that these lamps contain mercury. More technical information can be found in the final report of preparatory study for ecodesign of EuP products lot 5 for television sets[208].

6.1.7 White light HIDi-R lamps to retrofit high wattage reflector lamps

High wattage incandescent or halogen reflector lamps can be replaced by more efficient HID reflector lamps with integrated control gear (HIDi-R).

The main advantage compared to CFLi-R is that an HID burner is a point source that performs better when the light needs to be focused by optics, e.g. in reflector lamps or a luminaire. Normal HID lamps are mainly available in high lumen output versions (> 1000 lm) and hence users are also forced to use luminaires to prevent glare and distribute the light.
There currently exist HIDi-R lamp versions that directly offer cost effective integrated solutions for replacing high wattage PAR38 incandescent or halogen reflector lamps with E27 cap. These lamps are rarely used in indoor domestic applications. In outdoor applications (e.g. garden lighting) they are a good alternative. Compared to an incandescent reflector lamp PAR 38-120W the equivalent HIDi-R only needs 25W, with a high colour rendering Ra = 87 and a warm, suitable colour temperature of 3000K.
These HIDi-R lamps have of course the same warm up and restrike times of several minutes as the normal HID lamps that were discussed in the street lighting study; also dimming is not possible. This makes them not very suitable for indoor domestic applications with regular switch-on's and –off's. Nevertheless, for horeca and outdoor applications they provide an energy efficient, retrofit alternative without need to change the luminaire.
It is unlikely that much lower lumen output HIDi-R lamps will appear on the market in the near future. It is a strong technological challenge. Simply downscaling can compromise life expectancy. Obstacles are the thermal conduction losses from the arc and the electrode losses that become more important for low wattages
Also here must be stated that white HIDi-R lamps also contain mercury; for more information on HID lamps see the preparatory EuP-study on street lighting lot 9.

208 www.ecotelevision.org

Figure 6-4: HID-reflector lamp with integrated control gear.

The efficacy data for these lamps are shown in Table 6-7

Table 6-7: Data for HIDi-R lamps

Lamp type / Acronym	Wattage	LWFt[209]	Beam angle	Intensity	Luminous flux in a solid angle of 2π	Luminous flux in a solid angle of π (angular beam 120°)	Functional lumens in an angular beam of 90°	ηlamp(90°) @25 °C	Life time	Unit price (for end user)
	[W]		[°]	[cd]	[lm]	[lm]	[lm]	[lm/W]	[h]	[€]
HID retrofit reflector lamp, PAR38, E27 **HIDi-R**	25	1.05	10	26000	1275		1045	41.8	9000	40
HID retrofit reflector lamp, PAR38, E27 **HIDi-R**	25	1.05	25	5000	1275		1085	43.4	9000	40
HID retrofit reflector lamp, PAR38, E27 **HIDi-R**	25	1.05	40	2100	1275		1020	40.8	9000	40

The average LLMF for these lamps is 0.81.

6.1.8 DLS LED luminaire as improvement option to DLS luminaire + DLS lamps

Following the logic of Regulation 244/2009, integrated DLS LED luminaires would be considered as lamps and will have to comply with the requirements applicable to DLS lamps. Indeed, because of their integrated nature, they are an improvement option not only to luminaires (as discussed in section 6.1.9) but also to lamps, in the series of lamp improvement options started above. As the price is higher for retrofit the consumer might choose to replace the complete luminaire.

Compared to the use of DLS lamps (other than retrofit LEDs) in DLS luminaires, LED luminaires could bring the benefit of higher energy efficiency, reduced maintenance (lamps do not need to be changed) and as a consequence, reduced waste production.

[209] LWFt = Total Lamp Wattage Factor = LWFp x LWFe (see chapter 4).

Compared to the use of retrofit LED lamps in DLS luminaires, the main improvement through LED luminaires is brought by higher energy efficiency, thanks to an improved thermal design with LED modules and more efficient power supplies because they do not suffer from space limitations that similar retrofit LED lamps encounter.
A typical example is a downlighter luminaire, see Figure 6-4. The functional performance parameters are included in Table 6-8 and the estimated BOM (extra functional elements) in Table 6-9. Dimmable power supplies are available. As can be seen from Table 6-8 the approach of quantifying functional lumens in a 90 ° solid angle is less suitable compared to functional lumens in a 120 ° for luminaires with LED modules (see also chapter 1).

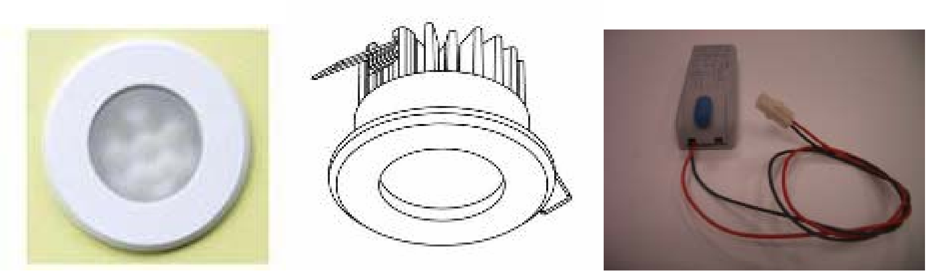

Figure 6-5: Sample LED downlighter incorporating a LED module and its dimmable external power supply

Table 6-8: Data for lamp efficacy, cost and life time of LED retrofit reflector lamps (source: manufacturer catalogue data)

Lamp type Acronym	Wattage LED module (ecl. Power supply)	LWFt[210]	Beam angle	Intensity	Functional lumens in an angular beam of 180°	Functional lumens in an angular beam of 120°	Functional lumens in an angular beam of 90°	ηlamp(90°) @25 °C with power supply losses	Life time (as used in this study)	Unit price luminaire (for end user) (excl. power supply)	Unit price dimmable power supply (for end user)
	[W]		[°]	[cd]	[lm]	[lm]	[lm]	[lm/W]	[h]	[€]	[€]
LED downlighter luminaire (CCT 3000 K) (32° beam angle) **LED module**	6.7	1.19	32	866	450	435	409	51	30000	99	44
LED downlighter luminaire (CCT 3000 K) (70° beam angle) **LED module**	6.7	1.19	32	866	450	395	309	38	30000	99	44

[210] LWFt = Total Lamp Wattage Factor = LWFp x LWFe (see chapter 4).

Table 6-9: Input data for the materials extraction and production of the LED module luminaire (expressed in g) (estimated)

MATERIALS Extraction & Production ***Description of component***	LED retrofit reflector lamp, R63, E27 – **7.5W**		Category	Material or Process MEEUP
Lens	15		7-Misc.	**13-PMMA**
Aluminium body for cooling	300		4-Non-ferro	**27-Alu die-cast**
LED	1.5			**48-SMD/LED's avg**
Copper plate (heat transfer)	15			**30-CU tube/sheet**
Plastic insulation plate	10			**8-PVC**
Printed circuit board, assembled	10			**53-PWB assembly**

6.1.9 Luminaires with reduced energy consumption (system level)

Scope of this section:
The purpose of this section is to evaluate how much energy can be saved with a particular improvement option taking into account that the compared luminaires should have an equal similar 'Light Output Function' (LOF) which is not the same as 'Light Output Ratio' (LOR) of the luminaire (see also discussion in chapter 1).

Remarks:
*All figures in the tables in **Annex 1** are estimated values based on the knowledge of CELMA[211] members as of July 2009.*
The average luminaire was defined in chapter 2.
The column in data tables of improvement options about 'What proportion of the energy can be saved comparing worst to best practice' is only related to luminaires that can be improved as indicated in the previous column (see **Annex 1**).

[211] Source: 'National Manufacturers Associations for Luminaires and Electrotechnical Components for Luminaires', www.celma.org

6.1.9.1 Luminaire improvement options related to lamp efficacy improvements

Note on the quantification of these improvement options:
In this section these options are discussed qualitatively however they are related to the most important and essential saving potential 'Increasing the lamp efficacy'. The related energy saving is calculated in more detail in chapter 8 and is also related to lamp stock and sales data and the related improvement options. The potential energy savings were already approximately calculated in scenarios in part 1 without lock-in effect, i.e. 'Scenario option 1'. The potential saving could be even more taking into account benefits from CFLni or future ultra-efficient LEDs when implemented in new luminaires. In part 2 it is the scenario related to replacing HL-MV-R with BAT or BNAT lamps, see chapter 8.

Avoid the lock-in effect into low efficient lamps class C or lower

This is also related to lamp sales data and the related improvement option in the scenario analysis. In part 2 it is the scenario related to replacing HL-MV-R with BAT HL-LV-R, see chapter 8. The proposed rule is very simple, the designer should verify that the luminaire is able to host an energy efficient lamp, e.g. at least label B.

Design luminaires that create a positive lock-in effect into efficient lighting by using CFLni lamps or ultra-efficient LED modules

CFLni lamps can have an improved efficacy and life time compared to CFLi lamps, moreover it is a positive lock-in effect for the end-user because these sockets only accept the efficient CFLni lamps. When incorporating CFLni lamps it should be carefully checked whether dimming is needed, if so dimmable ballasts should be considered. The ballast should be electronic in combination with 4-pin CFLni lamp sockets, keeping in mind Commission Regulation (EC) No 245/2009.

The same objective can also be obtained when a luminaire is constructed with ultra-efficient LED's. One of the main benefits of incorporating the LED modules directly in the luminaires is the optimisation of the LED cooling that can be improved compared to luminaires that rely on retrofit LED lamps. LEDs match also very well with optics to provide a desired light distribution.
Example: An example LED down lighter is included in this study, see section 6.1.8. The efficacy was found to be superior compared to the one of equivalent retrofit LED lamps.

Use coloured LEDs to create coloured light

LEDs are able to produce directly the desired colour which can be an alternative to a white light source with a colour filter screen.
Example from a similar lamp solution(Source ELC): LED retrofits are available in coloured versions. These have power consumptions of lower than 1 W system power and thus no need for special cooling provisions. They readily replace coloured light bulbs of 25 W regarding light output and colour with the same lumen output. Hence, the use of coloured LEDs in luminaires can create a similar saving.

6.1.9.2 Design luminaires with appropriate and efficient control electronics

Design luminaires that incorporate or are compatible with dimmers

A luminaire is in normal circumstances only operated at maximum power for functional use in occasional situations or 'scenes'. The rest of the time the luminiare can be dimmed. Situations that benefit from dimming are: change of ambient requirements, change of function (e.g. reading, watching TV, ..), change of age of users, change of mood, interference with other light sources or displays, lamp performance during lifetime (ageing), change in room reflectance, daylight entrance, etc. This improvement is applicable for external and internal dimmer systems. Special attention is needed when a CFLni ballast or LED power supply is incorporated in the luminaire as they are not always compatible with dimmers and could create lock in effects. When using filament lamps one should be aware about the reduced efficacy of the lamp. An option for filament lamps is to design a luminaire that can simply be dimmed by incorporating several lamps which can be switched on/off individually.

The energy saving of this improvement option has been estimated in consultation with CELMA members and is included in **Annex 1**.

Design Luminaires with incorporated motion sensors where appropriate

Specific luminaires can have low operational hours and should only be operated when the luminaire is approached. This is often the case in corridors where wall/ceiling mount luminaires are used (Figure 6-6). The benefit of incorporating the sensor in the luminaire is that the full power supply (230 VAC) is always available and no leakage current through the lamp is needed as explained in part 1 section 3.4.5 on the 'Electrical wiring and control system lock-in effect'. This lack of lamp leakage current lowers the standby power requirement for this application. When incorporating motion sensors the standby power requirement should be carefully examinated.

Figure 6-6: Luminaire with incorporated motion sensor

The energy saving of this improvement option has been estimated in consultation with major CELMA members and is included in **Annex 1**.

Design outdoor luminaires with incorporated day/night sensors

Outdoor luminaires should mainly be operated from dusk till dawn. The benefit of incorporating the sensor in the luminaire is that the full power supply (230 VAC) is always available and no leakage current through the lamp is needed as explained in part 1 section 3.4.5 on the 'Electrical wiring and control system lock-in effect'. This lack of lamp leakage current lowers the standby power requirement for this application. When incorporating day/night sensors the standby power requirement should be carefully examined (Figure 6-7). This option can be combined with dimming when the natural light level is insufficient, e.g. in workplaces where a minimum illumination level is required.

Figure 6-7: Outdoor luminaire with day/night sensor and motion detector

The energy saving of this improvement option has been estimated in consultation with major CELMA members and is included in **Annex 1**.

Eliminate standby losses when power supplies are incorporated in luminaires

It is important to install the switch before an incorporated lower voltage power supply instead of after the power supply. Also detectors or electronic ballasts could create losses without any light output.

According to CELMA only very few luminaires (less than 0.1%) do have today this standby loss, hence the impact is negligible.

Use electronic gears instead of magnetic (conventional) gears for CFLni and low voltage halogen

Please note that these savings were already documented and calculated in previous EuP preparatory studies on external power supplies (lot 7) and office lighting (lot 8). Magnetic ballasts are also covered by EC regulation 245/2009.

6.1.9.3 Options to increase the optical efficiency of luminaires

Use material with increased light transmittance for visible parts that are transparent / translucent

Significant differences can occur in light transmittance for visible parts that are transparent / translucent. This material is often used in luminaires to diffuse the light and luminaires can be improved with materials that have an increased light transmittance and still provide a similar outlook. Hence the Light Output Ratio (LOR) of the luminaire can be increased, see Figure 6-9: and Figure 6-10.

Examples are opal glass that has a significant lower light transmittance compared to surface treated glass, e.g. sand blasted or etched glass. Another example is white colouration PMMA (plexi-glass) that often can be replaced by satinated PMMA (see Figure 6-8). When assessing diffusor materials not only light transmittance counts but also the light reflection on the inner surface should be evaluated to avoid that the light gets 'trapped' within the luminaire . The best solution is to apply antireflective coatings at the inner surface of the diffusor, the same way as explained for halogens, see also section 6.1.2.

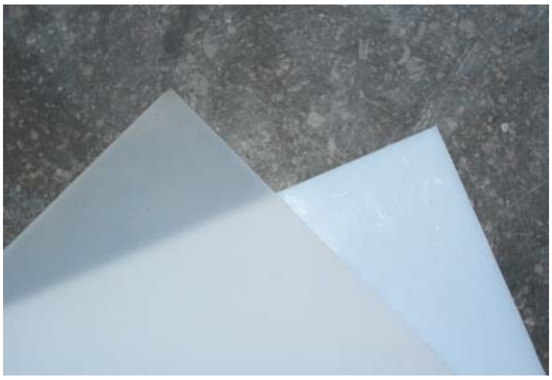

Figure 6-8: Left satinated PMMA and right white colouration PMMA diffusor material

Figure 6-9: Luiminaire(left) having LOR = 83 with special finish on the PMMA screen for direct&indirect lighting Luminaire (middle) with LOR = 70 having a glass diffuser with satin finish for direct lighting versus Luminaire (right) with LOR =62 having a white colouration PMMA screen for direct lighting

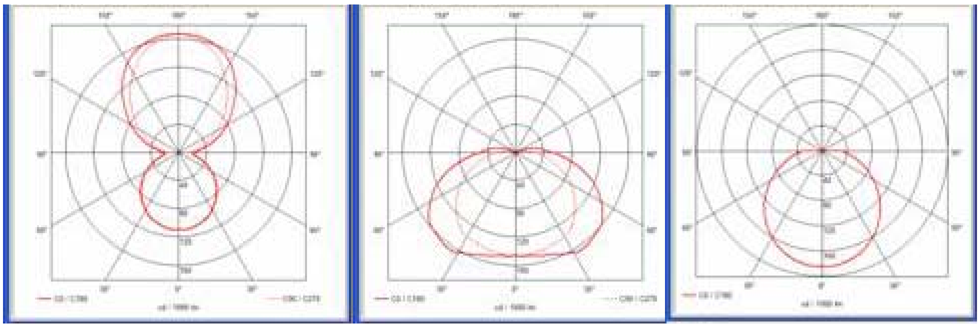

Figure 6-10: Light distribution for luminaires in Figure 6-9 left is for direct and indirect lighting while middle and left are for direct lighting

The energy saving for this improvement option has been estimated in consultation with major CELMA members and is included in Annex 1.

Use materials with increased reflectance for invisible parts that are not transparent/translucid

Significant differences can occur in light transmittance for visible parts that are not transparent / translucent, see Figure 6-1. This material is often used in luminaires to direct the light in a desired light distribution and can also be used to recover light from invisible parts. Hence the Light Output Ratio (LOR) of the luminaire can be increased.

Figure 6-11: Lampshade (left) with high internal reflectance (silver) and lampshade (right) with very low internal reflectance (black)

Related to this improvement option it should be noted that the lighting industry is working on a new EN standard within CEN/TC 169/WG 10, *'Performance of reflecting surfaces for luminaires'*.
The current proposal contains 10 efficiency classes vs total reflection in %, see Table 6-10.

Table 6-10: Proposal for reflection classes

Class	Total reflection in %
10	97 - 100
9	94 - 96.9
8	88 - 93.9
7	81 - 87.9
6	75 – 80.9
5	70 – 74.9
4	60 – 69.9
3	50 – 59.9
2	25 – 49.9
1	< 24.9

Note: The total reflectance ρtot measurement in accordance to Annex A (includes the relevant measurement procedure of CIE 130:1998).

The highest class 10 can only be achieved using advanced multi-layer coating techniques (final report lot 8, p. 168) (97%). Normal anodised aluminium for lighting applications has a total reflectivity of up to 87% (class 7) while standard white painting is about 80 % (class 6). To increase or enhance this total reflectivity to a higher level, several nanometre-thin optical coatings must be applied to the aluminium surface in a vacuum. This highly reflective surface allows the lighting manufacturer to achieve 5 up to 15 % increase in Light Output Ratio (LOR or CEN flux code). Especially luminaires that create a narrow beam and have multiple internal reflections to redirect the light from an NDLS can benefit from these materials. Therefore LOR or related LER requirements were formulated less stringent for narrow beam luminaires in lot 8 (final report lot 8, p. 185-189).

The energy saving of this improvement option has been estimated in consultation with major CELMA members and is included in Annex 1.

Summary of related LOR data found for domestic luminaires in simulation software

Important notice about LOR (see also chapter 1):

Luminaires that are used for functional lighting in the tertiary sector (e.g. office and street lighting) have photometric data that include the LOR. This approach to quantify the luminaire efficiency by its LOR cannot be applied one to one on decorative luminaires used for lamps within the scope of this study. The main reason is explained in section 1.1.5, i.e. part of the light transmitted through the luminaire shield is used to provide luminance on the decorative ornaments (of different transmittance) of the luminaire itself (another part of the light is absorbed in the luminaire and lost as heat). Moreover the reproduction and reliability of LOR data of decorative luminaire that rely on hand crafted parts (painting, glass, ..) will be very unreliable. Please note also that LOR might also rely on the used lamp type.

It is also not common practice to provide LOR data for those luminaires (CELMA communication in 2009), only very few manufacturers do so and mainly for the purpose of application in photometric simulation tools with high end architectural luminaires.

The next data (Figure 6-12, Table 6-11) contain collected LOR data found in electronic catalogues for about 49 typical domestic luminaires. It should be noted that this data is hard to find, only few manufacturers have this data and provide it in photometric simulation tools with high end architectural luminaires. There seems to be a plateau above LOR =60. Some sample luminaire pictures of this analysis are in Figure 6-13.

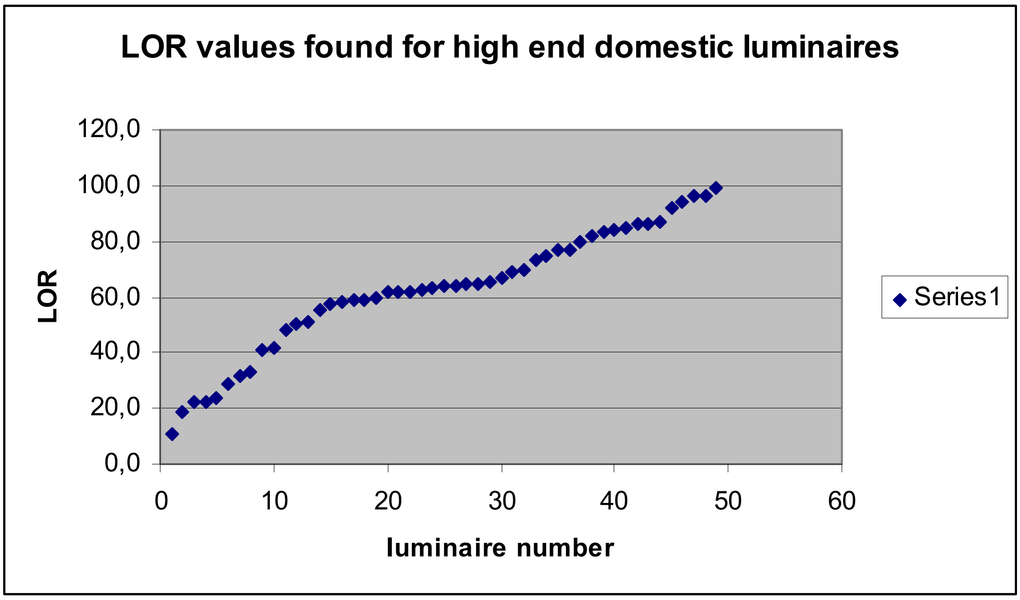

Figure 6-12: LOR found in electronic catalogues for different domestic luminaires.

Table 6-11: LOR statistics from 49 domestic luminaires

% of luminaires that have lower LOR	LOR
16	40
22	50
28	55
37	60
50	63
53	65
65	70
69	75

Figure 6-13: Luminaires with LOR = 19 (left), LOR = 62 (middle), LOR =84 (right)

Please note that the energy saving from this option has already been assessed in the two previous improvement options.

Use the correct category of luminaire for the correct application and provide appropriate user information

It is important that users are informed about the proper use of the luminaire.
Important application related issues that have an important influence on energy consumption are:

- Avoid the use of spotlights for general illumination by informing the consumer;
- Provide information on luminaire cleaning when diffusers, reflectors and/or dimmers are applied;
- Avoid continuous dimming with halogen lamps and change if possible to lower lamp power. This avoids lamp blackening with permanent efficacy decrease, moreover dimming also reduces efficacy;
- Do not put further shades on the products to reduce the light emission (it is possible to use those, if any, provided by the manufacturer and already evaluated;
- Warn users that indirect lighting is only beneficial with bright walls/ceiling;
- Warn users that indirect lighting needs an appropriated distance from the ceiling/walls, not to far but also not to close;
- Inform users about the light distribution for spot lights, e.g. beam angle;
- Warn the users for outdoor luminaires that have a high upward light flux (ULOR). This might create a high spilling of light and moreover creates light pollution (see also lot 9 on street lighting) (Figure 6-14).

The energy saving of this improvement option has been estimated in consultation with CELMA members and is included in **Annex 1**.

Figure 6-14: Example luminaire(left) that can createa spill of light when used against the open atmosphere versus an optimised luminaire(right) solution

6.1.9.4 Other luminaire related improvement options

Design outdoor luminaires with photovoltaic panels

Incorporating photovoltaic (PV) panels in outdoor luminaires could create a synergy and environmental benefits. Nevertheless a positive impact depends strongly on the application and is not always obvious. It will depend on the orientation, shading, seasonal variations in sunlight, the battery capacity, the battery life time and lighting needs. The 'saved' energy needs to be evaluated against the important environmental impact from PV panel production or PV panel production needs, this is often called energy pay-back time calculations[212].

Therefore it could be recommended in line with Annex 1 of the directive:
1. The manufacturer provides the energy pay back time for the system expressed in hours of operation of the luminaire.
2. The luminaire manufacturer provides the hours of operation per EU27 capital at a sunny unclouded day at equinox in optimum orientation.
3. The luminaire manufacturer provides instructions on optimum orientation.
4. The luminaire manufacturer provides the country average on sun vs cloudy days (e.g. Belgium is about 20 % sunny).

Figure 6-15: Outdoor luminaire with photovoltaic(PV) panel

Conclusion:
Situations where such an improvement option is beneficial were estimated very rare (see data provided by CELMA in **Annex 1**).

Use a reflector lamp instead of luminaire with reflector for downlighters

Source ELC, best LOR for reflector lamps are LOR = 85 %.
This should be compared to LOR = 65 % for an equal recessed reflector luminaire with a NDLS.

Nowadays reflector lamps are far more often used in spot lights, hence no big saving can be expected.

6.2 State-of the art of best existing product technology outside the EU

The EU has premises of leading international companies in the field of lighting with also important R&D related to office lighting within the EU. For the cited BAT above, similar technology exists around the world, mainly in the US and in Asia. Many European companies

[212] Alsema (1998): 'Energy pay-back time of photovoltaic systems: present status and prospects', Vienna, 1998, see http://igitur-archive.library.uu.nl/copernicus/2006-0307-200042/98053.pdf

are also internationally active and it is difficult to allocate their activities and achievements exclusively to the EU. The production of CFL is often located in China.
On the longer term (above 5 years), the proliferation of more advanced electronic lamp technology and solid state lighting such as LED's could be allocated to technology resulting from Asian technological developments.

6.3 BNAT in applied research

6.3.1 Low voltage halogen reflector lamps with super IRC

A stakeholder mentioned in his comments and explained in the 3rd stakeholder meeting that there is still improvement potential by replacing IRC by super IRC and even super super IRC. Efficacy could still rise with more than 10%.

6.3.2 OLED lamps

OLED's (Organic LED) are a new upcoming technology but they are not intended to give directional light. The reason for this is that the light producing element has typically a flat surface and the amount of generated lumens per m² is rather low. Due to the dimensions, a directional light source based on this technology is unlikely. The future of OLED's can mainly be found as backlights in flatscreens and mayby also as a NDLS in general room illumination. As a consequence they will not be discussed in this part 2 of the study.

6.3.3 The road map for WLED development

As mentioned before LEDs are under contineous development and LED efficacy is expected to furher increase.

LED manufacturers are claiming that LED performance will still improve in the next years.
At the 3rd stakeholder meeting, ELC has distributed a road map with their expectations until 2017 about the future LED system efficiency improvement for 3000K retrofit lamps.

This road map is displayed in Figure 6-16: ELC road map for LE

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The National Electrical Manufacturers Association of the USA has also published their expectations for LED improvement. This road map is displayed in Figure 6-17: National Electrical Manufacturers Association road map for LEDs

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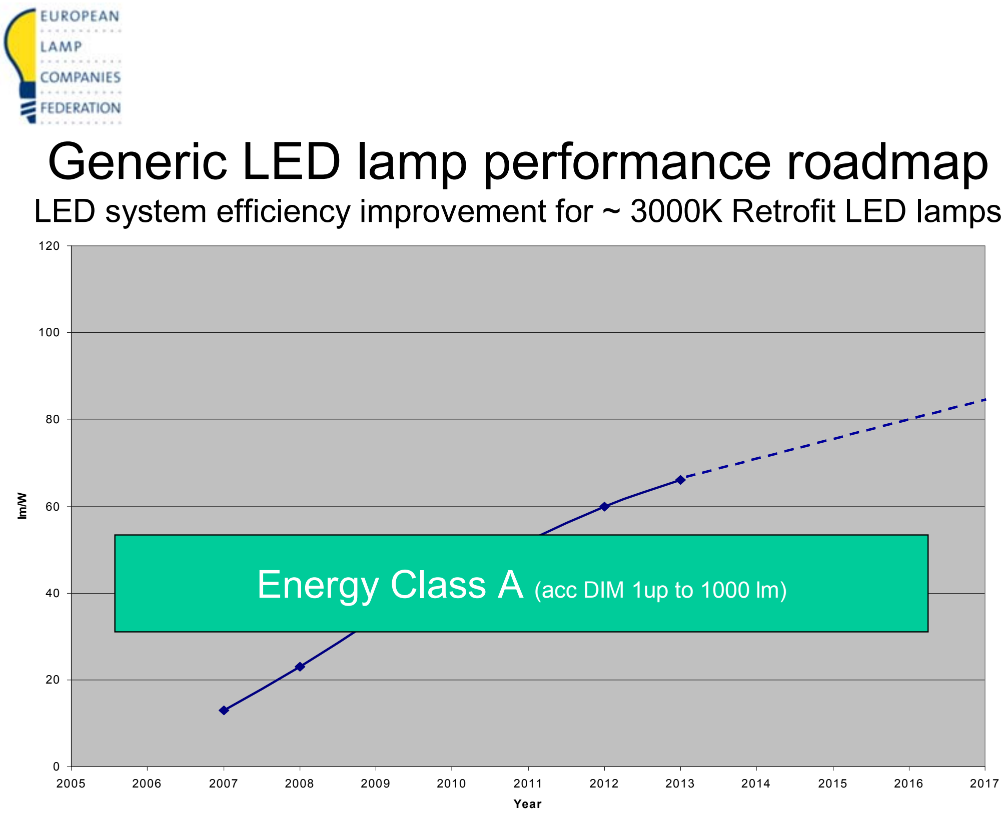

Figure 6-16: ELC road map for LE

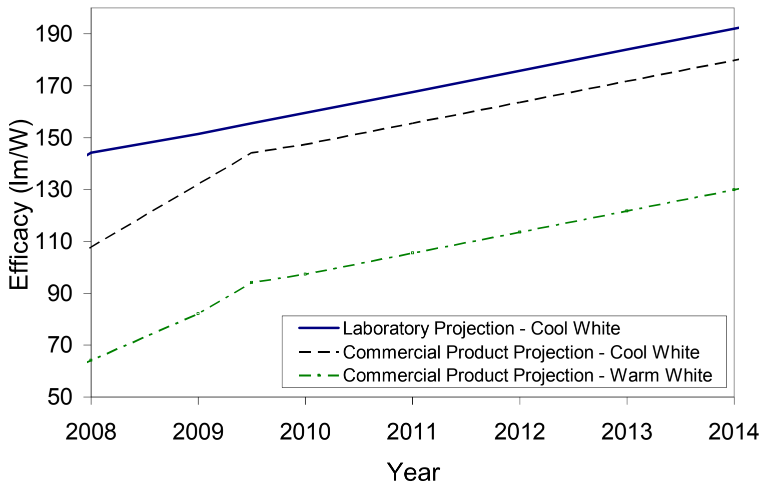

Figure 6-17: National Electrical Manufacturers Association road map for LEDs

Conclusion:

These projections suggest that the retrofit LED lamps that are discussed in section 6.1.4 could reach double lumen output and efficacy by 2016. In 2016 the total functional lumen output (90°) could be close to the base case halogen reflector lamps (HL-LV-R (GY5.3), HL-MV-

R(GU10)). Hence retrofit LED lamps with equivalent performance might become a realistic improvement option in 2016.

6.3.4 Theoretical maximum lamp efficacy

It is important to note that the lamp efficacy has a physical upper limit; this is when all light is converted into visible electromagnetic radiation.
This maximum lamp efficacy is related to the colour due to the definition of lumen and the relative spectral sensitivity of the human eye that was taken into account.
The maximum lamp efficacy for a perfect cool white light source is 348 lm/W and the absolute maximum for monochromatic yellow-green light (555 nm) sources is 683 lm/W (IESNA (1993), p. 204).

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[213]**	**Electricity consumption (Wh/h)**	**Average LLMF[214]**	***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[215] (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

[213] Total Lamp Wattage Factor
[214] Lamp Lumen Maintenance Factor
[215] Maximum 18 years based on consumer behaviour

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).

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.

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.

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.

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).

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.

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 7-7 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[216]) 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 %).

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

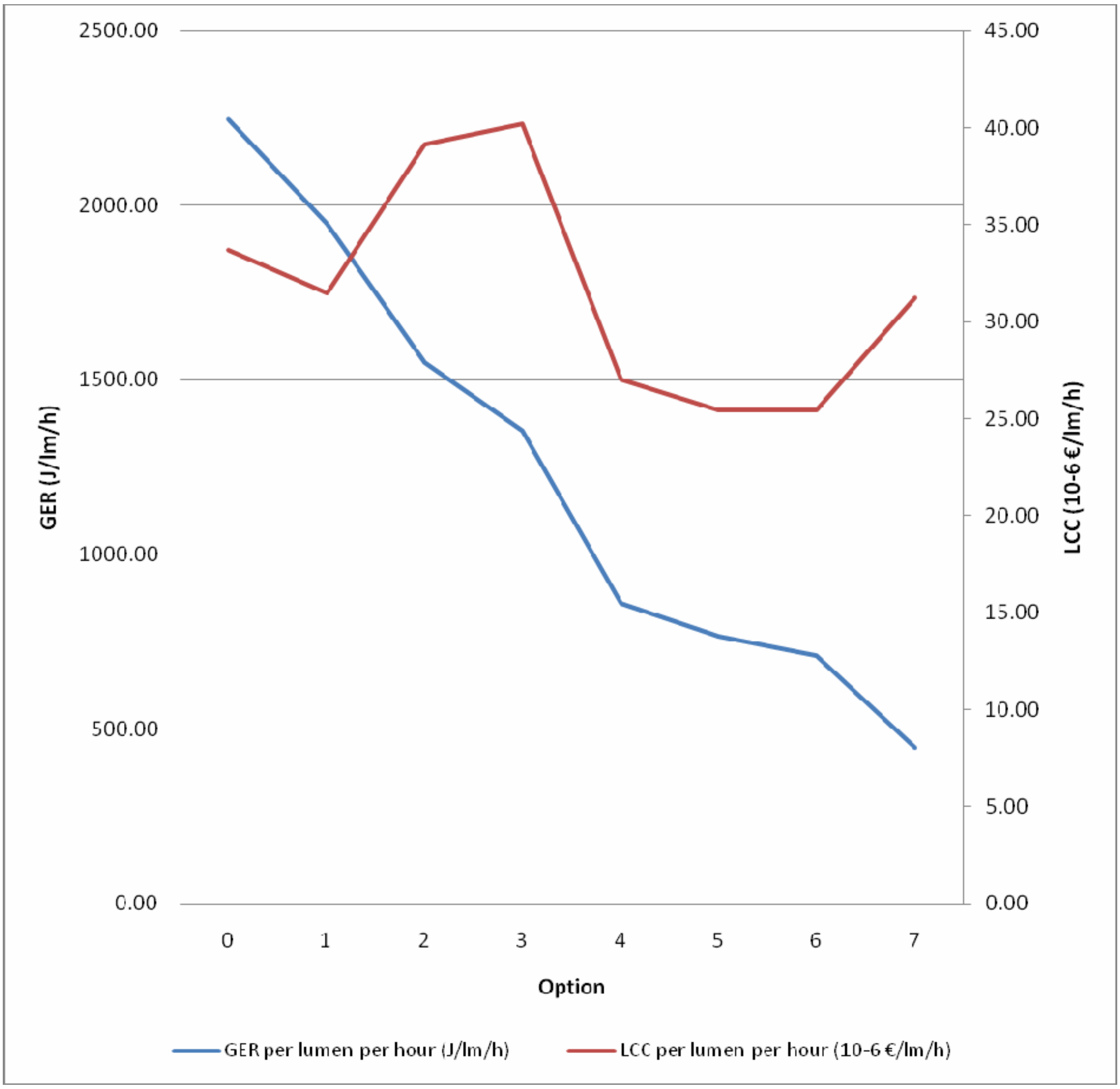

Figure 7-1: LCC curve – environmental performance expressed in total energy consumption (GER) for the improvement options for the base-case GLS-R

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.

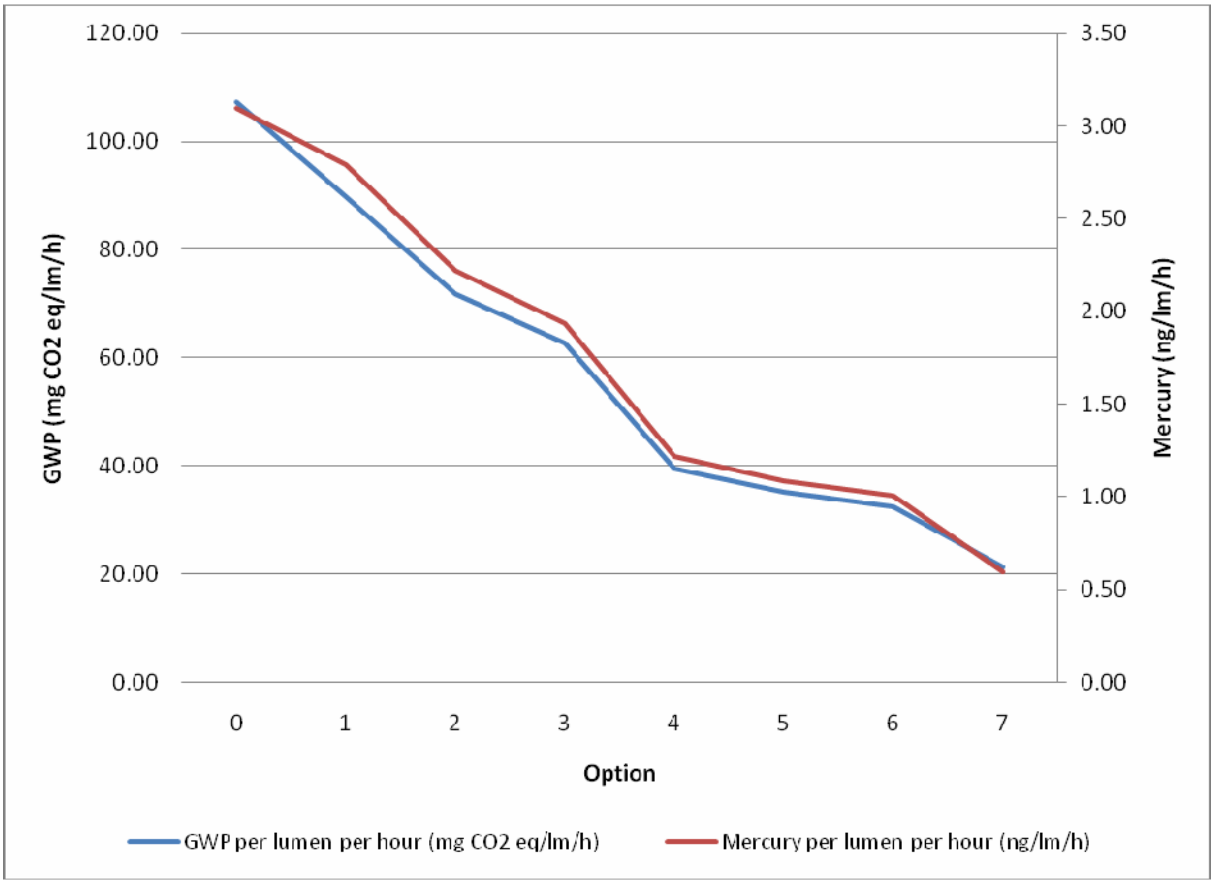

Figure 7-2: Environmental performance expressed in GWP and in mercury emissions for the improvement options for the base-case GLS-R

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%.

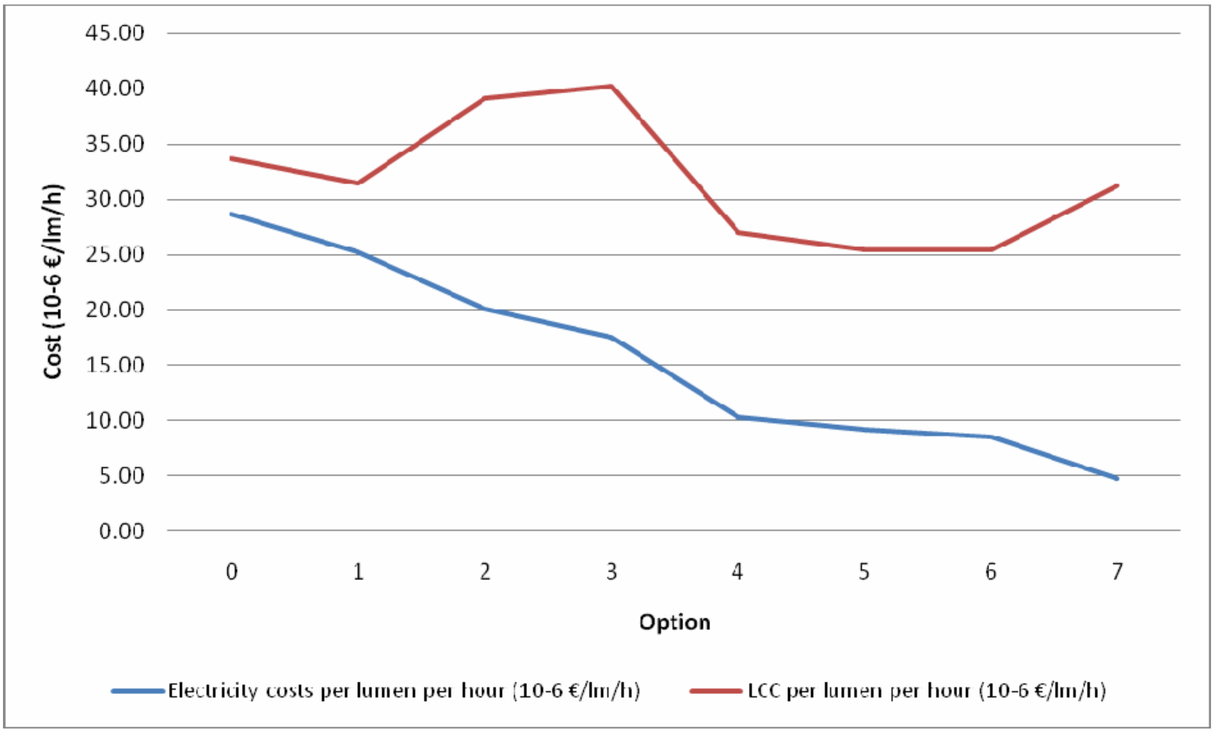

Figure 7-3: LCC curve – environmental performance expressed in total electricity costs for the improvement options for the base-case GLS-R

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 CO_2 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	µg SO_2 eq.	572.67	497.87	396.72	346.40	222.97	198.69	184.11	114.77

(AP)	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 7-9. 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 7-6. 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.

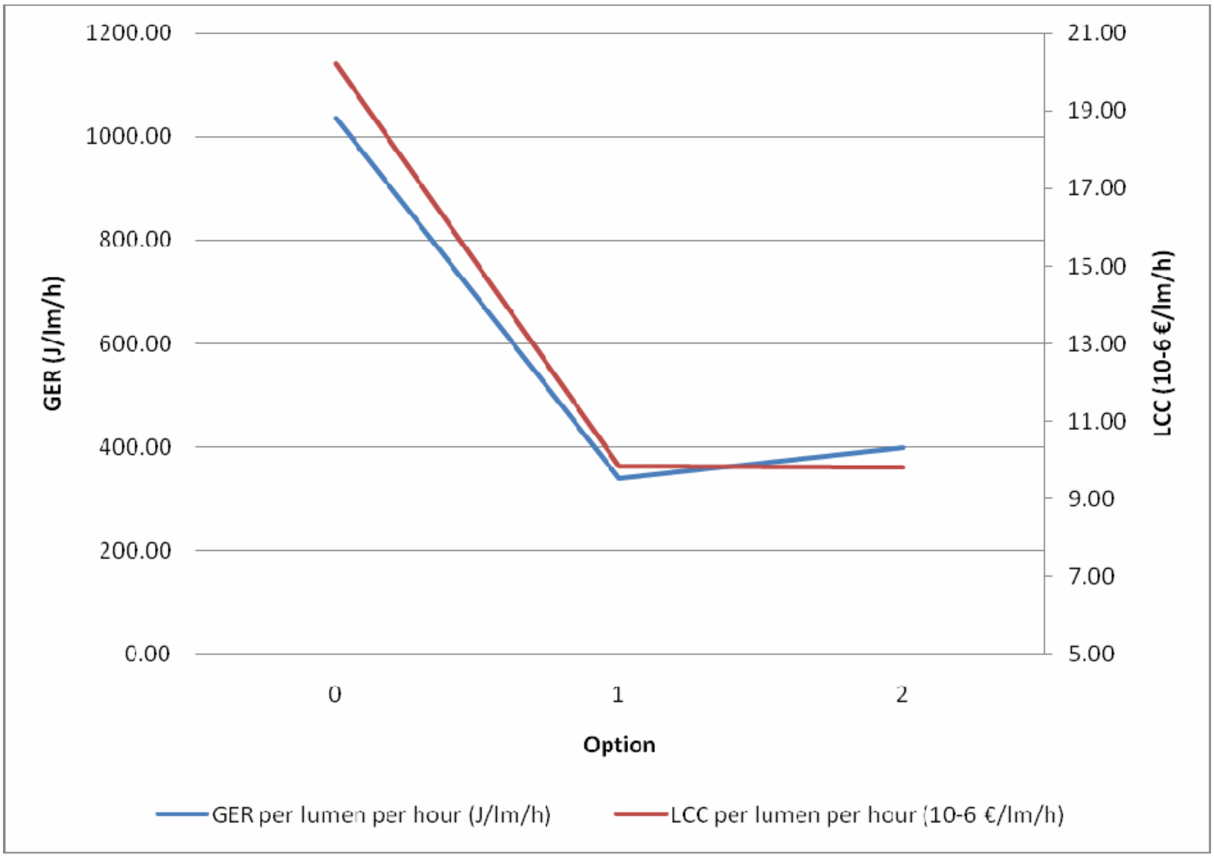

Figure 7-4: LCC curve – environmental performance expressed in total energy consumption (GER) for the improvement options for the base-case HL-MV-R-HW

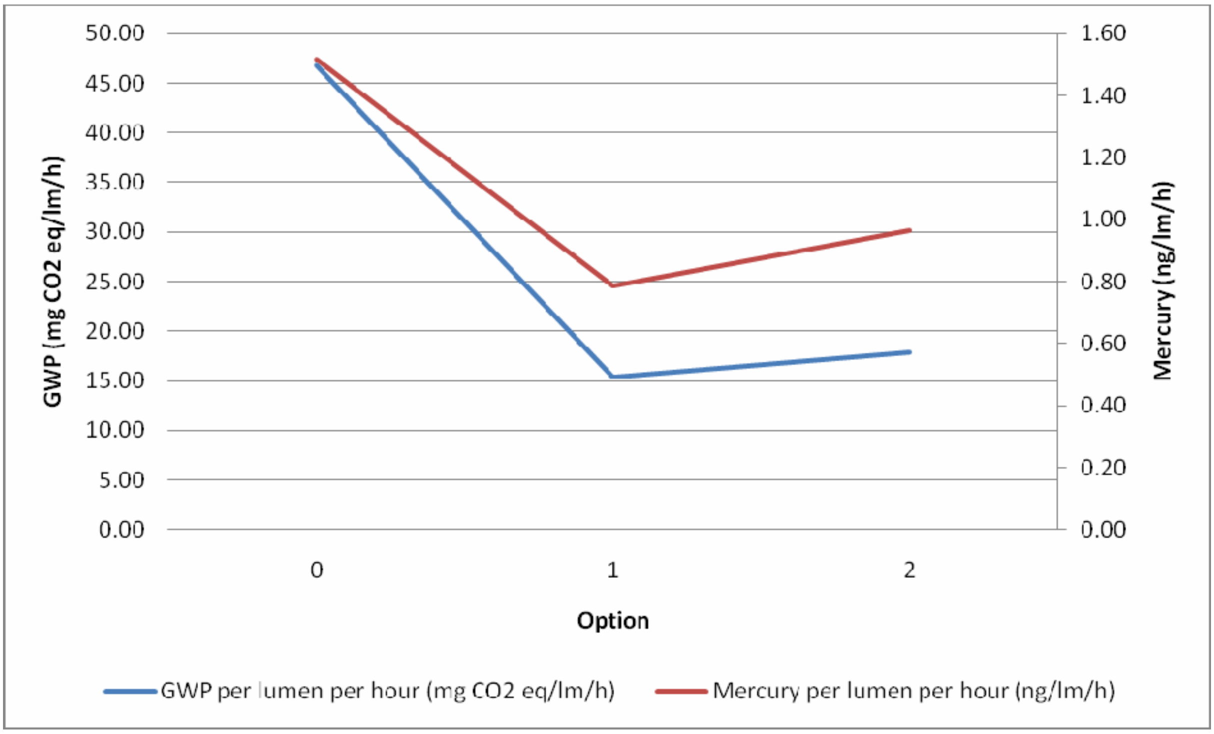

Figure 7-5: Environmental performance expressed in GWP and in mercury emissions for the improvement options for the base-case HL-MV-R-HW

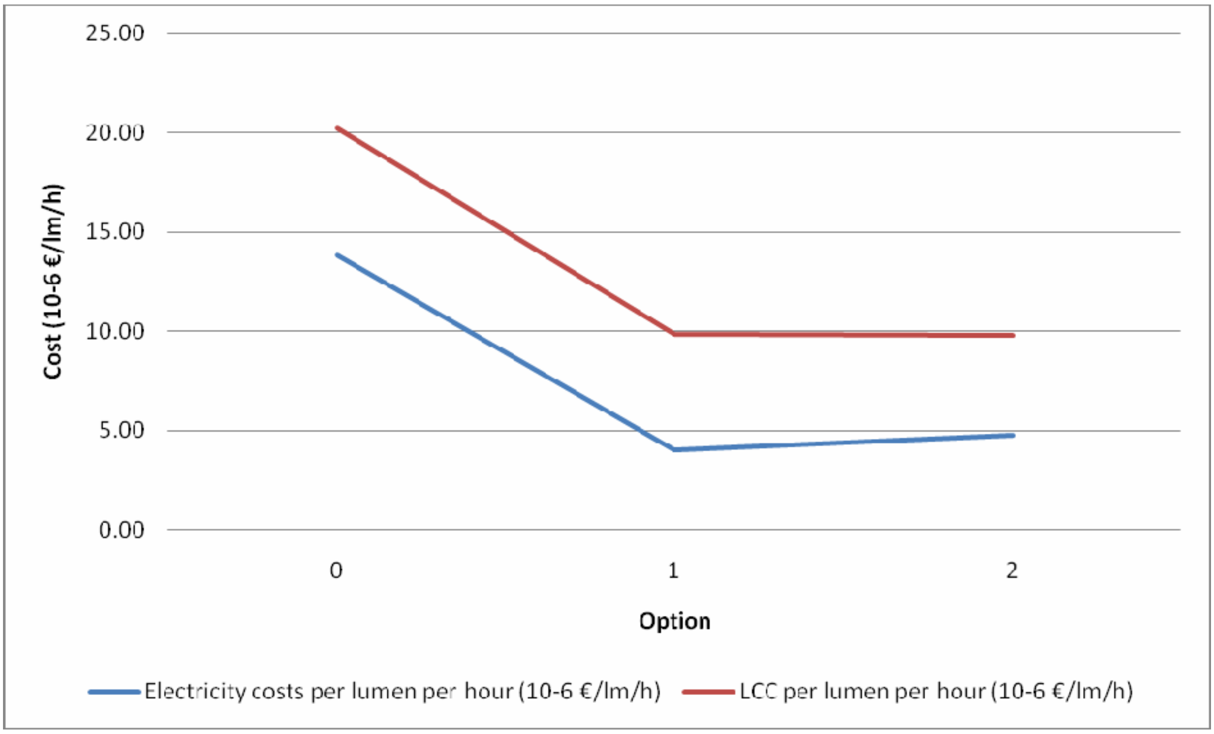

Figure 7-6: LCC curve – environmental performance expressed in total electricity costs for the improvement options for the base-case HL-MV-R-HW

Table 7-10 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.

