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Design Options

Energy

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Executive Summary

This document covers MEErP Task 6 and deals with the environmental and economic impacts of the design options for the various types of light sources. These options regard the substitution of classic technology lamps [1] by improved lamps of the same technology, or by LED lighting products.

For each lamp type the report presents two LED design options:

- The LED 2015 option represents the best currently available LED substitute. This can be the LED lamp with the highest efficacy, or with the most favourable combination of efficacy and price, according to the data gathered in Task 4. This represents the best available LED technology (BAT).

- The LED 2020 option represents the LED substitute that is expected to exist in 2020 according to the projections derived in Task 4, i.e. with an efficacy of 175 lm/W and a price of 7.5 euros/klm excl. VAT. This represents the best non-available technology (BNAT).

In addition to the two LED options, for many lamp types at least one classic technology BAT-option is presented.
The options are compared to each other and to the base case (BC), that represents the EU-28 average for the considered lamp type.

For each design option, and for the base case, the report provides the life cycle costs (LCC) and the total electricity consumption (kWh) during the lamp life. As the options typically have different lifetimes, the comparison of these data between the options is difficult. The focus is therefore on the presentation of normalized data, i.e. LCC/Mlmh and kWh/Mlmh [2].
As shown in Task 5, the electricity consumption during the use-phase of the lamps is by far the most important environmental impact. Other impacts, e.g. CO_2 emission or acidification, are proportional to this consumption in good approximation.
All the analyses are based on the EcoReports that have been presented in Task 5.

Results per mega-lumen-hour

For all lamp types, the (future) LED 2020 option has both the lowest electricity consumption (in terms of kWh/Mlmh) and the lowest life cycle costs (in terms of LCC/Mlmh).

A survey of the results for the currently available options is provided in Table 1. This table shows for each base case:

- the operating conditions used in the analyses (lm, h/a),
- the option with the lowest LCC/Mlmh and with the lowest kWh/Mlmh,
- the payback times of the LED 2015 and 2020 options with respect to the best available classic technology option.

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[1] Fluorescent lamps (LFL and CFL), high-intensity discharge lamps (HID), halogen (HL) and non-halogen (GLS) filament lamps.

[2] Mlmh = mega-lumen-hour, e.g. a 500 lm lamp burning for 2000 hours, or a 1000 lm lamp burning for 1000 hours.

For all lamp types except high-intensity discharge (HID) lamps, the LED 2015 option has the lowest electricity consumption (kWh/Mlmh). For HID-lamps, the BAT high-pressure sodium lamp has the lowest kWh/Mlmh.

For compact fluorescent lamps (CFLi, CFLni), halogen lamps (HL), and non-halogen filament lamps (GLS), the LED 2015 option also has the lowest life cycle costs (LCC/Mlmh).

For linear fluorescent lamps (LFL) and high-intensity discharge lamps (HPM, HPS, MH), the best available classic technology has the lowest life cycle costs per Mlmh.

Payback times

If LEDs meet the projected 2020 characteristics, and classic technologies maintain their current characteristics, the LEDs will have payback times [3] of less than 1 year for most lamp types that are typical for residential use (GLS, HL, CFLi). Payback times of 1-2.5 years for 2020 LEDs are also predicted for HID-lamps. Higher payback times for 2020 LEDs are expected for LFL and CFLni: from 2.5 to 4 years (Table 1, last column).

Current (2015) LEDs still have difficulties in being competitive with LFL, HID-lamps and CFL's (both with or without integrated control gear): payback times are long (5 to 12 years), and in some cases a 2015 investment in LED lighting may never pay back for these classic lamp types. It is recalled from the Task 4 report that for LFL T5, CFLni and HID-lamps the availability on the 2015 market of LED retrofit lamps is limited.

For halogen lamps and non-halogen filament lamps, 2015 LEDs are already competitive, with payback times from 1 to 4.5 years, depending on the classic lamp type. However, it is recalled from the Task 4 report that LED retrofit lamps for halogen capsules and for linear halogen lamps with R7s caps in general have larger dimensions than the lamps they aim to substitute: the consumer should check carefully if they fit in the existing luminaires.

Validity

The above results are valid for the examined operating conditions (see first column of Table 1), and under the choices made as regards purchase prices, installation costs, repair and maintenance costs, electricity rates, lamp efficacies, ballast efficiencies, useful lifetimes, and lumen-equivalence and operating-hours-equivalence between the options.

For many lamp types, in particular the initial costs (purchase + installation) have a high influence on the payback times. As shown in Task 4, the purchase prices for LEDs have a wide spread, and consequently so have payback times. In addition the market is very dynamic, so the presented LED 2015 results will soon be outdated.

The presented results are certainly not valid for every installed lamp in every situation, but they are retained to be indicative for the average EU-28 situation.

[3] LEDs typically require a higher initial investment (purchase price + installation cost), that is compensated in later years by lower annual electricity costs. Classic technology lamps typically have lower initial cost but higher annual electricity costs. The payback time is the time in years where the cumulative consumer expenditure for the two options is identical, i.e. where the higher initial LED costs have been paid back due to lower expenses for electricity consumption.

Table 1 Survey of main results of the Task 6 analyses. The results are valid only for the analysed conditions (reference power/lumen, operating hours per year), under the assumptions made, and for the prices and costs considered. They are NOT valid for every lighting situation, but indicative for the average EU-28 situation.

Base case (BC) [4] (analysis conditions)	Available option with lowest LCC/Mlmh	Available option with lowest kWh/Mlmh	Payback time for LED 2015 vs. best classic technology (years)	Payback time for LED 2020 vs. best classic technology (years)
LFL T8 tri-phosphor (2400 lm, 2017 h/a)	Long life LFL T8t	LED 2015	may never pay back [5]	4
LFL T5 (2275 lm, 2099 h/a)	High-efficiency T5	LED 2015	may never pay back [5]	4
LFL T8 halo-phosphor (2400 lm, 1398 h/a)	T8 tri-phosphor	LED 2015	may never pay back [5]	3
LFL T12 (2450 lm, 1623 h/a)	T8 tri-phosphor	LED 2015	may never pay back [5]	2.5
CFLni (633 lm, 1197 h/a)	LED 2015	LED 2015	no pay back in CFLni lifetime [6]	3.5
HPM (12000 lm, 4000 h/a) (higher lm for HPS)	HPS BAT	HPS BAT	5 [7]	1
HPS & MH (13200 lm, 4000 h/a) (same lm for all)	HPS BAT MH BAT	HPS BAT	may never pay back [7]	2.5
MV NDLS (GLS-X, HL-E, CFLi) (500 lm, 450 h/a) [8]	LED 2015	LED 2015	3.5-4 (GLS, HL) >12 (CFLi) [9]	1
MV DLS (GLS-R, HL-X) (450 lm, 450 h/a) [8]	LED 2015	LED 2015	2 [10]	0
HL-LV-R (MR16) (490 lm, 450 h/a) [8]	LED 2015	LED 2015	4.5 [11]	< 1
HL-LV-Capsules (490 lm, 450 h/a) [8]	LED 2015	LED 2015	3	2
HL-MV-Capsules (420 lm, 450 h/a) [8]	LED 2015	LED 2015	1	< 1
HL-MV-Linear (R7s) (3000 lm, 450 h/a) [8]	LED 2015	LED 2015	1	< 1

[4] 'LFL'=linear fluorescent lamp, 'CFL'=compact fluorescent lamp, 'HPM'=high-pressure mercury lamp, 'HPS'=high-pressure sodium lamp, 'MH'=metal-halide lamp, 'HL'=halogen lamp, 'GLS'=non-halogen filament lamp, 'MV'=mains voltage, 'LV'=low voltage, 'NDLS'=non-directional lamp, 'DLS'=directional lamp, '-R'=reflector lamp, 'ni'=non-integrated control gear.

[5] The 2015 LED tubes have high initial costs compared to the best available LFL-options while their efficacy advantage over LFL is still relatively small. Useful lifetimes for LED tubes are comparable to those of long life LFL's.

[6] There are few LED retrofit lamp models for CFLni replacement available on the market; data are uncertain

[7] Shorter payback times apply for HPM BC lamps and HPS retrofit lamps. There are few LED retrofit lamp models for HID-lamp replacement available on the market.

[8] For these lamp types a rebound effect of +10% on both capacity (lm) and annual operating hours (h/a) has been applied for the LED options.

[9] This is based on the average 2015 LED prices from Table 1 in the Task 4 report. Taking the lowest prices from the same table, the payback times would reduce to 2 years for GLS X and HL MV E, and to 8-9 years for CFLi.

[10] This is based on the median 2015 LED prices from Table 1 in the Task 4 report. Taking the lowest prices from the same table, the payback time would reduce to less than 1 year.

[11] This is based on the average 2015 LED prices from Table 1 in the Task 4 report. Taking the lowest prices from the same table, the payback time would reduce to 1-1.5 years.

1. Introduction

This document covers MEErP Task 6 and deals with design options for light sources. For the function of this Task in the context of the MEErP, see Annex B.

In the context of the light sources study, three main types of 'design options' can be distinguished:

1. Substitution of a lamp belonging to one of the non-LED base cases [12] by an improved one (best available) that uses the same classic lamp technology. This option is available only if lamps from this technology are still allowed on the market, and then considered only if lamps exist that are significantly better than the base case average.
2. Substitution of a lamp belonging to one of the non-LED base cases by a best available lamp from another technology. In this case the focus is on substitution by LED-lamps, but for LFLs and HID-lamps, other technologies are also taken into account.
3. Improvements in LED technology, mainly leading to efficacy improvements and to price reductions.

As regards the first two points, the replacement/improvement options have been discussed in detail in chapter 5 of the Task 4 report. The focus here will be on the evaluation of the environmental impacts and life cycle costs of the most relevant options.

As regards the third point, the improvement potential of LED technology has been discussed in detail in chapter 2 of the Task 4 report, leading to a projection for the future development of LED efficacy and LED prices. In particular the 2015 and 2020 data will be used here.

The analyses in this Task 6 are based on the EcoReports presented in Task 5. The analysis methodology and general remarks for all lamp types can be found in chapter 2. For details see the paragraphs for the evaluation of the options for the individual base cases in chapter 3.

[12] For the definition of the base cases see the Task 4 and Task 5 reports.

2. Analysis methodology

This chapter provides a general explanation of the analysis methodology. Details and deviations for specific base cases are explained in chapter 3.

- All analyses are based on the EcoReports developed in Task 5, but they have been adapted to enable an honest comparison between the base case and the design options. In particular the LED EcoReport, that is for a 1000 lm retrofit lamp, has been scaled in function of the luminous flux for each specific base case.
  In addition, for the LED 2015 option, the efficacy (influencing the power in the EcoReport) and the purchase price have been adapted on a case-by-case basis using the information from table 1 of the Task 4 report and its underlying data.
  For the LED 2020 option the projected efficacy and price for that year (175 lm/W and 7.5 euros/klm excl. VAT) have been used for all base cases.

- The base cases (BC) represent EU-28 average characteristics for a group of lamps of a certain type. For most lamp types, these BC-characteristics are significantly different from the best available (BAT) characteristics for the same lamp type. In these cases a non-LED BAT option has been examined. The EcoReport for this option is identical to the one for the BC, but with modified efficacy, price and/or lifetime. The non-LED BAT characteristics have usually been derived from the information presented in the Task 4 report.

- Prices, costs and electricity rates include 20% VAT for the residential sector and exclude VAT for the non-residential sector. The presented data (and the underlying Ecoreports) are a weighted average over both sectors and consequently the % VAT included depends on the ratio of sales or energy consumption between the two sectors, see details in the Task 4 report, chapter 5, tables with BC data. For all replacement options, the same % VAT as for the base case has been assumed.