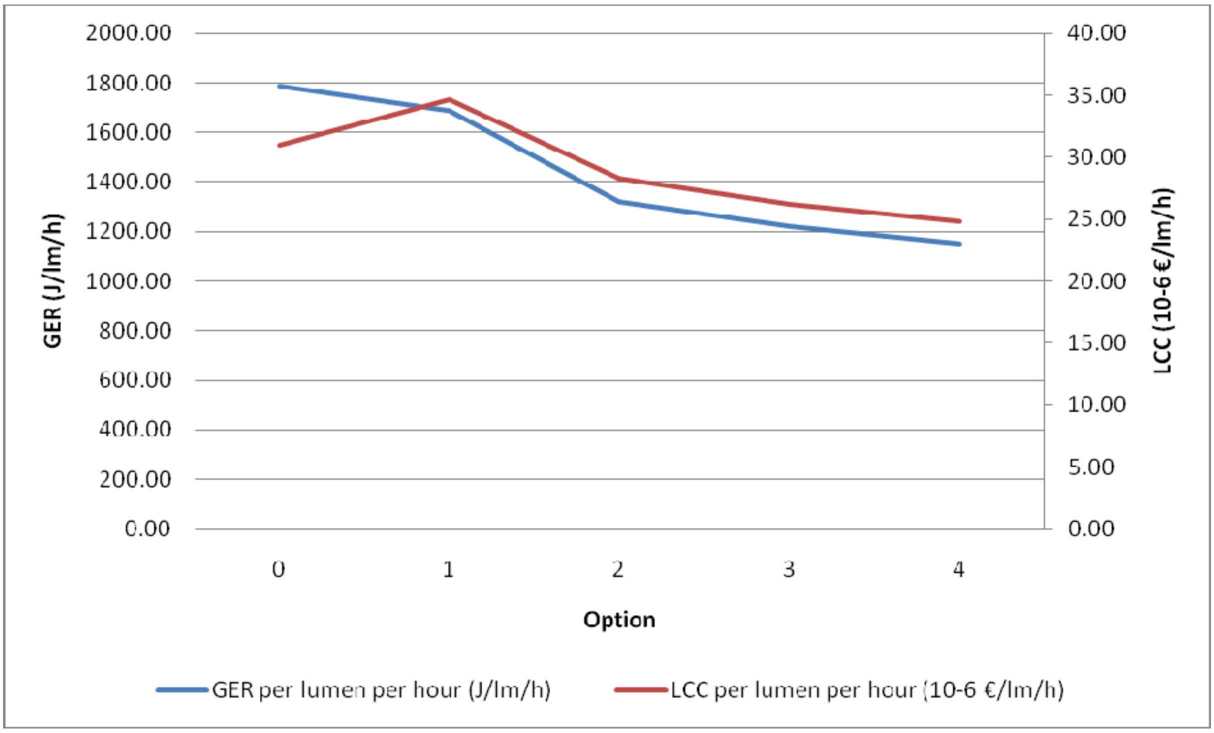

Figure 7-7: LCC curve – environmental performance expressed in total energy consumption (GER) for the improvement options for the base-case HL-MV-R-LW

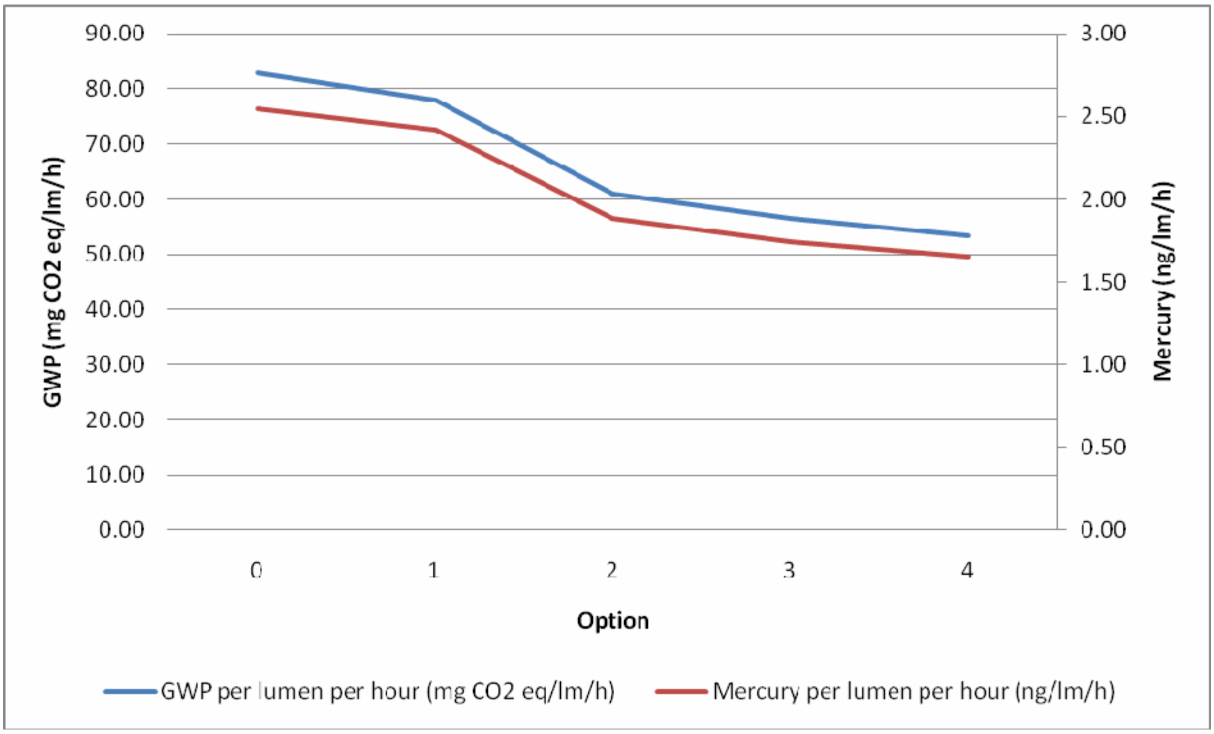

Figure 7-8: Environmental performance expressed in GWP and in mercury emissions for the improvement options for the base-case HL-MV-R-LW

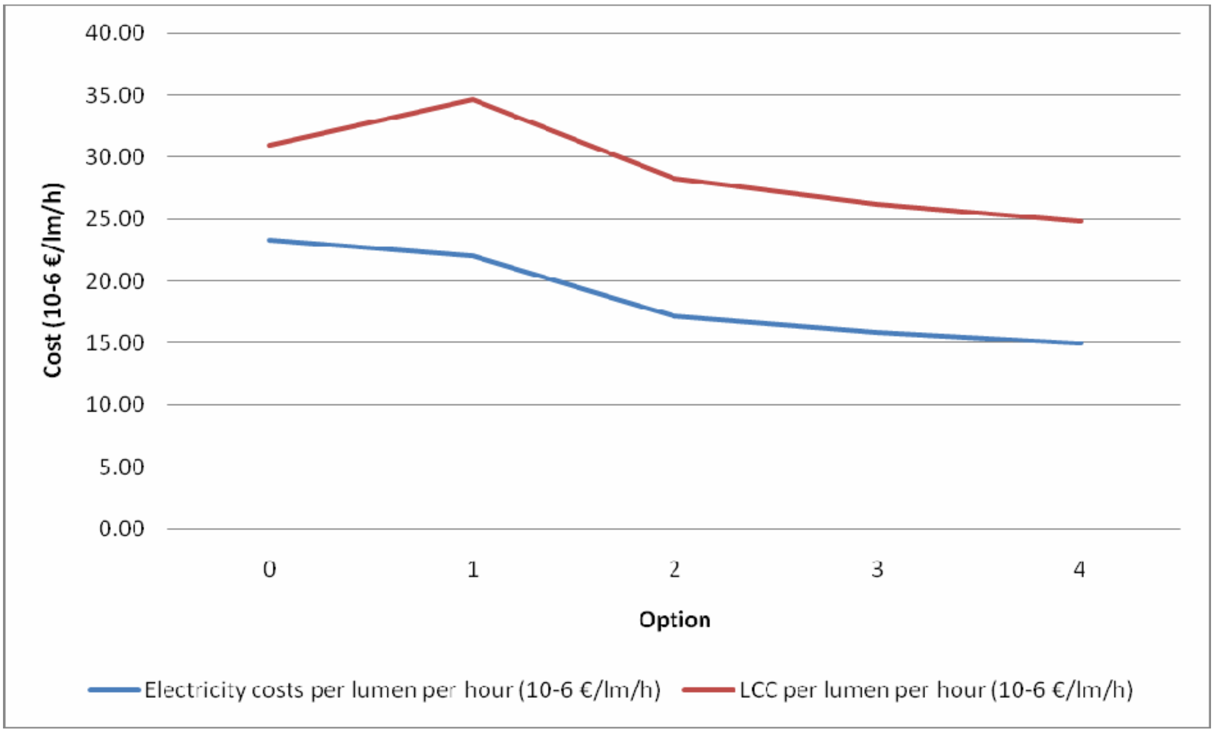

Figure 7-9: LCC curve – environmental performance expressed in total electricity costs for the improvement options for the base-case HL-MV-R-LW

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 CO_2 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 SO_2 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 PO_4	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).

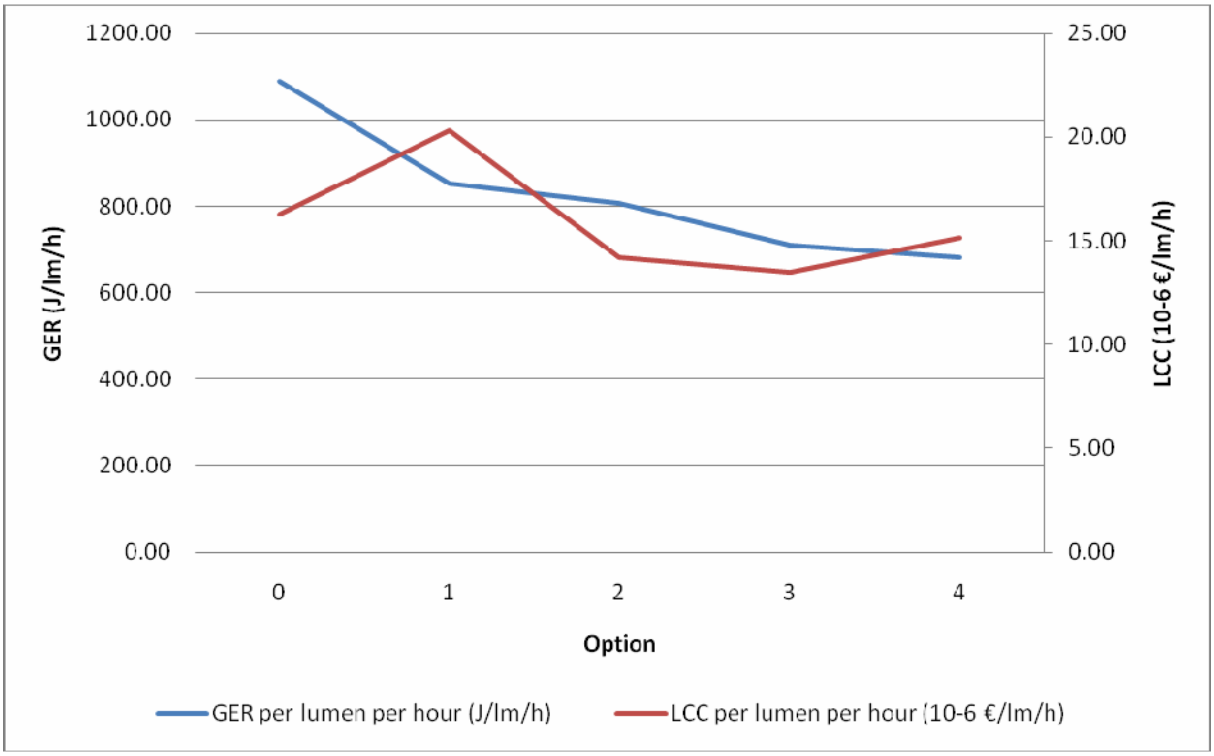

Figure 7-10: LCC curve – environmental performance expressed in total energy consumption (GER) for the improvement options for the base-case HL-LV-R

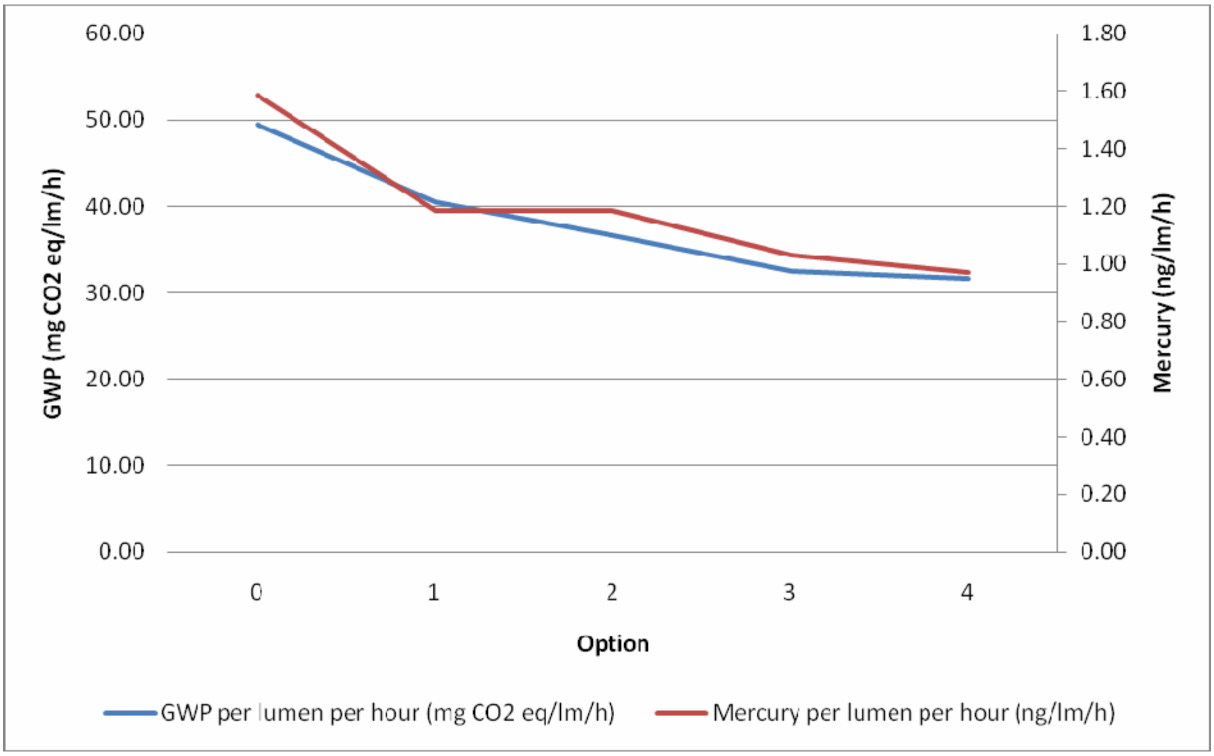

Figure 7-11: Environmental performance expressed in GWP and in mercury emissions for the improvement options for the base-case HL-LV-R

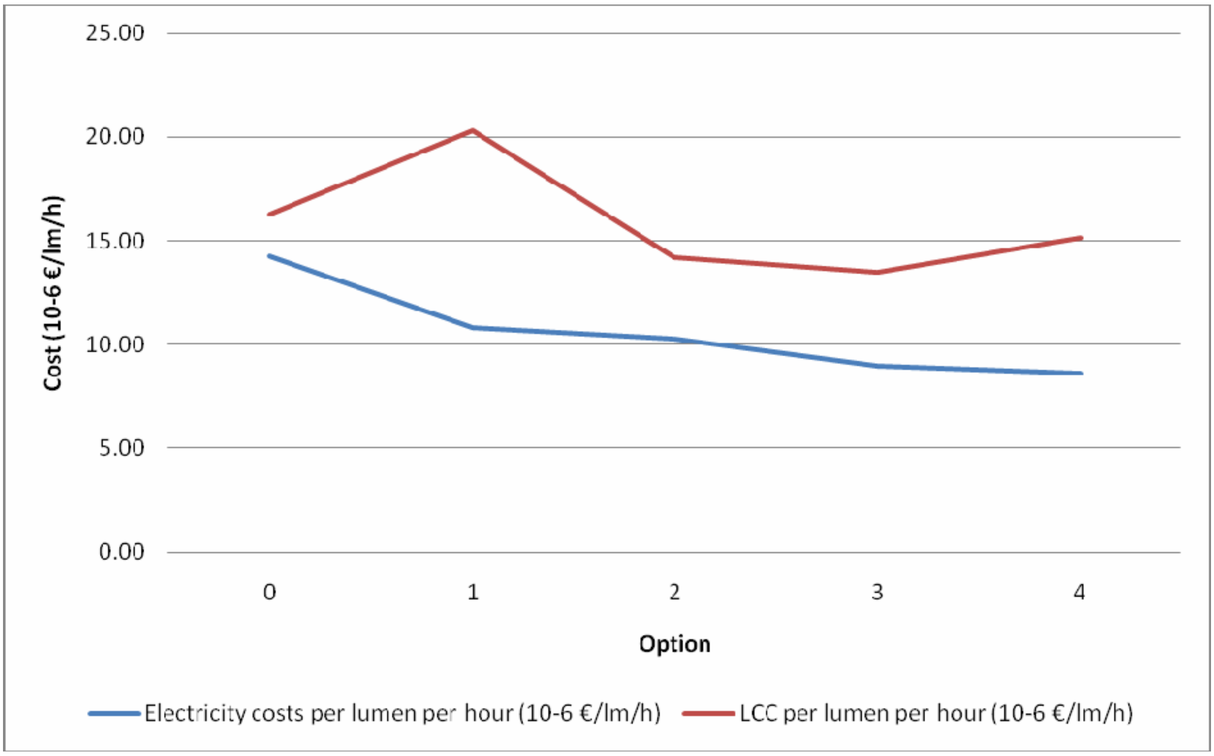

Figure 7-12: LCC curve – environmental performance expressed in total electricity costs for the improvement options for the base-case HL-LV-R

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

Important remark: This preliminary chapter 8 discusses part 2 of the study concerning directional light sources and household luminaires.

Scope: This chapter summarizes and totals the outcomes of all previous tasks. It looks at suitable policy means to achieve the improvement potential e.g. implementing LLCC as a minimum and BAT as a promotional target, using legislative or voluntary agreements, labelling and promotion. It draws up scenarios 2007 – 2020 quantifying the improvements that can be achieved vs. Business-as-Usual. It makes an estimate of the impact on consumers and industry as explicitly described in Annex 2 of the Directive.
Finally, in a sensitivity analysis of the main parameters the robustness of the outcomes is studied.

It has to be kept in mind that the conclusions represent solely the point of view of the consortium and they do not reflect the opinion of the European Commission in any way. Unlike chapters 1-7, which will serve as the baseline data for the future work (impact assessment, further discussions in the EuP Consultation Forum, and development of implementing measures, if any) conducted by the European Commission, the chapter 8 simply serves as a summary of policy implications as seen by the consortium. Further, some elements of this chapter may be analysed again in a greater depth during the impact assessment.

8.1 Policy- and scenario analysis

8.1.1 Eco-design requirements

In this chapter generic and specific product related eco-design requirements are described that can be used as suitable policy means to achieve BAT or LLCC scenario targets.
Please note that there was also a part 1 in this study concerning non directional light sources and there are also finalised preparatory studies on 'street' (lot 9) and 'office' (lot 8) lighting that include mainly topics related to HID lamps and fluorescent lamps with non integrated ballasts.
For these products the EC already adopted regulations: Commission Regulation (EC) No 244/2009 with regard to ecodesign requirements for non-directional household lamps and No 245/2009 with regard to ecodesign requirements for for fluorescent lamps without integrated ballast, for high intensity discharge lamps, and for ballasts and luminaires able to operate such lamps.

As domestic lighting products represent the baseline in terms of energy efficiency and performance, the measures that are suggested in this study (lot 19) are recommended for any directional lamp type or light source regardless of technology. Other ecodesign implementing measures are or will be formulating higher requirements on particular technologies that are used in other sectors than domestic lighting.
Because even the domestic lighting products examined in this study can be used in many other general lighting applications, the proposed measures hereafter obviously have a wider scope. Therefore, it is important to assess the potential negative impact beyond the domestic lighting sector (see 8.2).

8.1.1.1 Scope of proposed Eco-design requirements

For this study the impact is calculated in relationship to all installed lamps that were within the defined scope in chapter 1.
However, when the final legislation has to be developed the definition of the scope should be done more carefully.
Negative impact should be avoided for particular lamps or luminaires for other applications compared to this study. For more information on impact consult section 8.2. Please note that complementary to this study the EC will organise a consultation forum prior to voting on any regulation and will conduct a more detailed impact analysis, see links on the project website for further information on this process. Afterwards detailed legislation can be elaborated, hereafter are only included generic suggestions as a starting point. Apart from impact it is needed to create a synergy with other legislation, in particular already adopted EC regulation (244/2009, 245/2009) within the Eco-design Directive 2005/32/EC and the labelling Directive 98/11/EC.

Some recommendations on the scope of potential regulation are:

- In many cases it is impossible to distinguish, at the 'placing on the market' stage, lamps and luminaires that are intended for 'domestic' lighting from other indoor lighting applications as in restaurants, hotels, etc. It is therefore recommended to define a broader scope for lamps and luminaires within the specific eco-design requirements;
- Option 1: For luminaires with built-in LEDs or LED modules it is not recommended to impose minimum efficacy requirements on the system, this would create a high development cost for the many SMEs developing these luminaires and hamper market introduction of this promising new technology. Moreover, this LED technology changes frequently in performance and would require many remeasurements. However it is recommended that the luminaire construction files contain the documentation of the LED manufacturer that proves that the LED component or LED module satisfies the efficacy requirements given the particular conditions as specified by the LED manufacturer as a reference point. However, it is recommended to elaborate a standard approach for this. This exception needs to be evaluated again after a period of 4 years when the technology is expected to be more mature. The above proposed exemptions for LED lighting products should only be applicable for products that do not make any claim on equivalence to lighting products within the scope, to avoid false claims on performance. When no measurements are done the

product should not make any claims on equivalence or being an energy efficient solution;

- Option 2 alternative to option 1 above: Impose the same minimum efficacy and information requirements for luminaires with built-in LEDs or LED modules as for lamps. Some stakeholders urge for this in order to avoid loopholes in the market and to reduce poor consumer experiences with LED technology. As mentioned before this could increase luminaire R&D and hamper market introduction, time should be given to elaborate more measurement facilities. This offers more protection for the consumer. It is recommended to discuss these at the consulation forum;
- In many cases luminaires can be used in the tertiary sector and in general domestic lighting applications. Legislation should be developed coherently. Lamps, luminaires and ballasts for office lighting can also be used in certain domestic applications but they were already discussed in the dedicated preparatory study on office lighting (lot 8), and thus will not be considered again hereafter in this study. Street and office lighting products have more stringent needs for the provision of information, see preparatory study on lot 8 and lot 9. It is possible to develop tertiary lighting requirements on top of general lighting luminaires that can be used in domestic lighting. In many cases products can be shifted directly to tertiary lighting based on the light source for which they are designed, e.g. by light source (above 2000 lumen) or by lamp type (HID and LFL lamps). It is also proposed to distinguish luminaires for 'Functional illumination in the tertiary sector'(lot 8&9) and those for general lighting (lot 19);
- The definition of scope for the lamps should be coherent with EC regulation 244/2009 on household lamps;
- To exempt lamps with less than 50 lumen or more than 10000 lumen in a 90° cone (120° cone in some cases);
- A 'domestic luminaire' can be defined in the context of the proposed implementing measures hereafter in this chapter as any luminaire that can host the lamps within the scope of this study (maybe a rewording is needed in later legislation proposals);
- Lamps that make equivalence claims to products within the scope should never be exempted from product information requirements when placing on the market (e.g. any future lamp technology);

8.1.1.2 Generic Eco-design requirements on the supply of information for lamps (even when sold integrated as part of the luminaire or in the same package as the luminaire)

Optimal use of domestic lighting starts with adequate information on existing products. Therefore, it is proposed that the manufacturers provide information on the following 'most relevant' eco-design parameters and follow the proposals for the appropriate means for communicating these parameters to the consumer. The provision of information on these 'most relevant' parameters should satisfy article 15.4 (f) to reduce unnecessary administrative burden and allow verifying compliance with proposed specific implementing measures.

Information available to the end-users at the moment of purchase and on free access websites in a form that can be copied as characters for any white light source (Annex 11.1.1) within the scope of this study:

For directional lamps (even when sold as part of the luminaire or in the same package as the luminaire):

a) The nominal lamp power and, separately displayed in a font at least twice as large as the nominal lamp power display, the nominal luminous flux of the lamp, as defined in c), d) and e) below;
b) Voltage and cap type;
c) For halogen lamps, LED retrofit lamps and CFLi-DLS lamps with Ø < 70mm and cap GU10, E14 or E27, the nominal luminous flux in a 90° cone of the lamp shall be displayed (the nominal luminous flux shall never be higher than the rated luminous flux);
d) For other CFLi-DLS lamps claimed to be retrofit lamps to halogen lamps, the nominal luminous flux in a 90° cone of the lamp (the nominal luminous flux shall never be higher than the rated luminous flux);
e) For CFLi-DLS lamps that make no claim to retrofit halogen lamps, the nominal luminous flux in a solid angle of π sr or a 120° cone of the lamp shall be displayed and also the nominal luminous flux in a 90° cone (the nominal luminous flux shall never be higher than the rated luminous flux);
f) Nominal life time of the lamp in hours (in the case of LED lamps, both for retrofit lamps and LED lamps that are part of the luminaire) L70F50 as defined in Chapter 1. Section 1.1.3.1 (not higher than the rated life time);
g) Number of switching cycles at LSF = 0.5 or F50;
h) Colour temperature (also expressed as a value in K);
i) Colour rendering (also expressed as a value Ra). Only Ra = 100 can be shown as excellent or perfect, only $R_a \geq 90$ can be shown as very good or improved, and $R_a < 80$ must be shown as poor;
j) Warm-up time up to 60% of the full light output (may be indicated as "instant full light" if less than 1 second);
k) A warning if the lamp cannot be dimmed or can be dimmed only on specific dimmers and if the lamp cannot be operated on electronic switches (motion sensors etc.);
l) If designed for optimal use in non-standard conditions (such as ambient temperature $T_a \neq$ 25 °C), information on those conditions;
m) Lamp dimensions in millimetres (length and diameter);
n) Peak intensity in candela [cd]);
o) Beam angle in degrees [°];
p) Optional (not obligatory): If equivalence with a standard GLS-R or halogen reflector lamp is claimed, a uniform method shall be used that is agreed with the sector federations (needs to be elaborated in consultation with ELC who already has a proposal);

if the lamp contains mercury:

q) Lamp mercury content as X.X mg;
r) Indication which website to consult in case of accidental lamp breakage to find instructions on how to clean up the lamp debris.
s) UV emission data (to be considered).
t) When there is no laboratory responsible for measuring these parameters the product should mention ‘Indicative values’

Note: It should be noted that stakeholders have different opinion on the 90°-120°-180° functional lumen definition, hence it could be considered for discussion at the consulation forum.

The term "energy saving reflector lamp":

This can only be provided if the lamp meets the equivalent Tier 3 (2016) lamp efficacy requirements.

Information to be made publicly available on free-access websites:

The information shall also be expressed as values and in a form that can be copied as characters too.

a) The information specified above in points a-r;
b) Rated wattage (0.1 W precision);
c) Rated luminous flux in 90°, 120°(or solid angle π sr) and 180° cone;
d) Rated lamp life time (from Stage 2);
e) Lamp power factor;
f) Lumen maintenance factor at the end of the nominal life
g) Starting time (seconds);
h) For all LED-light sources, not only for the LED-component itself, the lifetime as L85F05.
i) Laboratory(ies) responsible for measuring the parameters, if not available see also information requirements for the package.

Proposed timing for this measure:

As soon as possible.
Please note that the introduction of an energy label is also recommended (see section 8.1.4.1).

8.1.1.3 Generic Eco-design requirements on the supply of information for domestic luminaires sold for general lighting

The user should be informed with the product purchase about application related issues that have an important influence on energy consumption; they are:

- the general use of their choosen luminaires, e.g the application of spotlights is intended for controlling light distribution;
- the importance of luminaire cleaning when diffusers or reflectors are applied;
- continuous deep dimming with halogen lamps has a negative impact on efficacy and change to lower lamp power should be considered. This avoids lamp blackening with permanent efficacy decrease, moreover dimming also reduces efficacy;
- the preferred set up of the luminaire.
- it is not beneficial to modify the luminaire itself, e.g. by using further shades to reduce the light emission, it is possible to use those, if any, provided by the manufacturer and already evaluated;
- for indirect lighting luminaires bright walls are needed and the luminaires need to be kept at a suitable minimum and maximum distance from the surface as specified by the manufacturer (the manufacturer should specify these distances);
- the light distribution for spot lights, e.g. beam angle;
- outdoor luminaires need to be correctly placed in order to light up the object or surface to be lit and not the sky;

It is recommended to agree on a uniform method with the sector federations.

8.1.1.4 Specific eco-design requirements for reducing losses in the electrical distribution grid due to a poor power factor

See part 1, however for reasons explained in chapter 3 it is proposed to excempt LED modules or lamps below 6 Watt. This can be considered for part 1 NDLS lamps too.

8.1.1.5 Specific ecodesign requirement for increasing lamp efficacy and decreasing system-power demand

The proposed ecodesign requirement are intended to set minimum efficacy levels (ηlamp) for all lamps as a horizontal entry requirement for all lamps in the EU market, irrespective of technology and application as far as possible.

For evaluation of efficacy, it is proposed to use a similar approach as in part 1 and in EC regulation 244/2009. This is a formula imposing a maximum rated system power Pmax system[W] for a given rated luminous flux (Φ) [lm] '$P_{max\ system} = Y * (0{,}88\sqrt{\Phi}+0{,}049\Phi)$'wherein Y is a constant depending on the level (see Table 8-23).

This formula is related to the lamp labelling directive[217] but that directive is currently not applied either to reflector lamps or to (safety) extra low voltage (ELV/SELV) lamps, see section 8.1.4.1.

For this part 2 study on DLS lamps it is also proposed to use the rated functional lumen in a cone with a correction factor and the corrected lamp power, for cases where the system power is different from lamp power due to equipment external to the lamp (see Table 8-3).

Table 8-1: Proposed correction factors on lamp power for the minimum criteria on level values

Correction factors	
Scope of the correction	**P max system [W]**
CFLi lamp with colour rendering index ≥ 90	P_{lamp} / 0.85
CFLi lamp with colour rendering index ≥ 90 and Tc >=5000K	P_{lamp} / 0.75
(Safe) Extra Low Voltage (ELV/SELV) lamps requiring external power supply for mains connections excluding light emitting diode.	P_{lamp} / 1.06
Light emitting diode requiring external power supply	P_{lamp} / 1.2

The proposal is to use the rated functional lumen in a cone depending on the lamp type (Table 8-2).

- For all GLS-R, HL-MV-R, HL-LV-R and retrofit LED-R lamps, it is proposed to use the rated functional lumen in a cone of 90° ($\Phi_{90°}$) (see chapter 1).

[217] COMMISSION DIRECTIVE 98/11/EC of 27 January 1998 implementing Council Directive 92/75/EEC with regard to energy labelling of household lamps

- For CFLi-DLS cap E27/E14/GU10 with diameter < 80 mm it is also proposed to use the rated functional lumen in a cone of 90° ($\Phi_{90°}$) (see chapter 1).The main reason is that those lamps should mainly be used as replacement for GLS- or halogen reflector lamps with the same cap and diameter commonly found on the market nowadays, otherwhise there is a risk to dissatisfy consumers and cause disposal of unused products. It must also be noted that most of those lamps that were found on the market (chapter 4&6) did in general not meet the requirements for a DLS and consequently they are submitted to the NDLS regulation 244/2009.
- For other CFLi-DLS lamps, HIDi-R or LED modules or luminaires that make no claim to retrofit halogen lamps, the nominal luminous flux in a solid angle of π sr or 120° cone can be used($\Phi_{120°}$), because these lamps can be useful for typical 'downlighter' applications. A down lighter (see chapter 6) is not intended to give a small light beam to give accent lighting but to illuminate a more extended surface and its characteristics are more similar to office lighting luminaires (see study on office lighting). In this case, all the luminous flux within a beam angle of π sr can be usefull; a larger beam angle can not be taken into account as this causes glare.

Table 8-2: Calculation of corrected luminious flux (ΦR) and cone

Lamp type	Φ_R
GLS-R, HL-MV-R, HL-LV-R and retrofit LED lamps	**$\Phi_{90°}$ x 1,25**
CFLi-DLS cap E27/E14/GU10 with diameter ≤80 mm	**$\Phi_{90°}$ x 1,25**
other CFLi-DLS lamps without retrofit halogen claim, HIDi-R or LED modules	**$\Phi_{120°}$ x 1,25**

Note: It should be noted that stakeholders have different opinion on the 90°-120°-180° functional lumen definition, hence it could be considered to discuss it at the consulation forum. The main point of discussion might be a too strong requirement for CFLi-DLS cap E27/E14/GU10 with diameter ≤80 mm, however it is expected that those CFLi-DLS will be replaced by LEDi-R in the upcoming years. Moreover those CFLi-DLS are currently a small market share. Hence a transition period on the minimum requirement (B instead of B+) is recommended for CFLi-DLS cap E27/E14/GU10 with diameter ≤80 mm (e.g. 3 years).

In a reflector lamp, there is always lumen loss due to the reflector; a typical LOR for a good reflector lamp, compared to a non reflector lamp can be considered as 0.8. To make a comparison between the labelling of a reflector lamp with the same formula as a non-reflector lamp, the rated luminous flux in the 90° cone shall be corrected by multiplying it by 1.25; this correction also reflects the opinion of representative stakeholders. Hence for reflector lamps the formula of part 1 should be corrected to (Table 8-2):

$$\mathbf{P_{max\ system} = Y * (0{,}88\sqrt{\Phi_R}+0{,}049\Phi_R)}$$

wherein

$$\mathbf{\Phi_R = \Phi_{90°} \text{ x } 1{,}25 \text{ or } \Phi_R = \Phi_{120°} \text{ x } 1{,}25}$$ **(see** Table 8-2**)**

In order to reduce negative impact on manufacturers and distributors (see section 8.2) it is recommended to apply a tiered approach for minimum lamp performance requirements over time, a proposal is included in the section with the scenarios (see 8.1.2). This tiered approach will enable them to redesign, retool and prepare products that will conform to the regulation and the market demand.

For some lamps it is proposed to apply corrections factors on the lamp power to calculate the system power demand ($\mathbf{P_{max\ system}}$), see Table 8-3. For CFLi-DLS these correction are needed to prevent that special application CFLi lamps are phased out. The other correction factors are to calculate system power demand from the rated lamp power taking BAT system losses from an external power supply into account.

Some lamp caps are nowadays frequently used in general illumination but have no energy efficient alternative with an efficacy level equivalent to level B or A (see section 8.1.4.1). It is connected to the so-called luminaire lock-in effect (see 8.1.1.7). Phasing out these lamps would repeal retrofit lamps from the market for existing luminaires. Therefore in certain scenarios it is proposed to phase out these luminaires first and to introduce special luminaire requirements (see 8.1.1.7) for the time being (see section 8.1.2). It is also possible to announce this phase out and allow people to stock sufficient retrofit lamps for existing luminaires (see chapter 3). The concerned lamp type is:

Lamp type	Lamp cap	Lamp power [W]	Minimum level
Halogen mains voltage (HL-MV-R)	GU10	< 55	D

The proposed requirements for the efficacy levels, depending on lamp types, can be found in the scenarios. To reduce mercury emissions it was assumed in scenarios (section 8.1.2) to require in the latest Tier 3 a minimum level B+ lamp efficacy for all CFLi-DLS or HIDi-R lamps instead of B for other types.

8.1.1.6 Specific ecodesign requirements for minimum lamp performance

These should be similar to Commission Regulation (EC) No 244/2009 for part 1 and completed for DLS&NDLS retrofit LED lamps (see Table 8-4).
Lamp requirements are proposed per technology. This can be justified in the opinion of the authors by their different LCA results and LCC. The details on environmental impact and LCC can be found in chapter 6.

Table 8-3: Staged performance requirements for MV-halogen lamps

Performance parameter	Tier 1	Tier 2	Tier 3	Benchmark
Efficacy level	F	E	D	D
Minimum rated lamp lifetime (LSF=0.5)	2000h	2000h	2000h	3000h
Premature failure rate (hours before $L_{95}F_{05}$)	≥100h	≥100h	≥200h	≥200h

Table 8-4: Staged performance requirements for LV-halogen lamps

Performance parameter	Efficacy level	Tier 1	Tier 2	Tier 3	Benchmark
Minimum rated lamp lifetime (LSF=0.5)	C	3000h	4000h	Not allowed	x
	B	2000h	3000h	4000h	5000h
	B+	1000h	1500h	2000h	2000h
Premature failure rate (hours before $L_{95}F_{05}$)	all	≥100h	≥100h	≥200h	≥200h

It is proposed to excempt special purpose low voltage halogen reflector lamps with colour rendering Ra=100 and Tc >4000K that are used in musea.

Different sources describe quality requirements of importance for the consumer when buying LED lamps, modules and luminaires:

- Eco-profile for LED-lamps (draft) from ELC (available on special request);
- ENERGY STAR (US);
- DOE (US) reports;
- IEC/PAS 62612 Ed.1 "Performance requirements for Self-ballasted LED lamps" giving a complete survey of relevant parameters;
- CIE 127:2007 standard addressing individual LEDs.

From a consumer perspective, the most important LED quality factors are those listed already in the proposal for ecodesign information requirements (see 8.1.1.3) and moreover:

1. **Lamp lumen maintenance** (efficacy as a function of time). A high-quality LED can maintain high lighting levels for tens of thousands of hours, while the output of low quality products declines more rapidly. Long-term measurements require 12+ months thus an accelerated test method needs to be developed in close consultation with the lamp sector federations (a.o. ELC);
2. **Light quality**: a.o. CCT (Correlated Colour Temperature), CRI (Colour Rendering Index) i.e. amenity and appearance of the light source and its ability to render colours accurately, UV and blue light radiation. See chapter 1 and section 8.1.6 for more details, the CRI is under discussion as correct parameter fore LEDs;
3. **Glare**: Measurement of the intensity of light from the source itself. Glare should be minimized to prevent discomfort or injury, and should not exceed that of a traditional DLS. However this is application dependent. At product level it could only result in warning users to not stare into high intensity lamps. This is not an LED product issue alone but mainly depends on the application, hence not a product requirement;
4. **Lamp features**: information concerning whether the lamp or luminaire is dimmable or can be operated on electronic switches such as automatic daylight shut-off and/or motion sensors (especially important for outdoor models);
5. **Minimum warranty in years.** This could be an issue especially in relation to the high price and long claimed life time. To be considered could be a warranty in years which is the claimed life time (L70) in hours divided by 8000x0.7 h or 5600 h.

Other lamp quality factors relevant for comsumers are often mentioned in literature but aren't recognised as weak points for LEDs available on the market nowadays, hence they are of lower importance for minimum requirements:

1. **Warm-up time**: time delay before lamp achieves full brightness. This is a general lamp issue but not really a weak point for LEDs that are available nowadays;

2. **Flicker**: Requirement that LED systems will minimize and/or eliminate any flicker or stroboscopic effect, which can lead to undesirable visual effects, particularly when the object or visual field is in motion. This is not an issue for LED alone but also relevant for filament lamps;
3. **Number of switching cycles**. This is mainly an issue for gas discharge lamps that suffer from ignition but irrelevant for LEDs.

LED lamp requirements are needed in order to avoid poor market introduction due to bad consumer experience, similar to CFLi (see also chapter 3). As a first step it is recommended to introduce minimum requirements (Table 8-5 and Table 8-6) for retrofit LED lamps both for NDLS & DLS. Therefore it is necessary to complete also the Commission Regulation (EC) No 244/2009 for NDLS. The minimum requirements should include the most important of the ten factors mentioned above while other or more strong requirements could be the subject of a new European quality label.

Table 8-5: Staged performance requirements for retrofit LED lamps (DLS&NDLS)

Performance parameter	Tier 1	Tier 2	Tier 3	Benchmark
Minimum rated lamp lifetime for $L_{70}F_{50}$	10 000 h	10 000 h	10 000 h	30 000 h
Premature failure lifetime (minimum hours before $L_{85}F_{05}$)	200h	400h	800h	3500h

For any LED lamp that explicitely refers to being a 'halogen or GLS retrofit lamp', normal as well as reflector lamps, additional requirements are:

- giving the same luminous flux (for directional light sources in the 90°/120° cone),
- maximum outlines do not exceed the IEC maximum outline dimensions of the targeted lamp to be replaced,
- fully dimmable and operational using standard household dimmer systems as applied for MV or LV Halogen systems (whichever is applicable for the LED lamp in question, being MV or LV),
- LV LED Retrofit lamps should be fully operational with conventional and electronic trans-formers,
- additional CRI and CCT requirements are recommended, as depicted in Table 8-6.

Table 8-6: Additional requirements for LED lamps claiming equivalence to a halogen or GLS lamp

Performance parameter	Tier 1	Tier 2	Tier 3	Benchmark
Minimum CRI	80	90	95	100
Maximum CCT [K]	3200	3100	3000	2700-2900

For HIDi-R lamps, similar requirements can be recommended as in the tertiary lighting sector for Metal-Halide lamps (see Table 8-7).

Table 8-7: Staged requirements for HIDi-R lamps (retrofit GLS-R-HW and HL-MV-R-HW)

Performance parameter	Tier 1	Tier 2	Tier 3	Benchmark
Minimum rated lamp lifetime (LSF>0.5)	8 000 h	10 000 h	12 000 h	16 000 h
Minimum lamp lumen maintenance (LLMF)	>0.6	>0.7	>0.8	>0.85
Minimum CRI	80	>80	>85	90

8.1.1.7 Specific ecodesign requirements for domestic luminaires

Requirements for any general illumination luminaire that is unable to host a lamp equivalent to at least level B

It is recommended to prohibit these lamps to be placed on the market together with the luminaires (coupled sales) to stimulate people to look for more efficient alternatives at the time of purchase and to create awareness about any lock-in effect. This is especially needed if no agreement is reached on banning G9 or R7s luminaires as proposed hereafter

Requirements for any luminaire with socket R7s, FA4 or RX7s:

The sales of all luminaires with holders R7s or FA4 without an incorporated presence detector and not at least IP 65 should be prohibited. The rationale behind this proposal was already introduced in part 1 of the study because no energy efficient alternatives for linear R7s-capped halogen lamps are currently available or expected in the near future.
Because consumers who have already installed luminaires for those lamps have a need for replacement lamps, a phase-out of these lamps can not be implemented. Moreover, in certain cases where instant full light is requested such as in outdoor security lighting, these luminaires are also needed. To prohibit the proliferation of luminaires for R7s lamps in places where energy efficient alternatives are available, the requirement for having at least an ingress protection of IP65 (outdoor application) and an incorporated presence detector is proposed.
Also all luminaires with RX7s can only be brought on the market if they have a built-in ballast.
Timing: ASAP

Requirements for any luminaire with socket G9:

It is proposed to prohibit the sales of these luminares, because there is no expected efficient retrofit (the lamp is too small for LED retrofit lamps).
Timing: ASAP

Note: A general GU10 ban is not proposed because energy efficient LED retrofit lamps are available in low lumen output versions and higher lumen output versions are expected in the near future.

Proposed stand by power requirements for all household luminaires with electronic power supply incorporated:

Luminaires that incorporate an on/off switch together with a low voltage halogen or LED power supply without dimming or intelligent controls, shall not consume any power when the operated lamps do not emit any light.

The incorporated low voltage halogen power supply efficiency shall be at least 85 %.

8.1.1.8 Generic ecodesign requirements for domestic luminaires

It is recommended that for any new domestic luminaire generic ecodesign requirements are required based on a public available design guide. The luminaire designer should report his coherence with this design guide and include it in the technical construction file of the luminaire. This part of the technical construction file should be freely available for lighting designers and all users of the luminaire; it can also be used for market surveillance.

The following items should be addressed in a design report (for background technical details consult chapter 6):

- Luminaire should be designed to host the most efficient lamps, therefore:
  - Design luminaires that create a positive lock-in effect into efficient lighting by using CFLni lamps or ultra-efficient LED modules;
  - Use coloured LEDs to create coloured light instead of filters;
  - Design luminaires with appropriate and efficient control electronics;
  - Design luminaires that incorporate or are compatible with dimmers where appropriate;
  - Design luminaires with incorporated motion sensors where appropriate;
  - Design outdoor luminaires that incorporate or are compatible with day/night sensors and motion detectors;
  - Reduce standby losses (<0.3 W) when power supplies are incorporated in luminaires;
  - Use electronic gears instead of magnetic (conventional) low voltage halogen;
- Options to increase the optical efficiency of luminaires:
  - Use material with increased light transmittance for visible parts that are transparent / translucent;
  - Use materials with increased reflectance for invisible parts that are not transparent/translucid;
  - Alternatively, luminaires can be designed with a high LOR or LER (for LED luminaires);

It is also recommended to agree with the sector federation on an uniform reporting method.

Please note that for existing luminaires imposing these approaches will cause a lot of administrative work without the desired impact on design and performance, therefore it is proposed to limit this requirement to new domestic luminaire designs only.
Some stakeholders are concerned about the weakness of such a generic ecodesign requirement. In the opinion of the authors of this study more research and data is needed prior to consider more strong specific ecodesign domestic luminaire requirements (see

recommendation later on in section 8.1.4.2). Finally, any specific domestic luminaire ecodesign requirements are included in an ecolabel proposal that can be found later in this chapter.

Proposed timing:
As soon as possible

8.1.2 Scenario analysis

Different policy scenarios 2007-2020 are drawn up to illustrate quantitatively the improvements that can be achieved through the replacement of the base-cases with lamps with higher energy efficiency at EU level by 2020 versus a business-as-usual scenario (reference scenario). Due to the specific properties of the lamp market the scenarios were calculated from 2007.

The four scenarios listed below have been analysed in order to provide an assessment of various alternative policy options as close as possible within the limits of the model of this study:

- Business-as-Usual (BAU)
- Best Available Technology with lock in and LLCC
- Best Available Technology without lock in
- Best Not Yet Available Technology

Note: These scenarios should in no way be taken as the only possibility for potential Ecodesign regulation by the European Commission. They are proposed only by the consultants writing this study and are not necessarily endorsed by the European Commission.

These scenarios are presented and analysed in the following sections. For each of them, results are presented for each year between 2007 and 2020 per lamp technology (i.e. GLS-R, HL-MV-R-HW, HL-MV-R-LW, HL-LV-R, HID-R,and LEDi-R in the last scenario) in terms of stock, sales, electricity consumption (during the use phase), CO_2 emissions[218] (during the use phase), and mercury emissions (due to electricity generation during the use phase and emissions at end-of-life for HID-R and CFLi-R).

Finally, a comparison of scenarios is presented in section 8.1.2.7 as a variation of environmental impacts in reference with the BAU scenario both for the specific year 2020, and for the cumulated total between 2010 (i.e. entry into force of the implementing measure) and 2020.