- Electricity rates are different for the residential and non-residential sector. The presented data are a weighted average over both sectors and consequently the applied electricity rate depends on the ratio of energy consumption between the two sectors. For all replacement options, the same electricity rate as for the base case has been assumed.

- Installation costs for the design options have usually been assumed identical to those for the base case, but in some cases additional costs have been considered for control gear change and/or re-wiring activities (details in chapter 3). Purchase and installation costs of luminaires are not included in the analyses.

- Annual repair and maintenance costs for the design options have been taken identical to those of the base case. Note that in the EcoReports these costs are specified over the lifetime, and on that basis they can differ between the options, being proportional to lifetime.

- The purchase cost of LED tubes for LFL replacement and of LED retrofit lamps for HID-lamp replacement has been assumed to include the costs for required auxiliary equipment such as starters or control gears, whether integrated in the lamp or not. The motivation is that most of the gathered price information regards retrofit kits that contain everything that is needed.

- The report concentrates on lifetime electricity consumption during the use-phase and on life cycle costs. Other environmental impacts are not addressed in detail, but as shown in the Task 5 report, electricity consumption during the use-phase is by far the most important impact, while most other environmental impacts, e.g. CO_2 emission and acidification emissions, are proportional to this consumption.

- Due to differences in the lifetimes of the base case and the design options, it is difficult to compare the life cycle costs (LCC) and the lifetime electricity consumption (kWh) between the options. The focus is therefore on the presentation of normalized data, i.e. LCC/Mlmh and kWh/Mlmh [13].

- For lamps that are mainly used in non-residential applications (LFL, HID, CFLni), no rebound effect [14] has been applied, meaning that the luminous flux and the operating hours of the base case have also been applied for the design options. An exception has been made only for HPS-lamps that substitute HPM-lamps (see par. 3.7).
  For lamps predominantly used in the residential sector (Halogen and GLS) a rebound effect of 10% has been applied for both luminous flux and operating hours (applied for the LED options and for CFLi).

- The electricity consumption of external control gears is not included in the EcoReports. Where applicable it has been added a posteriori for the analyses in this report. For the assumed control gear efficiencies, see chapter 3.

- The summary tables for the design options in chapter 3 contain a value for the CRM-indicator (critical raw material content in mg Sb equivalent). For LED this value is always high due to the assumed presence of germanium. As observed in Task 5, this value is probably excessive because Ge is not used in all LEDs. Therefore the content of rare earth elements (REE, part of the CRM-indicator) is separately indicated. This is relevant in particular when comparing LED-impacts with impacts of fluorescent lamps.

- For each base case and design option, chapter 3 presents the cumulative consumer expenditure over the useful lifetime of each option, both as a table and as a graph. Payback times have been derived from these data. The graphs are also useful to visually assess the effect of changes in purchase price (shift curves up and down) and changes in efficacy (slope of the curves).
  The cumulative data assume that the lamps exist on the market. This implies e.g. that legacy incandescent lamps, LFL T12, LFL T8 halo-phosphor and HPM-lamps are plotted as if they continued to be sold. It also implies that LED 2020 lamps are simulated to be available in year 1.
  Electricity rates are constant throughout the period (4% escalation rate and 4% discount rate).

[13] Mlmh = mega-lumen-hour, e.g. a 500 lm lamp burning for 2000 hours, or a 1000 lm lamp burning for 1000 hours.
[14] The 'rebound effect' indicates the consumer's tendency to buy energy saving lamps that have higher luminous flux than the classic technology lamps they replace, and/or to let them burn for longer times.

3. Evaluation of design options per base case

3.1. LFL T8 tri-phosphor

Design options considered:

- LFL T8t BC : this is the base case described in the Task 4 report, par. 5.4. It represents the EU-28 average LFL T8 tri-phosphor lamp. For this lamp the EcoReport presented in Task 5 was used.
- LFL T8t HE: a high-efficiency lamp of the same technology as the BC, representing a non-LED BAT option [15]. This lamp has an efficacy of 100 lm/W (as compared to 80 lm/W for the BC), which was identified in Task 4 as a BAT efficacy for LFL T8t lamps with a power comparable to that of the BC (around 30 W). The lifetime of this lamp is also slightly higher than that of the BC. The 15,000 hours represent the time after which the installed luminous flux has decreased to 90% of the initial value, considering the combined effect of LLMF and LSF. This option uses the same EcoReport as the BC, but with adapted power, lifetime, mercury content (2 mg instead of 3 mg) and product price.
- LFL T8t XL: an extra-long-life lamp of the same technology as the BC [16]. The 40,000 hours represent the time after which the installed luminous flux has decreased to 88% of the initial value, considering the combined effect of LLMF and LSF. The efficacy of this lamp is lower than that of the HE-option (93 lm/W), and the product price is slightly higher. This option uses the same EcoReport as the BC, but with adapted power, lifetime and product price.
- LED 2015: this option represents the average LED retrofit tube for an LFL T8t existing in this moment. The average characteristics identified in table 1 of the Task 4 report have been used, i.e. 109 lm/W and 18.21 euros/klm. The EcoReport for 1000 lm LEDs as presented in the Task 5 report has been used, but scaled to the 2400 lm flux of the LFL T8t BC reference lamp (see details below).
- LED 2020: this option represents the average LED retrofit tube for an LFL T8t that is expected to exist in 2020, based on the projections of the Task 4 report, i.e. 175 lm/W and 7.5 euros/klm. The same EcoReport has been used as for LED 2015, but adapting power and product price.

Remarks and explanations:

- The prices for the LFL T8t HE- and XL-options (respectively 6.05 and 7.81 euros excl. VAT) have been derived from on-line sales' sites. For honesty of comparison, a new product price was also derived for the BC-lamp, using the same sources, and this gave 4.74 euros excl. VAT [17].

[15] As a reference, the following lamp was used: Philips MASTER TL-D HF SUPER 80 32W/840 120 cm, http://download.p4c.philips.com/l4bt/3/322774/master_tl-d_eco_322774_ffs_aen.pdf

[16] As a reference, the following lamp was used: Philips MASTER TL-D Xtra 36W/840 120 cm, http://download.p4c.philips.com/l4bt/3/323206/master_tl-d_xtra_323206_ffs_aen.pdf

[17] This does not mean that the average price of 8.42 euros excl. VAT used in MELISA and in the EcoReport is wrong: shop prices are often significantly higher than prices for on-line sales, and it has been verified that LFLs similar to the BC-

- For all options, the same operating hours per year (2017 h/a) and the same luminous flux (2400 lm) as the base case have been assumed, implying that no rebound effect has been applied [18].

- The LED lifetime of 20,000 hours is assumed to correspond to a reduction of the installed luminous flux to 90% of the initial value (considering a combination of LSF and LLMF). The declared L70 lifetimes for LED tubes are usually much longer.

- The energy consumption by external control gears has been added in the current analysis by dividing the EcoReport results (that are without this energy) by the control gear efficiency. For the BC this efficiency is 91%, assuming electronic control gear, and the same efficiency has been assumed for all options. Stand-by energy, if any, is NOT included.

Table 2 provides a summary of the most relevant input and output data. For additional input data see the Task 5 report (EcoReports) and references therein.

The LCC per Mlmh and the electricity consumption in kWh per Mlmh are also shown graphically in Figure 1. The LED 2020 option has the lowest energy consumption and the lowest cost per Mlmh. Of the currently available options, the LED 2015 has the lowest energy consumption per Mlmh, but high cost. The LFL T8t high-efficiency (HE) and long life (XL) options are almost equivalent, one with slightly lower energy, the other with slightly lower cost.

The bottom part of Table 2 (see also Figure 2) shows the cumulative consumer expenditure over the useful lifetime for each option. Values for year 0 are purchase and installation cost. Each following year the amount increases by the running costs (electricity, repair and maintenance).

Figure 2 indicates that current (2015) average LED tubes for LFL T8t replacement still have too high purchase costs and a too small efficacy advantage to be competitive with the LFL T8t options [19]. Note that the LED 2015 curve in the graph is based on the average price from table 1 in the Task 4 report (18.21 euros/klm). Taking the lowest price from the same table (11.31 euros/klm), the LED 2015 curve would shift downwards by approximately 17 euros, but still remain above the curve for the long life LFL T8t XL option.

Compared with the LFL T8t BC, the HE-version has a payback time of 1 year, and the XL-version a payback time of 3 years.

lamp are being sold also for prices above 8.42 euros. In addition, note that in MELISA and in the EcoReport, the BC represents the average of all lamps of this type, which would also include the HE- and XL-lamps.

[18] See par. 5.4.5 in the Task 4 report for remarks regarding the lumen equivalence between LFL and LED tubes.

[19] Relatively small changes in purchase costs (e.g. assuming or not the inclusion of control gear costs; using on-line or shop prices for LFL) and installation costs (e.g. assuming or not the inclusion of re-wiring costs) do not change this situation.

Table 2 Summary of design options for LFL T8 tri-phosphor: input data, results over product lifetime, results per Mega-lumen-hour (Mlmh), and cumulative consumer expenditure up to option useful lifetime. In this table, electricity includes the control gear.

		LFL T8t BC	LFL T8t HE	LFL T8t XL	LED 2015	LED 2020
Annual operating hours	h/yr	2017	2017	2017	2017	2017
Capacity	lm	2400	2400	2400	2400	2400
Useful life (hours)	h	13000	15000	40000	20000	20000
Useful life (years)	yr	6.4	7.4	19.8	9.9	9.9
Power	W	30.0	24.0	25.8	22.0	13.7
Efficacy	lm/W	80	100	93	109	175
Product price	euros	4.8	6.1	7.9	44.2	18.2
Installation costs	euros	5.8	5.8	5.8	5.8	5.8
Repair & Maint. Costs	euros/life	2.6	3.0	8.0	4.0	4.0
Electricity rate	euros/kWh	0.122	0.122	0.122	0.122	0.122
Mercury content	mg	3	2	3	0	0
CRM indicator	mg Sb eq.	32	32	32	240	240
o/w REE	mg Sb eq.	28	28	28	0.06	0.06
EoL recycling	%	76%	76%	76%	85%	85%
Total weight	g	169	169	169	461	461
Results per product over lifetime						
Electricity (incl. CG)	kWh/life	429	396	1134	484	301
Electricity cost	euros/life	52.3	48.3	139.4	59.0	36.8
Life cycle cost	euros/life	65.4	63.1	161.1	113.0	64.7
Results per Mlmh						
Electricity (incl. CG)	kWh/Mlmh	13.7	11.0	11.8	10.1	6.3
Electricity cost	euros/Mlmh	1.68	1.34	1.45	1.23	0.77
Purchase cost	euros/Mlmh	0.15	0.17	0.08	0.92	0.38
Installation cost	euros/Mlmh	0.18	0.16	0.06	0.12	0.12
Repair & Maintenance cost	euros/Mlmh	0.08	0.08	0.08	0.08	0.08
Total costs per Mlmh	euros/Mlmh	2.10	1.75	1.68	2.35	1.35
Consumer expenditure						
purchase & installation	euros	10.55	11.88	13.66	49.98	23.97
annual running costs	euros/year	8.52	6.89	7.44	6.36	4.11
Cumulative consumer expenditure						
Year 0	euros	11	12	14	50	24
1	euros	19	19	21	56	28
2	euros	28	26	29	63	32
3	euros	36	33	36	69	36
4	euros	45	39	43	75	40
5	euros	53	46	51	82	45
6	euros	62	53	58	88	49
7	euros		60	66	94	53
8	euros			73	101	57
9	euros			81	107	61
10	euros			88	114	65
11	euros			95		
12	euros			103		
13	euros					