<u>**General remarks**</u>:

- **The first Tier for an implementing measure is in 2010 as this was the earliest possible date. In reality, however, a time shift will occur depending on the real timing of implementation measures.**

[218] The emissions factor used is 0.43kg/kWh according to the MEEuP methodology.

- **Scenarios are calculated not for the domestic sector only but for all sectors; they are based on the lamp technology and not the end application.**
- **The scenarios analysis is based on outcomes of chapters 1 to 7, and one has to keep in mind than they are average results based on assumptions (e.g. annual burning hours, wattage, and lamp efficacy).**
- **The model used is a simplification of reality based on 'discrete' base-cases as defined in chapter 5 and connected discrete improvement options as defined in chapter 7. This discrete base-case model approach is reflected in abrupt changes in calculated energy consumption and lamp sales. In reality, this would be smoother due to spreading in lamp wattages, operational hours, new products, and proactive user behaviour (storing phase out lamps, green procurement, promotional campaigns, choice of retrofit options, etc.). These items will be discussed qualitatively in the next sections. Note that this sharp jumps would be impossible for manufacturers to achieve, and thus the scenarios should only be considered as rough estimations and not absolute truths.**
- **For the scenario without lock in effect, a base-case is replaced with a lamp that also requires luminaire replacement, e.g. the base-case GLS-R E27 with a HL-LV-R GU5.3. Environmental impacts due to the luminaire replacement are not assessed and thus not taken into account in the scenario analysis. Differences in luminaires are considered in the sensitivity analysis.**
- **In some scenarios, a base-case is replaced with a lamp, identified as an improvement option for reducing life cycle cost and environmental impacts, whereas the light quality is not exactly similar, e.g. a GLS-R replaced with a LEDi-R. Therefore, the scenario analysis is done in a quantitative way as the qualitative assessment was already done in previous chapters.**
- **In the tables presenting the scenarios (except for the BAU), minimum requirements (i.e. minimum energy class) are set for each tier. In order to analyse these scenarios, a specific lamp technology is used as replacement lamp, e.g. HL-MV-R-LW xenon replacing the base-case GLS-R in the first tier (2010-2013) for the scenario 'BAT with lock in effect (slow)'. This assumption, based on improvement options identified in chapter 7, does not mean that this technology (HL-MV-R-LW xenon) is the only possible way to meet the requirement.**
- **The tables should be interpreted from the point of view of the defined base-cases and improvement options. For this reason, it was not required to discuss upper or lower lamp lumen limits for future legislation in this section.**
- **Sometimes reference is made to 'levels', this reference is in line to the recommendation for extending the household lamp label to DLS lamps as proposed in section 8.1.4.1. Please note that this level might change in future.**

8.1.2.1 Assumptions used for the scenario analysis

Several assumptions had to be made in order to define scenarios and to assess economic and environmental impacts:

- As the scenario analysis concerned all sectors, annual burning hours used for each base-case are those defined in section 2.2.6: 484 h for GLS-R, 555 h for HL-MV-R-HW, 555 h for HL-MV-R-LW, and 695 h for HL-LV-R. These values were based on a weighted average of sales and annual burning hours for both the "domestic sector" and "other sectors". Please note also that the same annual burning hours were used for the improvement options (see chapter 7) as for the base-case, e.g. even if we replace a GLS-R with an LEDi-R as an improvement option, the original annual burning hours were used.
- When a lamp with a specific technology is removed from the market, for the year 'n' (‘n’ being any year after the removal from the market), the stock of this lamp was calculated with the following formula, assuming that the lamp lifetime is X.YZ years:

  *Stock (n) = Stock (n-1) - 0.YZ*Sales (n-1-X) - (1-0.YZ)*Sales (n-X)*

  When the result of this calculation is null or negative, it means that this lamp is no longer operating in the EU-27.
- Mercury emissions to air due to electricity consumption were calculated using the emission factor of 0.016 mg Hg/kWh, as in chapters 5 and 7.
- For HID-R, we assumed that only 20% of lamps are recycled for all years and that the mercury content is 2.5 mg embedded in each lamp.
- For CFLi-R, we assumed that only 20% of lamps are recycled for all years and that the mercury content is 4 mg embedded in each lamp.
- Mercury emissions occurring at the end-of-life (EoL) for HID-R and CFLi-R sold during the year ‘n’ were integrated in the calculation of mercury emissions for the year ‘n’ and not for the year ‘n+HID-R/CFLi-R lifetime’, in order to facilitate the model. This assumption may have an influence when looking at mercury emissions for a specific year, but has a negligible impact when looking at total, cumulative mercury emissions from 2010 to 2020. Therefore, the formula for mercury emissions is:

  *Mercury emissions (n) = 0.016*Electricity consumption (n) + 0.8*mercury*Sales (n),*

  where mercury emissions is in kg, electricity consumption in GWh, mercury in mg, and sales in million units.
- Sales and stock data (and therefore environmental impacts) are similar for all scenarios (including the BAU) for the years 2007 - 2009, as the entry into force of any legislation is assumed to be in 2010.

8.1.2.2 Calculation principle used for the lamp scenario analysis

The general principle of the environmental analysis for 3 scenarios (excluding the BAU) is that the total annual lumen needed for each base-case (obtained in the BAU scenario) has to be kept constant and is the key parameter in estimating changes in sales when switching from a base-case to its improvement option(s). For a specific year ‘n’ the annual lumen needed for a base-case A is calculated in the BAU as follow:

$$\text{Annual lumen needed}_A\ (n) = \text{Stock}_A\ (n) \times \text{Annual Burning hours}_A \times \text{Lumen output}_A$$

Therefore, when analysing one of the 3 non-BAU scenarios, for the year ‘n’, for the base-case A with its improvement options (i.e. replacement lamps) A_1, A_2, A_3, the following formula was used:

$$\textit{Annual lumen needed}_A\ (n) = \textit{Annual lumen provided}_A\ (n) + \textit{Annual lumen provided}_{A1}\ (n) + \textit{Annual lumen provided}_{A2}\ (n) + \textit{Annual lumen provided}_{A3}\ (n)$$

And the 'Annual lumen provided$_{Ai}$' for the lamp Ai is computed with the following formula:

$$\textit{Annual lumen provided}_{Ai}\ (n) = \textit{Stock}_{Ai}\ (n) \times \textit{Annual Burning hours}_{Ai} \times \textit{Lumen output}_{Ai}$$

Until the base-case A is removed from the market, and therefore not replaced with an improvement option, the following equality has to be verified:

$$\textit{Annual lumen needed}_A\ (n) = \textit{Annual lumen provided}_A\ (n)$$

When the base-case is replaced with an improvement option (e.g. GLS-R with HL-MV-R-LW xenon) in the year 'n', the total amount of annual lumen provided by the GLS-R decreases gradually from the year 'n' onwards, until the stock of this specific lamp reaches zero. At the same time, the amount of annual lumen provided by the improvement option HL-MV-R-LW xenon is rising year by year in order to compensate decrease GLS-R sales and to keep the 'Annual lumen needed$_{GLS\text{-}R}$' constant.

In some scenarios, the replacement of the base-cases GLS-R and HL-MV-R-HW, may lead to an excess lumen output compared to the annual lumen needs of these base-cases in the BAU. This has two main causes: on one hand, this is due to the constant reduction of the 'Annual lumen needed' for these base-cases from 2010 to 2020 because the stock of these lamps is reducing naturally, and on the other hand, the higher lifetime of the replacement lamps, mainly with the HID-R. In this case, the 'lumen surplus' is compensated by adjusting the sales of the corresponding base-case(s). For instance, when the base-case HL-MV-R-HW is replaced with a HID-R, which some years after the replacement provides more annual lumen than needed by the HL-MV-R-HW according to the BAU, e.g. difference of 100 billion lumen, the number of new HID-R used as replacement lamp for the base-case HID-R is adjusted so as to provide 100 billion lumen less that needed for this base-case in BAU. Therefore, the total annual lumen needed for all base-cases remains constant.

8.1.2.3 Scenario "BAU" part 2 lamps

The first step required in order to build scenarios is to define the Business-as-Usual scenario that will serve as reference for the base-cases.

First, the number of DLS lamps per household (i.e. in the domestic sector) per lamp type for the year 2011 and 2020 was estimated as specified in chapter 2, section 2.2.3. Moreover, data in 2006 is already known and provided in chapter 2.

Data presented in Table 8-8 shows that the total number of lamps in the domestic sector was assumed to constantly increase (+54% in 2020 compared to 2007). Please note that CFLi-R, LEDi-R, and HIDi-R were not included due to lack of sales data and negligible DLS market share. A scenario based on a hypothetical expansion of the LED market is shown in section 8.1.2.6.

Table 8-8: Forecasts of number of DLS lamps per household in the domestic sector (BAU)

	GLS-R	**HL-MV-R-HW**	**HL-MV-R-LW**	**HL-LV-R**	**TOTAL**
	Nb/hh	**Nb/hh**	**Nb/hh**	**Nb/hh**	**Nb/hh**
2007	1.33	0.43	0.49	2.34	4.59
2008	1.22	0.57	0.68	2.41	4.88
2009	1.11	0.70	0.88	2.47	5.17
2010	1.01	0.83	1.09	2.54	5.46
2011	0.90	0.94	1.31	2.60	5.75
2012	0.89	0.95	1.41	2.65	5.90
2013	0.88	0.97	1.50	2.69	6.04
2014	0.87	0.98	1.60	2.74	6.19
2015	0.86	0.98	1.71	2.78	6.33
2016	0.85	0.99	1.81	2.83	6.48
2017	0.84	0.99	1.92	2.87	6.63
2018	0.84	0.98	2.04	2.92	6.77
2019	0.83	0.98	2.15	2.96	6.92
2020	0.82	0.97	2.27	3.01	7.07

Based on these lamp stocks per household, the stock and the sales per lamp type were calculated for the years from 2007 to 2020 for the domestic sector. In chapter 2, sales and stock data were also computed for 2007 for all sectors (i.e. domestic sector + other sectors). For the total stock and sales from 2007 to 2020, it was assumed that the share of the domestic sector remains constant in order to calculate data for all sectors. These estimates are presented in Table 8-9 and are similar to those presented in chapter 2 (see Table 2.16 in section 2.2.6), and detailed results are presented in Annexe 8-1.

Several observations can be made from this table:

- As expected, even without any legislation, the market share and the stock of incandescent lamps (GLS-R) decrease in line with the chapter 2 assumptions. Between 2010 and 2020 the stock and sales of GLS-R are assumed to be reduced by 18% (i.e. about 41 million units) and 8% (i.e. about 8 million units) respectively.
- According to the assumptions made in chapter 2, it is expected that the share of HL-MV-R-LW lamps in the HL-MV-R market increases (from 53% in 2007 to 70% in 2020), while that of HL-MV-R-HW decreases (from 47% in 2007 to 30% in 2020). This is based on projections of recent sales trends.

Sales and stock data are presented in Figure 8.1 to Figure 8.4 both in % and in units. As explained for Table 8-8, CFLi-R's, HID-R's and LEDi-R's were not included as they currently make up a negligible amount of overall DLS.

Table 8-9: Market data for the BAU scenario (for all sectors)

	GLS-R		HL-MV-R-HW		HL-MV-R-LW		HL-LV-R	
	Stock	Sales	Stock	Sales	Stock	Sales	Stock	Sales
2007	291 591 919	126 096 260	107 306 006	67 257 000	121 004 645	75 843 000	584 873 780	153 000 000
2008	268 863 050	115 731 193	136 773 513	75 207 279	162 562 458	91 406 649	599 377 647	155 109 283
2009	246 134 181	105 366 127	164 383 435	83 157 558	205 977 856	106 970 297	613 881 514	157 218 566
2010	223 405 311	95 001 060	190 135 771	91 107 837	251 250 840	122 533 946	628 385 381	159 327 849
2011	200 676 442	84 635 993	214 030 522	99 058 116	298 381 410	138 097 595	642 889 248	161 437 132
2012	198 644 874	84 924 172	217 465 872	95 023 187	319 997 310	145 576 591	654 094 289	163 600 532
2013	196 613 306	85 212 350	220 246 035	90 988 257	342 268 397	153 055 588	665 299 330	165 763 931
2014	194 581 739	85 500 529	222 371 012	86 953 328	365 194 670	160 534 585	676 504 372	167 927 331
2015	192 550 171	85 788 707	223 840 802	82 918 398	388 776 130	168 013 582	687 709 413	170 090 730
2016	190 518 603	86 076 886	224 655 406	78 883 469	413 012 776	175 492 578	698 914 455	172 254 129
2017	188 487 035	86 365 064	224 814 823	74 848 539	437 904 609	182 971 575	710 119 496	174 417 529
2018	186 455 467	86 653 243	224 319 053	70 813 610	463 451 629	190 450 572	721 324 537	176 580 928
2019	184 423 900	86 941 421	223 168 097	66 778 680	489 653 835	197 929 569	732 529 579	178 744 328
2020	182 392 332	87 229 600	221 361 955	62 743 751	516 511 227	205 408 565	743 734 620	180 907 727

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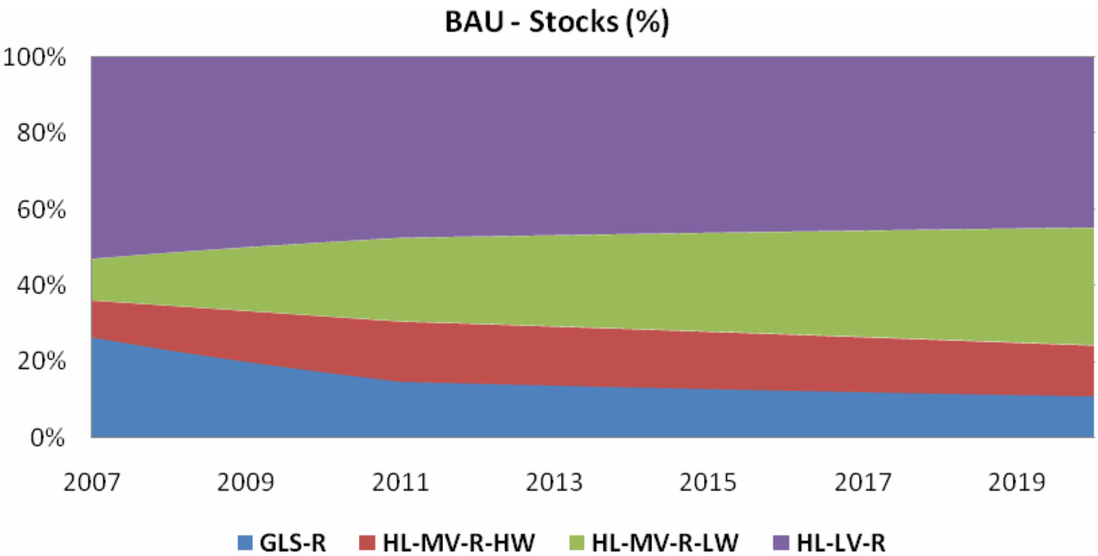

Figure 8.1: BAU – Evolution of lamps stocks (in %)

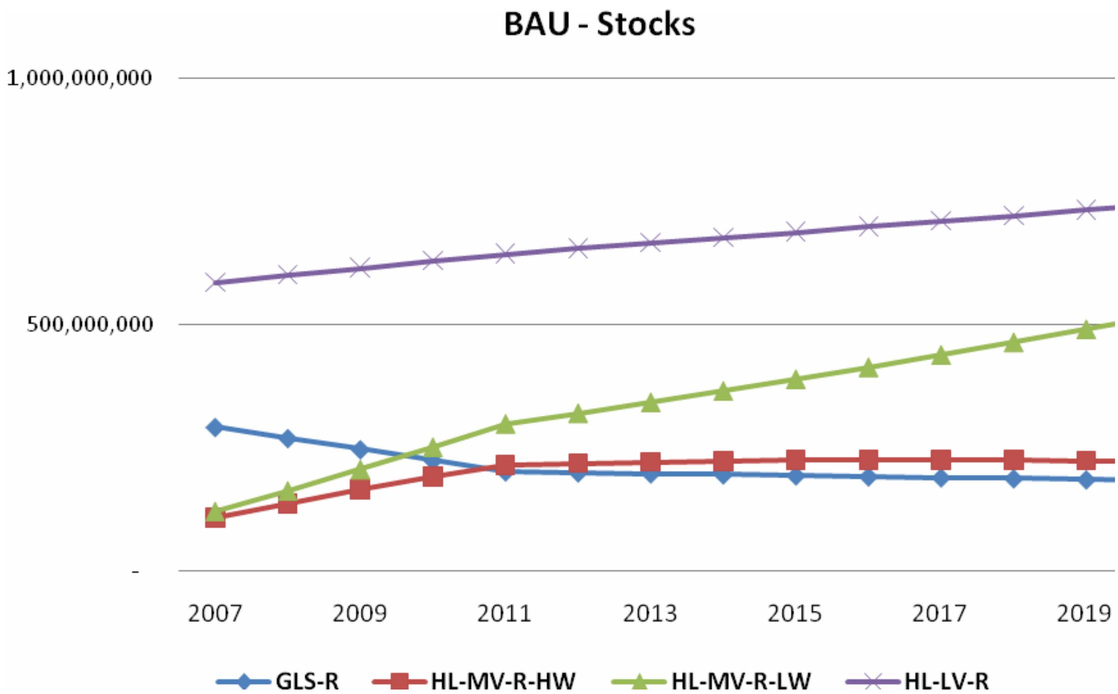

Figure 8.2: BAU – Evolution of lamps stocks (in units)

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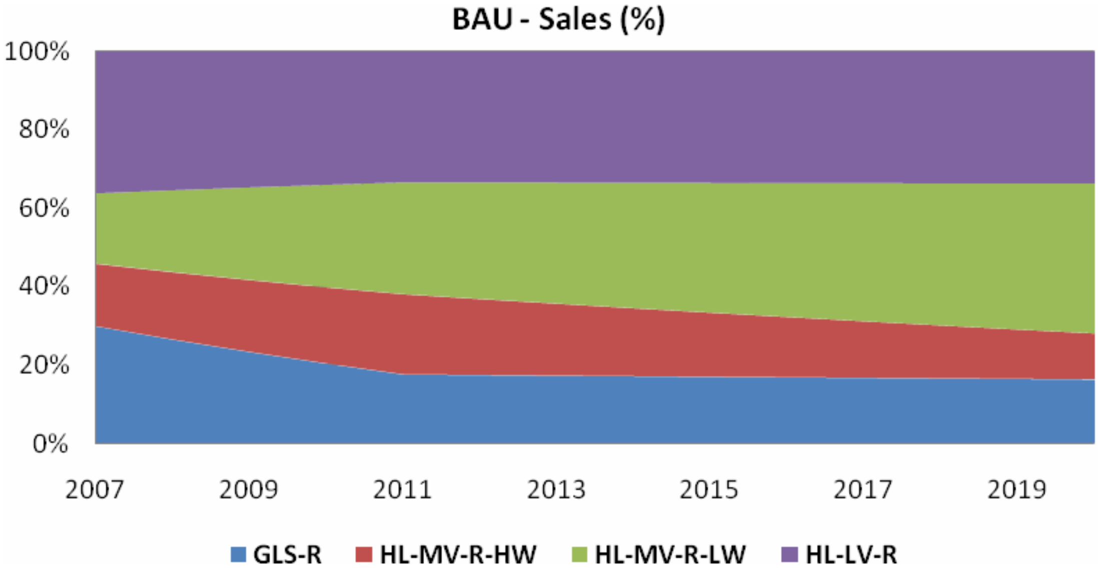

Figure 8.3: BAU – Evolution of lamps sales (in %)

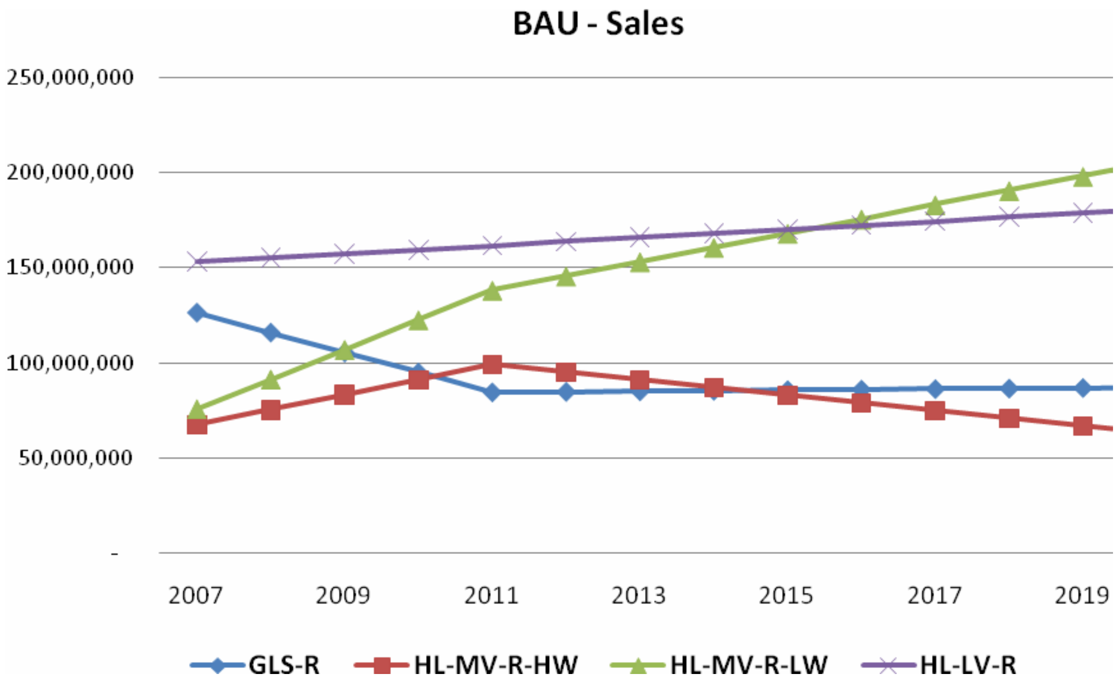

Figure 8.4: BAU – Evolution of lamps sales (in units)

The previous stock and sales analysis is required in order to proceed with the environmental analysis. Three environmental impacts were assessed:

- Electricity consumption during the use phase (this stage represents at least 90% of the total electricity consumption over the whole life cycle for the four base-cases);
- CO_2 emissions due to the electricity consumption during the use phase (proportional to the electricity consumption); and

- Mercury emissions to air due to the electricity consumption during the use phase and the end-of-life phase for HID-R, as this lamp type contains mercury.

The evolution of these environmental impacts is presented in Figure 8.5 from 2007 to 2020. It can be seen that in the Business-as-Usual scenario, the total electricity consumption will increase despite the slow replacement of GLS-R lamps with more efficient lamps (HL-MV-R-LW and HL-LV-R) because of an increasing use of number of lamps and lighting (in the domestic sector from 4.59 lamps/households in 2007 to 7.07 lamps/household in 2020). Thus, in 2020, the electricity consumption (during the use phase) would reach a level of 51 TWh owing to the use of these four lamp types whatever the sector, i.e. an increase of about 59% compared to 2007. The increases of CO_2 emissions (22.0 Mton in 2020 compared to 13.8 Mton in 2007) and mercury emissions (0.82 Mton in 2020 compared to 0.51 Mton in 2007) are similar.

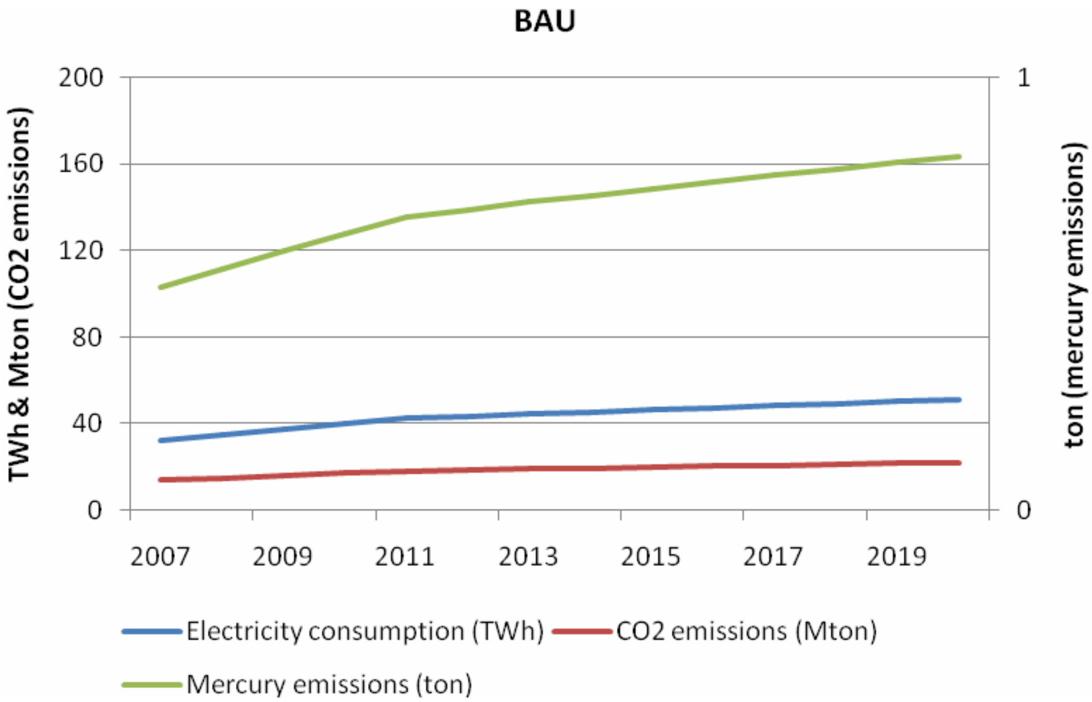

Figure 8.5: BAU – Evolution of annual environmental impacts

For the ‘Electricity consumption’, Figure 8.6 presents the contribution of each lamp technology from 2007 to 2020. Due to the large quantity on the market at that time, it is expected that HL-LV-R be the major consumer of electricity with 39%, followed by HL-MV-R-LW with 28% and HL-LV-R-HW with 24%.

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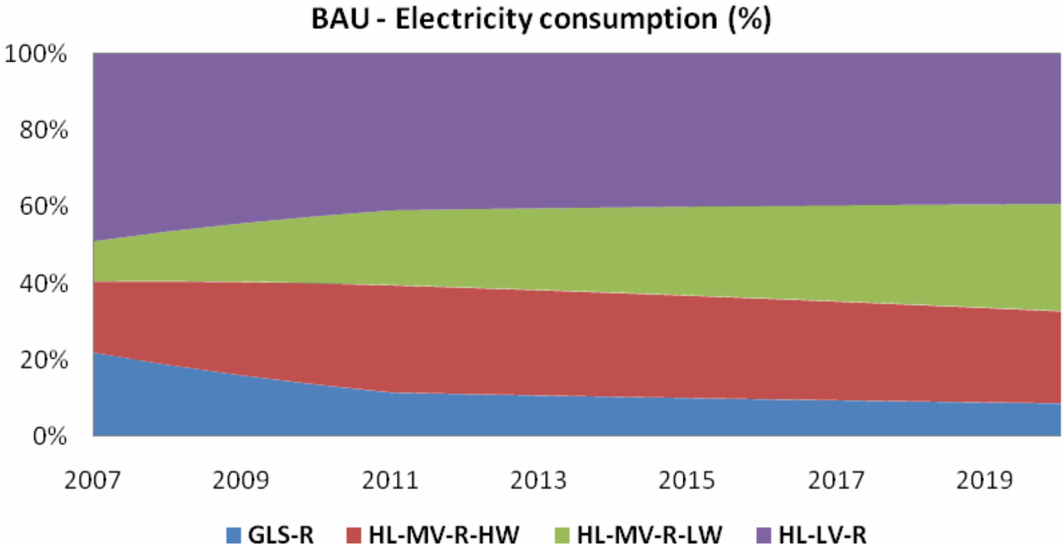

Figure 8.6: BAU - Evolution of the contribution of the lamp types to the electricity consumptions of the total lamp stock

The following sections present the analysis of the 3 scenarios that set minimum lamp efficacy requirements. For each section, the presentation of the analysis is similar and divided in three parts:

d) Presentation of the scenario with the requirements and the Tiers,

e) Presentation of sales and stocks data both in % and in units from 2007 to 2020,

f) Presentation of the environmental impact from 2007 to 2020.

For each scenario, detailed data (sales, stock and electricity consumption) are presented in Annexes.

Note that the model used for all scenarios to estimate future sales and stock is simplified, and does not take into account the effect on lamp supply. There are certain instances in which the model estimates a large jump in lamp sales in a short period of time, which is not possible in a realistic manufacturing situation. The results of these scenarios should be used as a rough guide for policy makers, not as an absolute truth.

8.1.2.4 Scenario "BAT with lock-in effect" part 2 lamps

The BAT with lock-in effect scenario is a scenario in which the best available retrofit technology is slowly introduced into the market. Please note that this is also the LLCC scenario, other scenarios BAT without lock-in are related to variable luminaire cost or BNAT LED to uncertain price and performance projections. LLCC and BAT coincides because the high impact of electricity cost on LCC, see chapter 7. These calculations are based on lamps currently on or expected to be on the market that meet the required minimum level as dictated by the scenario. A summary of the scenario is shown in Table 8-10 with the recommended requirements expressed in Energy Label classes together with the consequence in terms of replacement technology. Note that one of the replacement options chosen for HL-MV-R-HW was the HIDi-R. However, the improvement option of CFLi-R would also meet the energy standard of B+ for big reflector diameters (P30/38) and B for 50 mm (GU10) reflectors.

Table 8-10: BAT with lock in effect – Replacement lamps for each tier

Present	2010	2013	2016
GLS-R	Level F	Level E	Level B
	See section 8.1.4.1 for requirements and chapter 6 for technology details e.g. Halogen reflector lamp, PAR20, E27 (B22d), xenon	See section 8.1.4.1 for requirements and chapter 6 for technology details e.g. Halogen reflector lamp, PAR20, E27 (B22d), xenon +optimized filament wire design + ant-reflective	See section 8.1.4.1 for requirements and chapter 6 for technology details e.g. Halogen reflector lamp, PAR20, E27 (B22d) transfo inc + IRC
HL-MV-R-HW	Level D	Level C	Level B+
	See section 8.1.4.1 for requirements and chapter 6 for technology details e.g. Halogen reflector lamp, PAR38, E27 (B22d), xenon	See section 8.1.4.1 for requirements and chapter 6 for technology details e.g. Halogen reflector lamp, PAR38, E27 (B22d), xenon + optimized wire design + anti-reflective + dichroic	See section 8.1.4.1 for requirements and chapter 6 for technology details e.g. HID retrofit reflector lamp, PAR38, E27 (B22d)
HL-MV-R-LW	Level F	Level E	Level D
	See section 8.1.4.1 for requirements and chapter 6 for technology details e.g. Halogen reflector lamp, MR16, GU10, xenon	See section 8.1.4.1 for requirements and chapter 6 for technology details e.g. Halogen reflector lamp, MR16, GU10, xenon + optimized filament wire design	See section 8.1.4.1 for requirements and chapter 6 for technology details e.g. Halogen reflector lamp, MR16, GU10, xenon + optimized filament wire design + anti-reflective
HL-LV-R	Level C	Level B	Level B
	See section 8.1.4.1 for requirements and chapter 6 for technology details e.g. Halogen reflector lamp, MR16, 12V, GU5.3, xenon	See section 8.1.4.1 for requirements and chapter 6 for technology details e.g. Halogen reflector lamp, MR16, 12V, GU5.3, xenon + IRC	See section 8.1.4.1 for requirements and chapter 6 for technology details e.g. Halogen reflector lamp, MR16, 12V, GU5.3, xenon + IRC

Note: The lamps used to calculate the scenario analysis are used only for example purposes. There are many lamps possible which correspond to the performance levels indicated. The scenario analysis should not be interpreted as endorsing one technology over another.

The BAT with lock-in effect scenario could eventually imply the complete phase-out of GLS-R and HL-MV-R-HW lamps (if no performance improvements are made) with a large portion of HL-LV-R and HL-LV-R-LW, as seen in Figure 8.7. More detailed analysis can be found in Annexe 8-2 .

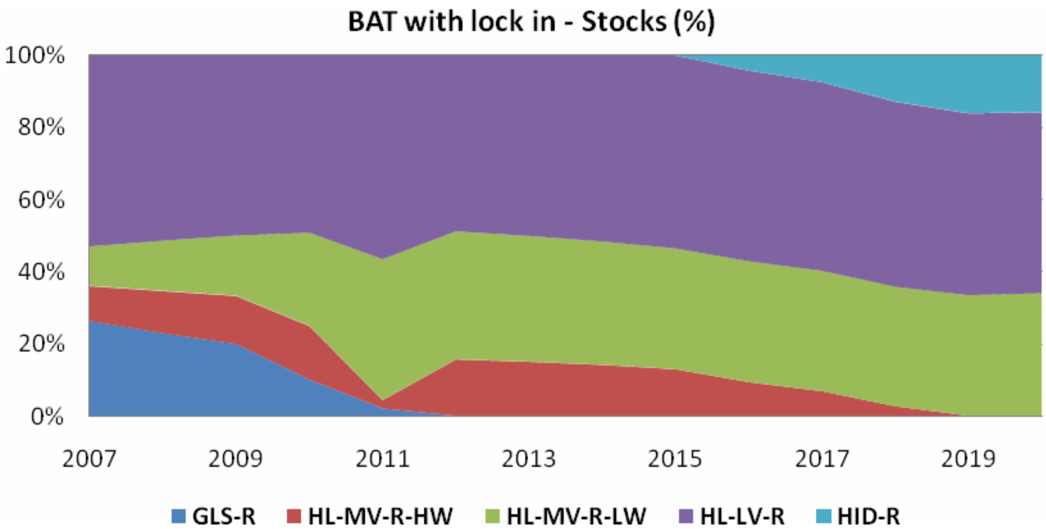

Figure 8.7: BAT with lock in - Evolution of lamps stocks (in %)

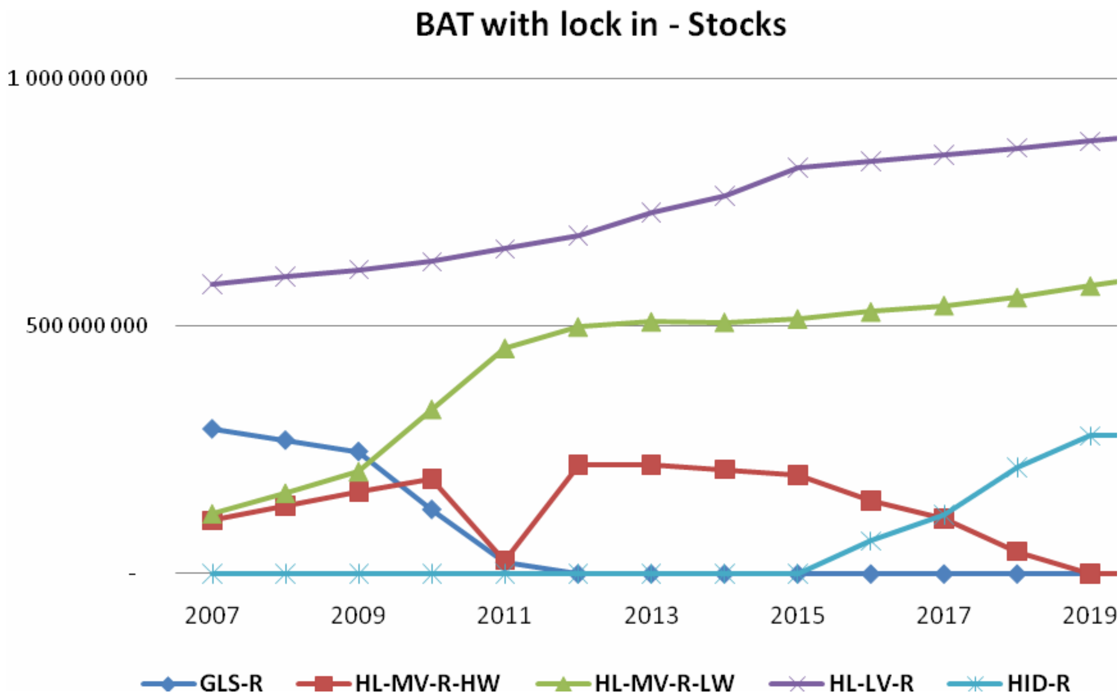

Figure 8.8: BAT with lock in - Evolution of lamps stocks (in units)

The sales of HL-MV-R-LW jump initially order to compensate for the lumen needed during the phase-out of GLS-R, and then again around 2014 as the original lamps need to be replaced. HL-LV-R sales peak in 2015 because of replacement sales and as standards are raised.

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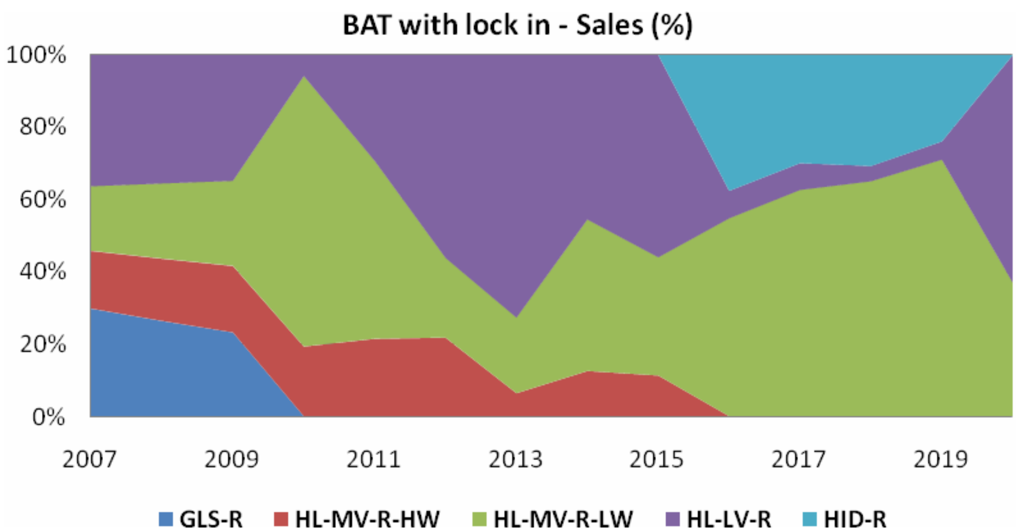

Figure 8.9: BAT with lock in - Evolution of lamps sales (in %)

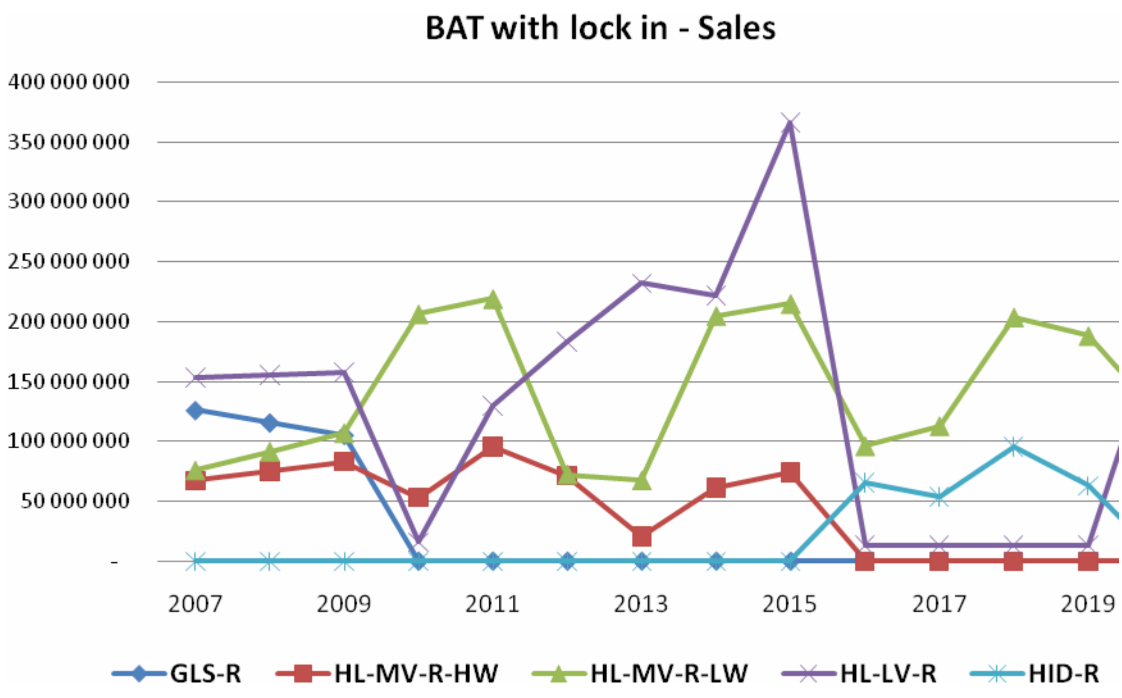

Figure 8.10: BAT with lock in - Evolution of lamps sales (in units)

From 2009 onwards, total electricity consumption (and therefore total CO_2 emissions) decreases until 2018 and then increases slightly until 2020.

In 2020, total electricity consumption is expected to be about 28 TWh, i.e. 44% lower than in the BAU scenario. The reduction is the same for CO_2 emissions (12 Mton in 2020).

Regarding mercury emissions, the total amount generally follows the electricity consumption curve. However, emissions spike after 2016 when HID-R are expected to have high sales, as they contain mercury. Mercury emissions decrease with HID-R sales. In 2020, total mercury emissions to air due to the electricity consumption of lamps during to the use phase, and due to emissions occurring at EoL of HID-R are about 450 kg, which means a reduction of about 44% compared to the BAU scenario.

Figure 8.12 shows that after 2020, electricity consumption is only due to HL-LV-R (45.8%), HL-MV-R-LW (40.0%) and HID-R (14.2%), as the other lamp types have been phased out.

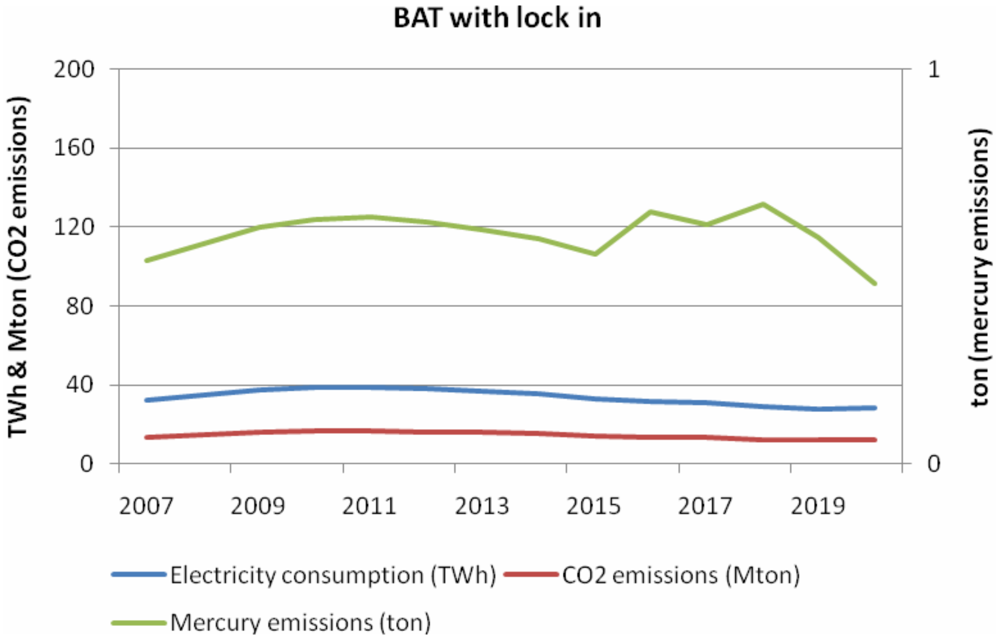

Figure 8.11: BAT with lock in– Evolution of annual environmental impacts

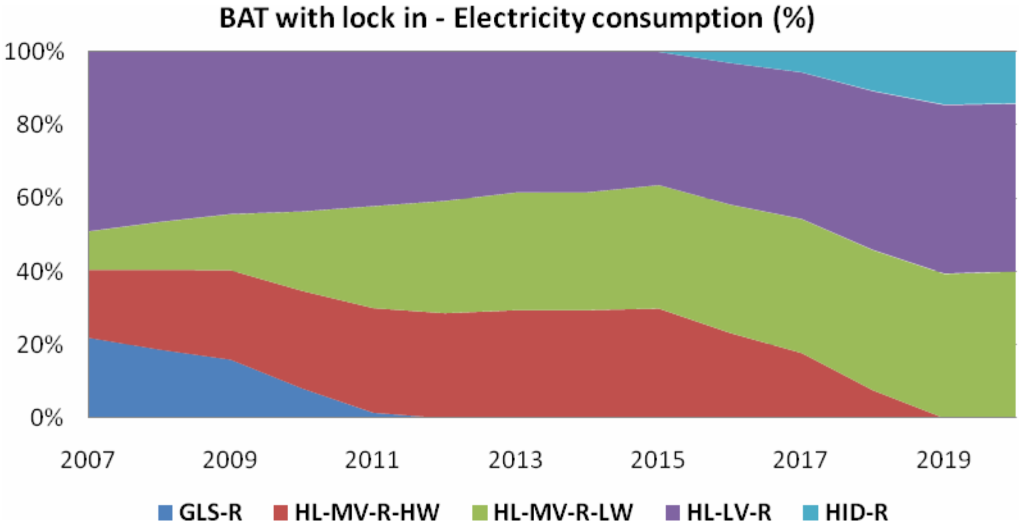

Figure 8.12: BAT with lock in - Evolution of the contribution of the lamp types to the electricity consumptions of the total lamp stock

8.1.2.5 Scenario "BAT without lock-in effect" part 2 lamps

The BAT without lock-in effect is a scenario in which the best available technology is quickly introduced into the market, regardless of retrofit ability or not. A summary of the scenario is shown in Table 8-11. It is important to understand that this is an unrealistic scenario in terms of timing, as it is very unlikely that a requirement resulting in luminaire change prior to 2020 could be established. However, in keeping with the time frame of this study, a luminaire change is assessed for 2016 in order to have a preliminary idea of possible outcomes. Additionally, as in the BAT with lock-in effect scenario, there is an assumed natural improvement in reflective coatings, regardless of legislative standards.

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Table 8-11: BAT without lock in effect – Replacement lamps for each tier

Present	2010	2013	2016
GLS-R	Level E	Level B	Level B
	HL-MV-R-LW xenon + opt fil + silv/dich + anti-ref	HL-MV-R-LW transf + IRC + silv/dich + anti-ref	HL-MV-R-LW transf + IRC + silv/dich + anti-ref
HL-MV-R-HW	Level B+	Level B+	Level B+
	HID-R[219]	HID-R[219]	HID-R[219]
HL-MV-R-LW	Level E	Level D	Level B
	HL-MW-R-LW xenon + opt fil	HL-MV-R-LW xenon + opt fil + silv + anti-ref	HL-LV-R IRC + silv/dich[220]
HL-LV-R	Level B	Level B	Level B
	HL-LV-R xenon + IRC	HL-LV-R IRC + silv/dich[221]	HL-LV-R IRC + silv/dich[221]

Note: The lamps used to calculate the scenario analysis are used only for example purposes. There are many lamps possible which correspond to the performance levels indicated. The scenario analysis should not be interpreted as endorsing one technology over another.

The BAT without lock-in effect scenario would imply the complete phase-out of GLS-R, HL-MV-R-HW and HL-MV-R-LW lamps by 2016, with all light being provided by HL-LV-R and HID-R, as seen in Figure 8.13. More detailed analysis can be found in Annexe 8-3.

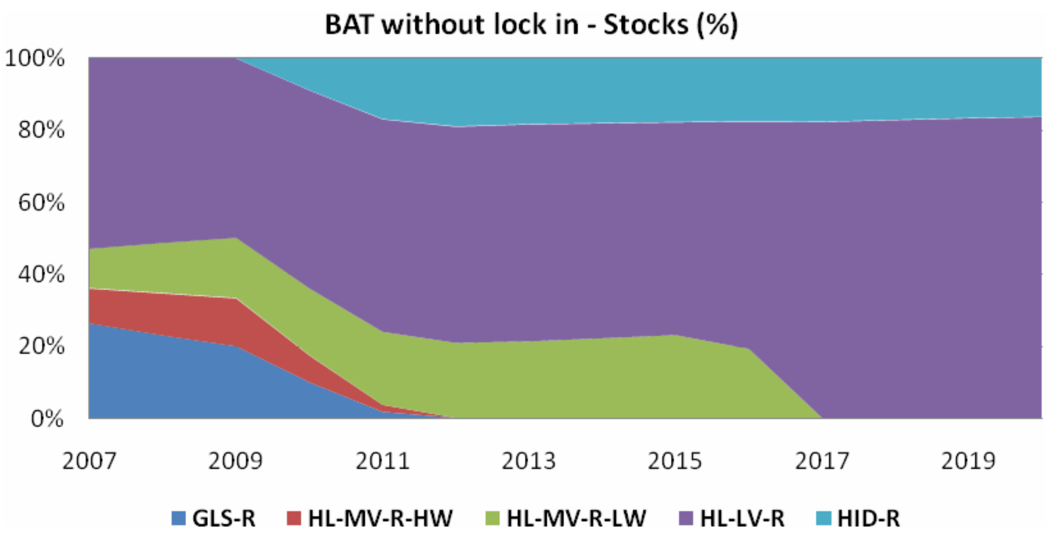

Figure 8.13: BAT without lock in - Evolution of lamps stocks (in %)

[219] CFLi-R would also be a sufficient replacement option.
[220] Low voltage lamps that do not come with an integrated transformer would require a luminaire change.
[221] Natural improvement in relective coatings.