REE= Rare earth elements, in particular from phosphors, see Task 5 report; CRM= Critical raw materials; CG= Control gear; Mlmh= Mega-lumen-hours (e.g. 500 lm over 2000 h or 1000 lm over 1000 h)

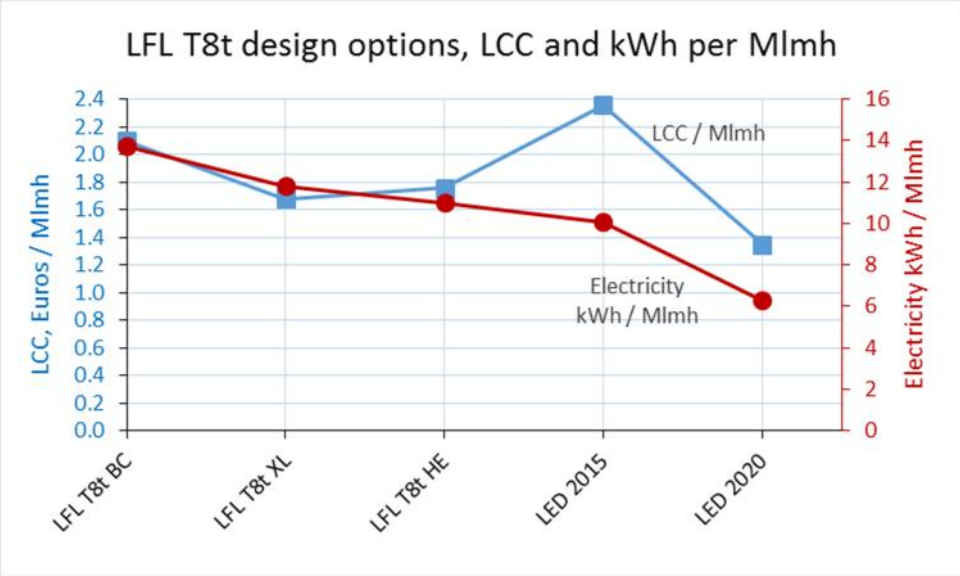

Figure 1 Design options for LFL T8 tri-phosphor lamps: life cycle cost (LCC, in euros/Mlmh, blue line with square markers, axis left) and electricity consumption (in kWh/Mlmh, red line with round markers, axis right). See Table 2 for underlying data.

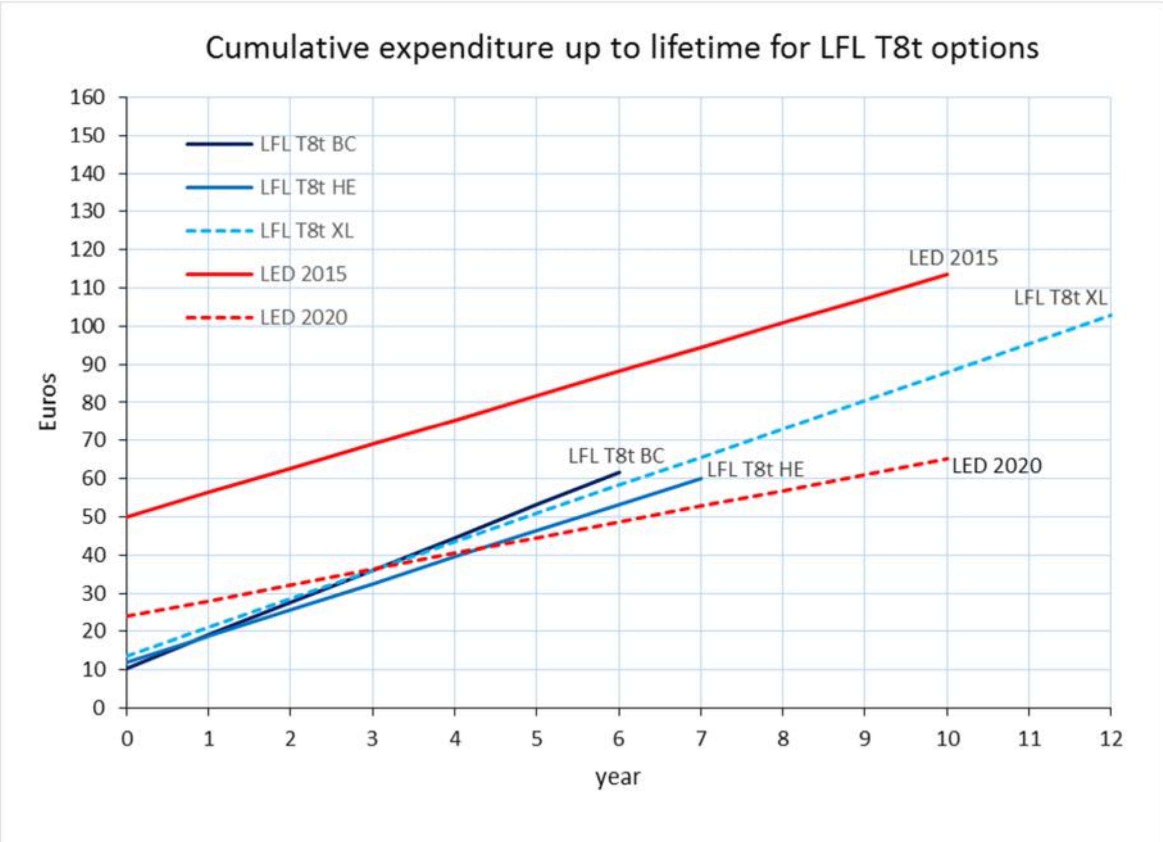

Figure 2 Cumulative consumer expenditure (fixed 2010 euros) for the design options for LFL T8 tri-phosphor lamps, up to their lifetime. Values for year 0 include purchase and installation. Each following year the amount increases by the running costs (electricity, repair and maintenance). See Table 2 (bottom part) for underlying data.

The curve for LED 2020 is of course hypothetical, because this option is not yet available, but if LFL characteristics remain the same up to 2020, and LED projections for 2020 are met, the curve shows that an investment in a LED 2020 tube will have payback times of 3 – 4 years. It can be deducted from the graph that this payback time is quite sensitive to increases in purchase and installation costs (shift the LED 2020 curve slightly up). On the other hand, these curves assume lumen equivalence, while using LED tubes it may be possible to install less lumen (directionality of the light, possibility to remove optical losses, see Task 4 report), and that would imply lower electricity costs (smaller slope for the curve).

In addition note from Table 2 that LED lamps offer advantages as regards the absence of mercury and the reduced use of rare earth elements [20]. On the other hand, LED tubes are still significantly heavier than LFL tubes of the same length and thus consume more material resources.

[20] The high LED value for the total CRM indicator (240) derives from the use of Germanium, but as observed in the Task 5 report this value is probably excessive, because not all LEDs use this material.

3.2. LFL T5

Design options considered:

- LFL T5 BC : this is the base case described in the Task 4 report, par. 5.5. It represents the EU-28 average LFL T8 tri-phosphor lamp. For this lamp the EcoReport presented in Task 5 was used [21].

- LFL T5 HE: a high-efficiency lamp of the same technology as the BC, representing a non-LED BAT option [22]. This lamp has an efficacy of 103 lm/W (as compared to 91 lm/W for the BC), which was identified in Task 4 as a BAT efficacy for LFL T5 lamps with a power comparable to that of the BC (around 25 W) [23]. This option uses the same EcoReport as the BC, but with adapted power, lifetime, mercury content (1.4 mg instead of 2 mg) and product price.

- LFL T8t XL: an extra-long-life lamp of the same technology as the BC [24]. The 30,000 hours represent the time to 10% failures, see remarks further below. The efficacy of this lamp is the same as that of the HE-option (103 lm/W) [23], but the product price is considerably higher. This option uses the same EcoReport as the BC, but with adapted power, lifetime, mercury content (3 mg instead of 2 mg) and product price.

- LED 2015: this option represents the average LED retrofit tube for an LFL T5 existing in this moment. The average characteristics identified in table 1 of the Task 4 report have been used, i.e. 109 lm/W and 18.21 euros/klm. The EcoReport for 1000 lm LEDs as presented in the Task 5 report has been used, but scaled to the 2275 lm flux of the LFL T5 BC reference lamp (see details below).

- LED 2020: this option represents the average LED retrofit tube for an LFL T5 that is expected to exist in 2020, based on the projections of the Task 4 report, i.e. 175 lm/W and 7.5 euros/klm. The same EcoReport has been used as for LED 2015, but adapting power and product price.

Remarks and explanations:

- The prices for the LFL T5 HE- and XL-options (respectively 6.57 and 17.17 euros excl. VAT) have been derived from on-line sales' sites. For honesty of comparison, a new product price was also derived for the BC-lamp, using the same sources, and this gave 3.56 euros excl. VAT [25].

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[21] The following lamps have been used as a reference: 'Philips TL5 HE 28W 840 (MASTER)', http://www.lighting.philips.com/main/prof/lamps/fluorescent-lamps/tl5/master-tl5-high-efficiency/927926583555_EU/product and 'Osram Lumilux T5 HE 28W 840 Cool White' http://www.osram.com/osram_com/products/lamps/fluorescent-lamps/fluorescent-lamps-t5/lumilux-t5-he/index.jsp?productId=ZMP_60153

[22] As a reference, the following lamp was used: Philips MASTER TL5 HE Eco 25=28W/840 1SL 115 cm, http://download.p4c.philips.com/l4bt/3/310750/master_tl5_high_efficiency_eco_310750_ffs_aen.pdf

[23] The 103 lm/W is at 25˚C. At a temperature of 35˚C for which the tube has been optimized, this would be 114 lm/W.

[24] As a reference, the following lamp was used: Philips MASTER TL5 HE Xtra Eco 25=28W/840 1SL 115 cm, http://download.p4c.philips.com/l4bt/3/383496/master_tl5_high_efficiency_xtra__383496_ffs_aen.pdf

[25] This does not mean that the average price of 7.92 euros excl. VAT used in MELISA and in the EcoReport is wrong: shop prices are often significantly higher than prices for on-line sales, and it has been verified that LFLs similar to the BC-

- As regards the useful lifetime of the LFL T5 BC-, HE- and XL-options, the source data from manufacturer catalogues are somewhat confusing. The times up to 10% failures are respectively declared as 19000 h, 21000 h and 30000 h, and these times have been used in the analyses, rounding the first two to 20000 h. Considering LSF and LLMF data however, the following is declared:
  - BC at 20,000 h: LSF= 84%, LLMF=90%, installed flux = 87%
  - HE at 20,000 h: LSF= 94%, LLMF=90%, installed flux = 88%
  - XL at 20,000 h: LSF= 94%, LLMF=88%, installed flux = not specified

  So, as regards lumen maintenance after 20000 h, the XL (long life) option does not seem to be better than the HE-option.

- For all options, the same operating hours per year (2099 h/a) and the same luminous flux (2275 lm) as the base case have been assumed, implying that no rebound effect has been applied [26].

- The LED lifetime of 20,000 hours is assumed to be representative for a reduction of the installed luminous flux to 90% of the initial value (comparable to the T5-options). The declared L70 lifetimes for LED tubes are usually much longer.

- The energy consumption by external control gears has been added in the current analysis by dividing the EcoReport results (that are without this energy) by the control gear efficiency. For the BC this efficiency is 91% (electronic control gear), and the same efficiency has been assumed for all options. Stand-by energy, if any, is NOT included.

- As noted in the Task 4 report par. 5.5.4, the number of models of LED tubes for LFL T5 replacement available on the market is limited, and major lamp manufacturers do not supply them. As a consequence, the LED 2015 option does exist on the market, but it is rather 'weak'.

Table 3 provides a summary of the most relevant input and output data. For additional input data see the Task 5 report (EcoReports) and references therein.