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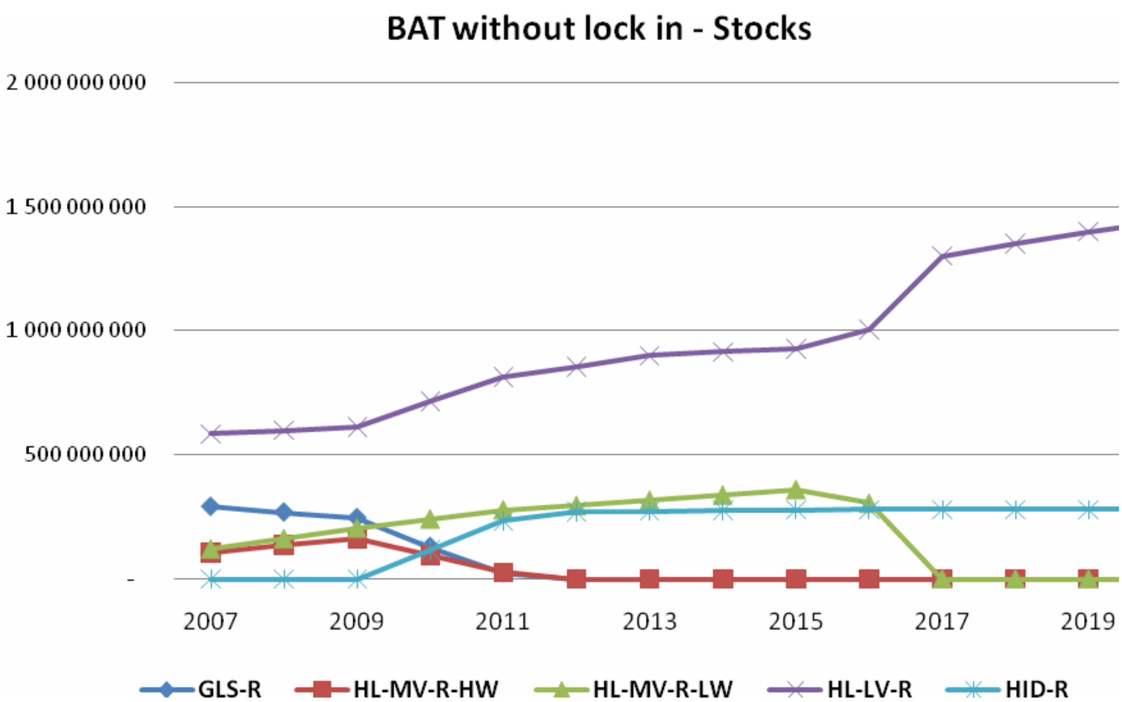

Figure 8.14: BAT without lock in - Evolution of lamps stocks (in units)

The sales of HL-LV-R and HID-R jump initially order to compensate for the lumen needed during the phase-out of the other lamps. HL-MV-R-LW needs to be replaced roughly after 3 years, which causes the small jump in 2014. HL-LV-R need to be replaced roughly every 7 years, and hence the next jump in sales seen in 2017.

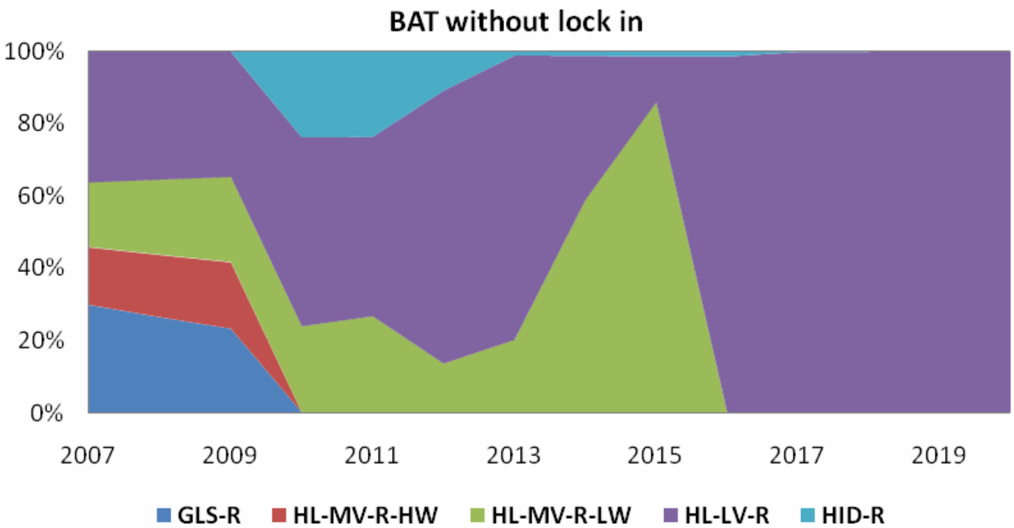

Figure 8.15: BAT without lock in - Evolution of lamps sales (in %)

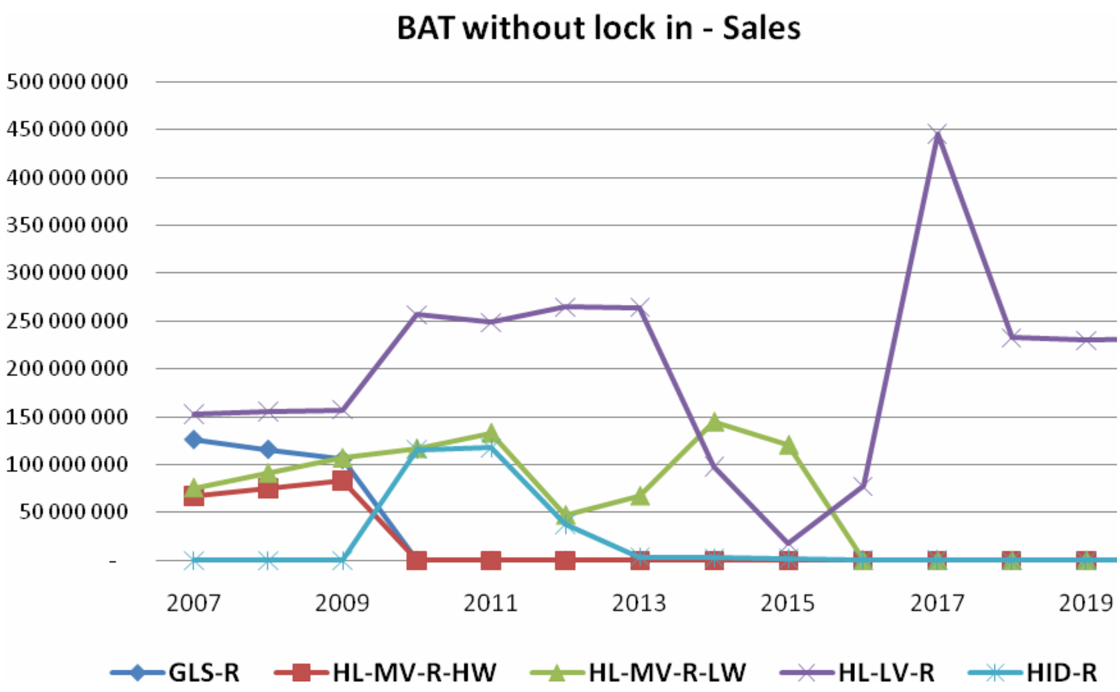

Figure 8.16: BAT without lock in - Evolution of lamps sales (in units)

From 2009 onwards, total electricity consumption (and therefore total CO_2 emissions) decreases until 2012 and again in 2016 with the luminaire change.

In 2020, total electricity consumption is expected to be about 24.5 TWh, i.e. 52% lower than in the BAU scenario. The reduction is the same for CO_2 emissions (10.5 Mton in 2020).

Regarding mercury emissions, the total amount increases in 2009 due to the high increase of HID-R sales (since mercury emissions occurring at their end-of-life are attributed to the sales year). Then, the emissions decrease until 2012 and afterwards stay relatively constant. In 2020, total mercury emissions to air due to the electricity consumption of lamps during to the use phase, and due to emissions occurring at EoL of HID-R are about 390 kg, which means a reduction of about 52% compared to the BAU scenario.

Figure 8.18 shows that after 2017, electricity consumption is only due to HL-LV-R (83%), and HIDi-R (17%), as the other lamp types have been completely phased out.

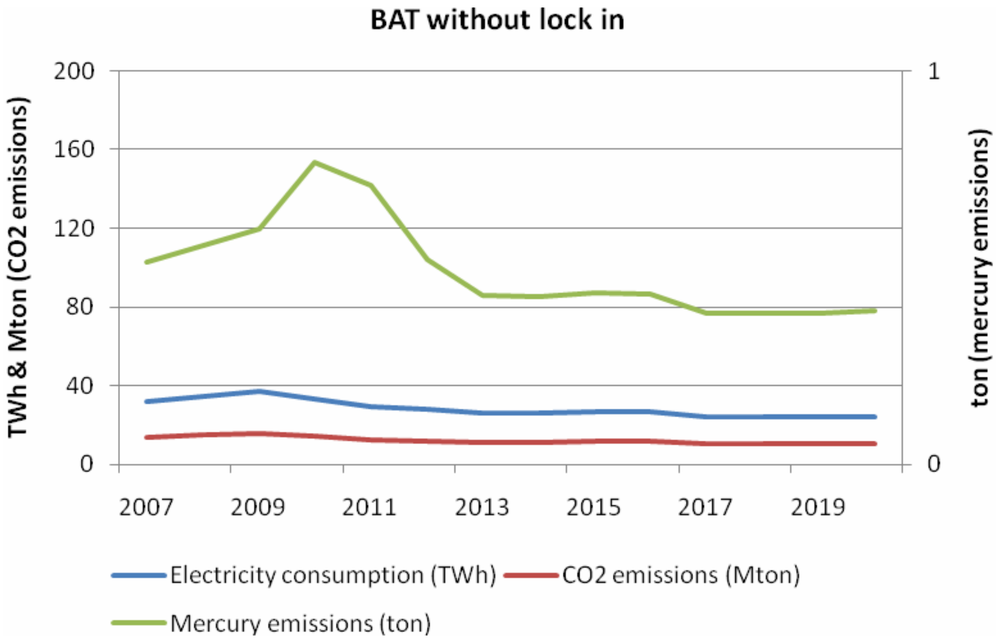

Figure 8.17: BAT without lock in – Evolution of annual environmental impacts

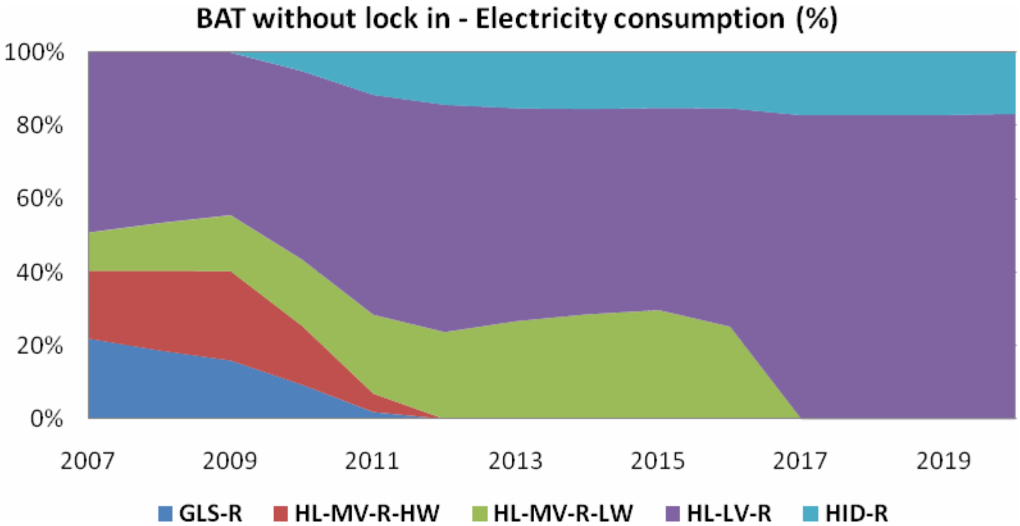

Figure 8.18: BAT without lock in - Evolution of the contribution of the lamp types to the electricity consumptions of the total lamp stock

8.1.2.6 Scenario "BNAT LED" part 2 lamps

The BNAT LED is a scenario in which LEDs are rapidly introduced to the market, assuming a double in efficacy by 2016 (see chapter 6). A summary of the scenario is shown in Table 8-12. Note that this scenario is assuming that retrofit available LEDi-R linearly increase in efficacy up to twice the current efficacy in 2016. It is suggested that the European Commission reviews the LEDi-R situation in 2013 in order to consider setting A level standards in order to require the use of LEDi-R on the market. This scenario is an exercise into showing the savings potential of LEDi-R replacements.

Table 8-12: BNAT LED – Replacement lamps for each tier

present	2010	2013	2016
GLS-R	linear increase to 2016 (28.4 lm/W)	linear increase to 2016 (42.6 lm/W)	LEDi-R x2 efficacy (56.8 lm/W)
HL-MV-R-HW	Level A/B+	Level A/B+	Level A/B+
	HID-R[222]	HID-R[5]	HID-R[5]
HL-MV-R-LW	linear increase to 2016 (30.9 lm/W)	linear increase to 2016 (46.3 lm/W)	LEDi-R x2 efficacy (61.7 lm/W)
HL-LV-R	linear increase to 2016 (26.4 lm/W)	linear increase to 2016 (39.5 lm/W)	LEDi-R x2 efficacy (52.7 lm/W)

Note: The lamps used to calculate the scenario analysis are used only for example purposes. There are many lamps possible which correspond to the performance levels indicated. The scenario analysis should not be interpreted as endorsing one technology over another. The LED efficacies are taken as averages from the technical analysis in Tasks 4 and 6.

The BNAT LED scenario would imply the complete phase-out of GLS-R, HL-MV-R-HW, HL-MV-R-LW and HL-LV-R lamps, with all light being provided by LEDi-R and HID-R, as seen in Figure 8.19. More detailed analysis can be found in Annexe 8-4.

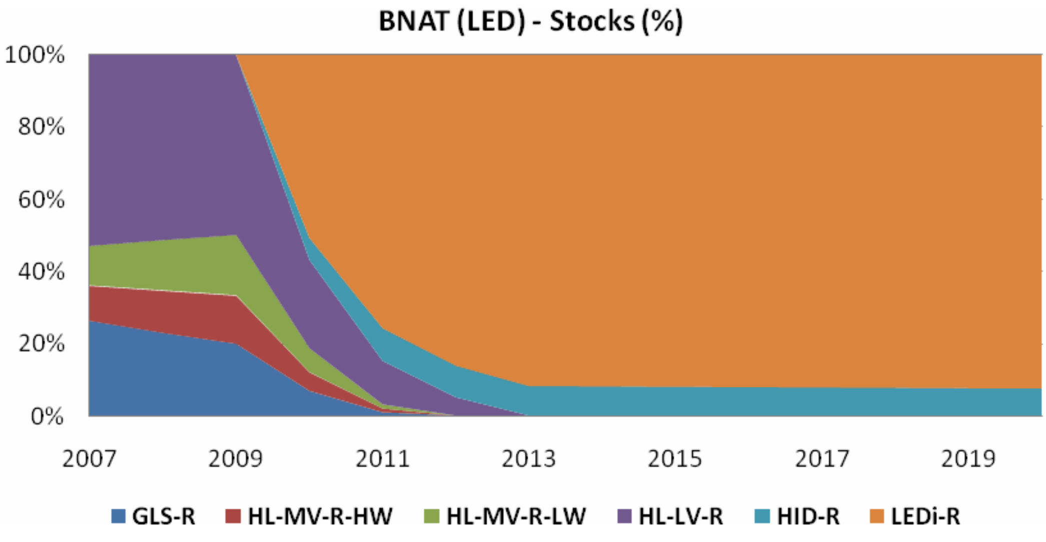

Figure 8.19: BNAT LED - Evolution of lamps stocks (in %)

[222] CFLi-R would also be a sufficient replacement option.

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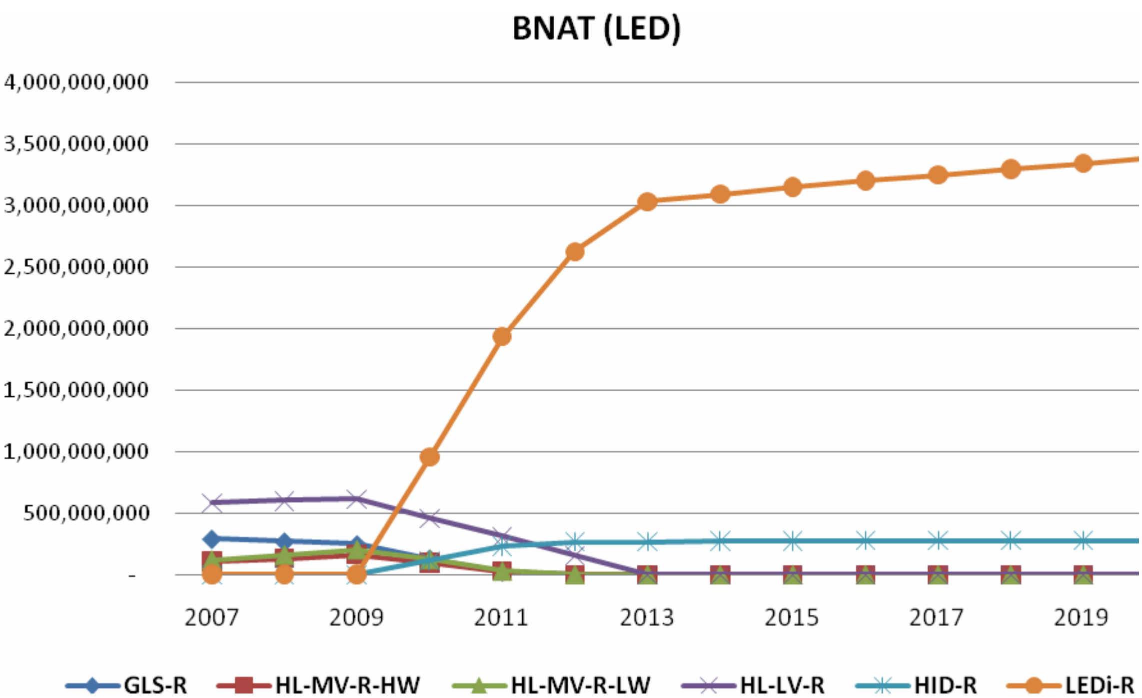

Figure 8.20: BNAT LED - Evolution of lamps stocks (in units)

The sales of LEDi-R and HID-R jump initially order to compensate for the lumen needed during the phase-out of the other lamps. The number of sales is quite high for LEDi-R as the luminous output is still low compared to the base-cases, and thus more lamps are needed to provide the same lumen output. Because of the very long lifetime of both LEDi-R and HID-R (18 years), additional sales are only due to increased lumen demand rather than replacement sales.

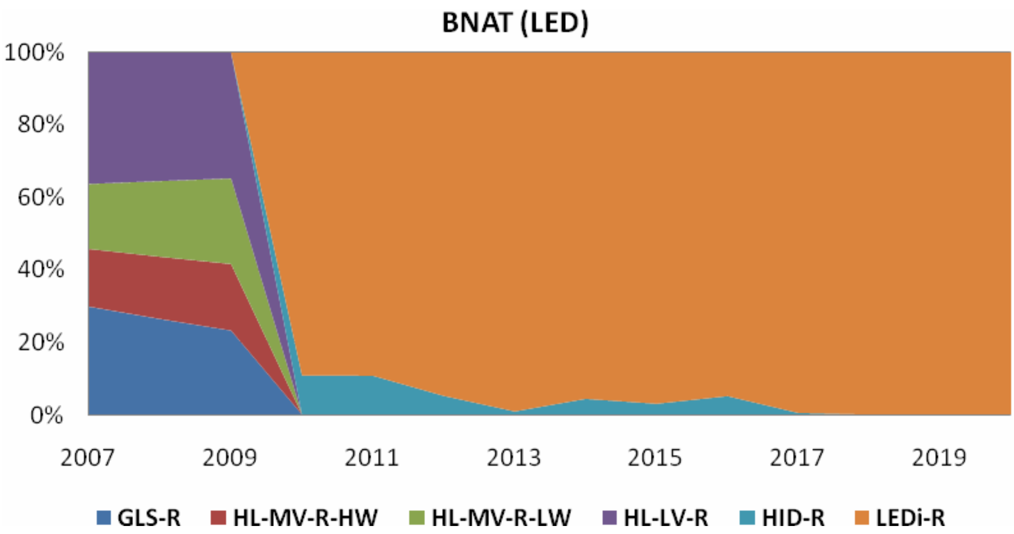

Figure 8.21: BNAT LED - Evolution of lamps sales (in %)

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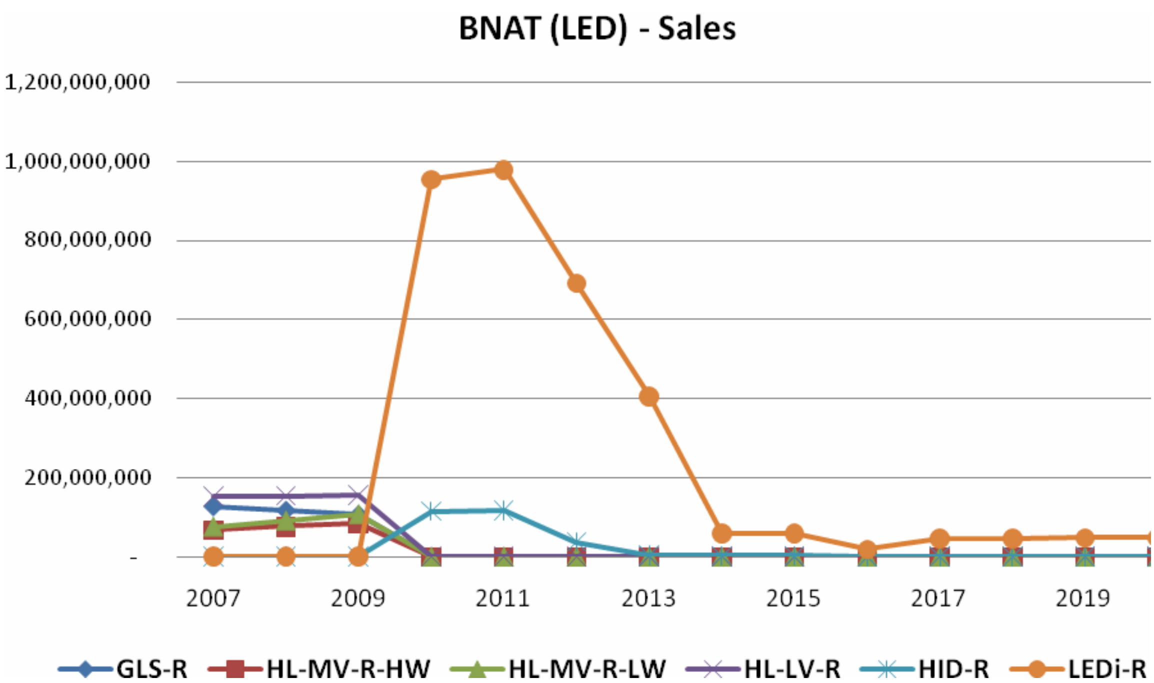

Figure 8.22: BNAT LED - Evolution of lamps sales (in units)

From 2009 onwards, total electricity consumption (and therefore total CO_2 emissions) decreases until 2012 and then increases slightly until 2020.

In 2020, total electricity consumption is expected to be about 15.5 TWh, i.e. 70% lower than in the BAU scenario. The reduction is the same for CO_2 emissions (6.65 Mton in 2020).

Regarding mercury emissions, the total amount increases in 2009 due to the high increase of HID-R sales (since mercury emissions occurring at their end-of-life are attributed to the sales year). Then, the emissions decrease until 2012 and afterwards stay relatively constant. In 2020, total mercury emissions to air due to the electricity consumption of lamps during to the use phase, and due to emissions occurring at EoL of HID-R are about 250 kg, which means a reduction of about 70% compared to the BAU scenario.

Figure 8.24 shows that after 2012, electricity consumption is only due to LEDi-R (74%), and HID-R (26%), as the other lamp types have been phased out.

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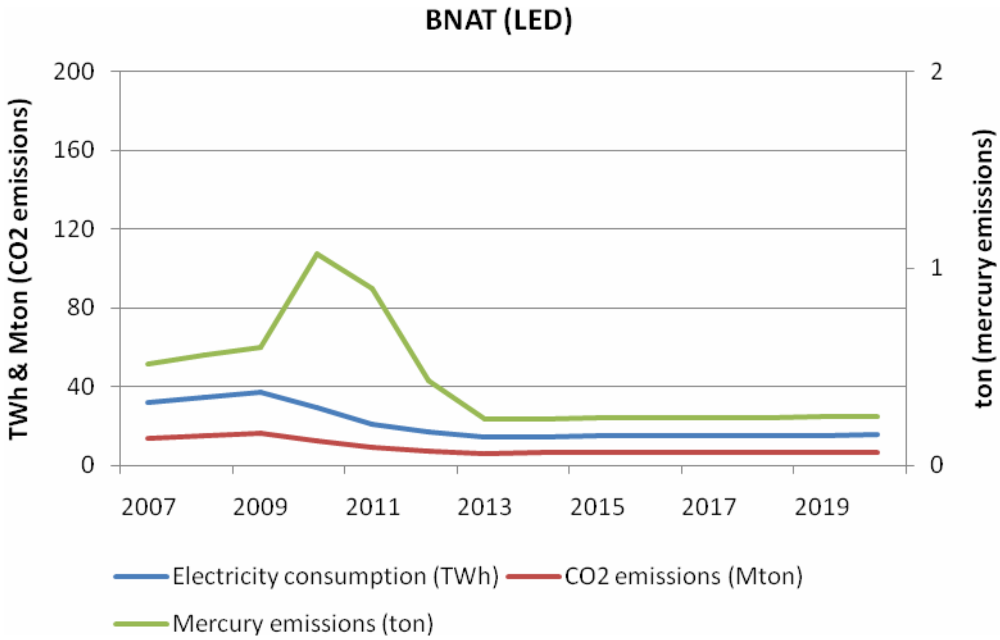

Figure 8.23: BNAT LED – Evolution of annual environmental impacts

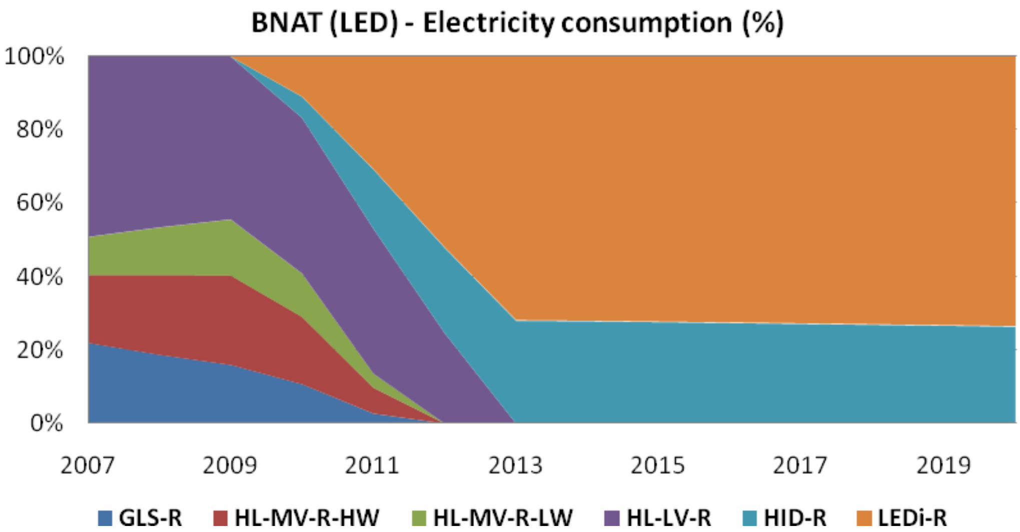

Figure 8.24: BNAT LED - Evolution of the contribution of the lamp types to the electricity consumptions of the total lamp stock

8.1.2.7 Comparison of scenarios part 2 lamps

Based on the analysis of the four scenarios (BAU + 3 'improvement' scenarios), environmental impacts in 2020 are presented in Table 8-13, including variations both in units and in % with reference to the BAU scenario, and illustrated in Figure 8.25.

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Table 8-13: Environmental impacts in 2020 for each scenario

		Electricity consumption (TWh) in 2020	CO_2 emissions (Mton) in 2020	Mercury emissions (ton) in 2020
BAU	**Value**	51.1	22.0	0.82
	Difference to BAU	*0.0%*	*0.0%*	*0.0%*
BAT with lock in	**Value**	28.5	12.3	0.46
	Difference to BAU (units)	*-23.6*	*-10.0*	*-0.36*
	Difference to BAU (%)	*-44.3%*	*-44.3%*	*-44.3%*
BAT without lock in	**Value**	24.5	10.5	0.39
	Difference to BAU (units)	*-26.7*	*-11.5*	*-0.43*
	Difference to BAU (%)	*-52.1%*	*-52.1%*	*-52.1%*
BNAT (LED)	**Value**	15.5	6.7	0.25
	Difference to BAU (units)	*-35.6*	*-15.3*	*-0.57*
	Difference to BAU (%)	*-69.7%*	*-69.7%*	*-69.7%*

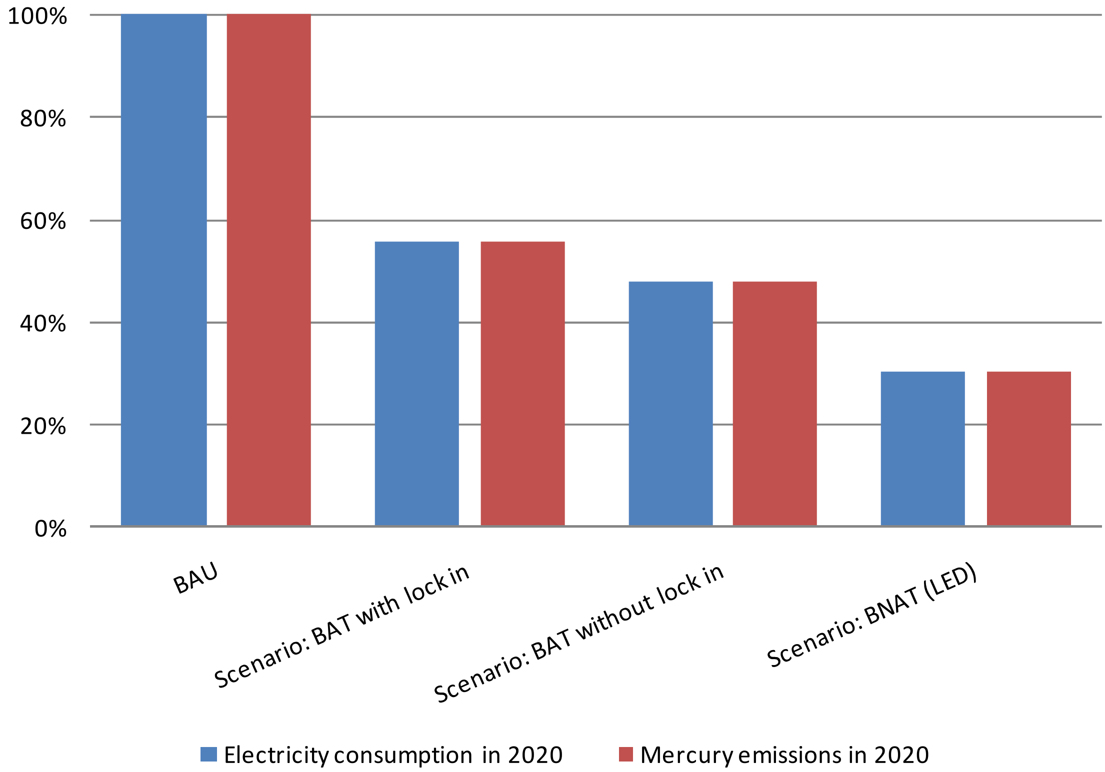

Figure 8.25: Comparison of scenarios in 2020

As already mentioned, looking only at the environmental impacts in 2020 can be confusing. For example, the mercury emissions on 2020 are reduced by the same amount as the electricity consumption because there are few sales of HID-R, which have mercury embedded. Therefore, in order to allow a 'fair' comparison, cumulated environmental impacts from 2010 (assumed as the entry into force of the legislation) to 2020 need to be analysed. Such a comparison presents more logical results and the resulting ranking of 'the most environmental friendly scenario' is as expected: the BNAT LED scenario presents the greatest reductions in environmental impacts.

Table 8-14: Cumulated environmental impacts from 2010 to 2020 for each scenario

		Electricity consumption (TWh) from 2010 until 2020	CO2 emissions (Mton) from 2010 until 2020	Mercury emissions (ton) from 2010 until 2020
BAU	**Value**	508.4	218.6	8.1
	Difference to BAU	*0%*	*0%*	*0%*
BAT with lock in	**Value**	370.1	159.1	6.6
	Difference to BAU (units)	*-138.4*	*-59.5*	*-1.5*
	Difference to BAU (%)	*-27.2%*	*-27.2%*	*-18.6%*
BAT without lock in	**Value**	293.9	126.4	5.4
	Difference to BAU (units)	*-214.5*	*-92.2*	*-2.7*
	Difference to BAU (%)	*-42.2%*	*-42.2%*	*-33.5%*
BNAT (LED)	**Value**	186.8	80.3	4.3
	Difference to BAU (units)	*-321.6*	*-138.3*	*-3.8*
	Difference to BAU (%)	*-63.3%*	*-63.3%*	*-46.8%*

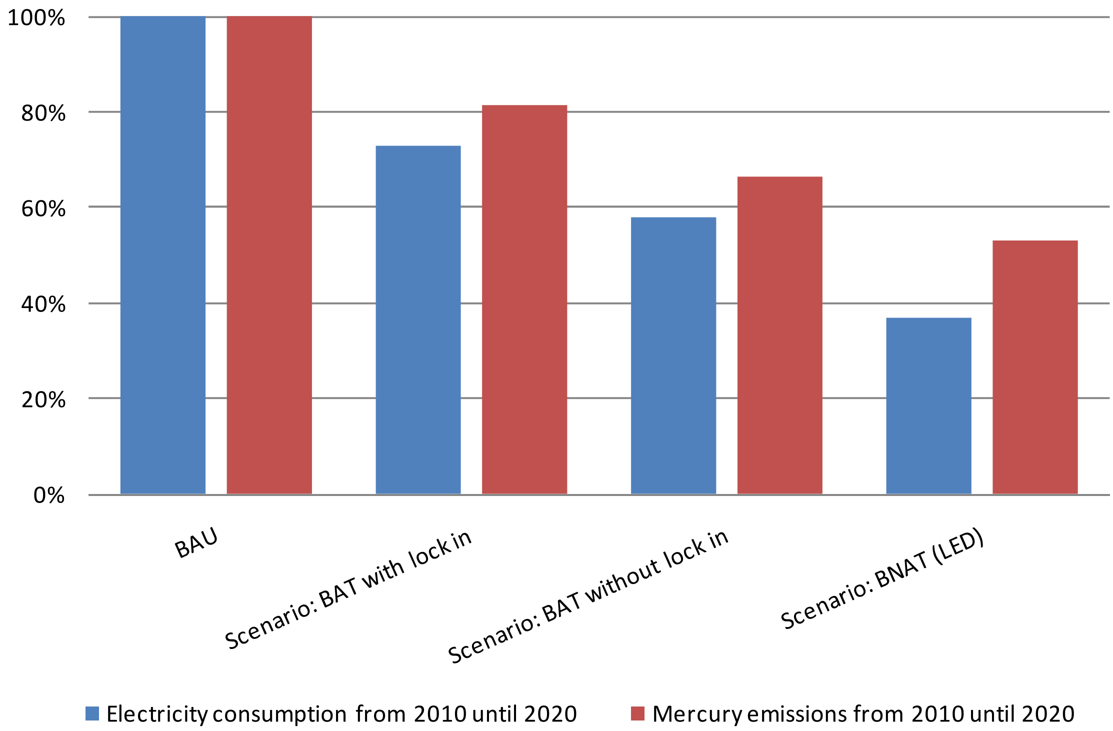

Figure 8.26: Comparison of scenarios between 2010 and 2020

8.1.2.8 Calculation principle used for the luminaire scenario analysis

In addition to improvements related on the lamp efficacy, optic and control system improvements on the luminaire are also possible (see chapter 6 and section 8.1.1.8). Please note that luminaires can also create a positive lock-in effect, e.g. by using a pin based CFLni [see remark on CFLni in 8.1.1.7]. After extensive consultation with CELMA, educated estimations were made in order to determine the quantity of savings currently possible from luminaire improvements. An example of these estimates can be found in Figure 8.27. The full spreadsheet with all calculations is available on the project website[223].

[223] www.eup4light.net

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General comment: all figures in the tables are estimated values with the knowledge of CELMA members as of today.

Option:	dimmable application
Your country:	CELMA
Saving method description	Luminaire is only operated at max power for functional use. The rest of the time the luminaire is dimmed. This is applicable for external and internal dimmer systems.
Sample picture best practice	
Sample picture worst practice	

Category of luminaires	Is this option applicable to this category or not	How big is the market share [EU27 sales] of improvable luminaires in its category	What proportion of the energy can be saved comparing worst to best practice	How many luminaires [EU27 sales] are among the worst 30 % performers in the category	How many luminaires [EU27 sales] are among the best 30% performers in the category	What proportion of the energy can be saved assuming all luminaires sold are in the range of 30 % best performers	Chararactertic parameter best performer	Energy Chararactertic parameter worst performer
	Y/N	%	%	%	%		*max operational energy consumption (W)*	*min operational energy consumption (W)*
Downlights (recessed mounted)	y	75	30	50	25	15	<=30	>=60
Suspension (chandeliers)	y	75	30	70	10	21	<=30	>=60
wall&ceiling	y	70	30	60	10	18	<=30	>=60
Desk	n							
Table	y	30	30	80	20	24	<=20	>=40
Floor	y	75	30	70	20	21	<=50	>=100
Spotlights	y	75	30	80	20	24	<=30	>=60
Outdoor	n							
							lower powerconsumption because used at 50% dimming or use of low wattage lamps	higher powerconsumption because of use of high wattage lamps in not dimmable applications

Note: For dimmable applications cleaning is relevant since the consumer will use more energy in direct relation with the dust on the luminaire
Dimmability is focused on filament lamps, only a very small quantity of CFLI(ni) is dimmable today.

Figure 8.27: Example of CELMA luminaire improvement data

Data was aggregated in the following manner:

- The analysis begins by taking the market share for each category of luminaire, as presented in Table 2.12 of Part 2.
- The average wattages given by CELMA are used to find a weighted average of the total market of 79.75 W.
- The wattage for each category is divided by the weighted average of the total market to obtain the "relative energy weight" for each category. This value means the variation away from the weighted average for each category wattage.
- Multiplying the relative energy weight by market share, a per unit "market average wattage" is obtained. After this, the market shares and wattages have been converted to a more useful "energy share" for each category, which is the percentage of energy out of the total market that each category consumes.
- As we know the total market to use 141.4 TWh/year (for both NDLS and DLS applications), this figure is multiplied by the "market average wattage" to obtain an energy usage in TWh for each category.
- The savings potential in TWh was found by multiplying energy usage by columns "How big is the market share of improvable luminaires in its category?", "how many luminaires are among the worst 30% performers in the category?", and "what proportion of the energy can be saved comparing worst to best practice?". The reasoning is the following:
    - How big is the market share of improvable luminaires in its category? – defined what part of the market share is improvable.

  - How many luminaires are among the worst 30% performers in the category? – defines the percentage of improvable luminaires that are among the worst 30%.
  - What proportion of the energy can be saved comparing worst to best practice? – defines the percentage of energy that is saved when replacing a worst practice luminaire with a best practice luminaire.
- Rather than summing, this savings potential is multiplied as a weighted percentage in order to avoid overlap of savings. For example, starting with 100% energy use, and 10% energy savings in two separate categories, total energy savings would be 100% - (100%-10%)*(100%-10%) = 100% - 90%*90% = 100% - 81% = 19%.
- Taking the percentage of energy savings, this is then multiplied with energy usage to find the energy savings in TWh.

These improvements with their quantified savings potential are summarised in Table 8-15: Luminaire technical savings potential. Note that only percentage savings can be given, as the luminaire improvement is applied on top of other lamp improvements. Thus, the absolute improvement potential due to luminaires is reduced as lamps become more efficient. For other scenarios please see section 8.1.2.10.

Table 8-15: Luminaire technical savings potential

Luminaire improvement option	Applicable to regulation EC 244/2009	Applicable to part 2	Savings potential (%)
Dimmable	y	y	8.32%
Motion sensor	y	y	5.76%
Day/night sensor	y	y	2.44%
Reflectors	y	n	5.64%
Correct application of luminaire (education)	y	y	4.99%
Diffusing material	y	y	1.05%
Total (%)	**25.2%**	**20.8%**	**24.1%**

8.1.2.9 Scenario "Luminaire improvement options introduced on top of scenarios BAT" part 1&2 lamp stock

As additional information on future predictions of implementation of luminaire improvements that are not related to lamp efficacy is not available, the full technical savings potential is assumed to be achieved on a linear basis by 2020. Thus, the scenarios already analysed could see additional improvements.

The accepted luminaire lifetime is assumed to be 13 years (as stated in section 2.2.5). The replacement of luminaires is considered to naturally occur during the scenario. More background information on the impacts is included in section 8.2.

As Table 8-16 shows, the relative savings over BAU (with improved luminaires) remains almost exactly the same as those in Table 8-13. Please note that the most important savings are due to increasing the lamp efficacy. Luminaires can contribute as well by avoiding a negative but creating positive lock-in effect, e.g. pin based CFLni luminaire or efficient LED luminaire (see chapter 3 and 6 for details). Table 8-17 considers possible savings due to luminaire improvement over that of the scenario resulting from regulation 244/2009/EC on non-directional lighting.

Table 8-16: Environmental impacts 2020 without and with luminaire improvement for DLS

		Electricity consumption (TWh) in 2020	CO2 emissions (Mton) in 2020	Mercury emissions (ton) in 2020
BAU	Value WITHOUT luminaire improvement	51.1	22.0	0.82
	Value WITH luminaire improvement	40.5	17.4	0.6
BAT with lock in	Value WITHOUT luminaire improvement	28.5	12.3	0.46
	Value WITH luminaire improvement	22.6	9.7	0.4
BAT without lock in	Value WITHOUT luminaire improvement	24.5	10.5	0.39
	Value WITH luminaire improvement	19.4	8.3	0.3
BNAT (LED)	Value WITHOUT luminaire improvement	15.5	6.7	0.25
	Value WITH luminaire improvement	12.3	5.3	0.2

Table 8-17: Environmental impacts 2020 without and with luminaire improvement for NDLS

		Electricity consumption (TWh) in 2020	CO2 emissions (Mton) in 2020	Mercury emissions (ton) in 2020
BAU	Value WITHOUT luminaire improvement	134.7	57.9	3.1
	Value WITH luminaire improvement	100.7	43.3	2.3
Option 2 clear B fast	Value WITHOUT luminaire improvement	96.0	41.3	1.6
	Value WITH luminaire improvement	71.8	30.9	1.2
BAT	Value WITHOUT luminaire improvement	47.5	20.4	0.85

	Value WITH luminaire improvement	35.5	15.3	0.6

8.1.3 Sensitivity analysis

The robustness of the outcomes of the study depends on the underlying assumptions. These assumptions have been explicitly mentioned at the relevant steps of the study. In this section, the sensitivity of the results to the most critical parameters and assumptions is tested, related namely to:

- The economic data, such as the electricity tariff, the discount rate, and the purchase price of BAT lamps, which have an influence on the LCC when implementing improvement options,
- The behavioural data such as the annual operational hours as well as the maximum lamp lifetime, which have an influence on the LCC of base-cases and their improvement options,
- The replacement of a lamp and its luminaire compared to the replacement of the lamp only.

8.1.3.1 Assumptions related to the electricity tariff

For the base-cases, an average EU-27 electricity tariff of 0.1528 €/kWh was used, based on the data from Eurostat (see chapter 2, section 2.4.2). However, if the lowest electricity tariff (i.e. 0.0658 €/kWh in Latvia) and the highest electricity tariff (i.e. 0.2580 €/kWh in Denmark) are applied, this could lead to different LCC for the base-cases.

As shown in in the following figures, the modifications in the electricity tariff have a strong impact on the LCC. Indeed, the major part of the LCC is due to the electricity costs during the use phase as specified in chapter 5. Because of this, the economics of improvement options changes with the electricity tariff.

The EU-27 average electricity tariff of 0.1528 €/kWh is denoted by the dashed line in the figures, whereas 0.1619 €/kWh represents the average between the lowest and the highest rate.

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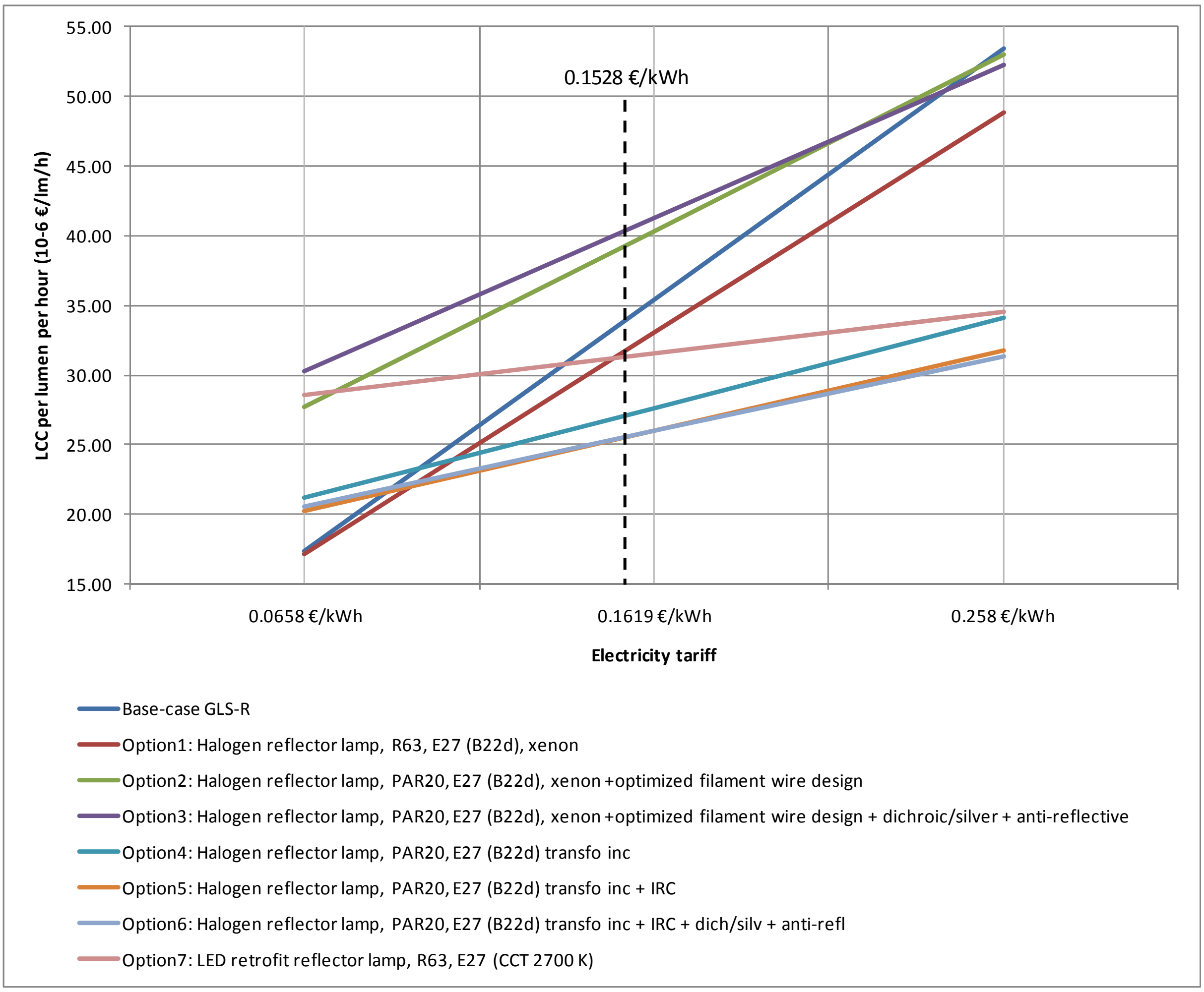

Figure 8.28: GLS-R sensitivity of LCC to electricity tariff

In the case of GLS-R and its improvement options, there is a wide change of LLCC option as the electricity tariff changes. At the low end, option 1 is the LLCC option. In the midrange, option 5 is just barely the LLCC, and afterwards option 6 becomes the LLCC option.