The LCC per Mlmh and the electricity consumption in kWh per Mlmh are also shown graphically in Figure 3. The LED 2020 option has the lowest energy consumption and the lowest cost per Mlmh. Of the currently available options, the LED 2015 has the lowest energy consumption per Mlmh, but high cost. The LFL T5 high-efficiency (HE) and long life (XL) options are almost equivalent, but the HE-option has slightly lower cost per Mlmh.

The bottom part of Table 3 (see also Figure 4) shows the cumulative consumer expenditure over the useful lifetime for each option. Values for year 0 are purchase and installation cost. Each following year the amount increases by the running costs (electricity, repair and maintenance).

Figure 4 indicates that current (2015) LED tubes for LFL T5 replacement still have too high purchase and installation costs and a too small efficacy advantage to be competitive

lamp are being sold also for prices above 7.92 euros. In addition, note that in MELISA and in the EcoReport, the BC represents the average of all lamps of this type, which would also include the HE- and XL-lamps.

[26] See par. 5.4.5 in the Task 4 report for remarks regarding the lumen equivalence between LFL and LED tubes.

with the LFL T5 options [27]. Note that the LED 2015 curve in the graph is based on the average price from table 1 in the Task 4 report (18.21 euros/klm). Taking the lowest price from the same table (11.31 euros/klm), the LED 2015 curve would shift downwards by approximately 17 euros, but anyway remain above the LFL T5 options. The difference between LED and LFL T5 is larger than that found between LED and LFL T8t. The difference would be even higher when considering efficacy values at 35˚C, that for LFL T5 are higher than the 25˚C values assumed in the analyses, but for LED would be lower than assumed.

The curve for LED 2020 is of course hypothetical, because this option is not yet available, but if LFL characteristics remain the same up to 2020, and LED projections for 2020 are met, the curve shows that an investment in a LED 2020 tube will have a payback time around 4 years as compared with the BC- and HE-options. LED 2020 tubes would immediately offer economic advantages with respect to LFL T5 XL tubes. It can be deducted from the graph that this payback time is sensitive to increases in purchase and installation costs (shift the LED 2020 curve slightly up) and to temperature influences (slightly decrease slope of the LFL T5 options, slightly increase the slope of the LED option). On the other hand, these curves assume lumen equivalence, while using LED tubes it may be possible to install less lumen (directionality of the light, possibility to remove optical losses, see Task 4 report), and that would imply lower electricity costs (smaller slope for the curve).

In addition note from Table 3 that LED lamps offer advantages as regards the absence of mercury and the reduced use of rare earth elements [28]. On the other hand, LED tubes are still significantly heavier than LFL tubes of the same length and thus consume more material resources.

[27] Relatively small changes in purchase costs (e.g. assuming or not the inclusion of control gear costs; using on-line or shop prices for LFL) and installation costs (e.g. assuming or not the inclusion of re-wiring costs) do not change this situation.

[28] The high LED value for the total CRM indicator (227) derives from the use of Germanium, but as observed in the Task 5 report this value is probably excessive, because not all LEDs use this material.

Table 3 Summary of design options for LFL T5: input data, results over product lifetime, results per Mega-lumen-hour (Mlmh), and cumulative consumer expenditure up to option useful lifetime. In this table, electricity includes the control gear.

		LFL T5 BC	LFL T5 HE	LFL T5 XL	LED 2015	LED 2020
Annual operating hours	h/yr	2099	2099	2099	2099	2099
Capacity	lm	2275	2275	2275	2275	2275
Useful life (hours)	h	20000	20000	30000	20000	20000
Useful life (years)	yr	9.5	9.5	14.3	9.5	9.5
Power	W	25.0	22.1	22.1	20.9	13.0
Efficacy	lm/W	91	103	103	109	175
Product price	euros	3.6	6.6	17.4	42.0	17.3
Installation costs	euros	5.8	5.8	5.8	5.8	5.8
Repair & Maint. Costs	euros/life	4.1	4.1	6.1	4.1	4.1
Electricity rate	euros/kWh	0.122	0.122	0.122	0.122	0.122
Mercury content	mg	2	1.4	3	0	0
CRM indicator	mg Sb eq.	21	21	21	227	227
o/w REE	mg Sb eq.	17	17	17	0.05	0.05
EoL recycling	%	76%	76%	76%	85%	85%
Total weight	g	109	109	109	437	437
Results per product over lifetime						
Electricity (incl. CG)	kWh/life	549	485	728	459	286
Electricity cost	euros/life	67.0	59.2	88.8	56.0	34.9
Life cycle cost	euros/life	80.5	75.7	116.1	107.8	62.0
Results per Mlmh						
Electricity (incl. CG)	kWh/Mlmh	12.1	10.7	10.7	10.1	6.3
Electricity cost	euros/Mlmh	1.47	1.30	1.30	1.23	0.77
Purchase cost	euros/Mlmh	0.08	0.15	0.25	0.92	0.38
Installation cost	euros/Mlmh	0.13	0.13	0.08	0.13	0.13
Repair & Maint. cost	euros/Mlmh	0.09	0.09	0.06	0.09	0.09
Total costs per Mlmh	euros/Mlmh	1.77	1.66	1.70	2.37	1.36
Consumer expenditure						
purchase & installation	euros	9.37	12.42	23.16	47.72	23.05
annual running costs	euros/year	7.46	6.64	6.50	6.30	4.09
Cumulative consumer expenditure						
Year 0	euros	9	12	23	48	23
1	euros	17	19	30	54	27
2	euros	24	26	36	60	31
3	euros	32	32	43	67	35
4	euros	39	39	49	73	39
5	euros	47	46	56	79	43
6	euros	54	52	62	86	48
7	euros	62	59	69	92	52
8	euros	69	66	75	98	56
9	euros	77	72	82	104	60
10	euros	84	79	88	111	64
11	euros			95		
12	euros			101		
13	euros			108		
14	euros			114		
15	euros					