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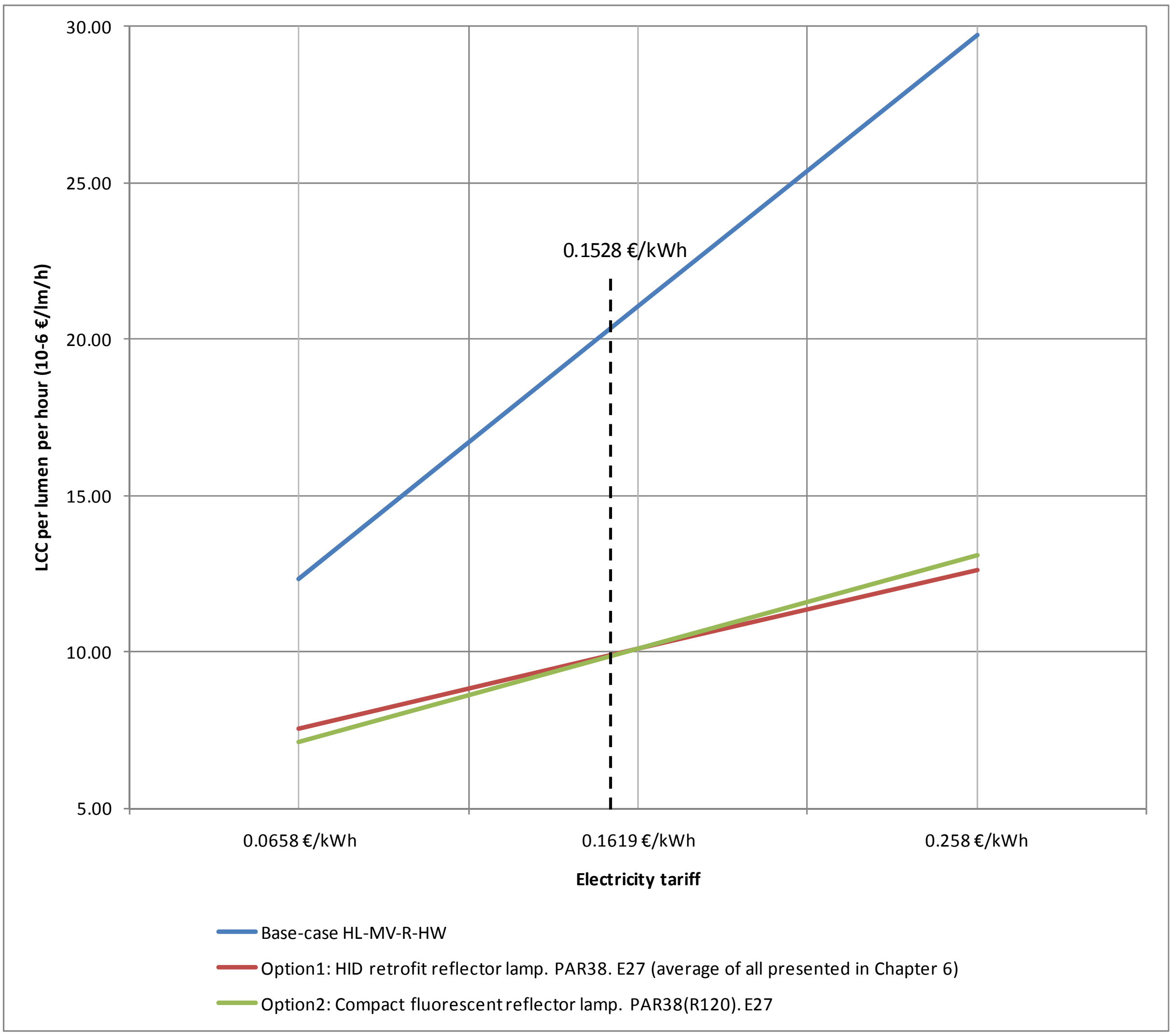

Figure 8.29: HL-MV-R-HW sensitivity of LCC to electricity tariff

As the electricity tariff increases, the LCC of option 1 reduces until it becomes the LLCC option. If the electicity tariff of Latvia is used as reference, however, option 2 leads to the LLCC.

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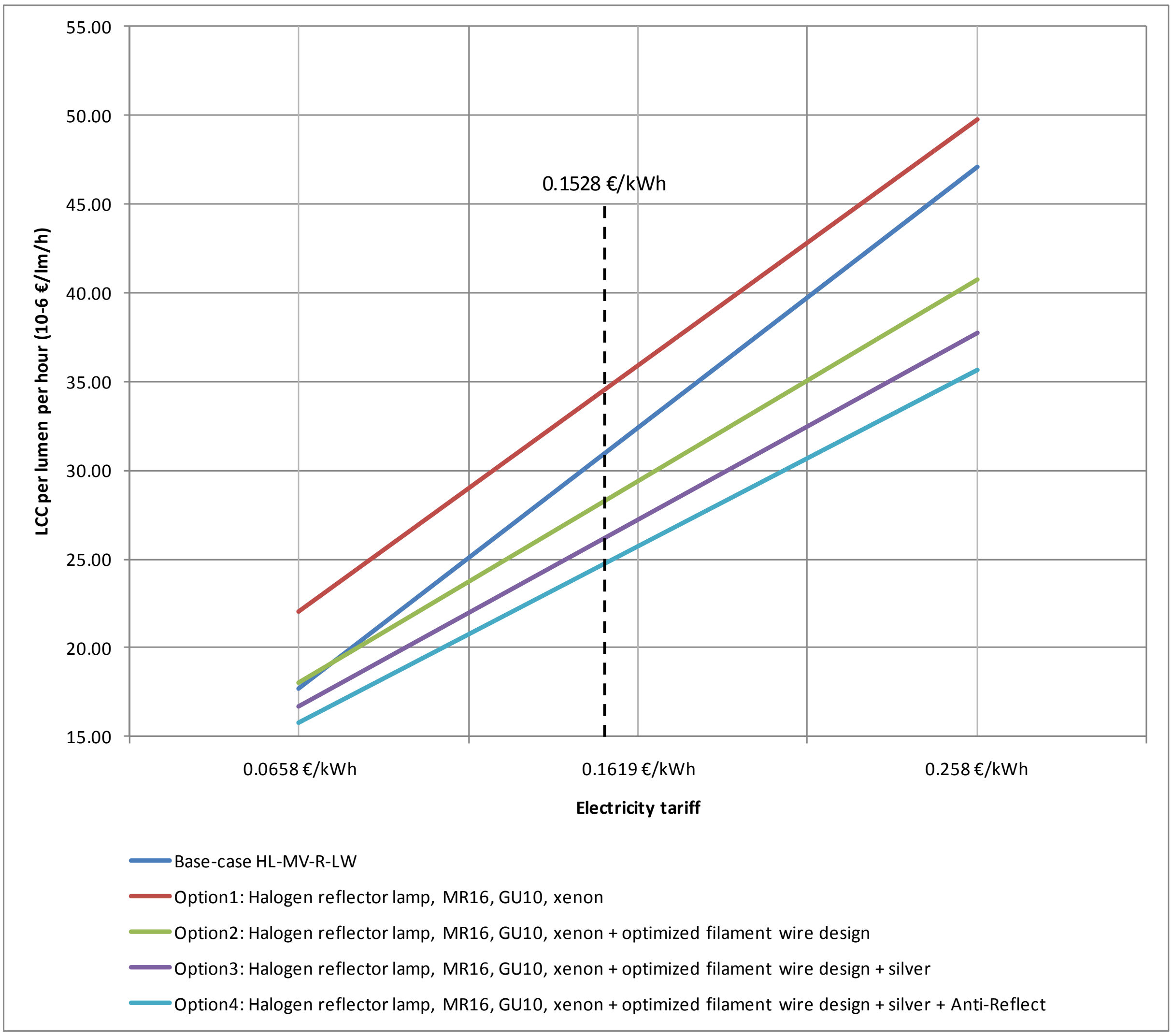

Figure 8.30: HL-MV-R-LW sensitivity of LCC to electricity tariff

The LLCC option does not change as electricity tariff changes.

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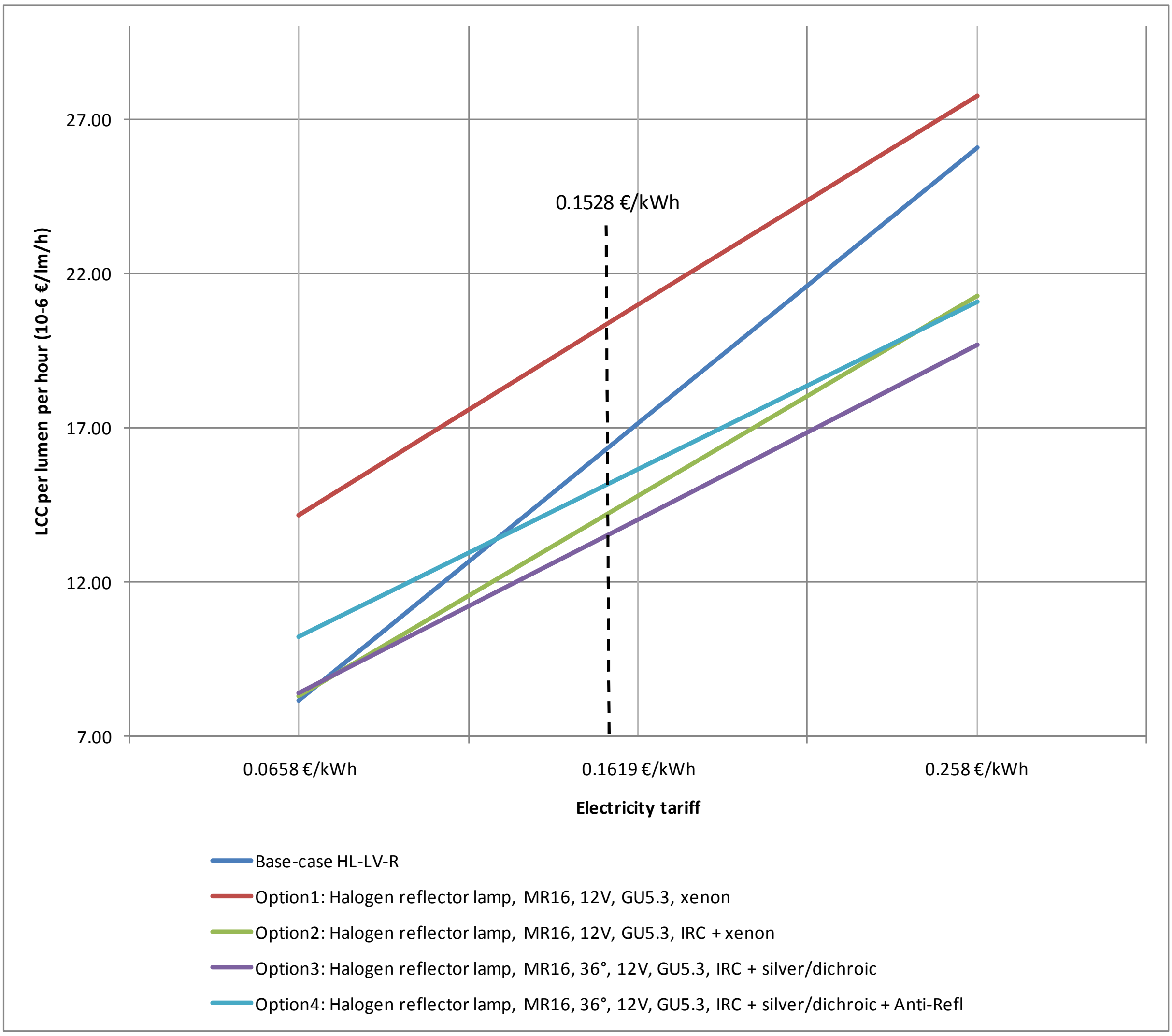

Figure 8.31: HL-LV-R sensitivity of LCC to electricity tariff

At the very lowest electricity tariff, the base-case is the LLCC option. Afterwards, option 3 is the LLCC.

8.1.3.2 Assumptions related to discount rate

For the base-cases, the EU-27 discount rate (interest rate minus inflation rate) was assumed to be 1.8%. This could be considered as very low, especially for the year 2009. Thus, the sensitivity to the discount rate is analyed considering a much wider range of discounts rates of all the Member States, from 1.77% in multiple to 15.54% in Latvia. However, as the following figures show, the discount rate does not have a significant impact on the LCC of the base-cases and improvement options. For all base-cases, the LLCC option remains the same despite changes in the discount rate (keeping the EU-27 averal electricity tariff).

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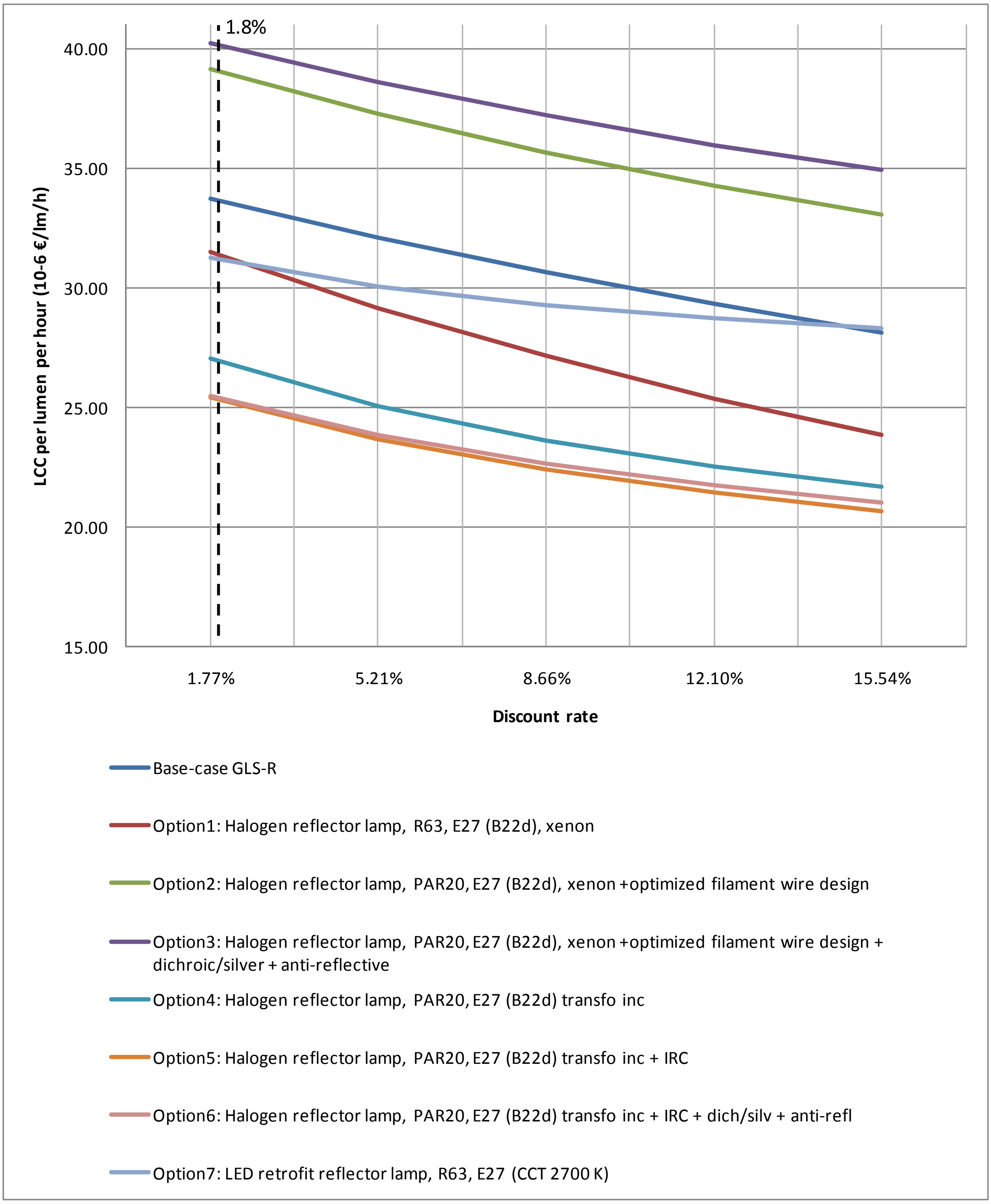

Figure 8.32: GLS-R sensitivity of LCC to discount rate

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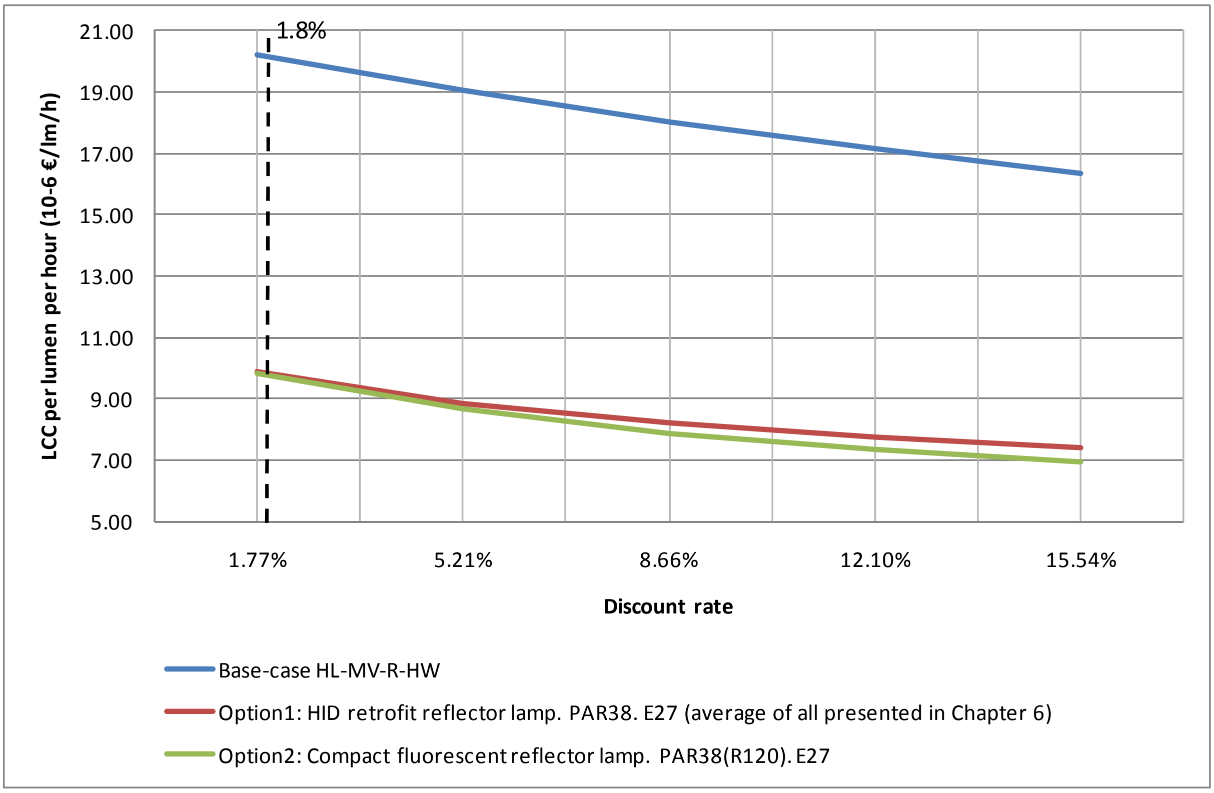

Figure 8.33: HL-MV-R-HW sensitivity of LCC to discount rate

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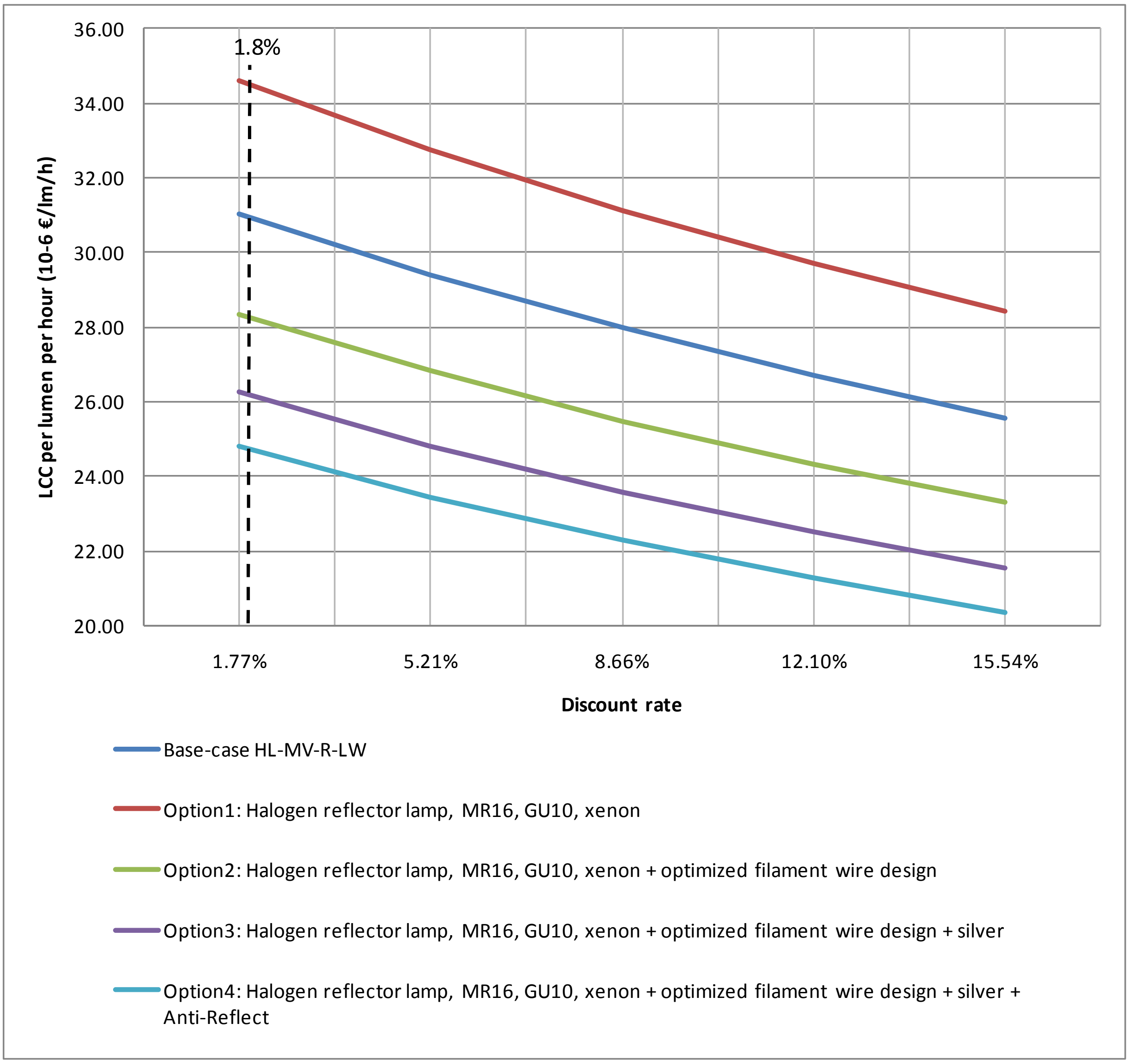

Figure 8.34: HL-MV-R-LW sensitivity of LCC to discount rate

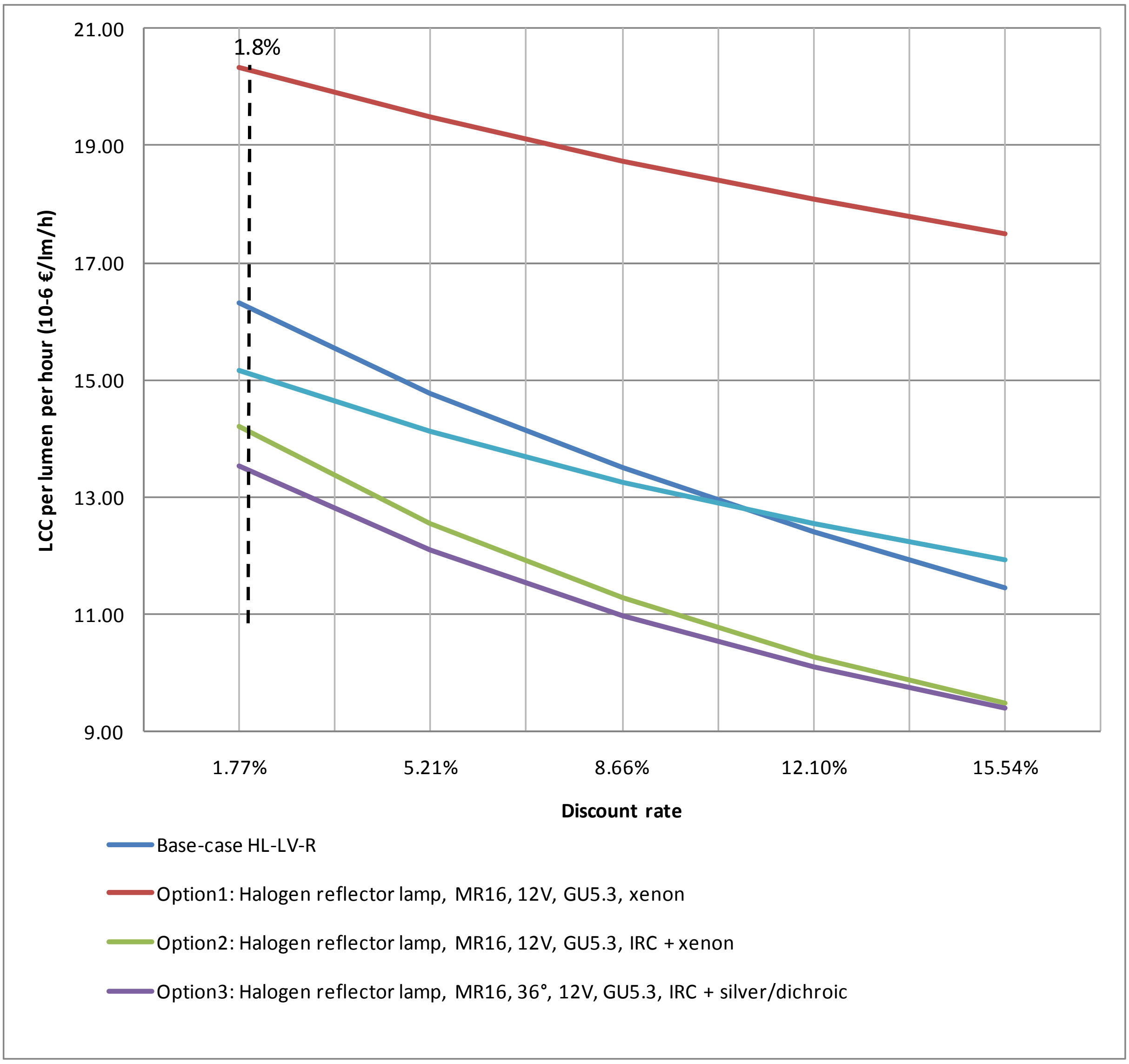

Figure 8.35: HL-LV-R sensitivity of LCC to discount rate

8.1.3.3 Assumptions related to the price of BAT products

Due to uncertainty in the prices of the BAT products used as improvement options, the prices are analysed +/- 30% to determine the effects, if any, on the LLCC option. As seen in the following figures, only the LLCC option of base-case HL-MV-R-HW changes from option 1 to option 2 as price increases.

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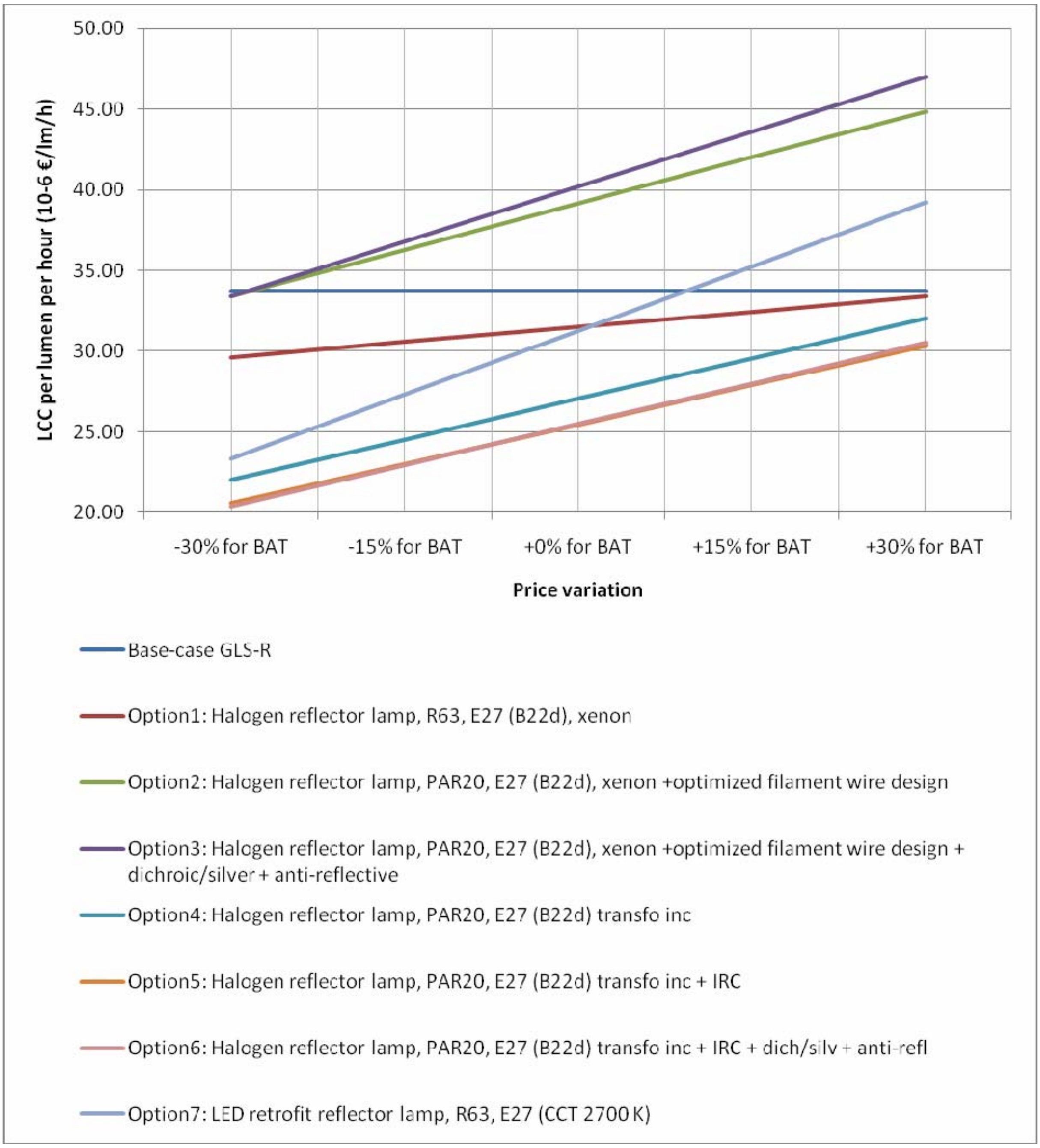

Figure 8.36: GLS-R sensitivity of LCC to BAT product price

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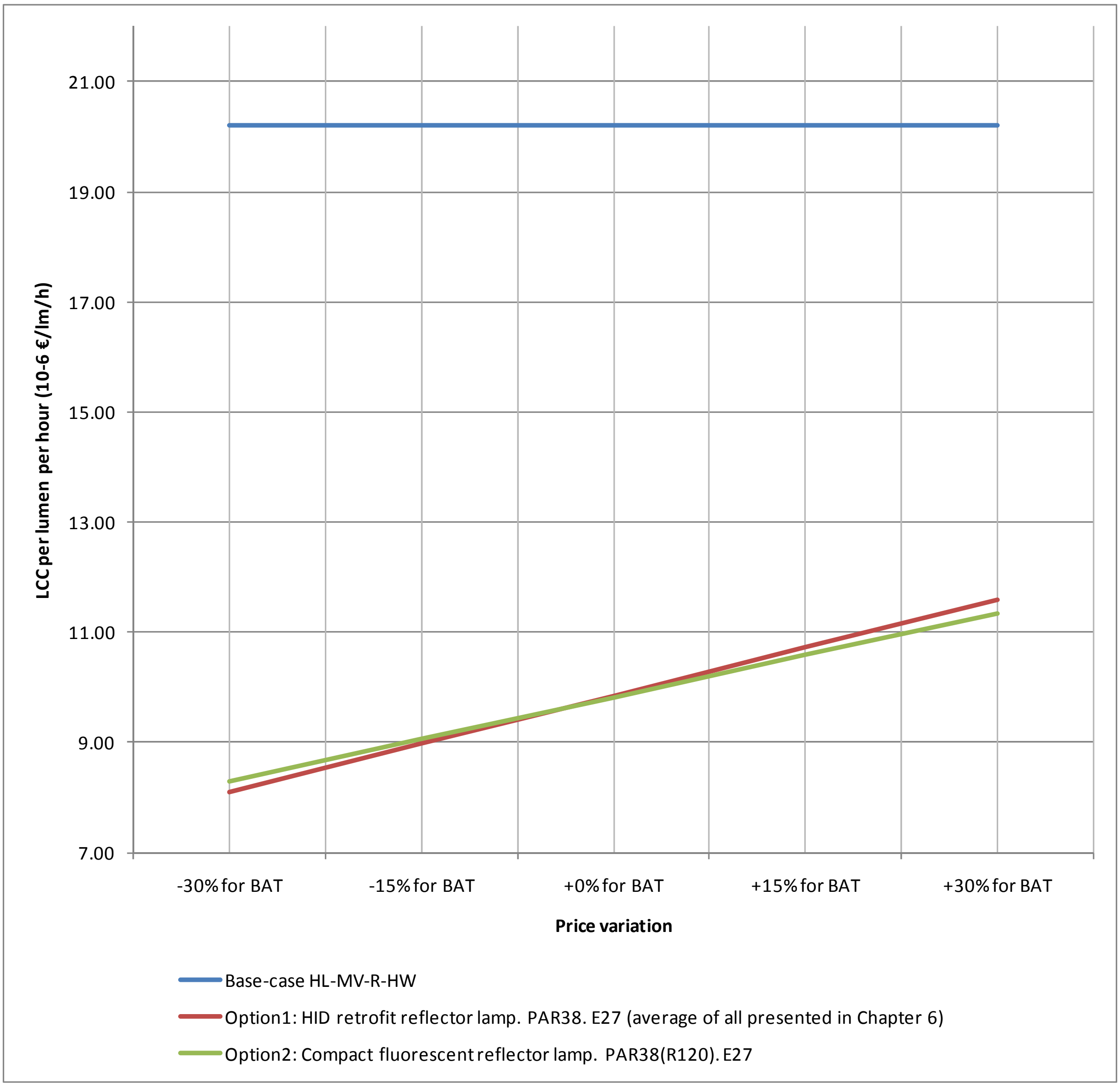

Figure 8.37: HL-MV-R-HW sensitivity of LCC to BAT product price

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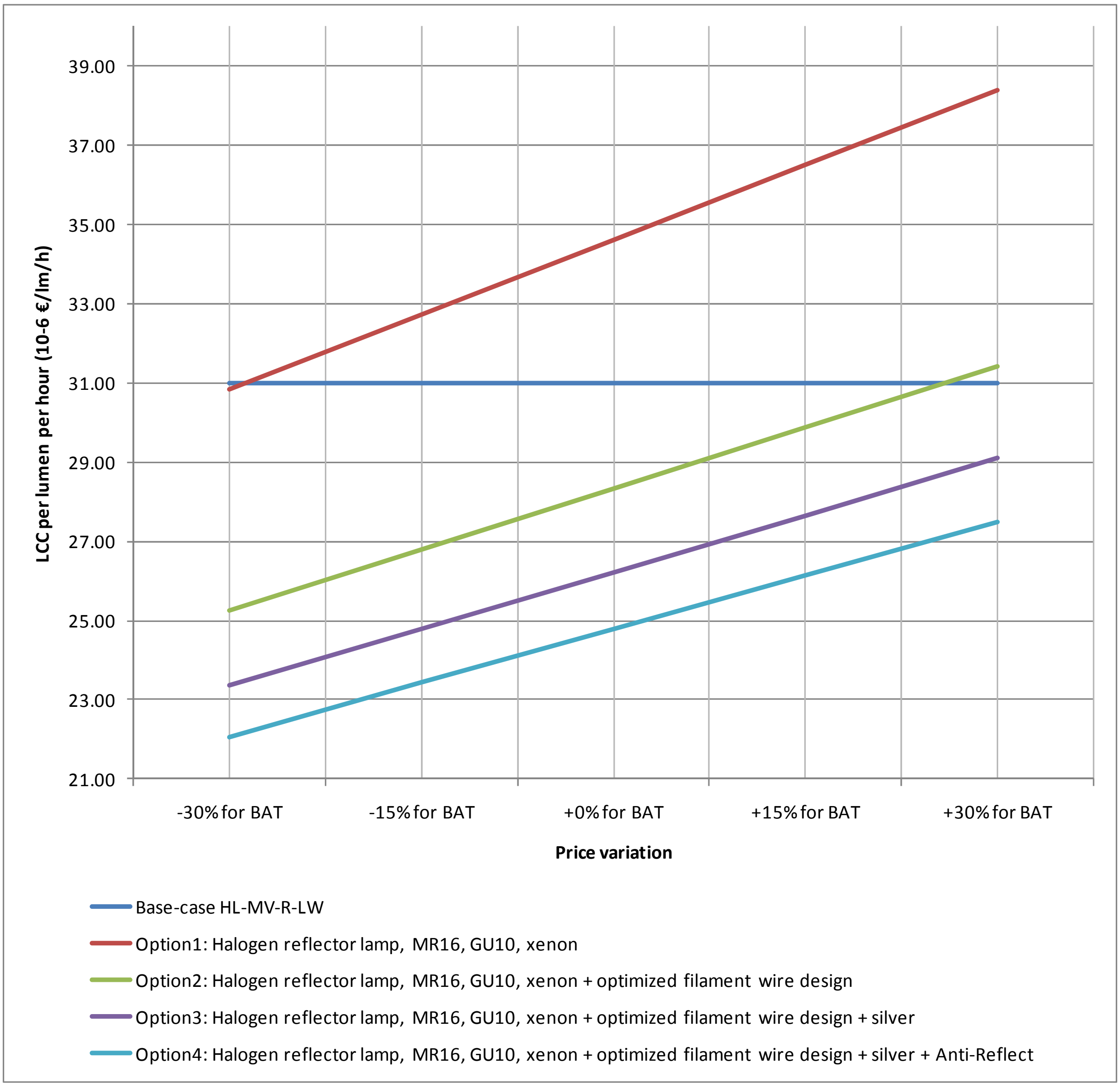

Figure 8.38: HL-MV-R-LW sensitivity of LCC to BAT product price

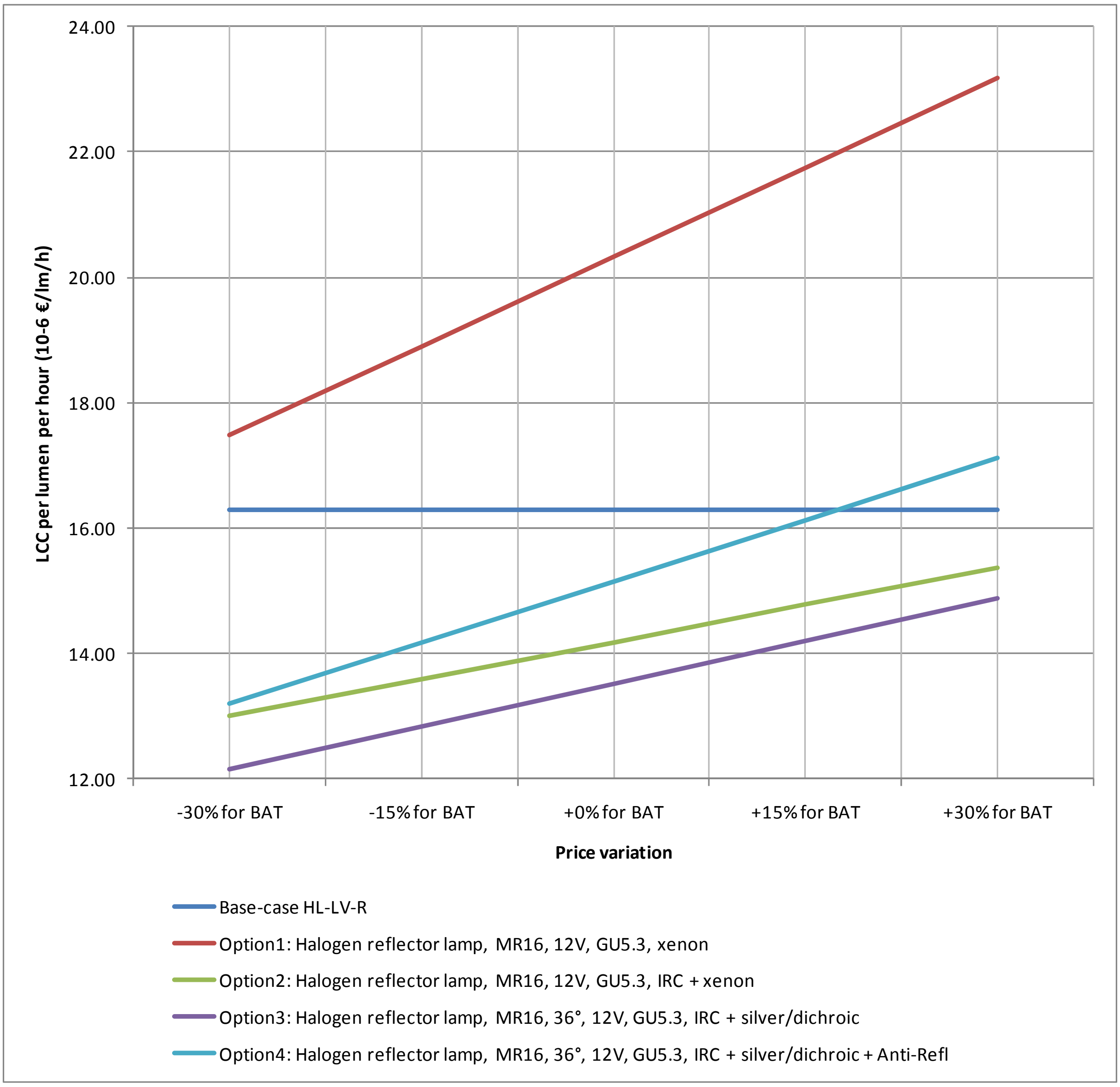

Figure 8.39: HL-LV-R sensitivity of LCC to BAT product price

8.1.3.4 Assumptions related to operational hours

The sensitivity of the life cycle analysis to changes in operation hours per year is conducted by varying operating hours by -20% / +40%. As the figures below show, all lamps generally change in the same manner, thus keeping the differences in LCC relatively constant. However, it is important to note that for the longer lifetime lamps (LEDi-R, CFLi-R, HIDi-R), there are greater changes because of the assumed behavioural lifetime limit of 18 years. As operating hours change, the actual usage hours of these long-life lamps change and therefore the LCC changes more drastically. Nonetheless, only the LLCC option of the GLS-R base-case changes due to variations in operation hours.

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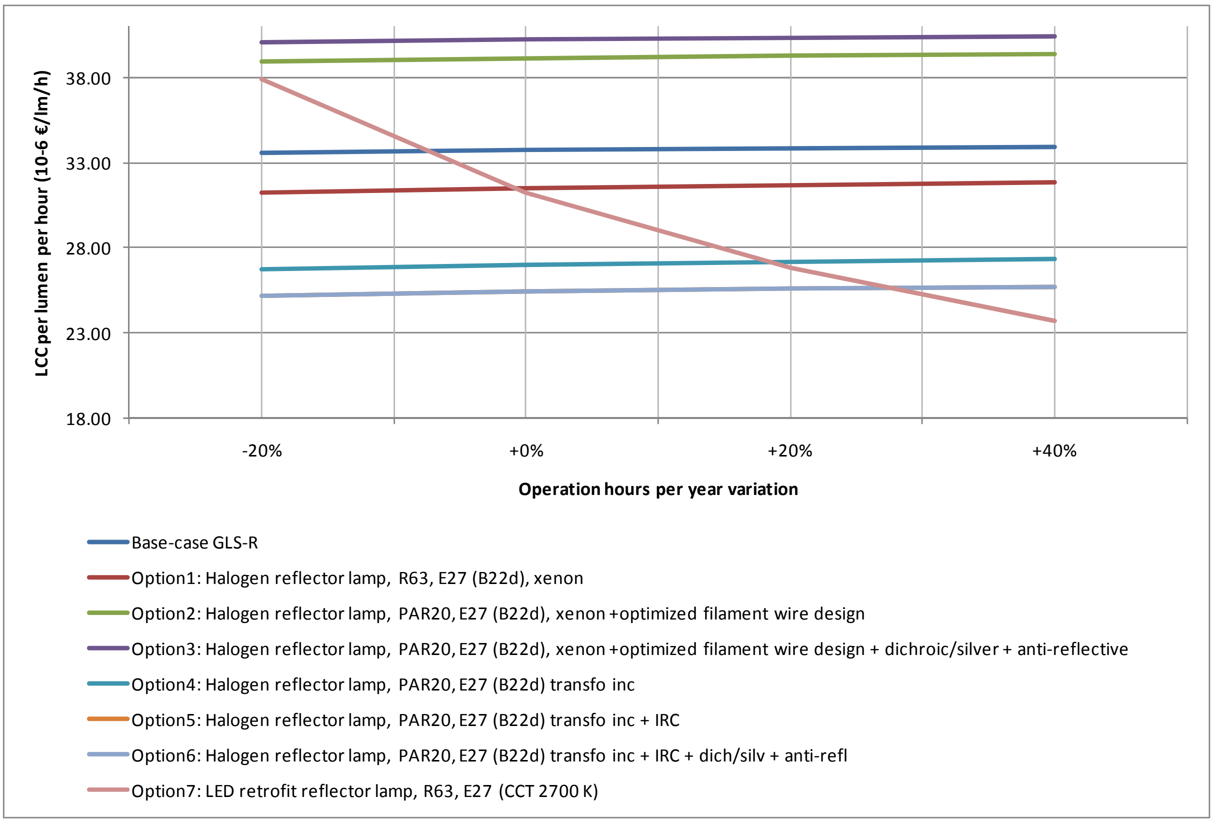

Figure 8.40: GLS-R sensitivity of LCC to operational hours per year

As the lifetime of the LEDi-R is capped by the behavioural lifetime limit of 18 years, there is a very strong variation due to operation hours. At -20%, it has of the highest LCCs and at 40%, it is the LLCC option.

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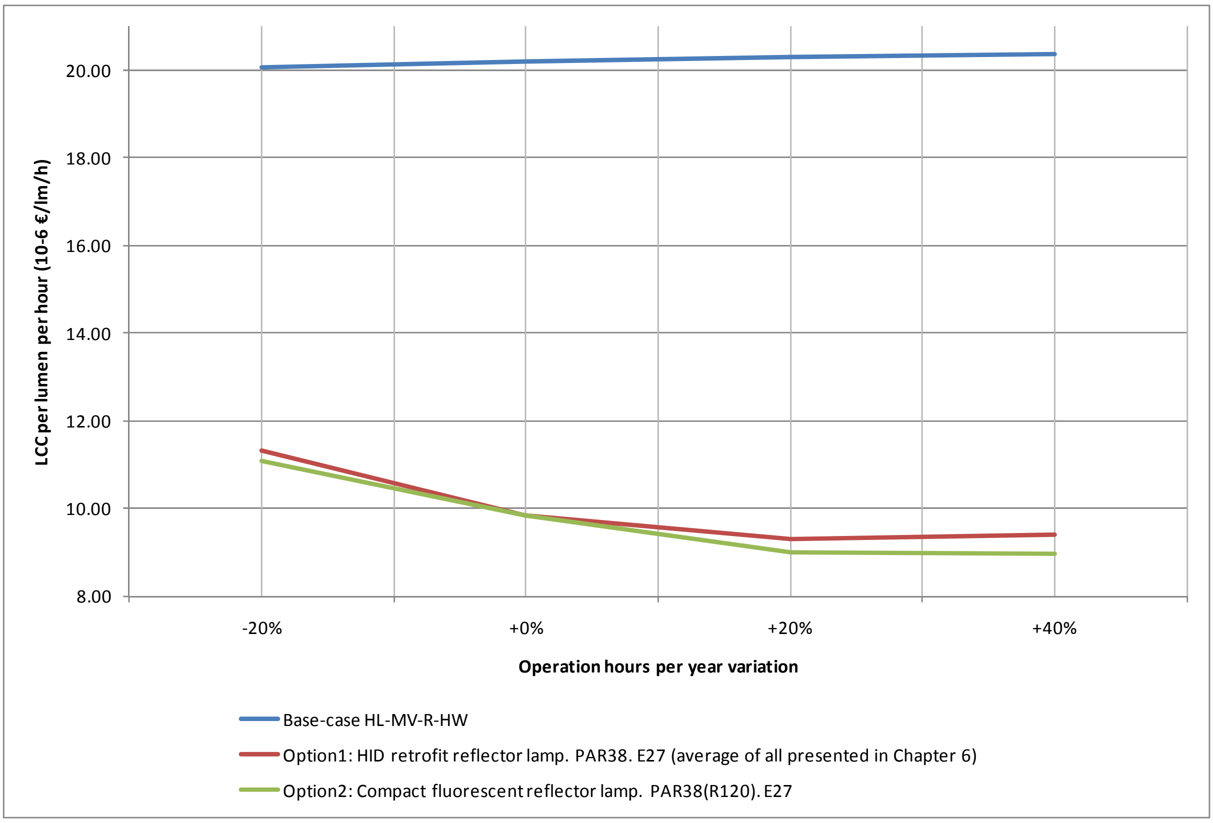

Figure 8.41: HL-MV-R-HW sensitivity of LCC to operational hours per year

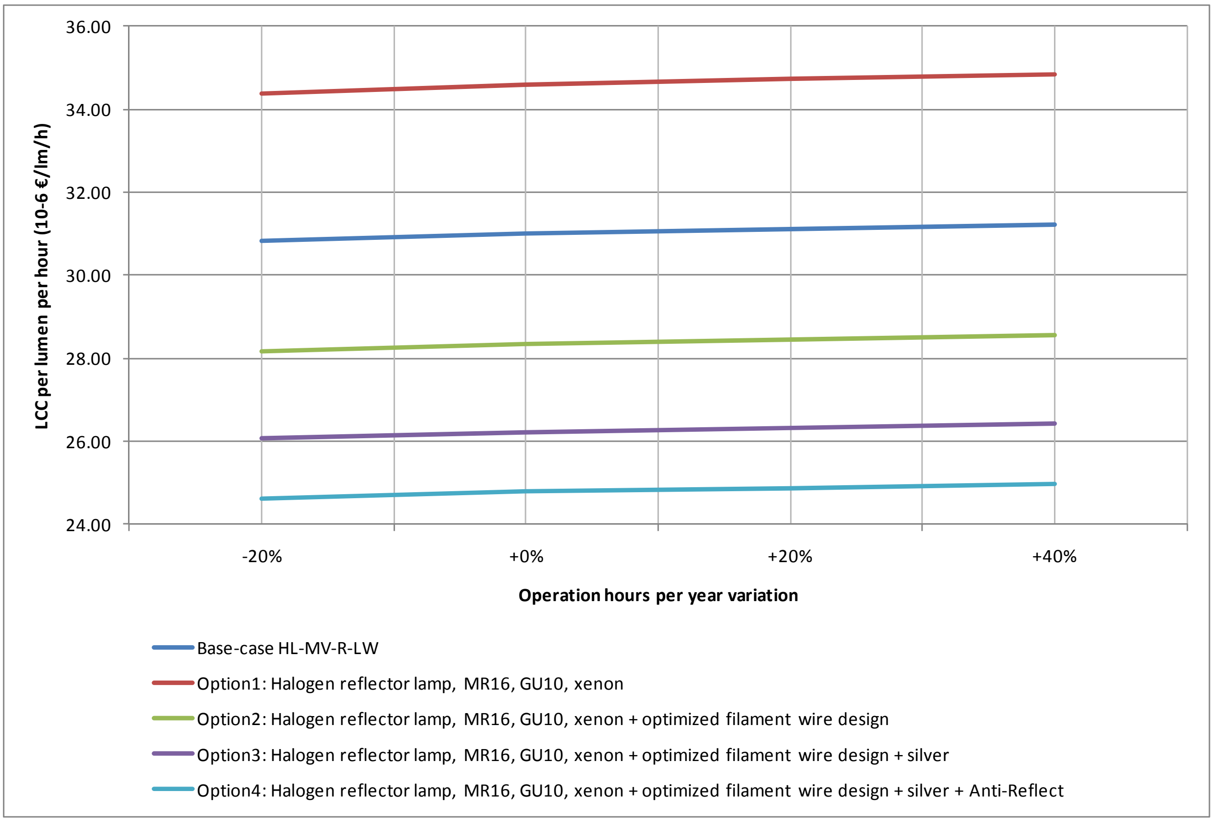

Figure 8.42: HL-MV-R-LW sensitivity of LCC to operational hours per year

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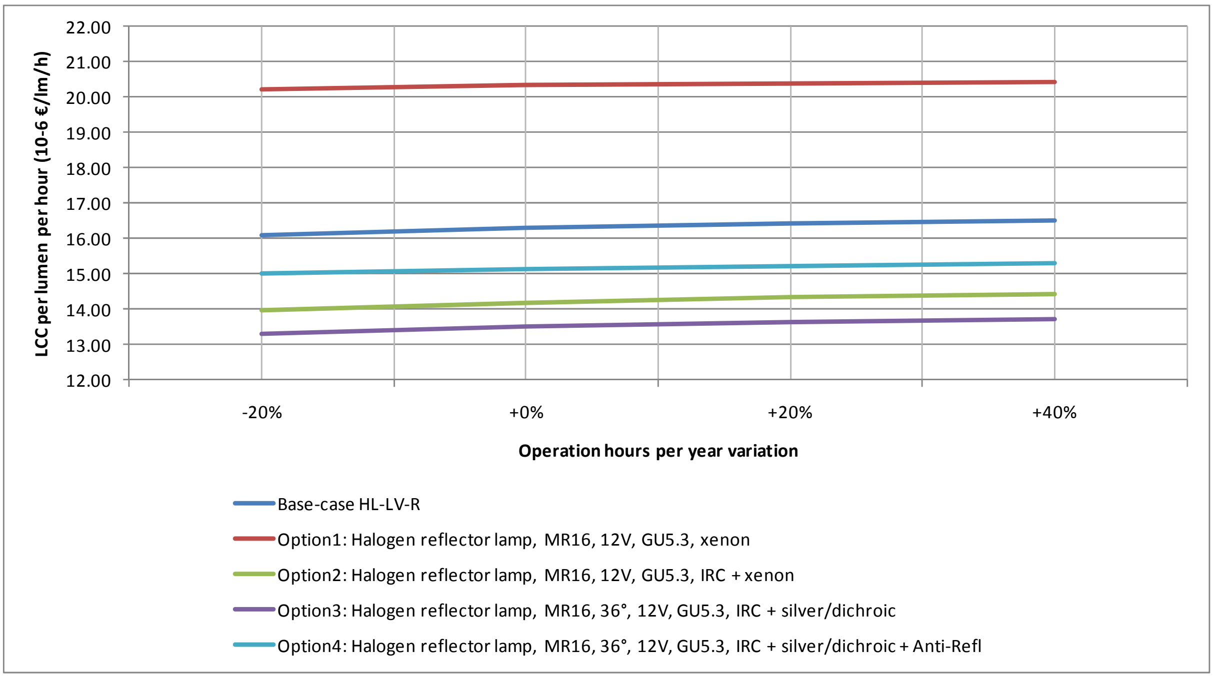

Figure 8.43: HL-LV-R sensitivity of LCC to operational hours per year

8.1.3.5 Assumptions related to behavioural lamp lifetime limit

The behavioural lamp lifetime limit is used because consumers often replace lamps due to renovations or redecorating, rather than at the end of lamp lifetime. Considering this, a preliminary value of 18 years was assumed. The sensitivity of this value is considered -20% (i.e. 14.4 years) / +40% (i.e. 25.2 years) in the following figures. Only the base-cases of GLS-R and HL-MV-R-HW show changes as their improvement options are restricted by the behavioural lifetime limit. The LLCC option of GLS-R base-case changes to the LEDi-R as behavioural lifetime increases, while HL-MV-R-HW has no change in LLCC option.

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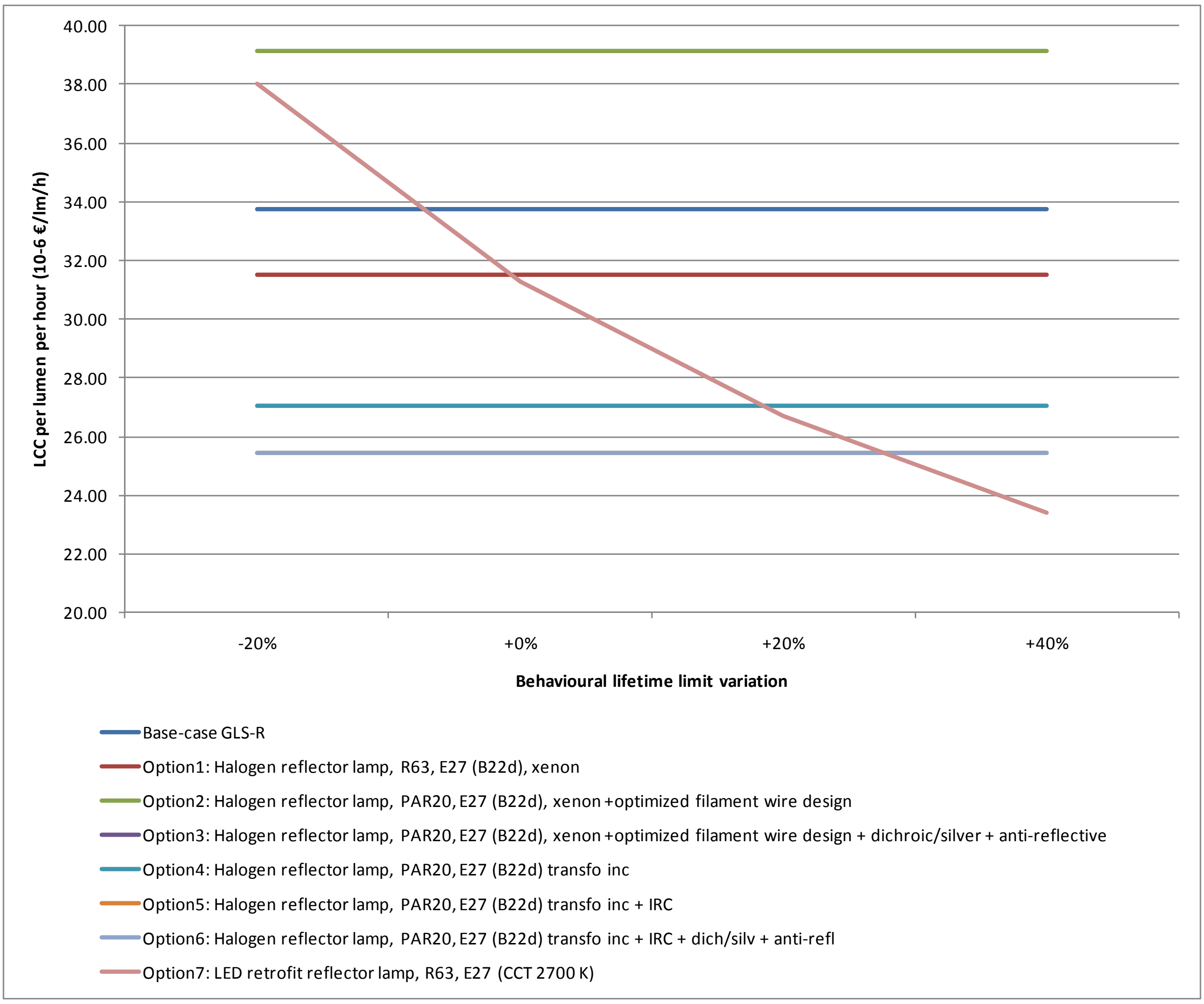

Figure 8.44: GLS-R sensitivity of LCC to behavioural lifetime limit variation

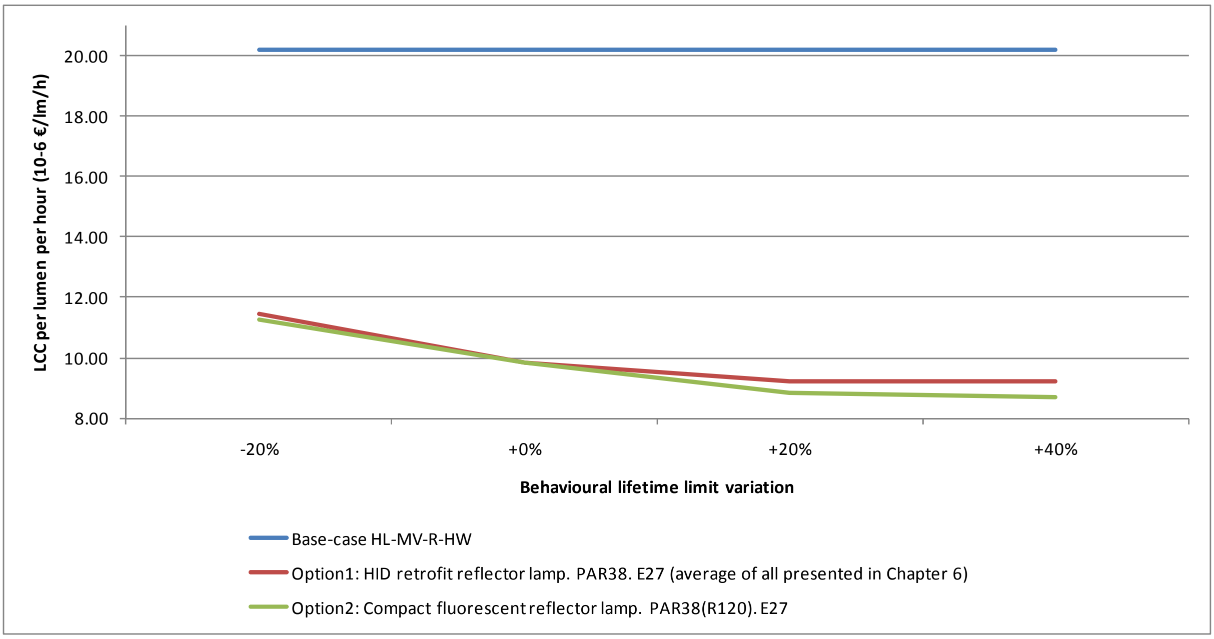

Figure 8.45: HL-MV-R-HW sensitivity of LCC to behavioural lifetime limit variation

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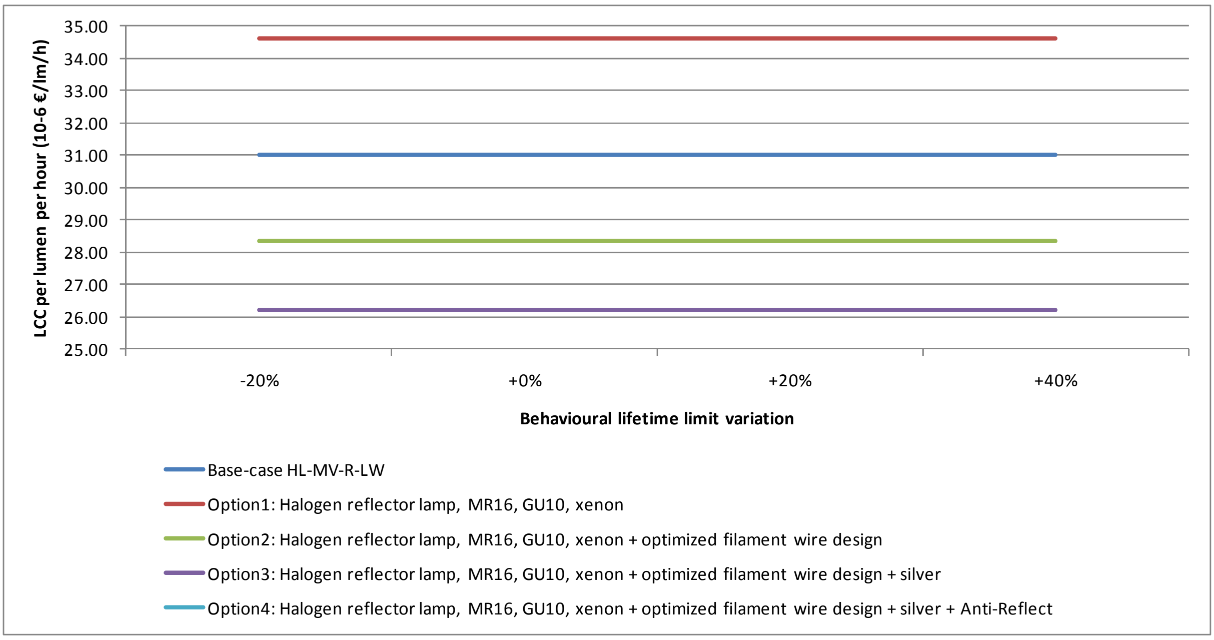

Figure 8.46: HL-MV-R-LW sensitivity of LCC to behavioural lifetime limit variation

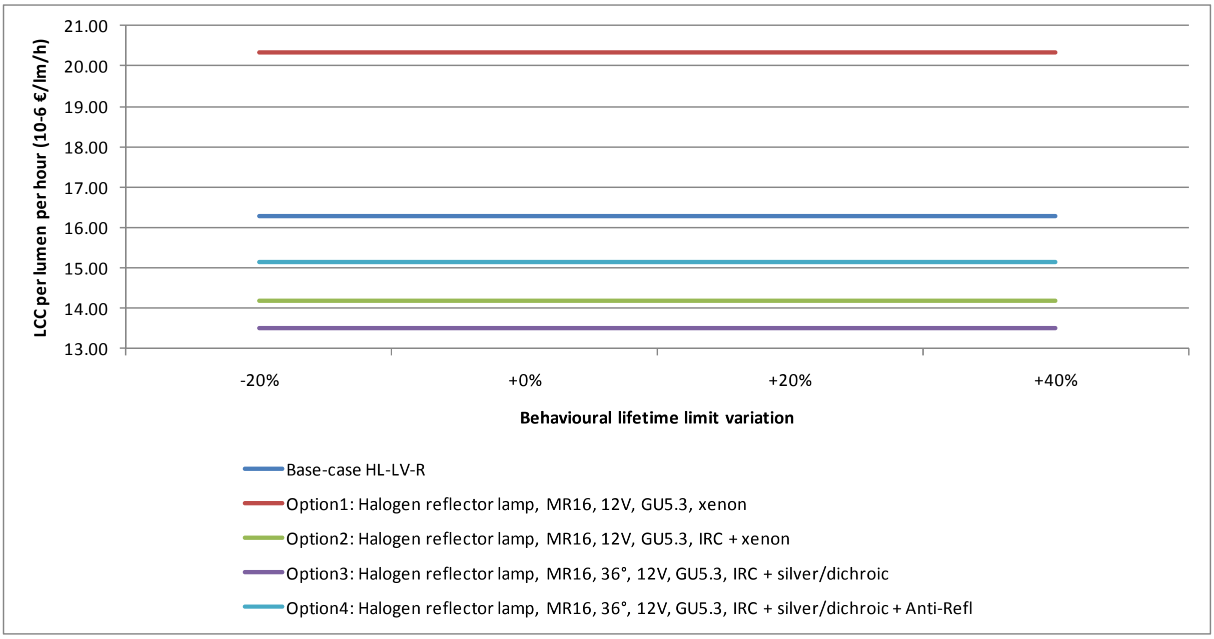

Figure 8.47: HL-LV-R sensitivity of LCC to behavioural lifetime limit variation

8.1.3.6 *Assumptions related to life-cycle impact and LCC of luminaire replacement due to lamp improvement*

As presented in Section 4.1.5, two EcoReport comparisons are conducted between a typical lamp and an alternative lamp requiring luminaire change.
In the first comparions, the lamps chosen were the base-case HL-MV-R-LW, and the HL-LV-R to accompany the replacement of the mains voltage luminaire by a low-voltage one

(Case1DLS). As the figures below show, the luminaire and lamp replacement offers reduced energy consumption by 34%, as well as decreased LCC by 20%.

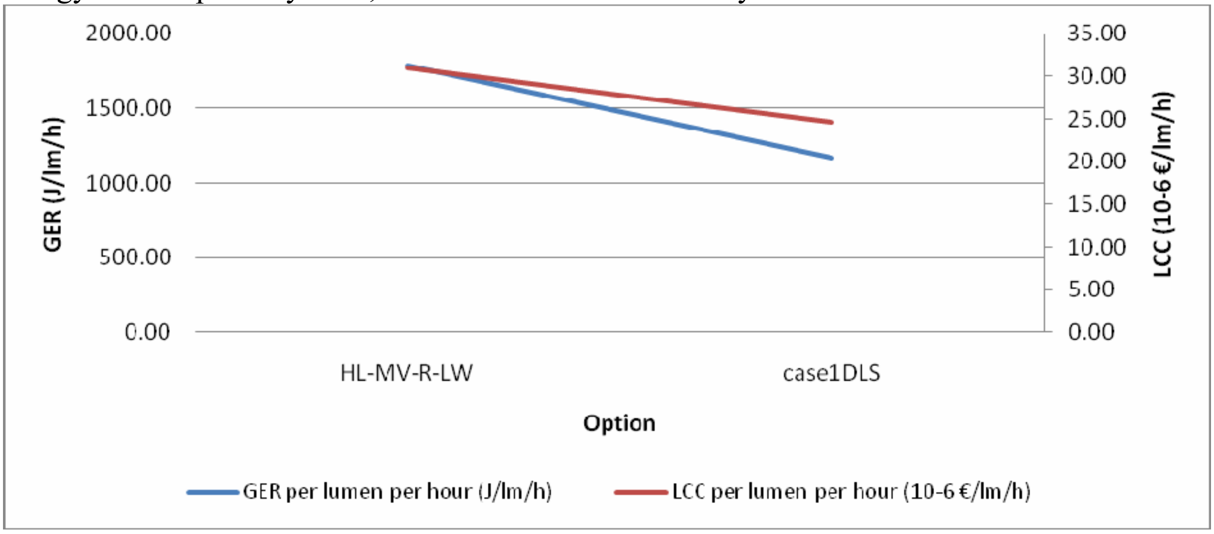

Figure 8.48: Lamp vs luminaire + lamp replacement, GER and LCC comparison

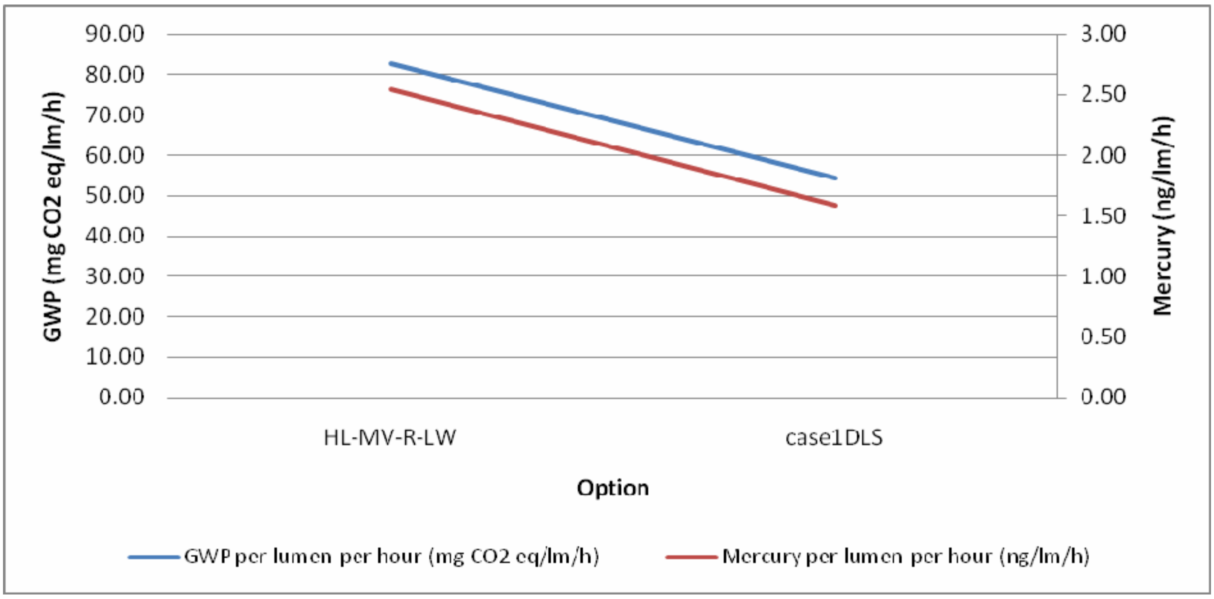

Figure 8.49: Lamp vs luminaire + lamp replacement, GWP and Mercury comparison

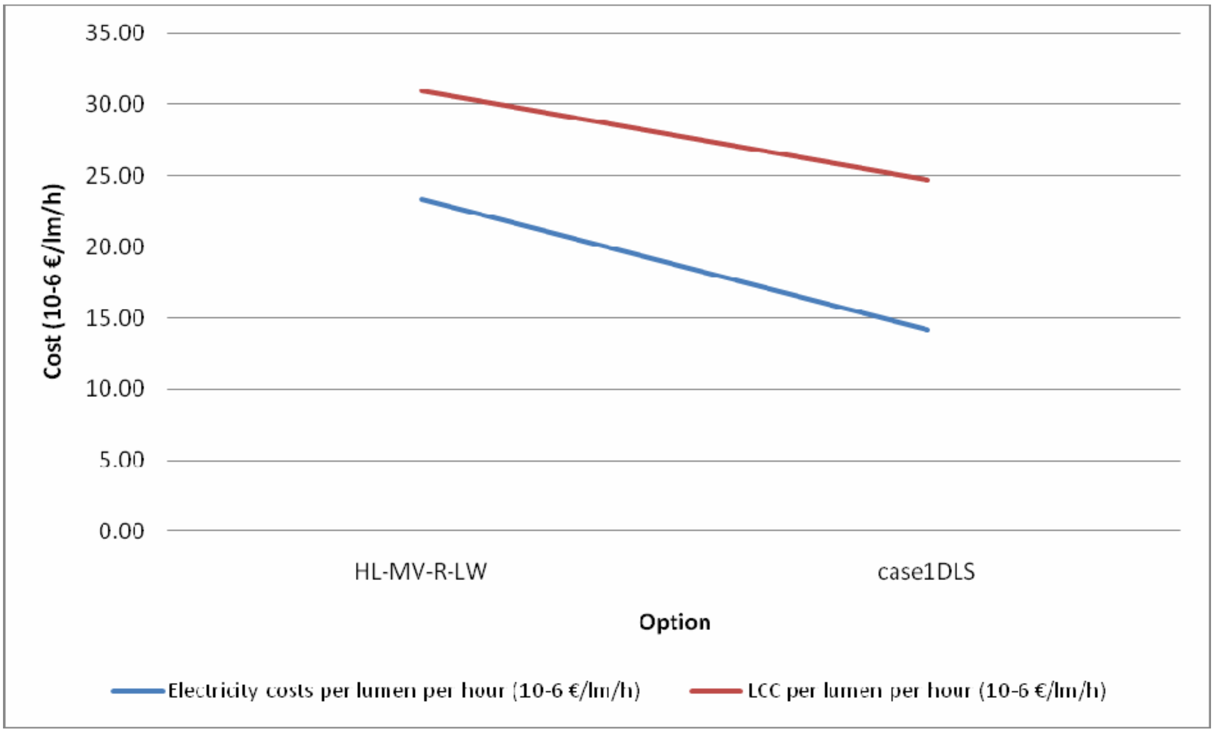

Figure 8.50: Lamp vs luminaire + lamp replacement, Electricity cost and LCC comparison

Table 8-17 shows a more detailed comparison of the environmental impacts. As the table shows, the replacement luminaire often causes increases in environmental impacts. The biggest increases include hazardous waste (+151%), PAHs (+208%), and eutrophication (+251%). This increases are due mainly to the production of materials needed to construct the luminaire.

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Table 8-18: Comparison of luminaire replacement option environmental factors

		Base-case HL-MV-R-LW	***Case 1 DSL***
main environmental indicators	**unit**	**value per lumen per hour**	**value per lumen per hour**
Total Energy (GER)	J	1783.70	1169.41
	variation with the base-case	0.00%	-34.44%
of which, electricity	J	1667.70	1046.13
	variation with the base-case	0.00%	-37.27%
Water (process)	µltr	111.77	77.71
	variation with the base-case	0.00%	-30.47%
Water (cooling)	µltr	4444.46	2788.94
	variation with the base-case	0.00%	-37.25%
Waste, non-haz./ landfill	µg	2165.96	1856.47
	variation with the base-case	0.00%	-14.29%
Waste, hazardous/ incinerated	µg	40.60	101.82
	variation with the base-case	0.00%	150.81%
Emissions (Air)			
Greenhouse Gases in GWP100	mg CO2 eq.	82.86	54.37
	variation with the base-case	0.00%	-34.38%
Acidifying agents (AP)	µg SO2 eq.	456.01	309.09
	variation with the base-case	0.00%	-32.22%
Volatile Org. Compounds (VOC)	ng	775.62	849.20
	variation with the base-case	0.00%	9.49%
Persistent Org. Pollutants (POP)	10^{-3} pg i-Teq	12.26	9.59
	variation with the base-case	0.00%	-21.75%
Heavy Metals (HM)	ng Ni eq.	35.89	27.96
	variation with the base-case	0.00%	-22.08%
PAHs	ng Ni eq.	8.88	27.32
	variation with the base-case	0.00%	207.68%
Particulate Matter (PM, dust)	µg	19.68	36.65
	variation with the base-case	0.00%	86.28%
Emissions (Water)			
Heavy Metals (HM)	ng Hg/20	11.49	15.39
	variation with the base-case	0.00%	33.95%
Eutrophication (EP)	ng PO4	80.15	281.42
	variation with the base-case	0.00%	251.14%

The second EcoReport comparison is conducted for an NDLS example. The lamps chosen were the base-case HL-MV-HW, and the LFL-T5 to accompany the replacement of the halogen luminaire by a fluorescent one. As the figures below show, the luminaire plus lamp replacement results in significantly lower energy use (-81%)and LCC (-70%). Mercury emissions are also reduced by 64%, despite the embedded mercury within the fluorescent lamp.

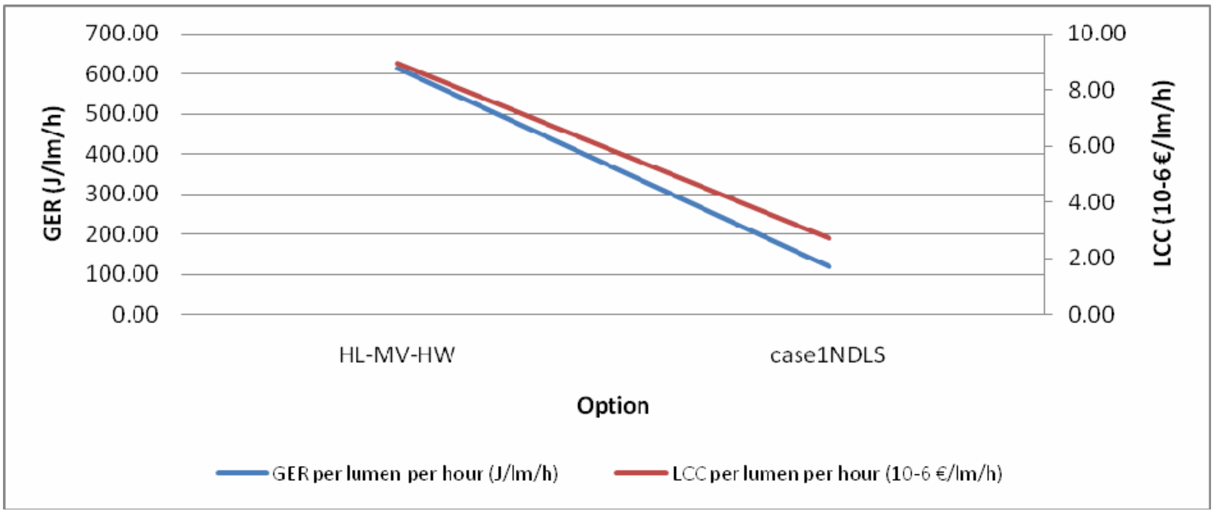

Figure 8.51: Lamp vs luminaire + lamp replacement, GER and LCC comparison

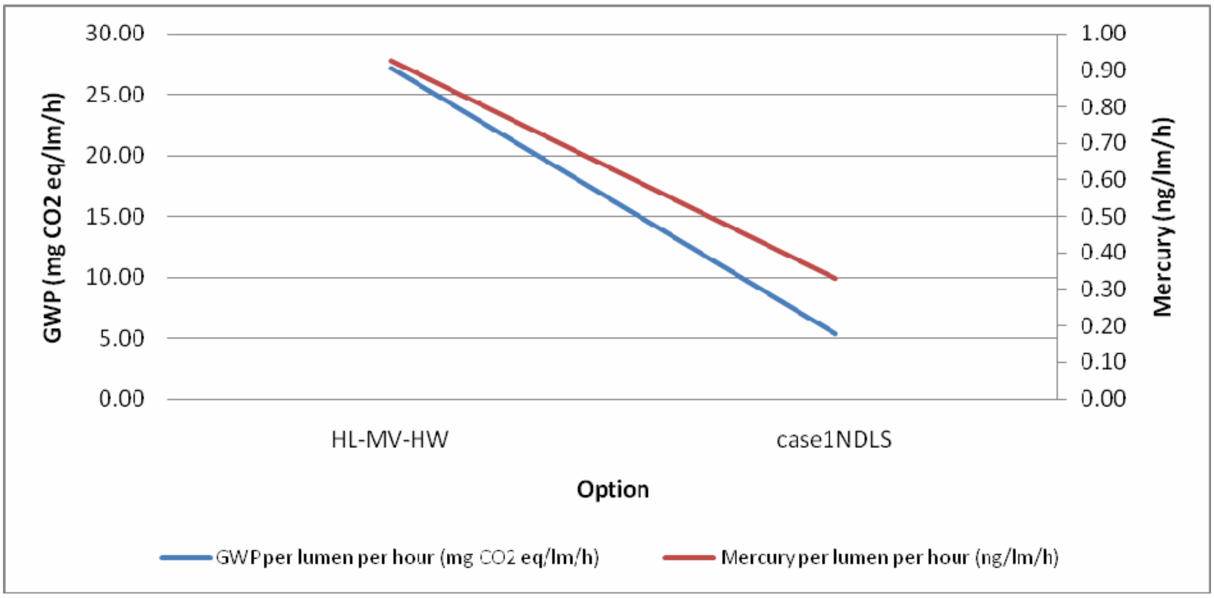

Figure 8.52: Lamp vs luminaire + lamp replacement, GWP and Mercury comparison

DISCLAIMER: The statements, figures and graphs provided on this page have to be read in the context set out in the beginning of section 8.1.2 and in sections 8.1.2.1 and 8.1.2.2

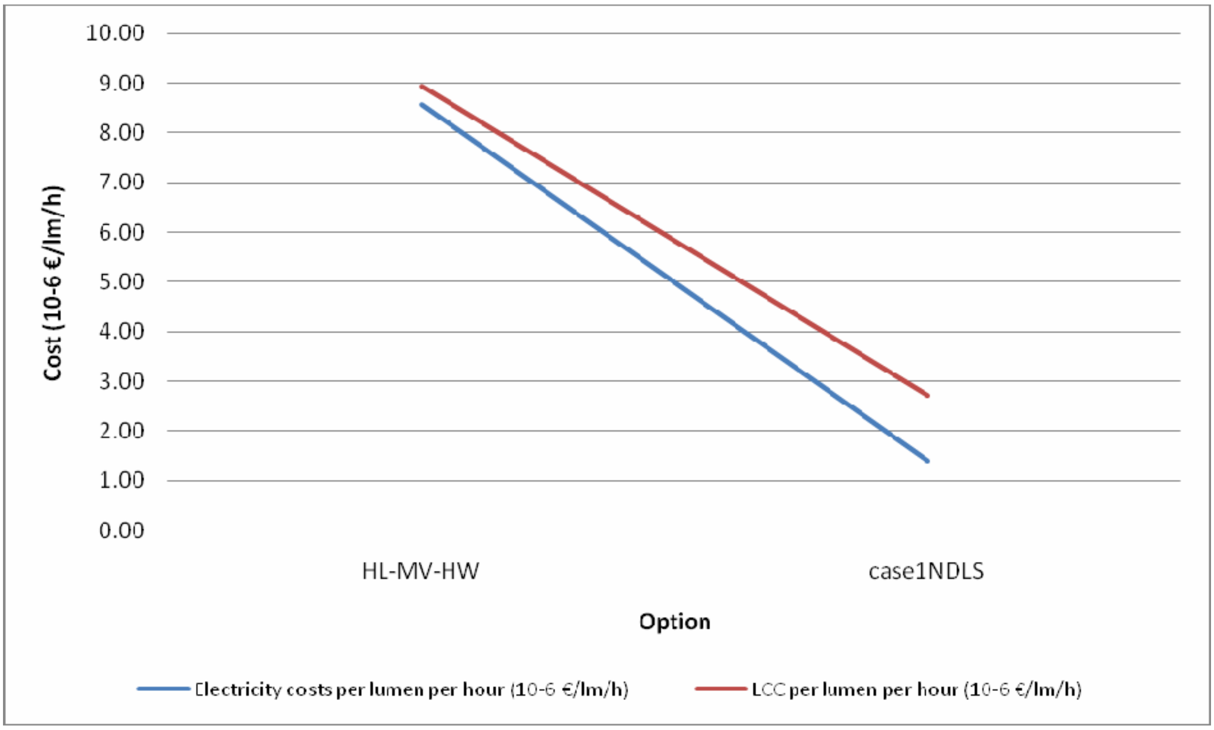

Figure 8.53: Lamp vs luminaire + lamp replacement, Electricity cost and LCC comparison

Table 8-19 shows a more detailed comparison of the environmental impacts. As the table shows, the replacement luminaire causes decrease in environmental impacts of around 60-80% for all categories except PAHs (-36%), Particulate Matter (-38%), and Eutrophication (-24%), which is due to environmental impacts from production.

Table 8-19: Comparison of luminaire replacement option environmental factors

		Base-case HL-MV-R-LW	***Case 1 NDSL***
main environmental indicators	**unit**	**value per lumen per hour**	**value per lumen per hour**
Total Energy (GER)	J	615.22	118.37
	variation with the base-case	0.00%	-80.76%
of which, electricity	J	608.48	113.17
	variation with the base-case	0.00%	-81.40%
Water (process)	µltr	40.57	7.79
	variation with the base-case	0.00%	-80.80%
Water (cooling)	µltr	1622.56	301.67
	variation with the base-case	0.00%	-81.41%
Waste, non-haz./ landfill	µg	713.54	166.23
	variation with the base-case	0.00%	-76.70%
Waste, hazardous/ incinerated	µg	14.15	5.67
	variation with the base-case	0.00%	-59.96%
Emissions (Air)			
Greenhouse Gases in GWP100	mg CO2 eq.	27.14	5.32
	variation with the base-case	0.00%	-80.40%
Acidifying agents (AP)	µg SO2 eq.	158.24	30.60
	variation with the base-case	0.00%	-80.66%
Volatile Org. Compounds (VOC)	ng	236.44	64.11
	variation with the base-case	0.00%	-72.89%
Persistent Org. Pollutants (POP)	10^{-3} pg i-Teq	4.04	1.03
	variation with the base-case	0.00%	-74.48%
Heavy Metals (HM)	ng Ni eq.	10.80	2.45
	variation with the base-case	0.00%	-77.30%
PAHs	ng Ni eq.	1.54	0.99
	variation with the base-case	0.00%	-35.70%
Particulate Matter (PM, dust)	µg	3.55	2.21
	variation with the base-case	0.00%	-37.65%
Emissions (Water)			
Heavy Metals (HM)	ng Hg/20	3.94	1.03
	variation with the base-case	0.00%	-73.96%
Eutrophication (EP)	ng PO4	19.26	14.68
	variation with the base-case	0.00%	-23.79%

Impact related to 'lamp' vs 'luminaire + lamp replacement' NDLSAs presented in Section 6.1.8, an EcoReport comparison is conducted between a luminaire with HL-LV-R and a luminaire with LED. As the figures below show, the LED offers significantly reduced energy consumption by 80%, as well as decreased LCC by 42%.

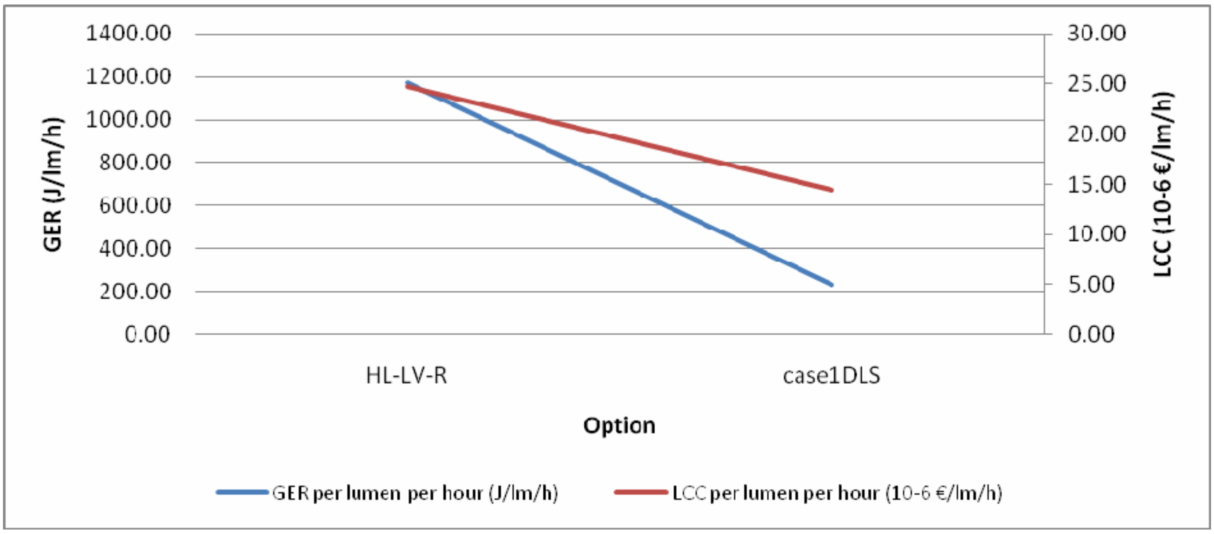

Figure 8.54: Lamp vs luminaire + lamp replacement, GER and LCC comparison

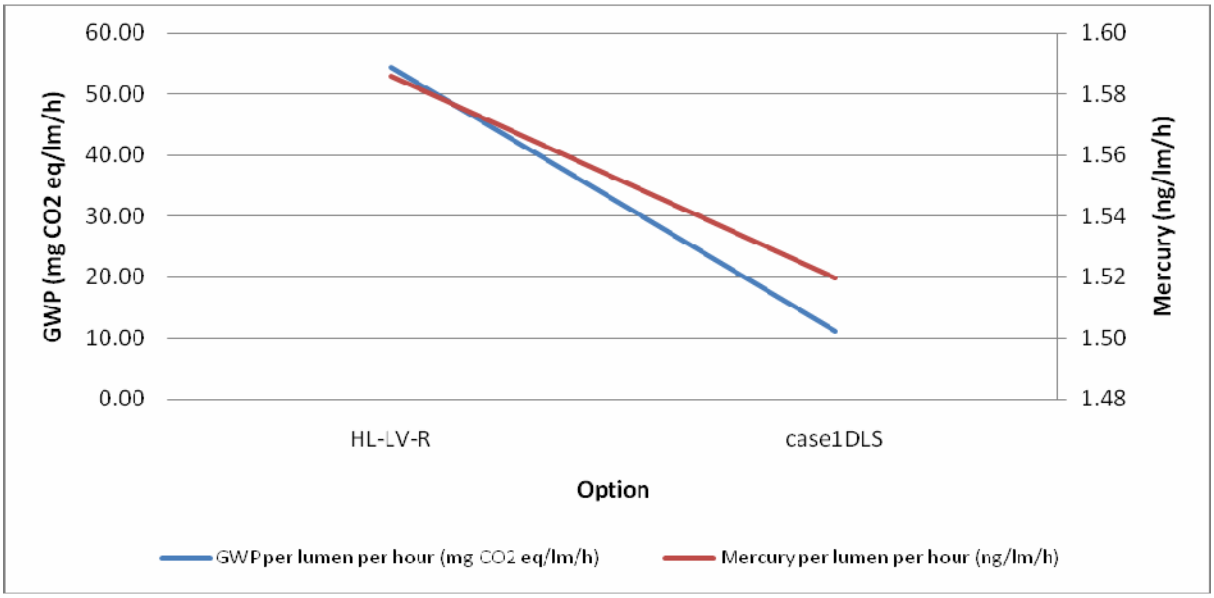

Figure 8.55: Lamp vs luminaire + lamp replacement, GWP and Mercury comparison

DISCLAIMER: The statements, figures and graphs provided on this page have to be read in the context set out in the beginning of section 8.1.2 and in sections 8.1.2.1 and 8.1.2.2

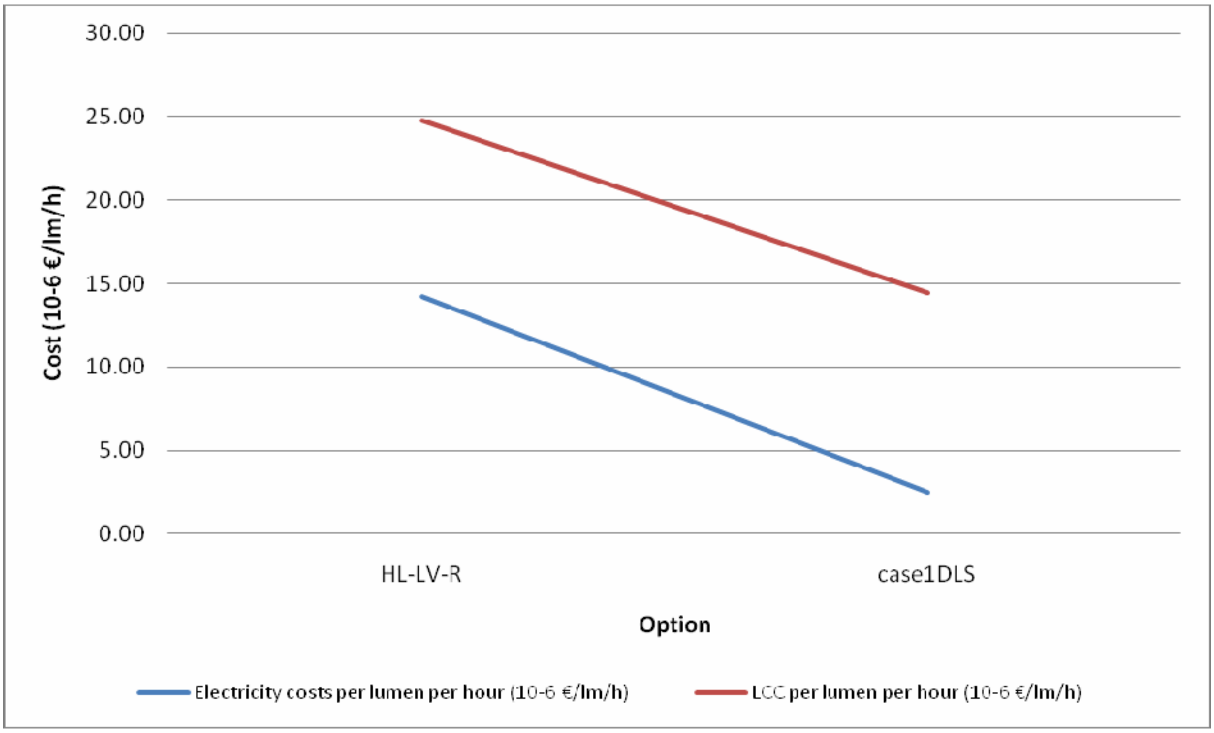

Figure 8.56: Lamp vs luminaire + lamp replacement, Electricity cost and LCC comparison

Table 8-23 shows a more detailed comparison of the environmental impacts. As the table shows again, environmental impacts are reduced significantly, roughly between 75% and 90%, except for POPs at 47% reduction.

DISCLAIMER: The statements, figures and graphs provided on this page have to be read in the context set out in the beginning of section 8.1.2 and in sections 8.1.2.1 and 8.1.2.2

Table 8-20: Comparison of luminaire replacement option environmental factors

		Base-case HL-MV-R-LW	***Case 1 DSL***
main environmental indicators	**unit**	**value per lumen per hour**	**value per lumen per hour**
Total Energy (GER)	J	1169.41	234.64
	variation with the base-case	0.00%	-79.94%
of which, electricity	J	1046.13	207.32
	variation with the base-case	0.00%	-80.18%
Water (process)	µltr	77.71	15.17
	variation with the base-case	0.00%	-80.49%
Water (cooling)	µltr	2788.94	546.72
	variation with the base-case	0.00%	-80.40%
Waste, non-haz./ landfill	µg	1856.47	474.28
	variation with the base-case	0.00%	-74.45%
Waste, hazardous/ incinerated	µg	101.82	23.55
	variation with the base-case	0.00%	-76.87%
Emissions (Air)			
Greenhouse Gases in GWP100	mg CO2 eq.	54.37	11.20
	variation with the base-case	0.00%	-79.40%
Acidifying agents (AP)	µg SO2 eq.	309.09	60.33
	variation with the base-case	0.00%	-80.48%
Volatile Org. Compounds (VOC)	ng	849.20	139.21
	variation with the base-case	0.00%	-83.61%
Persistent Org. Pollutants (POP)	10^{-3} pg i-Teq	9.59	5.05
	variation with the base-case	0.00%	-47.37%
Heavy Metals (HM)	ng Ni eq.	27.96	6.74
	variation with the base-case	0.00%	-75.89%
PAHs	ng Ni eq.	27.32	2.61
	variation with the base-case	0.00%	-90.46%
Particulate Matter (PM, dust)	µg	36.65	11.16
	variation with the base-case	0.00%	-69.56%
Emissions (Water)			
Heavy Metals (HM)	ng Hg/20	15.39	3.48
	variation with the base-case	0.00%	-77.39%
Eutrophication (EP)	ng PO4	281.42	60.28
	variation with the base-case	0.00%	-78.58%

8.1.4 Suggested additional requirements for appropriate implementation

Important notice: please note that these recommendations are not in the direct scope of the EuP directive implementing measures they should be seen as input and recommendations to potential other EU policies and legislation.

8.1.4.1 Additional recommendations for lamp labelling (Directive 98/11/EC)

These recommendations aim to initiate a revision of the existing Directive 98/11/EC of 27 January 1998 implementing Council Directive 92/75/EEC with regard to energy labelling of household lamps.

It is recommended that the labelling also includes:

- lamps not operated on the mains voltage;
- reflector lamps or directional light sources as defined in part 2 of this study (LED modules or luminaires could be voluntary for reducing administrative impact that could hamper the introduction of these new technologies that frequently changes in performance);
- the lamp lumen maintenance factor (also for non-directional light sources). This can be done easily by introducing a correction factor (e.g. x0,87) for the nominal luminous flux.

It could also be considered to lower the efficacy requirements for DLS lamps with a very narrow beam angle (<20 °, <10 °) because it is optical slightly more difficult to produce them, ELC[224] is working on such a proposal. Nevertheless these small beam angles are not frequently used by the general public and might complicate the label system unneeded and might overly promote narrow beam lamps. Therefore this approach should be discussed with all stakeholders.

It is recommended to redefine the label minimum requirements in order to:

- introduce a label between the current B and A as the gap between both is too large (see Figure 8-53 where level 5 = B and level 7 = A);
- streamline the A-label formula with the B label formula as done hereafter;
- have more ambitious labels compared to A;

Please note that the equivalent 'levels' used in this study are intended for this study alone, the debate on the revision and the format of the label is outside the scope of this preparatory study on the Ecodesign Directive 2005/32/EC. The levels used in part 2 are equivalent to those of part 1 for reasons of comparison. In principle the levels used in this study are to the extent possible similar to those in the current Labelling Directive 98/11/EC as applicable in 2009.

The used energy levels in this study are presented in Table 8-23 and they are graphically shown in Figure 8-53.

[224] www.elcfed.org

Table 8-21: New definition of lamp efficacy levels used in this study part 2

Level (this study)	**Maximum system power demand (P_{system}) related to lamp' corrected' luminous flux (ΦR) [W]**		**Minimum light source efficacy (including control gear losses) $\eta_{source} = \Phi R / P_{system}$ [lm/W]**	
	Y factor			
G	>1,30			
F	1,30		ΦR / 1,30	
E	1,10		ΦR/ 1,10	
D	0,95		ΦR / 0,95	
C	0,80		ΦR/ 0,80	
B	0,6	x (0,88√ΦR+0,049ΦR)	ΦR / 0,6	x 1/(0,88√ΦR + 0,049ΦR)
B (B+)*	0,4		ΦR / 0,4	
A *	0,225		ΦR / 0,225	
A (A+)*	0,209		ΦR / 0,209	
A (A++)*	0,178		ΦR / 0,178	
A (A+++)*	0,116		ΦR / 0,116	

*It must be noted that the formula for the current label **A** as defined in Directive 98/11/EC does not completely correspond with the proposed new formula, but the difference is very small (the current formula is 0.24√Φ+0.0103Φ).*

For evaluation of efficacy, it is proposed to use a similar approach as Commission Regulation (EC) No 244/2009 that uses a formula imposing a maximum rated system power Pmax system [W] in the case of DLS lamps for the corrected luminous flux (ΦR) [lm]:

$$\text{‘}P_{max\ system} = Y * (0,88\sqrt{\Phi R}+0,049\Phi R)\text{’}$$

wherein Y is a constant depending on the level.

The corrections to obtain P max system from Plamp and how to obtain ΦR from the lamp luminous flux are explained in the section on the proposed minimum efficacy requirements, see section 8.1.1.5 for all details.

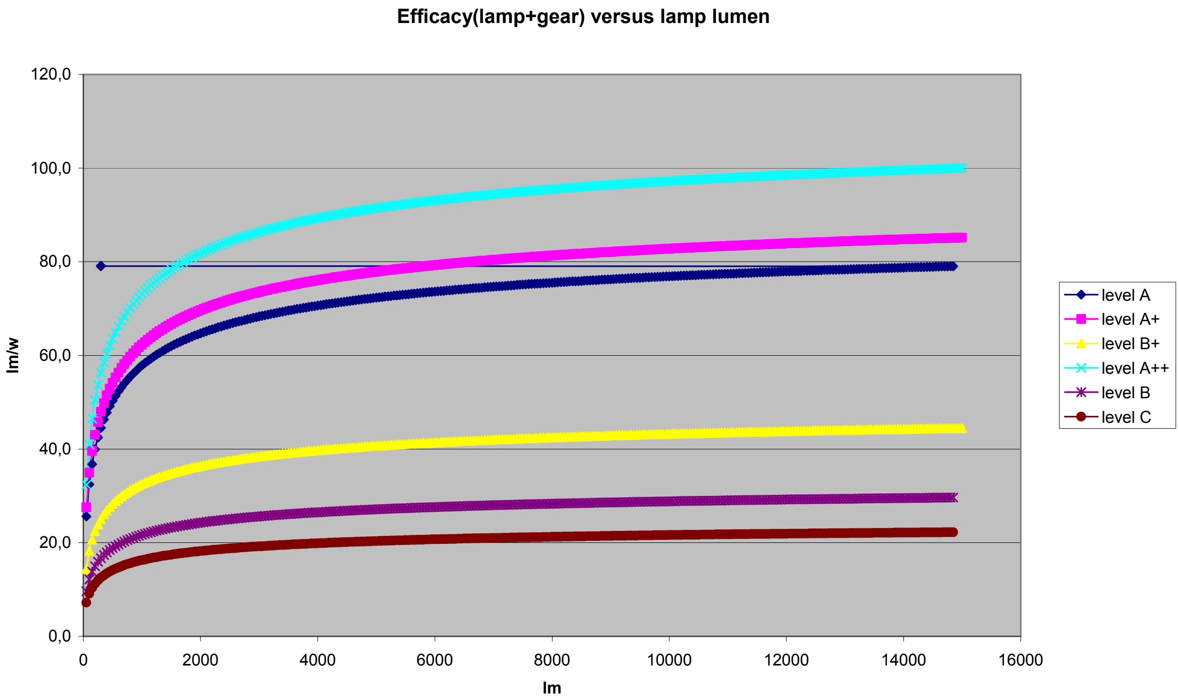

Figure 8.57: Defined lamp efficacy levels 4 - 9

A table with corresponding values per defined lamp efficacy level is included in part 1 of this study.

Table 8-22: Examples of efficacy levels for existing lamp types

Factor Y In formula	Proposed level (this study)	Example for domestic lighting	
Y>1,3	G		GLS-R HL-MV-R
Y≤1,3	F		HL-MV-R
Y≤1,1	E		GLS-MV-R HL-MV-R-HW HL-LV-R
Y≤0,95	D		HL-MV-R (B*N*AT)
Y≤0,8	C		HL-MV-R-transfo inc HL-LV-R
Y≤0,6	B		HL-MV-R-transfo inc (B*N*AT) HL-LV-R (BAT) CFLi-DLS(R63) as retrofit and non retrofit
Y≤0,4	B (B+)[*]		HIDi-R CFLi-DLS (R120 or B*N*AT) as retrofit LED-MV-i-R
Y≤0,225	A		
Y≤0,209	A (A+)[*]		LED-MV-i-R
Y≤0,178	A (A++)[*]		None
Y≤0,116	A (A+++)[*]		None

Annex 8.6 contains the DLS lamp data used in part 2 of this study with their corresponding levels. Figure 8.58 and Figure 8.59 contain a graphical representation with the level related Y factor for various lamp groups. The data were otained from ELC members, Megaman, www.olino.org and photometric files from websites and processed in cooperation with UBA (www.uba.de)), product overview data are presented in Figure 8.60 and Figure 8.61.

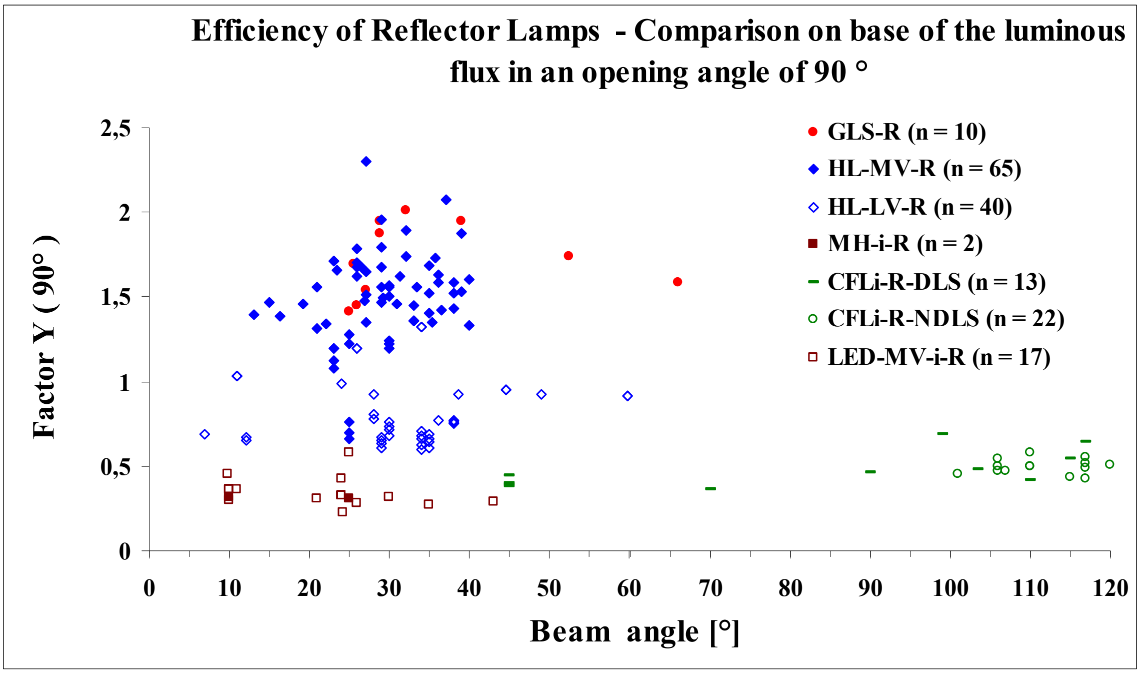

Figure 8.58: Factor Y related to levels for various DLS lamps calculated with luminous flux in an opening angle of 90 °.

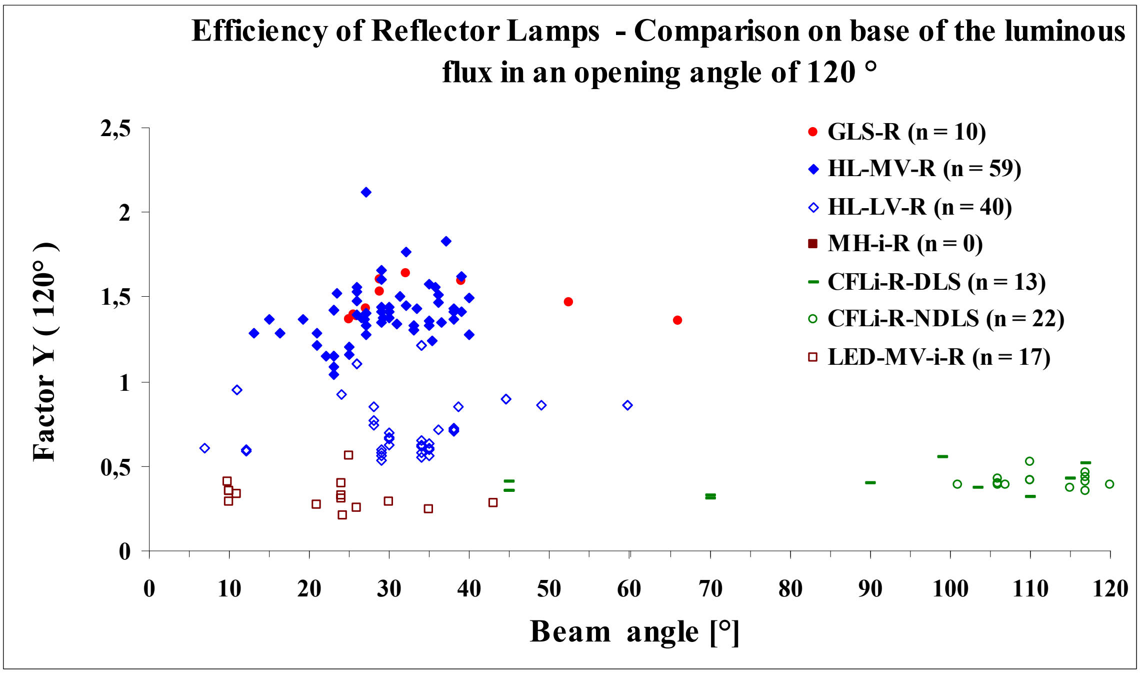

Figure 8.59: Factor Y related to levels for various DLS lamps calculated with luminous flux in an opening angle of 120 °.

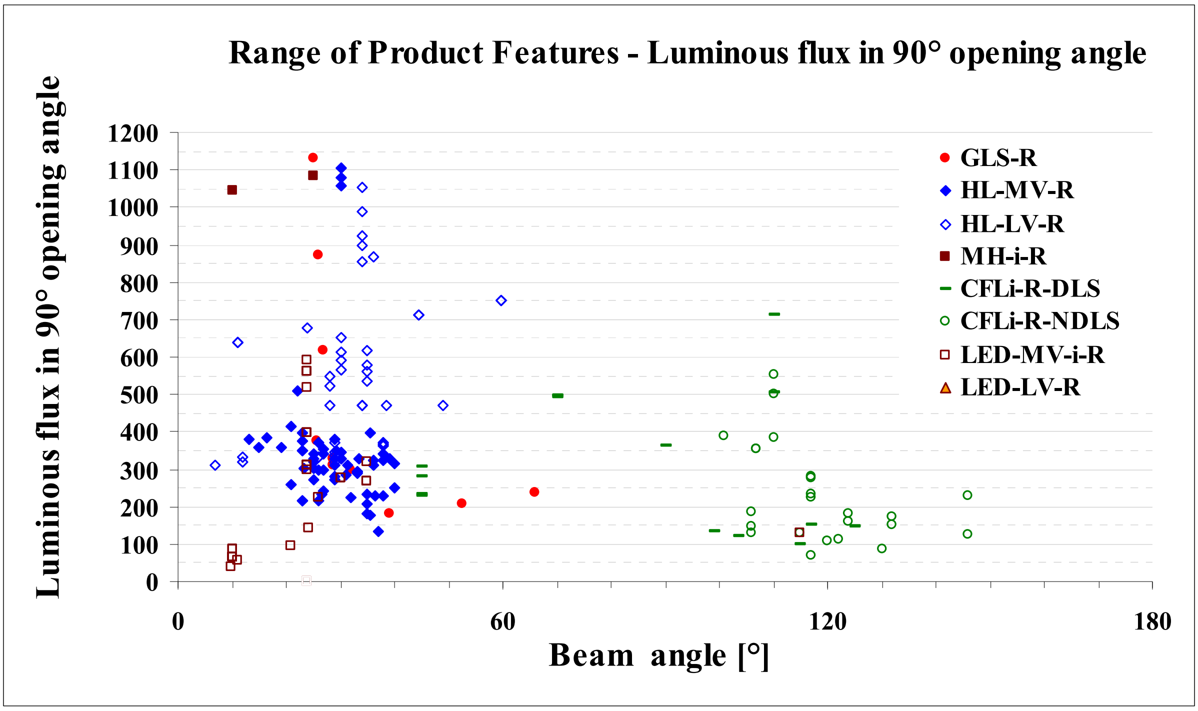

Figure 8.60: Range of data otained from ELC members, Megaman , Olino and photometric files from websites used in previous figure(processed in cooperation with UBA (www.uba.de))

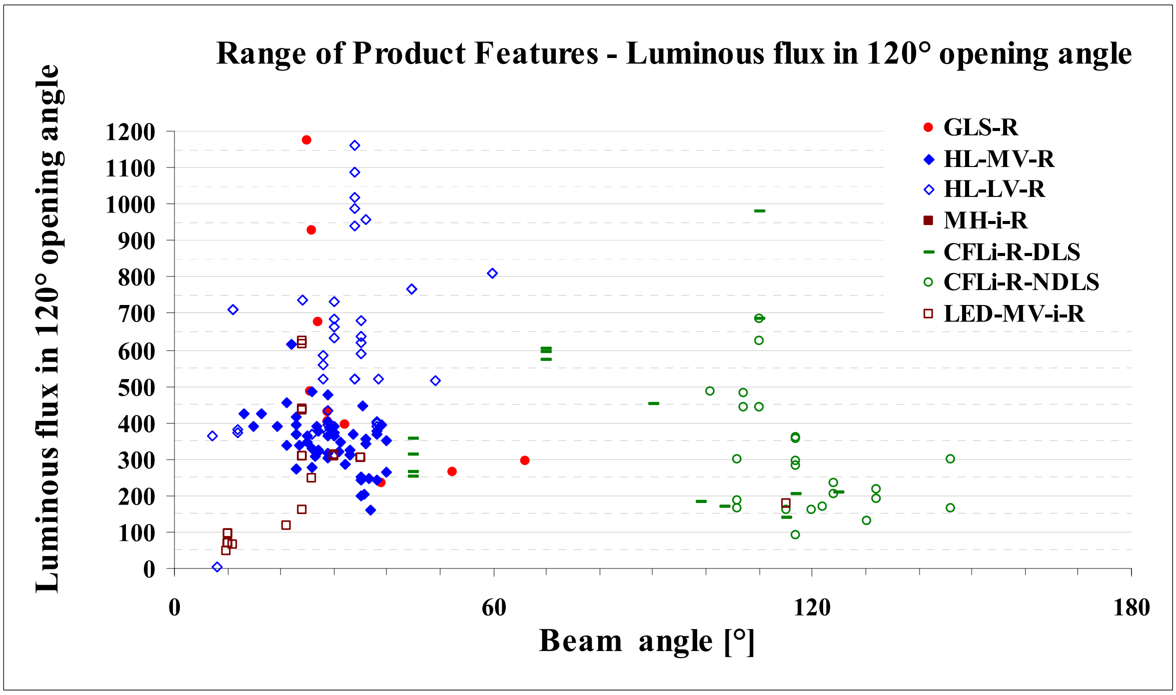

Figure 8.61: Range of data otained from ELC members, Megaman , Olino and photometric files from websites used in previous figure(processed in cooperation with UBA (www.uba.de))

8.1.4.2 Recommendations to promote the most efficient luminaires for general illumination with a voluntary ecolabel or as bench mark values

It is recommended to introduce an ecolabel or other voluntary labelling for the most efficient luminaires, this will facilate horizontal promotional campaigns and rebate programmes (see 8.1.4.3 and 8.1.4.4).
The proposed ecolabel criteria (see Table 8-23) are connected to the luminaire improvement options as discussed in chapter 6. However it is proposed to limit the ecolabel to luminaires that have photometric data available and as a consequence LOR or LER criteria are proposed. Please note that for the tertiary sector similar but often stronger proposals were made in lot 8 and 9 for office and street lighting.
The 'Minimum lock-in label' means that it is proposed to limit the label to those luminaires that have a positive lock-in effect as discussed in chapter 6, e.g. incorporated ballast for CFLni (minimum A label) or incorporated transformer (minimum B label).

Table 8-23: Proposed criteria for awarding an ecolabel to domestic luminaires

	Non LED		LED						
Category of luminaires	min. lock-in label	LOR	LER	Light in phi (120°) CEN flux code N2	DLOR	motion sensor	day/night sensor	dimmer incorporated	dimmer compatible
		%	lm/W	%	%				
Downlights (recessed mounted)	A	80	45	≥80	99	n	n	n	n
Suspension (chandeliers)-D	A	75	45		≥80	n	n	n	y
Suspension (chandeliers)-DLS	A	70	40	≥80	>50	n	n	n	y
Suspension (chandeliers)-DI	A	80	50		<80	n	n	n	y
wall&ceiling	A	70	40	-	-	n	n	n	n
wall&ceiling (uplighter)	A	80	50	-	-	y	n	n	n
Desk	A	70	40	-	-	n	n	n	n
Table	A	70	40	-	-	n	n	y	n
Floor -D or -DI	A	75	45	-	>80	n	n	y	-
Floor-I (uplighter)	A	85	55	-	≤80	n	n	y	-
Spotlights	B(CRI>90) or A	80	30	≥80	95	n	n	n	y
Outdoor -B	B(CRI>90) or A	80	30	≥80	95	y	y	n	y
Outdoor -A	A	70	40	-	95	n	n	n	y

note: D=Direct I = Indirect lighting

Moreover these luminaires should be free of hazardous material, designed for recycling and contain cleaning and maintenance instructions.

Please note that these LOR/LER criteria could be reviewed when more market data is available, see recommendations for further R&D. Alternatively, the LOR requirement could be temporally exempted for designs that strictly follow the suggested design guide and use the highest grades of optical materials as long as insufficient goniophotometers are available for measurement.

Notes:
The discussion of the Ecolabel is outside the scope of the EuP directive implementing measure. Please note that the manufacturers association CELMA did not support having such a voluntary ecolabel.
However, this proposal should be seen as complementary to the potential weakness of the proposed generic ecodesign requirements for luminaires and the proposal to exempt luminaires from minimum efficacy requirements at system level.

8.1.4.3 Recommendations to introduce rebate programmes for the replacement of luminaires with lamp sockets G9 or GU10

It is recommended to focus rebate programmes on those luminaire categories that show a large lock-in effect with G9 and GU10 lamp sockets and are not easy to replace. For more details consult the relevant sections on luminaire lock-in effect as described in chapter 3.

Desk, Table and Floor luminaires have a plug and can easily be replaced by the end users themselves. Hence the retrofit cost is low and the focus should be on the other categories of luminaires, especially downlights or spotlights.

8.1.4.4 Recommendations to introduce a voluntary quality label for LED lighting

Section 8.1.1.4 describes the minimum requirements for LED lighting.
These requirements can avoid barriers for sales of LED due to bad consumer experience with LED lamps/luminaires.
A new European quality label for LED lighting should include those minimum requirements, as well as other or stronger requirements to improve quality and consumer acceptance can be added. Such a voluntary quality label can also be introduced in case of weak minimum ecodesign requirements, especially to be considered for LED luminaires.

8.1.4.5 Awareness campaign for luminaire or lighting designers and end users

In order to have a maximum effect it is recommended to create an awareness campaign about the proposed ecodesign requirements in section 8.1.1.8 towards luminaire and lighting designers. Complementary to this campaign it is important to collect feedback in order to improve and update any further requirement. Lighting comfort is a very subjective parameter and on the other hand it is closely related to design and art, therefore the future role of designers cannot be underestimated. Potential awareness campaigns are: luminaire design competitions, interior design competitions (e.g. restaurants, living room, kitchen, ..), stimulate art expositions with efficient lighting, ..

8.1.4.6 Warning about a potential direct rebound effect caused by the introduction of new energy efficient lighting (e.g. LED)

See part 1.

8.1.4.7 Reduced impact caused by lack of market surveillance and loopholes in legislation

See part 1.

8.1.4.8 Complementary recommendations on users information, product developers and service providers skills

See part 1.

8.1.4.9 Complementary recommendations on policy actions to smoothen market transformation and lamp sales

See part 1.

8.1.4.10 Complementary recommendations on policy actions to increase mercury recycling

See part 1.

8.1.4.11 Warning on comparing US with EU minimum lamp efficacy targets

See part 1.

8.1.4.12 Complementary recommendations to reduce the sensitivity of lighting to line voltage variations

See part 1.

8.1.4.13 Complementary recommendations to reduce negative impact from UV radiation

See part 1.

8.1.4.14 Complementary recommendations to reduce barriers for SMEs and market surveillance authorities by improving access to EN standards and standards development related to eco-design requirements

See part 1.

8.1.4.15 Recommendations for the revision

A revision period of 4 years is recommended. Special attention should be given to LED light sources and luminaires because of the fast evolution in this market.

There is also a broad range of products on the market and the legislation might need exemptions for special applications. Some lamp types might be banned accidentally but are needed for a certain application.

Some inefficient lamp exemptions (e.g. GU10) might be initially allowed and might become obsolete when more efficient retrofits become available. Therefore an earlier revision might be needed, e.g. 2013.

The definition of Ra (colour rendering) is currently under revision, especially for LED products. When a new definition is available an update might be needed.

After R&D of domestic luminaires (see section 8.1.5) updated luminaire requirements might be considered, e.g. 4 years on the condition of supported R&D in the field.

8.1.5 Suggested additional research

This study has been made with the few luminaire performance data and user application data available. As a consequence the proposed measures might be weak for some end users beause no measurable or strict luminaire efficiency information or minimum performance requirements are imposed. However the affected industry expressed its concern about potential negative impact, when luminaire photometric measurements and/or minimum LOR requirements are imposed. Therefore it is recommended to further study user behaviour and the possibilities to measure application parameters for domestic luminaires.

See also part 1.

8.1.6 Required new or updated measurement or product standards

None of the existing EN or IEC lamp standards refer specifically to reflector lamps; it should be proposed to complete these standards (see chapter 1).

Standard EN 13032 (*Lighting applications — Measurement and presentation of photometric data of lamps and luminaires)* should be adapted by introducing a system power measurement P_{system} [W] in operational conditions together with the LOR measurement; for luminaires that can house different lamp types, it is also necessary to do the measurents for all these types.

Standard EN 12665 (*Light and lighting - Basic terms and criteria for specifying lighting requirements)* should be revised by introducing requirements for the lamp lumen maintenance in the definition of the lifetime.

It becomes urgent to draw up standards for LED light sources, especially for the sources that claim to retrofit GLS and halogen lamps, to avoid the introduction of incompatible and low quality products that could create aversion against energy efficient solutions. A start was already taken by introducing a draft EN 62612 (see chapter 1).
In this draft, the definition of lifetime is not only based on LSF as in other lamp standards; lifetime in this draft standard also takes into account the lumen maintenance (LLMF) of the lamp. It should be suggested to introduce this principle in the existing standards for other lamp types.

More guidance is needed to clarify the status of retrofit lamps for luminaires with regard to responsibility because the General Product Safety Directive 2001/95/EC gives the responsibility to the luminaire manufacturer for the whole product lifetime (to be checked by the EC legal services). It would be impossible for manufacturers to monitor the evolution of the retrofit products as long as no standards are agreed.

It is also recommended to elaborate a standard on how to integrate LED modules or components into luminaires for general illumination. Especially in view of the proposed exemption on minimum efficacy for LED luminaires. It should clearly specify the evaluation of thermal conditions and the applicable derating on the minimum performance requirements for the LED module or component.

Currently, colour rendering of light sources is under discussion:

- *EN 60013-2 (CIE 13.3) : 'Method of Measuring and Specifying Colour Rendering Properties of Light Sources'* is not applicable to LED's and is even contested for the other light sources;
- *CIE 177 (2007) : 'Colour Rendering of White LED Light* Sources' is also under discussion (see chapter 1 for more background information).

See also part 1.

8.1.7 Suggestion to support more measurement facilities

There is a lack of independent measurement facilities to support market surveillance and SMEs involved in product design, especially for luminaires.

8.2 Impact analysis for industry and consumers

Implementing measures might affect light sources marketed for applications other than general illumination for human vision.

Similar to part 1.

About the projected EU27 annual sales peak and/or periodic waves.

Similar to part 1.

A potential negative impact on EU27 GLS-R lamp producers, transporters and distributors:

Similar to part 1. The main similarities with part 1 are negative impacts from longer life time products resulting in lower annual sales volume and the need for more sophisticated production lines (e.g. infrared coating, ..) could affect smaller low tech producers. the same, main issue is the same]

Potential barriers created by protected intellectual property:

All the proposed BAT scenarios rely on *basic* technology already available for over 20 years, hence for these scenarios there is a weak expected impact due to intellectual property (more info see chapter 6). Nevertheless, on infrared coating still some applicable patents on technological refinements were requested in the last decade. Therefore, further analysis is recommended in the framework of an impact assessment to be carried out after this study. The BNAT scenario however relies on LED technology wherein above 1000 patents are involved (more info see chapter 6). As a consequence the expected impact of intellectual property is high.

Impact of the proposed generic ecodesign requirement on luminaires:

The implementation of the proposed generic ecodesign requirement on luminaires in 8.1.1.8 should be closely monitored. The expected impact should mainly come from creating awareness with the many luminaire designers active in industry. The impact should come from the assumption that there is a general positive attitude towards ecodesign and that awareness will stimulate adoption and motivate material suppliers to increase production of more advanced and efficient optic luminaire materials. (see also R&D recommendation in 8.1.5).

Background information about the impact of mercury brought into circulation with household lamps:

See part 1.

8.3 Annexes

DISCLAIMER: The figures provided on this page have to be read in the context set out in the beginning of section 8.1.2 (General remarks) and in sections 8.1.2.1 and 8.1.2.2

Annexe 8-1: Main economic and environmental data for the scenario "BAU"

		GLS-R		HL-MV-R-HW		HL-MV-R-LW		HL-LV-R		TOTAL	
2007	Total stock	291 591 919	26.4%	107 306 006	9.7%	121 004 645	11.0%	584 873 780	52.9%	1 104 776 349	100%
	Total sales	126 096 260	29.9%	67 257 000	15.9%	75 843 000	18.0%	153 000 000	36.2%	422 196 260	100%
	Electricity consumption (GWh)	7 057	21.9%	5 955	18.5%	3 358	10.4%	15 792	49.1%	32 162	100%
2008	Total stock	268 863 050	23.0%	136 773 513	11.7%	162 562 458	13.9%	599 377 647	51.3%	1 167 576 667	100%
	Total sales	115 731 193	26.5%	75 207 279	17.2%	91 406 649	20.9%	155 109 283	35.5%	437 454 404	100%
	Electricity consumption (GWh)	6 506	18.7%	7 591	21.8%	4 511	13.0%	16 184	46.5%	34 792	100%
2009	Total stock	246 134 181	20.0%	164 383 435	13.4%	205 977 856	16.7%	613 881 514	49.9%	1 230 376 985	100%
	Total sales	105 366 127	23.3%	83 157 558	18.4%	106 970 297	23.6%	157 218 566	34.7%	452 712 548	100%
	Electricity consumption (GWh)	5 956	15.9%	9 123	24.4%	5 716	15.3%	16 575	44.4%	37 371	100%
2010	Total stock	223 405 311	17.3%	190 135 771	14.7%	251 250 840	19.4%	628 385 381	48.6%	1 293 177 304	100%
	Total sales	95 001 060	20.3%	91 107 837	19.5%	122 533 946	26.2%	159 327 849	34.0%	467 970 692	100%
	Electricity consumption (GWh)	5 406	13.6%	10 553	26.4%	6 972	17.5%	16 967	42.5%	39 898	100%
2011	Total stock	200 676 442	14.8%	214 030 522	15.8%	298 381 410	22.0%	642 889 248	47.4%	1 355 977 622	100%
	Total sales	84 635 993	17.5%	99 058 116	20.5%	138 097 595	28.6%	161 437 132	33.4%	483 228 836	100%
	Electricity consumption (GWh)	4 856	11.5%	11 879	28.0%	8 280	19.5%	17 358	41.0%	42 374	100%
2012	Total stock	198 644 874	14.3%	217 465 872	15.6%	319 997 310	23.0%	654 094 289	47.1%	1 390 202 345	100%
	Total sales	84 924 172	17.4%	95 023 187	19.4%	145 576 591	29.8%	163 600 532	33.4%	489 124 482	100%
	Electricity consumption (GWh)	4 807	11.1%	12 069	27.8%	8 880	20.5%	17 661	40.7%	43 418	100%
2013	Total stock	196 613 306	13.8%	220 246 035	15.5%	342 268 397	24.0%	665 299 330	46.7%	1 424 427 069	100%
	Total sales	85 212 350	17.2%	90 988 257	18.4%	153 055 588	30.9%	165 763 931	33.5%	495 020 127	100%

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	Electricity consumption (GWh)	4 758	10.7%	12 224	27.5%	9 498	21.4%	17 964	40.4%	44 443	100%
2014	**Total stock**	194 581 739	13.3%	222 371 012	15.2%	365 194 670	25.0%	676 504 372	46.4%	1 458 651 792	100%
	Total sales	85 500 529	17.1%	86 953 328	17.4%	160 534 585	32.0%	167 927 331	33.5%	500 915 772	100%
	Electricity consumption (GWh)	4 709	10.4%	12 342	27.2%	10 134	22.3%	18 266	40.2%	45 451	100%
2015	**Total stock**	192 550 171	12.9%	223 840 802	15.0%	388 776 130	26.0%	687 709 413	46.1%	1 492 876 516	100%
	Total sales	85 788 707	16.9%	82 918 398	16.4%	168 013 582	33.2%	170 090 730	33.6%	506 811 417	100%
	Electricity consumption (GWh)	4 660	10.0%	12 423	26.8%	10 789	23.2%	18 569	40.0%	46 440	100%
2016	**Total stock**	190 518 603	12.5%	224 655 406	14.7%	413 012 776	27.0%	698 914 455	45.8%	1 527 101 239	100%
	Total sales	86 076 886	16.8%	78 883 469	15.4%	175 492 578	34.2%	172 254 129	33.6%	512 707 062	100%
	Electricity consumption (GWh)	4 611	9.7%	12 468	26.3%	11 461	24.2%	18 871	39.8%	47 411	100%
2017	**Total stock**	188 487 035	12.1%	224 814 823	14.4%	437 904 609	28.0%	710 119 496	45.5%	1 561 325 963	100%
	Total sales	86 365 064	16.7%	74 848 539	14.4%	182 971 575	35.3%	174 417 529	33.6%	518 602 707	100%
	Electricity consumption (GWh)	4 561	9.4%	12 477	25.8%	12 152	25.1%	19 174	39.6%	48 364	100%
2018	**Total stock**	186 455 467	11.7%	224 319 053	14.1%	463 451 629	29.0%	721 324 537	45.2%	1 595 550 687	100%
	Total sales	86 653 243	16.5%	70 813 610	13.5%	190 450 572	36.3%	176 580 928	33.7%	524 498 352	100%
	Electricity consumption (GWh)	4 512	9.2%	12 450	25.3%	12 861	26.1%	19 476	39.5%	49 299	100%
2019	**Total stock**	184 423 900	11.3%	223 168 097	13.7%	489 653 835	30.0%	732 529 579	44.9%	1 629 775 410	100%
	Total sales	86 941 421	16.4%	66 778 680	12.6%	197 929 569	37.3%	178 744 328	33.7%	530 393 997	100%
	Electricity consumption (GWh)	4 463	8.9%	12 386	24.7%	13 588	27.1%	19 779	39.4%	50 216	100%
2020	**Total stock**	182 392 332	11.0%	221 361 955	13.3%	516 511 227	31.0%	743 734 620	44.7%	1 664 000 134	100%
	Total sales	87 229 600	16.3%	62 743 751	11.7%	205 408 565	38.3%	180 907 727	33.7%	536 289 643	100%
	Electricity consumption (GWh)	4 414	8.6%	12 286	24.0%	14 333	28.0%	20 081	39.3%	51 114	100%

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Annexe 8-2: Main economic and environmental data for the scenario "BAT with lock in"

		BAT with lock in											
		GLS-R		HL-MV-R-HW		HL-MV-R-LW		HL-LV-R		HID-R		TOTAL	
2007	Total stock (mln)	291 591 919	26.4%	107 306 006	9.7%	121 004 645	11.0%	584 873 780	52.9%	0	0.0%	1 104 776 349	100%
	Total sales (mln)	126 096 260	29.9%	67 257 000	15.9%	75 843 000	18.0%	153 000 000	36.2%	0	0.0%	422 196 260	100%
	Electricity consumption (TWh)	7 057	21.9%	5 955	18.5%	3 358	10.4%	15 792	49.1%	0	0.0%	32 162	100%
2008	Total stock (mln)	268 863 050	23.0%	136 773 513	11.7%	162 562 458	13.9%	599 377 647	51.3%	0	0.0%	1 167 576 667	100%
	Total sales (mln)	115 731 193	26.5%	75 207 279	17.2%	91 406 649	20.9%	155 109 283	35.5%	0	0.0%	437 454 404	100%
	Electricity consumption (TWh)	6 506	18.7%	7 591	21.8%	4 511	13.0%	16 184	46.5%	0	0.0%	34 792	100%
2009	Total stock (mln)	246 134 181	20.0%	164 383 435	13.4%	205 977 856	16.7%	613 881 514	49.9%	0	0.0%	1 230 376 985	100%
	Total sales (mln)	105 366 127	23.3%	83 157 558	18.4%	106 970 297	23.6%	157 218 566	34.7%	0	0.0%	452 712 548	100%
	Electricity consumption (TWh)	5 956	15.9%	9 123	24.4%	5 716	15.3%	16 575	44.4%	0	0.0%	37 371	100%
2010	Total stock (mln)	129 677 433	10.1%	190 691 098	14.9%	331 965 016	25.9%	629 762 843	49.1%	0	0.0%	1 282 096 391	100%
	Total sales (mln)	0	0.0%	53 210 464	19.3%	206 499 255	74.9%	15 881 329	5.8%	0	0.0%	275 591 048	100%
	Electricity consumption (TWh)	3 138	8.1%	10 288	26.6%	8 352	21.6%	16 868	43.6%	0	0.0%	38 646	100%
2011	Total stock (mln)	23 585 751	2.0%	26 689 323	2.3%	455 053 846	39.2%	655 525 066	56.5%	0	0.0%	1 160 853 986	100%
	Total sales (mln)	0	0.0%	95 326 734	21.5%	219 164 573	49.3%	129 802 223	29.2%	0	0.0%	444 293 530	100%
	Electricity consumption (TWh)	571	1.5%	11 140	28.6%	10 845	27.8%	16 449	42.2%	0	0.0%	39 006	100%
2012	Total stock (mln)	0	0.0%	219 759 376	15.7%	498 169 889	35.6%	682 461 219	48.7%	0	0.0%	1 400 390 484	100%
	Total sales (mln)	0	0.0%	71 222 178	21.8%	72 506 062	22.2%	183 276 225	56.0%	0	0.0%	327 004 465	100%
	Electricity consumption (TWh)	0	0.0%	10 977	28.6%	11 733	30.6%	15 620	40.8%	0	0.0%	38 330	100%
2013	Total stock (mln)	0	0.0%	218 905 839	15.0%	508 605 735	34.9%	728 393 213	50.0%	0	0.0%	1 455 904 787	100%
	Total sales (mln)	0	0.0%	20 430 648	6.4%	67 446 349	21.1%	232 027 426	72.5%	0	0.0%	319 904 423	100%
	Electricity consumption (TWh)	0	0.0%	10 934	29.5%	11 901	32.1%	14 267	38.5%	0	0.0%	37 103	100%
2014	Total stock (mln)	0	0.0%	210 075 816	14.2%	507 577 637	34.3%	763 384 874	51.5%	0	0.0%	1 481 038 327	100%
	Total sales (mln)	0	0.0%	61 226 949	12.6%	205 050 622	42.0%	221 520 706	45.4%	0	0.0%	487 798 276	100%
	Electricity consumption (TWh)	0	0.0%	10 493	29.5%	11 429	32.1%	13 664	38.4%	0	0.0%	35 586	100%

DISCLAIMER: *The figures provided on this page have to be read in the context set out in the beginning of section 8.1.2 (General remarks) and in sections 8.1.2.1 and 8.1.2.2*

2015	**Total stock (mln)**	0	0.0%	198 308 401	12.9%	514 437 080	33.6%	819 398 450	53.5%	0	0.0%	1 532 143 931	100%
	Total sales (mln)	0	0.0%	73 917 497	11.3%	215 028 643	32.8%	365 850 318	55.9%	0	0.0%	654 796 458	100%
	Electricity consumption (TWh)	0	0.0%	9 906	29.9%	11 149	33.7%	12 073	36.4%	0	0.0%	33 127	100%
2016	**Total stock (mln)**	0	0.0%	147 402 835	9.4%	528 677 479	33.6%	832 749 137	52.9%	65 580 745	4.2%	1 574 410 197	100%
	Total sales (mln)	0	0.0%	0	0.0%	96 091 499	54.9%	13 350 688	7.6%	65 580 745	37.5%	175 022 932	100%
	Electricity consumption (TWh)	0	0.0%	7 363	23.2%	11 084	35.0%	12 270	38.7%	955	3.0%	31 672	100%
2017	**Total stock (mln)**	0	0.0%	110 653 667	6.8%	541 301 636	33.5%	846 099 825	52.3%	119 208 999	7.4%	1 617 264 127	100%
	Total sales (mln)	0	0.0%	0	0.0%	112 867 778	62.8%	13 350 688	7.4%	53 628 254	29.8%	179 846 720	100%
	Electricity consumption (TWh)	0	0.0%	5 527	17.8%	11 352	36.5%	12 466	40.1%	1 737	5.6%	31 082	100%
2018	**Total stock (mln)**	0	0.0%	44 350 498	2.6%	557 558 209	33.3%	859 450 512	51.3%	214 989 562	12.8%	1 676 348 782	100%
	Total sales (mln)	0	0.0%	0	0.0%	203 877 129	65.1%	13 350 688	4.3%	95 780 562	30.6%	313 008 379	100%
	Electricity consumption (TWh)	0	0.0%	2 215	7.6%	11 146	38.2%	12 663	43.4%	3 132	10.7%	29 157	100%
2019	**Total stock (mln)**	0	0.0%	0	0.0%	580 545 484	33.5%	872 801 200	50.4%	278 036 849	16.1%	1 731 383 533	100%
	Total sales (mln)	0	0.0%	0	0.0%	188 127 364	71.1%	13 350 688	5.0%	63 047 288	23.8%	264 525 339	100%
	Electricity consumption (TWh)	0	0.0%	0	0.0%	10 963	39.3%	12 860	46.1%	4 051	14.5%	27 873	100%
2020	**Total stock (mln)**	0	0.0%	0	0.0%	602 843 081	34.1%	886 151 888	50.1%	278 036 849	15.7%	1 767 031 817	100%
	Total sales (mln)	0	0.0%	0	0.0%	118 747 041	37.1%	201 292 903	62.9%	0	0.0%	320 039 944	100%
	Electricity consumption (TWh)	0	0.0%	0	0.0%	11 386	40.0%	13 057	45.8%	4 051	14.2%	28 493	100%

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Annexe 8-3: Main economic and environmental data for the scenario "BAT without lock in"

		BAT without lock in											
		GLS-R		HL-MV-R-HW		HL-MV-R-LW		HL-LV-R		HID-R		TOTAL	
2007	Total stock (mln)	291 591 919	26.4%	107 306 006	9.7%	121 004 645	11.0%	584 873 780	52.9%	0	0.0%	1 104 776 349	100%
	Total sales (mln)	126 096 260	29.9%	67 257 000	15.9%	75 843 000	18.0%	153 000 000	36.2%	0	0.0%	422 196 260	100%
	Electricity consumption (TWh)	7 057	21.9%	5 955	18.5%	3 358	10.4%	15 792	49.1%	0	0.0%	32 162	100%
2008	Total stock (mln)	268 863 050	23.0%	136 773 513	11.7%	162 562 458	13.9%	599 377 647	51.3%	0	0.0%	1 167 576 667	100%
	Total sales (mln)	115 731 193	26.5%	75 207 279	17.2%	91 406 649	20.9%	155 109 283	35.5%	0	0.0%	437 454 404	100%
	Electricity consumption (TWh)	6 506	18.7%	7 591	21.8%	4 511	13.0%	16 184	46.5%	0	0.0%	34 792	100%
2009	Total stock (mln)	246 134 181	20.0%	164 383 435	13.4%	205 977 856	16.7%	613 881 514	49.9%	0	0.0%	1 230 376 985	100%
	Total sales (mln)	105 366 127	23.3%	83 157 558	18.4%	106 970 297	23.6%	157 218 566	34.7%	0	0.0%	452 712 548	100%
	Electricity consumption (TWh)	5 956	15.9%	9 123	24.4%	5 716	15.3%	16 575	44.4%	0	0.0%	37 371	100%
2010	Total stock (mln)	129 677 433	10.0%	97 126 435	7.5%	242 345 702	18.6%	717 350 345	55.1%	115 876 880	8.9%	1 302 376 794	100%
	Total sales (mln)	0	0.0%	0	0.0%	116 879 940	23.9%	256 468 831	52.4%	115 876 880	23.7%	489 225 651	100%
	Electricity consumption (TWh)	3 138	9.4%	5 391	16.1%	6 076	18.1%	17 237	51.4%	1 688	5.0%	33 530	100%
2011	Total stock (mln)	23 585 751	1.7%	26 689 323	1.9%	279 337 771	20.3%	812 740 060	59.1%	233 401 447	17.0%	1 375 754 353	100%
	Total sales (mln)	0	0.0%	0	0.0%	133 067 813	26.7%	248 389 715	49.8%	117 524 567	23.6%	498 982 095	100%
	Electricity consumption (TWh)	571	1.9%	1 481	5.0%	6 364	21.5%	17 741	60.0%	3 400	11.5%	29 558	100%
2012	Total stock (mln)	0	0.0%	0	0.0%	297 342 633	20.9%	856 340 536	60.1%	270 932 659	19.0%	1 424 615 827	100%
	Total sales (mln)	0	0.0%	0	0.0%	47 394 880	13.6%	264 543 277	75.7%	37 531 212	10.7%	349 469 369	100%
	Electricity consumption (TWh)	0	0.0%	0	0.0%	6 601	23.7%	17 247	62.1%	3 947	14.2%	27 795	100%
2013	Total stock (mln)	0	0.0%	0	0.0%	318 037 006	21.3%	900 171 874	60.3%	274 396 361	18.4%	1 492 605 241	100%
	Total sales (mln)	0	0.0%	0	0.0%	67 446 349	20.1%	264 256 050	78.8%	3 463 702	1.0%	335 166 101	100%
	Electricity consumption (TWh)	0	0.0%	0	0.0%	7 060	26.7%	15 354	58.1%	3 998	15.1%	26 412	100%
2014	Total stock (mln)	0	0.0%	0	0.0%	339 340 180	22.2%	915 015 265	59.8%	277 043 790	18.1%	1 531 399 236	100%
	Total sales (mln)	0	0.0%	0	0.0%	144 658 263	58.9%	98 203 137	40.0%	2 647 430	1.1%	245 508 830	100%
	Electricity consumption (TWh)	0	0.0%	0	0.0%	7 533	28.6%	14 759	56.1%	4 036	15.3%	26 328	100%

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2015	**Total stock (mln)**	0	0.0%	0	0.0%	361 252 156	23.1%	926 946 015	59.2%	278 874 947	17.8%	1 567 073 119	100%
	Total sales (mln)	0	0.0%	0	0.0%	120 710 616	86.0%	17 862 784	12.7%	1 831 157	1.3%	140 404 557	100%
	Electricity consumption (TWh)	0	0.0%	0	0.0%	8 020	29.7%	14 884	55.2%	4 063	15.1%	26 967	100%
2016	**Total stock (mln)**	0	0.0%	0	0.0%	305 836 688	19.2%	1 004 425 259	63.2%	279 889 832	17.6%	1 590 151 779	100%
	Total sales (mln)	0	0.0%	0	0.0%	0	0.0%	77 479 243	98.7%	1 014 884	1.3%	78 494 128	100%
	Electricity consumption (TWh)	0	0.0%	0	0.0%	6 790	25.2%	16 026	59.6%	4 078	15.2%	26 893	100%
2017	**Total stock (mln)**	0	0.0%	0	0.0%	0	0.0%	1 301 555 707	82.3%	280 088 443	17.7%	1 581 644 150	100%
	Total sales (mln)	0	0.0%	0	0.0%	0	0.0%	445 694 213	100.0%	198 612	0.0%	445 892 825	100%
	Electricity consumption (TWh)	0	0.0%	0	0.0%	0	0.0%	19 856	83.0%	4 081	17.0%	23 937	100%
2018	**Total stock (mln)**	0	0.0%	0	0.0%	0	0.0%	1 350 606 150	82.8%	280 088 443	17.2%	1 630 694 593	100%
	Total sales (mln)	0	0.0%	0	0.0%	0	0.0%	232 462 499	100.0%	0	0.0%	232 462 499	100%
	Electricity consumption (TWh)	0	0.0%	0	0.0%	0	0.0%	19 903	83.0%	4 081	17.0%	23 984	100%
2019	**Total stock (mln)**	0	0.0%	0	0.0%	0	0.0%	1 399 899 637	83.3%	280 088 443	16.7%	1 679 988 080	100%
	Total sales (mln)	0	0.0%	0	0.0%	0	0.0%	229 779 724	100.0%	0	0.0%	229 779 724	100%
	Electricity consumption (TWh)	0	0.0%	0	0.0%	0	0.0%	19 965	83.0%	4 081	17.0%	24 045	100%
2020	**Total stock (mln)**	0	0.0%	0	0.0%	0	0.0%	1 436 796 184	83.7%	280 088 443	16.3%	1 716 884 627	100%
	Total sales (mln)	0	0.0%	0	0.0%	0	0.0%	231 349 729	100.0%	0	0.0%	231 349 729	100%
	Electricity consumption (TWh)	0	0.0%	0	0.0%	0	0.0%	20 383	83.3%	4 081	16.7%	24 463	100%

DISCLAIMER: The figures provided on this page have to be read in the context set out in the beginning of section 8.1.2 (General remarks) and in sections 8.1.2.1 and 8.1.2.2

Annexe 8-4: Main economic and environmental data for the scenario "BNAT (LED)"

		BNAT (LED)													
		GLS-R		HL-MV-R-HW		HL-MV-R-LW		HL-LV-R		HID-R		LED-R		TOTAL	
2007	Total stock (mln)	291 591 919	26.4%	107 306 006	9.7%	121 004 645	11.0%	584 873 780	52.9%	0	0.0%	0	0.0%	1 104 776 349	100%
	Total sales (mln)	126 096 260	29.9%	67 257 000	15.9%	75 843 000	18.0%	153 000 000	36.2%	0	0.0%	0	0.0%	422 196 260	100%
	Electricity consumption (TWh)	7 057	21.9%	5 955	18.5%	3 358	10.4%	15 792	49.1%	0	0.0%	0	0.0%	32 162	100%
2008	Total stock (mln)	268 863 050	23.0%	136 773 513	11.7%	162 562 458	13.9%	599 377 647	51.3%	0	0.0%	0	0.0%	1 167 576 667	100%
	Total sales (mln)	115 731 193	26.5%	75 207 279	17.2%	91 406 649	20.9%	155 109 283	35.5%	0	0.0%	0	0.0%	437 454 404	100%
	Electricity consumption (TWh)	6 506	18.7%	7 591	21.8%	4 511	13.0%	16 184	46.5%	0	0.0%	0	0.0%	34 792	100%
2009	Total stock (mln)	246 134 181	20.0%	164 383 435	13.4%	205 977 856	16.7%	613 881 514	49.9%	0	0.0%	0	0.0%	1 230 376 985	100%
	Total sales (mln)	105 366 127	23.3%	83 157 558	18.4%	106 970 297	23.6%	157 218 566	34.7%	0	0.0%	0	0.0%	452 712 548	100%
	Electricity consumption (TWh)	5 956	15.9%	9 123	24.4%	5 716	15.3%	16 575	44.4%	0	0.0%	0	0.0%	37 371	100%
2010	Total stock (mln)	129 677 433	6.9%	97 126 435	5.2%	125 465 762	6.7%	460 881 514	24.5%	115 876 880	6.2%	954 456 184	50.7%	1 883 484 207	100%
	Total sales (mln)	0	0.0%	0	0.0%	0	0.0%	0	0.0%	115 876 880	10.8%	954 456 184	89.2%	1 070 333 064	100%
	Electricity consumption (TWh)	3 138	10.7%	5 391	18.4%	3 482	11.9%	12 444	42.4%	1 688	5.8%	3 207	10.9%	29 349	100%
2011	Total stock (mln)	23 585 751	0.9%	26 689 323	1.0%	29 390 019	1.2%	307 881 514	12.1%	233 401 447	9.1%	1 934 024 271	75.7%	2 554 972 325	100%
	Total sales (mln)	0	0.0%	0	0.0%	0	0.0%	0	0.0%	117 524 567	10.7%	979 568 088	89.3%	1 097 092 655	100%
	Electricity consumption (TWh)	571	2.7%	1 481	7.0%	816	3.9%	8 313	39.5%	3 400	16.2%	6 469	30.7%	21 050	100%
2012	Total stock (mln)	0	0.0%	0	0.0%	0	0.0%	154 881 514	5.1%	270 932 659	8.9%	2 626 210 882	86.0%	3 052 025 055	100%
	Total sales (mln)	0	0.0%	0	0.0%	0	0.0%	0	0.0%	37 531 212	5.1%	692 186 611	94.9%	729 717 822	100%
	Electricity consumption (TWh)	0	0.0%	0	0.0%	0	0.0%	4 182	24.6%	3 947	23.2%	8 858	52.1%	16 987	100%
2013	Total stock (mln)	0	0.0%	0	0.0%	0	0.0%	0	0.0%	274 396 361	8.3%	3 032 637 569	91.7%	3 307 033 930	100%
	Total sales (mln)	0	0.0%	0	0.0%	0	0.0%	0	0.0%	3 463 702	0.8%	406 426 687	99.2%	409 890 389	100%
	Electricity consumption (TWh)	0	0.0%	0	0.0%	0	0.0%	0	0.0%	3 998	28.0%	10 285	72.0%	14 282	100%
2014	Total stock (mln)	0	0.0%	0	0.0%	0	0.0%	0	0.0%	277 043 790	8.2%	3 091 084 679	91.8%	3 368 128 469	100%
	Total sales (mln)	0	0.0%	0	0.0%	0	0.0%	0	0.0%	2 647 430	4.3%	58 447 110	95.7%	61 094 539	100%
	Electricity consumption (TWh)	0	0.0%	0	0.0%	0	0.0%	0	0.0%	4 036	27.8%	10 466	72.2%	14 502	100%

DISCLAIMER: The figures provided on this page have to be read in the context set out in the beginning of section 8.1.2 (General remarks) and in sections 8.1.2.1 and 8.1.2.2

2015	**Total stock (mln)**	0	0.0%	0	0.0%	0	0.0%	0	0.0%	278 874 947	8.1%	3 150 480 679	91.9%	3 429 355 627	100%
	Total sales (mln)	0	0.0%	0	0.0%	0	0.0%	0	0.0%	1 831 157	3.0%	59 396 001	97.0%	61 227 158	100%
	Electricity consumption (TWh)	0	0.0%	0	0.0%	0	0.0%	0	0.0%	4 063	27.6%	10 650	72.4%	14 713	100%
2016	**Total stock (mln)**	0	0.0%	0	0.0%	0	0.0%	0	0.0%	279 889 832	8.0%	3 204 514 685	92.0%	3 484 404 517	100%
	Total sales (mln)	0	0.0%	0	0.0%	0	0.0%	0	0.0%	1 014 884	5.1%	18 932 656	94.9%	19 947 540	100%
	Electricity consumption (TWh)	0	0.0%	0	0.0%	0	0.0%	0	0.0%	4 078	27.4%	10 814	72.6%	14 891	100%
2017	**Total stock (mln)**	0	0.0%	0	0.0%	0	0.0%	0	0.0%	280 088 443	7.9%	3 250 485 022	92.1%	3 530 573 465	100%
	Total sales (mln)	0	0.0%	0	0.0%	0	0.0%	0	0.0%	198 612	0.4%	45 970 337	99.6%	46 168 948	100%
	Electricity consumption (TWh)	0	0.0%	0	0.0%	0	0.0%	0	0.0%	4 081	27.1%	10 956	72.9%	15 036	100%
2018	**Total stock (mln)**	0	0.0%	0	0.0%	0	0.0%	0	0.0%	280 088 443	7.8%	3 297 167 027	92.2%	3 577 255 470	100%
	Total sales (mln)	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	46 682 005	100.0%	46 682 005	100%
	Electricity consumption (TWh)	0	0.0%	0	0.0%	0	0.0%	0	0.0%	4 081	26.9%	11 099	73.1%	15 180	100%
2019	**Total stock (mln)**	0	0.0%	0	0.0%	0	0.0%	0	0.0%	280 088 443	7.7%	3 344 560 700	92.3%	3 624 649 143	100%
	Total sales (mln)	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	47 393 673	100.0%	47 393 673	100%
	Electricity consumption (TWh)	0	0.0%	0	0.0%	0	0.0%	0	0.0%	4 081	26.6%	11 245	73.4%	15 325	100%
2020	**Total stock (mln)**	0	0.0%	0	0.0%	0	0.0%	0	0.0%	280 088 443	7.6%	3 392 666 041	92.4%	3 672 754 484	100%
	Total sales (mln)	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	48 105 341	100.0%	48 105 341	100%
	Electricity consumption (TWh)	0	0.0%	0	0.0%	0	0.0%	0	0.0%	4 081	26.4%	11 393	73.6%	15 473	100%

For more info see website www.eup4light.net.

9 ANNEXES

Annex 1 Luminaire improvement options data[225]

Option:	dimmable application								
Your country:	CELMA								
Saving method description	Luminaire is only operated at max power for functional use. The rest of the time the luminiare is dimmed. This is applicable for external and internal dimmer systems.								
Sample picture best practice		**Sample picture worst practice**							Energy
Category of luminaires	**Is this option applicable to this category or not**	**How big is the market share [EU27 sales] of improvable luminaires in its category**	**What proportion of the energy can be saved comparing worst to best practice**	**How many luminaires [EU27 sales] are among the worst 30 % performers in the category**	**How many luminaires [EU27 sales] are among the best 30% performers in the category**	**What proportion of the energy can be saved on average assuming all luminaires sold are in the range of 30 % best performers**	**Chararactertic parameter best performer**	**Chararactertic parameter worst performer**	
	Y/N	**%**	**%**	**%**	**%**		***max operational energy consumption (W)***	***min operational energy consumption (W)***	
Downlights (recessed mounted)	y	75	30	50	25	15	<=30	>=60	
Suspension (chandeliers)	y	75	30	70	10	21	<=30	>=60	
wall&ceiling	y	70	30	60	10	18	<=30	>=60	
Desk	n								
Table	y	30	30	80	20	24	<=20	>=40	
Floor	y	75	30	70	20	21	<=50	>=100	
Spotlights	y	75	30	80	20	24	<=30	>=60	
Outdoor	n								
							lower powerconsumpti on because used at 50% dimming or use of low wattage lamps	higher powerconsumpti on because of use of high wattage lamps in not dimmable applications	

Note: For dimmable applications cleaning is relevant since the consumer will use more energy in direct relation with the dust on the luminaire
Dimmability is focused on filament lamps, only a very small quantity of CFLI(ni) is dimmable today.

[225] All figures in the tables in Annex 1 are estimated values with the knowledge of CELMA members as of July 2009.

Option:	Motion sensors	
Your country:	CELMA	
Saving method description	Luminaire is only operated when luminaire is approached	
Sample picture best practice		**Sample picture worst practice**

Energy

Category of luminaires	**Is this option applicable to this category or not**	**How big is the market share [EU27 sales] of improvable luminaires in its category**	**What proportion of the energy can be saved comparing worst to best practice**	**How many luminaires [EU27 sales] are among the worst 30 % performers in the category**	**How many luminaires [EU27 sales] are among the best 30% performers in the category**	**What proportion of the energy can be saved on average assuming all luminaires sold are in the range of 30 % best performers**	**Chararactertic parameter best performer**	**Chararactertic parameter worst performer**
	Y/N	**%**	**%**	***%***	***%***	***%***	***max average operating time (h)***	***min average operating time (h)***
Downlights (recessed mounted)	y	5	80	80	1		<= 0.5	>= 3h
Suspension (chandeliers)	n							
wall&ceiling	y	30	80	80	1	64	<= 0.5	>= 3h
Desk	n							
Table	n							
Floor	n							
Spotlights	y							
Outdoor	y	50	93%	90	5	80%	<= 0.5	>= 12h

Note:

Option:	Day/Nightsensor								
Your country:	CELMA								
Saving method description	Luminaire is only operated when luminaire is approached								
Sample picture best practice		**Sample picture worst practice**							
Category of luminaires	**Is this option applicable to this category or not**	**How big is the market share [EU27 sales] of improvable luminaires in its category**	**What proportion of the energy can be saved comparing worst to best practice**	**How many luminaires [EU27 sales] are among the worst 30 % performers in the category**	**How many luminaires [EU27 sales] are among the best 30% performers in the category**	**What proportion of the energy can be saved on average assuming all luminaires sold are in the range of 30 % best performers**	**Chararactertic parameter best performer**	**Chararactertic parameter worst performer**	
	Y/N	**%**	**%**	**%**	**%**	**%**	***max average operating time (h)***	***min average operating time (h)***	
Downlights (recessed mounted)	n								
Suspension (chandeliers)	n								
wall&ceiling	n								
Desk	n								
Table	n								
Floor	n								
Spotlights	n								
Outdoor	y	50	45	90	5	40,5	<=8h	>=12h	

Note:

Option:	Used material							
Your country:	CELMA							
Saving method description	In some cases the material used to diffuse the light can be improved with a similar acceptable outlook							
Sample picture best practice		Sample picture worst practice						
Category of luminaires	Is this option applicable to this category or not	How big is the market share [EU27 sales] of improvable luminaires in its category	What proportion of the energy can be saved comparing worst to best practice	How many luminaires [EU27 sales] are among the worst 30 % performers in the category	How many luminaires [EU27 sales] are among the best 30% performers in the category	What proportion of the energy can be saved on average assuming all luminaires sold are in the range of 30 % best performers	Chararactertic parameter best performer	Chararactertic parameter worst performer
	Y/N	%	%	%	%	%	*LOR*	*LOR*
Downlights (recessed mounted)	y	15	20	10	70	2	100	50
Suspension (chandeliers)	y	30	20	10	70	2	50	30
wall&ceiling	y	50	20	30	50	6	70	50
Desk	n							
Table	y	30	20	5	80	1	60	50
Floor	n							
Spotlights	n							
Outdoor	y	20	20	20	70	4	80	65

Note:	please estimate, collected data will be aggregated.

Option:	Relectors	
Your country:	CELMA	
Saving method description	Use reflectors or reflective surfaces to avoid light absorption in the luminaire	
Sample picture best practice		**Sample picture worst practice**

Category of luminaires	**Is this option applicable to this category or not**	**How big is the market share [EU27 sales] of improvable luminaires in its category**	**What proportion of the energy can be saved comparing worst to best practice**	**How many luminaires [EU27 sales] are among the worst 30 % performers in the category**	**How many luminaires [EU27 sales] are among the best 30% performers in the category**	**What proportion of the energy can be saved on average assuming all luminaires sold are in the range of 30 % best performers**	**Chararactertic parameter best performer**	**Chararactertic parameter worst performer**
	Y/N	**%**	**%**	***%***	***%***	**%**	***LOR%***	***LOR%***
Downlights (recessed mounted)	y	10	30	5	80	1,5	>= 90	<=40
Suspension (chandeliers)	y	20	30	30	30	9	>= 70	<=40
wall&ceiling	y	70	30	70	10	21	>= 70	<=40
Desk	y	40	30	30	30	9	>= 60	<=40
Table	n					0		
Floor	y	70	30	20	30	6	>= 70	<=40
Spotlights	y	20	30	20	50	6	>= 90	<=40
Outdoor	y	20	30	5	80	1,5	>= 60	<=40

seen as the % lumenoutput of lumir

Note: please estimate, collected data will be aggregated.

Option:	Correct application of the luminaire	
Your country:	CELMA	
Saving method description	Use the correct category of luminaire for the correct application. Eg. Avoid use of spotlights for general illuminiation, by informing the consumer	
Sample picture best practice		**Sample picture worst practice**

Energy

Category of luminaires	**Is this option applicable to this category or not**	**How big is the market share [EU27 sales] of improvable luminaires in its category**	**What proportion of the energy can be saved comparing worst to best practice**	**How many luminaires [EU27 sales] are among the worst 30 % performers in the category**	**How many luminaires [EU27 sales] are among the best 30% performers in the category**	**What proportion of the energy can be saved on average assuming all luminaires sold are in the range of 30 % best performers**	**Chararactertic parameter best performer**	**Chararactertic parameter worst performer**
	Y/N	**%**	**%**	***%***	***%***	***%***	***average applicable wattage in correct use***	***average applicable wattage in faulty use***
Downlights (recessed mounted)	y	80	20	30	70	6	45	60
Suspension (chandeliers)	n	80				0		
wall&ceiling	y	80	20	50	50	10	45	60
Desk	n					0		
Table	y	60	20	30	70	6	45	60
Floor	y	80	20	30	70	6	70	100
Spotlights	y	80	20	50	50	10	45	60
Outdoor	y	80	30	50	50	15	45	60
		is applicable to all		% of miss use				

Note: A lot of environments can improved to a more efficient system, with the color of the wall, kind of the use of luminaire.
As example: 'Don't use a desk lamp", or 'only one table lamp for general lighting, it should part of the general lighting'

Option:	Solar							
Your country:	CELMA							
Saving method description	Luminaire is not connected to network.							
Sample picture best practice		Sample picture worst practice						

Energy

Category of luminaires	Is this option applicable to this category or not	How big is the market share [EU27 sales] of improvable luminaires in its category	What proportion of the energy can be saved comparing worst to best practice	How many luminaires [EU27 sales] are among the worst 30 % performers in the category	How many luminaires [EU27 sales] are among the best 30% performers in the category	What proportion of the energy can be saved on average assuming all luminaires sold are in the range of 30 % best performers	Chararactertic parameter best performer	Chararactertic parameter worst performer
	Y/N	%	%	%	%	%	*max % net power consumption*	*min % net power consumption*
Downlights (recessed mounted)	n							
Suspension (chandeliers)	n							
wall&ceiling	n							
Desk	n							
Table	n							
Floor	n							
Spotlights	n							
Outdoor	Y	3%	100	100	0	100	0	100

Note:	combined with motion sensors/day-night sensors

Lamp type Acronym	Wattage	Average LWFt	Intensity	Beam angle	Luminous flux in 2π	Luminous flux in π (opening angle 120°)	Functional lumen in 90° opening angle	ηlamp(90°) @25 °C (without LFWt)	ηlamp(90°) @25 °C (LFWt incl)	Operational Life time	Unit price (for end user)	% Lumen in 120° cone related to forward output	Comment	System Wattage	Corrected Luminous Flux	Level
	[W]		[cd]	[°]	[lm]	[lm]	[lm]	[lm/W]	[lm/W]	[h]	[€]			[W]	[lm]	
R63 - E27																
Incandescent reflector lamp, R63, E27 (B22d) **GLS-R**	40	1	321	40	296	264	209	5,2	5,2	1000	1.3			40	261	**G**
Incandescent reflector lamp, R63, E27 (B22d) **GLS-R**	60	1	836	29	487	427	328	5,5	5,5	1000	1.3			60	410	**G**
Halogen reflector lamp, R63, E27 (B22d) **HL-MV-R**	40	1	714	23	315	275	214	5,3	5,3	2000	3			40	267	**G**
Halogen reflector lamp, R63, E27 (B22d) **HL-MV-R**	60	1	1037	29	529	475	380	6,3	6,3	2000	3			60	475	**G**
PAR38 - E27																

Lamp type Acronym	Wattage	Average LWFt	Intensity	Beam angle	Luminous flux in 2π	Luminous flux in π (opening angle 120°)	Functional lumen in 90° opening angle	ηlamp(90°) @25 °C (without LFWt)	ηlamp(90°) @25 °C (LFWt incl)	Operational Life time	Unit price (for end user)	% Lumen in 120° cone related to forward output	Comment	System Wattage	Corrected Luminous Flux	Level
	[W]		[cd]	[°]	[lm]	[lm]	[lm]	[lm/W]	[lm/W]	[h]	[€]			[W]	[lm]	
GLS reflector lamp, PAR38, E27 (B22d) **HL-MV-R**	80	1	1882	27	699	677	617	7,7	7,7	1000	5,4					
GLS reflector lamp, PAR38, E27 (B22d) **HL-MV-R**	120	1	3562	25	1230	1176	1131	9,4	9,4	1000	5,4					
GLS reflector lamp, PAR38, E27 (B22d) **HL-MV-R**	100	1	2722	26	965	927	874	8,7	8,7	1000	5,4		*Calculated average*	100	1093	**F**
Halogen reflector lamp, PAR38, E27 (B22d) **HL-MV-R**	100	1	2620	30	1251		1081	10,8	10,8	2750	13,5			100	1351	**E**

HL-MV-GU10

Lamp type Acronym	Wattage	Average LWFt	Intensity	Beam angle	Luminous flux in 2π	Luminous flux in π (opening angle 120°)	Functional lumen in 90° opening angle	ηlamp(90°) @25 °C (without LFWt)	ηlamp(90°) @25 °C (LFWt incl)	Operational Life time	Unit price (for end user)	% Lumen in 120° cone related to forward output	Comment	System Wattage	Corrected Luminous Flux	Level
Halogen reflector lamp, MR16, GU10 **HL-MV-R**	35	1	416	36	219	202	175	5,0	5,0	2000	4.0					
Halogen reflector lamp, MR16, GU10 **HL-MV-R**	50	1	851	31	367	346	313	6,3	6,3	1000	3.1					
Halogen reflector lamp, MR16, GU10 **HL-MV-R**	50	1	790	34	392	369	329	6,6	6,6	2000	4.0			50	411	**G**

Lamp type Acronym	Wattage	Average LWFt	Intensity	Beam angle	Luminous flux in 2π	Luminous flux in π (opening angle 120°)	Functional lumen in 90° opening angle	ηlamp(90°) @25 °C (without LFWt)	ηlamp(90°) @25 °C (LFWt incl)	Operational Life time	Unit price (for end user)	% Lumen in 120° cone related to forward output	Comment	System Wattage	Corrected Luminous Flux	Level
	[W]		[cd]	[°]	[lm]	[lm]	[lm]	[lm/W]	[lm/W]	[h]	[€]			[W]	[lm]	
CFLi-R																
Compact fluorescent reflector lamp, R50, E14 **CFLi-R**	7	1,05		130,2	189	130	85	12,2	11,6	8000		0,69				
Compact fluorescent reflector lamp, R120, E27 (B22d) **CFLi-R**	20	1,05	265	110,0	638	440	385	19,3	18,3	6000		0,69				
HL-LV-GU5,3																
Halogen reflector lamp, MR16, 12V, 38°, GU5.3 **HL-LV-R**	35	1,11	1297	26	392	370	333	9,5	8,6	2000	1.5					
Halogen reflector lamp, MR16, 12V, 38°, GU5.3 **HL-LV-R**	50	1,11	1290	34	546	521	470	9,4	8,5	2000	1.5			55,5	588	**E**
Halogen reflector lamp, MR16, 12V, 36/38°, GU5.3 **HL-LV-R**	35	1,11	1261	39	537	519	471	13,5	12,1	4000	3,3					

Lamp type Acronym	Wattage	Average LWFt	Intensity	Beam angle	Luminous flux in 2π	Luminous flux in π (opening angle 120°)	Functional lumen in 90° opening angle	ηlamp(90°) @25 °C (without LFWt)	ηlamp(90°) @25 °C (LFWt incl)	Operational Life time	Unit price (for end user)	% Lumen in 120° cone related to forward output	Comment	System Wattage	Corrected Luminous Flux	Level
	[W]		[cd]	[°]	[lm]	[lm]	[lm]	[lm/W]	[lm/W]	[h]	[€]			[W]	[lm]	
Halogen reflector lamp, MR16, 12V, 10°, GU5.3 **HL-LV-R**	50	1,11	5643	11	744	709	640	12,8	11,5	4000	3,3					
Halogen reflector lamp, MR16, 12V, 24°, GU5.3 **HL-LV-R**	50	1,11		24	763	737	677	13,5	12,2	4000	3,3					
Halogen reflector lamp, MR16, 12V, 38°, GU5.3 **HL-LV-R**	50	1,11	1309	45	782	765	714	14,3	12,9	4000	3,3			55,5	893	**C**
Halogen reflector lamp, MR16, 12V, 60°, GU5.3 **HL-LV-R**	50	1,11	830	60	828	809	750	15	13,5	4000	3,3					

Improvement options:

R63 - E27 - Xenon

Lamp type Acronym	Wattage	Average LWFt	Intensity	Beam angle	Luminous flux in 2π	Luminous flux in π (opening angle 120°)	Functional lumen in 90° opening angle	ηlamp(90°) @25 °C (without LFWt)	ηlamp(90°) @25 °C (LFWt incl)	Operational Life time	Unit price (for end user)	% Lumen in 120° cone related to forward output	Comment	System Wattage	Corrected Luminous Flux	Level
Halogen reflector lamp, R63, E27 (B22d) xenon **HL-MV-R**	42	1	570	27	367	307	235	5,6	5,6	2000	3.0			42	294	**G**

Lamp type / Acronym	Wattage	Average LWFt	Intensity	Beam angle	Luminous flux in 2π	Luminous flux in π (opening angle 120°)	Functional lumen in 90° opening angle	ηlamp(90°) @25 °C (without LFWt)	ηlamp(90°) @25 °C (LFWt incl)	Operational Life time	Unit price (for end user)	% Lumen in 120° cone related to forward output	Comment	System Wattage	Corrected Luminous Flux	Level
	[W]		[cd]	[°]	[lm]	[lm]	[lm]	[lm/W]	[lm/W]	[h]	[€]			[W]	[lm]	
PAR20 - E27																
Halogen reflector lamp, PAR20, 10°, E27 (B22d) **HL-MV-R**	50	1	1851	16	446	423	383	7,7	7,7	2000	11			50	479	**F**
Halogen reflector lamp, PAR20, 25°, E27 (B22d) **HL-MV-R**	50	1	1056	27	405	391	353	7,1	7,1	2000	11			50	441	**F**
Halogen reflector lamp, PAR20, 25°, E27 (B22d), + xenon + optimized wire design **HL-MV-R**	40	1	1126	25	367	345	320	8,0	8,0	2000	13,0			40	400	**E**
Halogen reflector lamp, PAR20, 25°, E27 (B22d), + xenon + optimized wire design + dichroic/silver **HL-MV-R**	40	1	1216	25	396	373	346	8,6	8,6	2000	14,5		*calculated based on preceding *1.08*	40	432	
Halogen reflector lamp, PAR20, 25°, E27 (B22d), + xenon + optimized wire design + dichroic/silver + Anti-Reflective	40	1	1277	25	416	391	366	9,2	9,2	2000	15,0		*calculated based on preceding *1.06 (1.05)*			

Lamp type Acronym	Wattage	Average LWFt	Intensity	Beam angle	Luminous flux in 2π	Luminous flux in π (opening angle 120°)	Functional lumen in 90° opening angle	ηlamp(90°) @25 °C (without LFWt)	ηlamp(90°) @25 °C (LFWt incl)	Operational Life time	Unit price (for end user)	% Lumen in 120° cone related to forward output	Comment	System Wattage	Corrected Luminous Flux	Level
	[W]		[cd]	[°]	[lm]	[lm]	[lm]	[lm/W]	[lm/W]	[h]	[€]			[W]	[lm]	
HL-MV-R														40	458	**E**
Halogen reflector lamp, PAR20, 25°, E27 (B22d), + xenon + optimized wire design + Anti-Reflective **HL-MV-R**	40	1	1182	25	385	362	339	8,5	8,5	2000	14		*calculated based on row (84-85) *1.06 (1.05)*	40	424	**E**
Halogen reflector lamp, PAR20, E27 (B22d) transfo inc **HL-MV-R**	20	1,05	1200	25			270	13,5	12,9	5000	26.0		*estimated*	21	337,5	**C**
Halogen reflector lamp, PAR20, E27 (B22d) transfo inc + IRC **HL-MV-R**	20	1,05	1300	25			303	15,1	14,4	5000	26.0		*calculated based on GU5,3/1.06*	21	379	**B**
Halogen reflector lamp, PAR20, E27 (B22d) transfo inc + IRC + Anti-Reflective **HL-MV-R**	20	1,05	1400	25			327	16,4	15,6	5000	26.0		*calculated based on preceeding *1.08*	21	409	**B**
PAR38 - E27																
Halogen reflector lamp, PAR38, E27 (B22d) + xenon **HL-MV-R**	100	1	2882	30	1376		1189	11,9	11,9	2000	14,5		*Calculated: +xenon = +10%*	100	1486	**D**

Lamp type / Acronym	Wattage	Average LWFt	Intensity	Beam angle	Luminous flux in 2π	Luminous flux in π (opening angle 120°)	Functional lumen in 90° opening angle	ηlamp(90°) @25 °C (without LFWt)	ηlamp(90°) @25 °C (LFWt incl)	Operational Life time	Unit price (for end user)	% Lumen in 120° cone related to forward output	Comment	System Wattage	Corrected Luminous Flux	Level
	[W]		[cd]	[°]	[lm]	[lm]	[lm]	[lm/W]	[lm/W]	[h]	[€]			[W]	[lm]	
Halogen reflector lamp, PAR38, E27 (B22d) + xenon **HL-MV-R**	90	1	2594	30	1238		1070	11,9	11,9	2000	14,5		*Calculated: 100W*0,9*	90	1338	**D**
Halogen reflector lamp, PAR38, E27 (B22d) + xenon + anti-refl **HL-MV-R**	90	1	2723	30	1300		1134	12,6	12,6	2000	14,5		*Calculated: preceding * 1,06 (1,05)*	90	1418	**D**
Halogen reflector lamp, PAR38, E27 (B22d) + xenon + anti-refl + optimized wire design **HL-MV-R**	90	1	2805	30	1339		1168	13,0	13,0	2000	14,5		*Calculated: preceding * 1,03*	90	1461	**D**
Halogen reflector lamp, PAR38, E27 (B22d) + xenon + anti-refl + optimized wire design **HL-MV-R**	90	1	3030	30	1447		1262	14,0	14,0	2000	14,5		*Calculated: preceding * 1,08*	90	1577	**C**
Metal Halide reflector lamp, PAR38, E27 (B22d) ballast inc **MH-i-R**	25	1	26000	10	1275		1045	41,8	41,8	9000					1306	**B+**
Metal Halide reflector lamp, PAR38, E27 (B22d) ballast inc **MH-i-R**	25	1	5000	25	1275		1085	43,4	43,4	9000					1356	**B+**

Lamp type Acronym	Wattage	Average LWFt	Intensity	Beam angle	Luminous flux in 2π	Luminous flux in π (opening angle 120°)	Functional lumen in 90° opening angle	ηlamp(90°) @25 °C (without LFWt)	ηlamp(90°) @25 °C (LFWt incl)	Operational Life time	Unit price (for end user)	% Lumen in 120° cone related to forward output	Comment	System Wattage	Corrected Luminous Flux	Level
	[W]		[cd]	[°]	[lm]	[lm]	[lm]	[lm/W]	[lm/W]	[h]	[€]			[W]	[lm]	
Metal Halide reflector lamp, PAR38, E27 (B22d) ballast inc **MH-i-R**	25	1	2100	40	1275		1020	40,8	40,8	9000					1275	**B+**
HL-MV-GU10																
Halogen reflector lamp, MR16, 30°, GU10, xenon **HL-MV-R**	42	1	826	31	340	319	285	6,8	6,8	2000	7.0			42	356	**F**
Halogen reflector lamp, MR16, 40°, GU10, xenon + optimized wire design **HL-MV-R**	35	1	500	40	278	265	251	7,2	7,2	2000	7.0				313,75	**F**
Halogen reflector lamp, MR16, 40°, GU10, xenon + optimized wire design **HL-MV-R**	40	1	731	33	330	310	292	7,3	7,3	2000	7.0					
Halogen reflector lamp, MR16, 25°, GU10, xenon + optimized wire design **HL-MV-R**	40	1	1571	23	386	367	348	8,7	8,7	2000	7.0				435	**E**
Halogen reflector lamp, MR16, 25°, GU10, xenon + optimized wire design + anti-reflective	40	1	1649,55	23	405,3	385,35	368,88	9,2	9,2	2000	7.0		*calculated based on preceding *1.05/1.06*			

Lamp type Acronym	Wattage	Average LWFt	Intensity	Beam angle	Luminous flux in 2π	Luminous flux in π (opening angle 120°)	Functional lumen in 90° opening angle	ηlamp(90°) @25 °C (without LFWt)	ηlamp(90°) @25 °C (LFWt incl)	Operational Life time	Unit price (for end user)	% Lumen in 120° cone related to forward output	Comment	System Wattage	Corrected Luminous Flux	Level
	[W]		[cd]	[°]	[lm]	[lm]	[lm]	[lm/W]	[lm/W]	[h]	[€]			[W]	[lm]	
HL-MV-R															461,1	**D**
Halogen reflector lamp, MR16, 25°, GU10, xenon + optimized wire design + dichroic/silver coating **HL-MV-R**	40	1	1697	23	417	396	376	9,4	9,4	2000	7.7		*calculated based on (1+)preceeding *1.08*		469,8	**D**
Halogen reflector lamp, MR16, 25°, GU10, xenon + optimized wire design + dichroic/silver coating + Anti-Refl **HL-MV-R**	40	1	1782	23	438	416	398	10,0	10,0	2000	8.1		*calculated based on preceeding *1.05/1.06*		497,988	**D**

CFLi-R

Compact fluorescent reflector lamp, R50, E14 **CFLi-R**	7	1,05		120,0	226	160	108	15,4	14,6	15000		0,71
Compact fluorescent reflector lamp, R50, E14 **CFLi-R**	7	1,05	68	115,0	164	140	98	14,0	13,3	10000		0,85
Compact fluorescent reflector lamp, R50, GU10 **CFLi-R**	7	1,05		103,5	198	167	119	17,0	16,2	6000		0,85
Compact fluorescent reflector lamp, R50, GU10	11	1,05	119	99,0	220	182	134	12,2	11,6	15000		0,83

Lamp type Acronym	Wattage	Average LWFt	Intensity	Beam angle	Luminous flux in 2π	Luminous flux in π (opening angle 120°)	Functional lumen in 90° opening angle	ηlamp(90°) @25 °C (without LFWt)	ηlamp(90°) @25 °C (LFWt incl)	Operational Life time	Unit price (for end user)	% Lumen in 120° cone related to forward output	Comment	System Wattage	Corrected Luminous Flux	Level
	[W]		[cd]	[°]	[lm]	[lm]	[lm]	[lm/W]	[lm/W]	[h]	[€]			[W]	[lm]	
CFLi-R																
Compact fluorescent reflector lamp, R63, E27 **CFLi-R**	11	1,05		122,0	215	171	114	10,3	9,8	10000		0,79				
Compact fluorescent reflector lamp, R63, E27 **CFLi-R**	11	1,05	111	125,0	240	206	145	13,2	12,6	10000		0,86		11,55	181,25	**B**
Compact fluorescent reflector lamp, R63, E27 **CFLi-R**	11	1,05	124	117,0	240	203	149	13,5	12,9	15000		0,85		11,55	186,25	**B**
Compact fluorescent reflector lamp, R63, E27 **CFLi-R**	11	1,05		105,9	458	298	187	17,0	16,2	10000		0,65				
Compact fluorescent reflector lamp, PAR38, E27 (B22d) **CFLi-R**	15	1,05	450	70,0	680	604	492	32,8	31,2	15000		0,89		15,75	615	**B+**
Compact fluorescent reflector lamp, PAR38, E27 (B22d) **CFLi-R**	23	1,05	450	110,0	1200	980	711	30,9	29,4	10000		0,82		24,15	888,75	**B+**

Lamp type Acronym	Wattage	Average LWFt	Intensity	Beam angle	Luminous flux in 2π	Luminous flux in π (opening angle 120°)	Functional lumen in 90° opening angle	ηlamp(90°) @25 °C (without LFWt)	ηlamp(90°) @25 °C (LFWt incl)	Operational Life time	Unit price (for end user)	% Lumen in 120° cone related to forward output	Comment	System Wattage	Corrected Luminous Flux	Level
	[W]		[cd]	[°]	[lm]	[lm]	[lm]	[lm/W]	[lm/W]	[h]	[€]			[W]	[lm]	
HL-LV-GU5,3																
Halogen reflector lamp, MR16, 10°, 12V, GU5.3, IRC **HL-LV-R**	20	1,06	5720	12	418,0	374	321	16,1	15,1	4000	7.5			21,2	401,3	**B**
Halogen reflector lamp, MR16, 36°, 12V, GU5.3, IRC **HL-LV-R**	20	1,06	1110	29	418	374	321	16,1	15,1	5000	7.5					
Halogen reflector lamp, MR16, 36°, 12V, GU5.3, IRC + silver/dichroic **HL-LV-R**	20	1,06	1166	29	439	393	337	16,9	15,9	5000	8.0		*calculated based on preceeding *1.05*			
Halogen reflector lamp, MR16, 36°, 12V, GU5.3, IRC + silver/dichroic + Anti-Refl **HL-LV-R**	20	1,06	1200	29	452	404	347	17,4	16,4	5000	8.5		*calculated based on preceeding *1.03*	21,2	434	**B**
Halogen reflector lamp, MR16, 36°, 12V, GU5.3, IRC + silver/dichroic + Anti-Refl **HL-LV-R**	20	1,06	1284	29	484	433	371	18,6	17,5	**2000**	8.5		*calculated based on 5000h *1.07*	21,2	464	**B**
Halogen reflector lamp, MR16, 36°, 12V, GU5.3, xenon	25	1,06	862	38	421	398	367	14,7	13,8	4000	7.0					

Lamp type / Acronym	Wattage	Average LWFt	Intensity	Beam angle	Luminous flux in 2π	Luminous flux in π (opening angle 120°)	Functional lumen in 90° opening angle	ηlamp(90°) @25 °C (without LFWt)	ηlamp(90°) @25 °C (LFWt incl)	Operational Life time	Unit price (for end user)	% Lumen in 120° cone related to forward output	Comment	System Wattage	Corrected Luminous Flux	Level
	[W]		[cd]	[°]	[lm]	[lm]	[lm]	[lm/W]	[lm/W]	[h]	[€]			[W]	[lm]	
HL-LV-R														26,5	459	**C**
Halogen reflector lamp, MR16, 36°, 12V, GU5.3, IRC **HL-LV-R**	30	1,06	1486	35	605	588	533	17,8	16,8	5000	7.5			31,8	666,5	**B**
Halogen reflector lamp, MR16, 36°, 12V, GU5.3, IRC + silver/dichroic **HL-LV-R**	30	1,06	1560	35	635	617	560	18,7	17,6	5000	7.5		*calculated based on preceeding *1.05*	31,8	699,825	**B**
Halogen reflector lamp, MR16, 36°, 12V, GU5.3, IRC + silver/dichroic + Anti-Refl **HL-LV-R**	30	1,06	1607	35	654	636	577	19,2	18,1	5000	7.5		*calculated based on preceeding *1.03*	31,8	720,81975	**B**
Halogen reflector lamp, MR16, 36°, 12V, GU5.3, IRC + silver/dichroic + Anti-Refl **HL-LV-R**	30	1,06	1720	35	700	680	617	20,6	19,4	2000	7.5		*calculated based on 5000h *1.07*	31,8	771,27713	**B**
Halogen reflector lamp, MR16, 36°, 12V, GU5.3, IRC **HL-LV-R**	35	1,06	1898	30	655	631	565	16,1	15,2	5000	7.5			37,1	706,125	**C**
Halogen reflector lamp, MR16, 36°, 12V, GU5.3, IRC + silver/dichroic **HL-LV-R**	35	1,06	1993	30	688	663	593	16,9	16,0	5000	7.5		*calculated based on preceeding *1.05*			

Lamp type Acronym	Wattage	Average LWFt	Intensity	Beam angle	Luminous flux in 2π	Luminous flux in π (opening angle 120°)	Functional lumen in 90° opening angle	ηlamp(90°) @25 °C (without LFWt)	ηlamp(90°) @25 °C (LFWt incl)	Operational Life time	Unit price (for end user)	% Lumen in 120° cone related to forward output	Comment	System Wattage	Corrected Luminous Flux	Level
	[W]		[cd]	[°]	[lm]	[lm]	[lm]	[lm/W]	[lm/W]	[h]	[€]			[W]	[lm]	
Halogen reflector lamp, MR16, 36°, 12V, GU5.3, IRC + silver/dichroic + Anti-Refl **HL-LV-R**	35	1,06	2053	30	708	682	611	17,5	16,5	5000	7.5		*calculated based on preceeding *1.03*	37,1	763,67419	**C**
Halogen reflector lamp, MR16, 36°, 12V, GU5.3, IRC + silver/dichroic + Anti-Refl **HL-LV-R**	35	1,06	2196	30	758	730	654	18,7	17,6	2000	7.5		*calculated based on 5000h *1.07*	37,1	817,13138	**B**
Halogen reflector lamp, MR16, 36°, 12V, GU5.3, xenon **HL-LV-R**	35	1,06	1992	28	584	558	524	15,0	14,1	2000	7.0			37,1	655	**C**
Halogen reflector lamp, MR16, 36°, 12V, GU5.3, xenon **HL-LV-R**	35	1,06	2092	28	613	586	550	15,7	14,8	1000	7.0		*calculated based on preceeding *1.05*	37,1	687,75	**C**
Halogen reflector lamp, MR16, 36°, 12V, GU5.3, IRC **HL-LV-R**	45	1,06	2530	34	991	941	853	19,0	17,9	5000	7.5			47,7	1066	**B**
Halogen reflector lamp, MR16, 36°, 12V, GU5.3, IRC + silver/dichroic **HL-LV-R**	45	1,06	2657	34	1040	988	896	19,9	18,8	5000	8.0		*calculated based on preceeding *1.05*			

Lamp type Acronym	Wattage	Average LWFt	Intensity	Beam angle	Luminous flux in 2π	Luminous flux in π (opening angle 120°)	Functional lumen in 90° opening angle	ηlamp(90°) @25 °C (without LFWt)	ηlamp(90°) @25 °C (LFWt incl)	Operational Life time	Unit price (for end user)	% Lumen in 120° cone related to forward output	Comment	System Wattage	Corrected Luminous Flux	Level
	[W]		[cd]	[°]	[lm]	[lm]	[lm]	[lm/W]	[lm/W]	[h]	[€]			[W]	[lm]	
Halogen reflector lamp, MR16, 36°, 12V, GU5.3, IRC + silver/dichroic + Anti-Refl **HL-LV-R**	45	1,06	2736	34	1071	1018	923	20,5	19,3	5000	8.5		*calculated based on preceeding *1.03*	47,7	1153	**B**
Halogen reflector lamp, MR16, 36°, 12V, GU5.3, IRC + silver/dichroic + Anti-Refl **HL-LV-R**	45	1,06	2928	34	1146	1089	987	21,9	20,7	2000	8.5		*calculated based on 5000h *1.07*	47,7	1234	**B**
Halogen reflector lamp, MR16, 36°, 12V, GU5.3, IRC + silver/dichroic + Anti-Refl **HL-LV-R**	45	1,06	3119	34	1221	1160	1052	23,4	22,1	1000	8.5		*calculated based on 5000h *1.14*	47,7	1315	**B**
Halogen reflector lamp, MR16, 38°, 12V, GU5.3, IRC **HL-LV-R**	50	1,06	2428	36	1000	958	868	17,4	16,4	4000	7.5					
LED's																
LED retrofit reflector lamp, 2700K, R63, 230V, E27 **LED-MV-i-R**	7,4	1,05	360	45				*33,4*	*31,8*		40					
LED retrofit reflector lamp, 4000K, R63, 25°, 230V, E27 **LED-MV-i-R**	6,4	1,05	788	26	275	249	226	35,3	33,6	45000	40			6,72	282	**B+**

Lamp type / Acronym	Wattage	Average LWFt	Intensity	Beam angle	Luminous flux in 2π	Luminous flux in π (opening angle 120°)	Functional lumen in 90° opening angle	ηlamp(90°) @25 °C (without LFWt)	ηlamp(90°) @25 °C (LFWt incl)	Operational Life time	Unit price (for end user)	% Lumen in 120° cone related to forward output	Comment	System Wattage	Corrected Luminous Flux	Level
	[W]		[cd]	[°]	[lm]	[lm]	[lm]	[lm/W]	[lm/W]	[h]	[€]			[W]	[lm]	
LED retrofit reflector lamp, MR16, 230V, GU10 **LED-MV-i-R**	4,7	1,05	382	32				*36,1*	*34,4*		30					
LED retrofit reflector lamp, 3000K, MR16, 20°, 230V, GU10 **LED-MV-i-R**	3,8	1,05	657	24	181	160	143	38,2	36,4	15000	30			3,9375	179,25	**A+**
LED retrofit reflector lamp, *MR16*, 10°, 230V, GU10 **LED-MV-i-R**	3,3	1,05	913	10	67	49	41	12,4	11,8	45000	40		*different form - halo*	3,465	51	**B+**
LED retrofit reflector lamp, *MR16*, 10°, 230V, GU10 **LED-MV-i-R**	3,3	1,05	1012	11	84	66	57	17,4	16,5	45000	40		*different form - halo*	3,465	71,625	**B+**
LED retrofit reflector lamp, 3000K,MR16, 230V, GU10 **LED-MV-i-R**	3,9	1,05	310	21	137	115	96	24,3	23,1	15000	30			4,137	119,5	**B+**
LED retrofit reflector lamp, MR16, 12V, GU5.3 **LED-LV-R**	4,4	1,12	405	29				***31,0***	***27,7***							

10 LIST OF ACRONYMS

BAT	Best Available Technology
BAU	Business-As-Usual
BNAT	Best Not yet Available Technology
BOM	Bill Of Materials
Cd	candela (unit for light intensity)
cd / m²	candela per square meter (unit for luminance)
CELMA	Federation of National Manufacturers Associations for Luminaires and Electrotechnical Components for Luminaires in the European Union
CEN	Comité Européen de Normalisation European Committee for Standardization
CEN/TR	CEN Technical Report (no standard)
CENELEC	Comité Européen de Normalisation Electrotechnique European Committee for Electrotechnical Standardization
CFL	Compact Fluorescent Lamp
CFLi	Compact Fluorescent Lamp with integrated ballast
CFLi-R-DLS	Compact Fluorescent Reflector Lamp with integrated ballast that meets the requirement for a Directional Light Source
CFLi-R-NDLS	Compact Fluorescent Reflector Lamp with integrated ballast that does Not meet the requirement for a Directional Light Source
CFLni	Compact Fluorescent Lamp non integrated ballast
CIE	Commission Internationale de l'Eclairage International Commission on Illumination
CRI	Colour Rendering Index (see also Ra)
DG TREN	Directorat General for Transport and Energy
DIY	Do It Yourself (shop)
DLOR	Downward Light Output Ratio
E	Illuminance [lx]
Eavg	Average illuminance [lx]
EC	European Commission
EEI	Energy Efficiency Index
ELC	European Lamp Companies Federation
EMC	ElectroMagnetic Compatibility
Emin	minimum illuminance
EN xxxxx	Prefix for a European Standard
EOL	End Of Life
EuP	Energy using Product
FL	Fluorescent Lamp
FU	Functional Unit
GER	Gross Energy Requirements
GLS	Incandescent lamp
GLS-C	Clear incandescent lamp
GLS-C-HW	Clear incandescent lamp where $W \geq 200W$
GLS-F	Frosted (or non-clear) incandescent lamp
GLS-R	Incandescent Reflector lamp

GLS-R-HW	Incandescent Reflector lamp where W ≥ 200W
HL-LV	Halogen lamp for use on extra Low Voltage 12V
HL-LV-R	Halogen Reflector lamp for use on extra Low Voltage 12V
HL-MV	Halogen lamp for use on Mains Voltage 230V
HL-MV-HW	Halogen lamp for use on Mains Voltage 230V where W ≥ 80W
HL-MV-R	Halogen Reflector lamp for use on Mains Voltage 230V
HL-MV-R-HW	Halogen Reflector lamp for use on Mains Voltage 230V where W ≥ 80W
IEA	International Energy Agency
IEC	International Electrotechnical Committee
IEE	Intelligent Energy for Europe
IESNA	Illuminating Engineering Society of North America
ILCOS	International Lamp COding System
IP (rating)	Ingress Protection
ISO	International Standards Organisation
L	Luminance [cd/m²]
LCA	Life Cycle Assessment
LCC	Life-Cycle Cost
LED	Light Emitting Diode
LER	Luminaire Efficacy Rating
LERc	Luminaire Efficacy Rating corrected
LFL	Linear Fluorescent Lamp
LLCC	Least Life-Cycle Cost
LLMF	Lamp Lumen Maintenance Factor
LMF	Luminaire Maintenance Factor
LOR	Light Output Ratio
LSF	Lamp Survival Factor
LVD	Low Voltage Directive
Lx	lux (unit for illumination)
MEEUP	Methodology study for Ecodesign of Energy-using Products
MEPS	Minimum Energy Performance Standard
MH	MetalHalide lamp
MH-R	MetalHalide Reflector lamp
MHi-R	MetalHalide Reflector lamp with integrated ballast
Mtoe	Megaton oil equivalent
NA	Not Applicable
OLED	Organic Light Emitting Diode
PAH	Polycyclic Aromatic Hydrocarbons
PJ	PetaJoule = 1015 Joule
Plamp	Lamp power [W]
PM	Particulate Matter
POP	Persistant Organic Pollutants
Preal	Real power consumption of a luminaire
Psystem	Real power consumption of the lamp and ballast/transformer/electronics
Ra	Colour rendering index (see also CRI)
RoHS	Restriction of the use of certain Hazardous Substances
VOC	Volatile Organic Compounds
WEEE	Waste of Electrical and Electronic Equipment

WLED	White LED
WLEDi-DLS	White LED lamp that retrofits an incandescent or halogen mains voltage reflector lamp and meets the requirement for a Directional Light Source
WLEDi-NDLS	White LED lamp that retrofits an incandescent or halogen mains voltage lamp and does not meet the requirement for a Directional Light Source
WLED-LV-DLS	White LED lamp that retrofits a halogen reflector lamp for extra Low Voltage (12V) and meets the requirement for a Directional Light Source
Hballast	Ballast efficiency
Hlamp	Luminous efficacy of a lamp [lm/W]
Φ	(luminous) Flux [lm]