REE= Rare earth elements, in particular from phosphors, see Task 5 report; CRM= Critical raw materials; CG= Control gear; Mlmh= Mega-lumen-hours (e.g. 500 lm over 2000 h or 1000 lm over 1000 h)

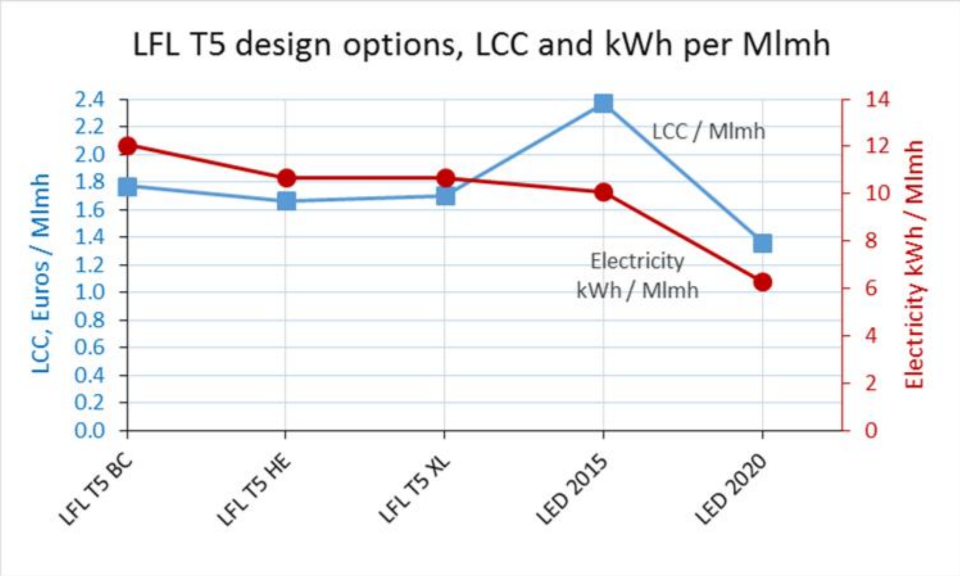

Figure 3 Design options for LFL T5 lamps: life cycle cost (LCC, in euros/Mlmh, blue line with square markers, axis left) and electricity consumption (in kWh/Mlmh, red line with round markers, axis right). See Table 3 for underlying data.

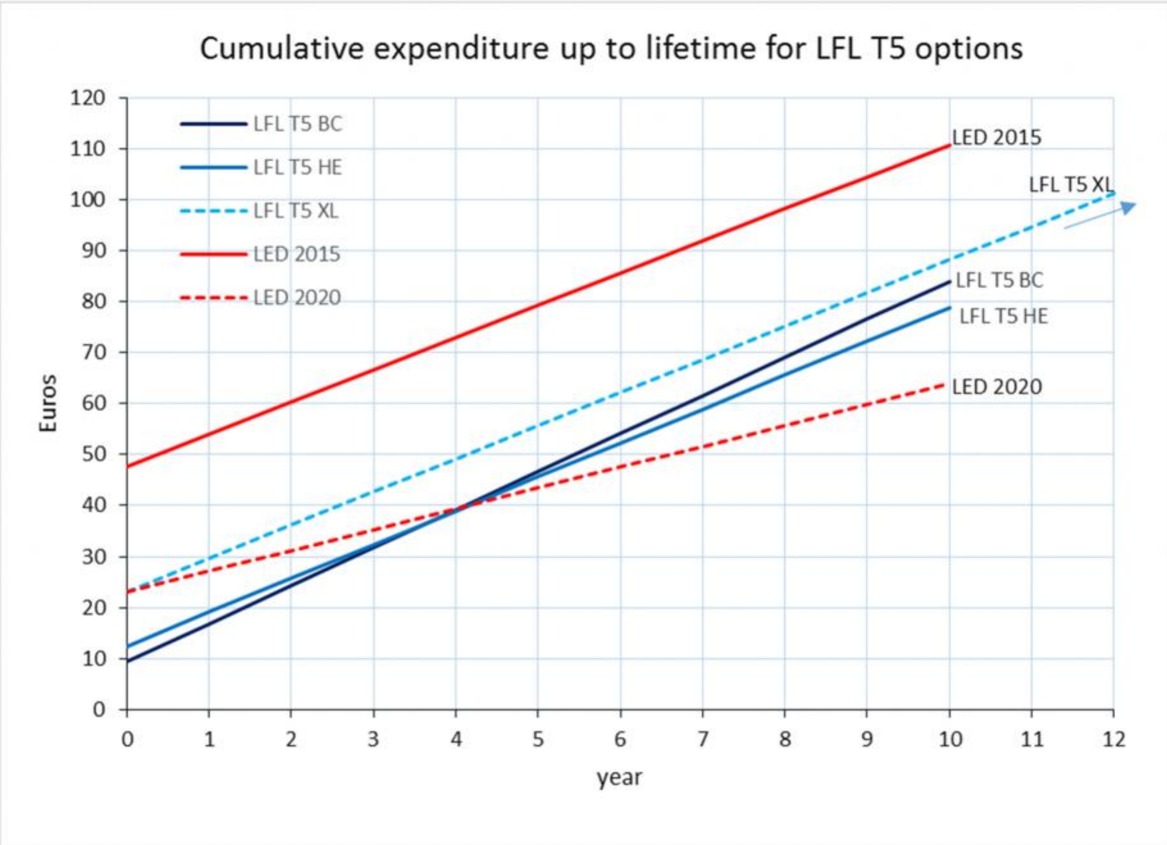

Figure 4 Cumulative consumer expenditure (fixed 2010 euros) for the design options for LFL T5 lamps, up to their lifetime. Values for year 0 include purchase and installation. Each following year the amount increases by the running costs (electricity, repair and maintenance). See Table 3 (bottom part) for underlying data.

3.3. LFL T8 halo-phosphor

Design options considered:

- LFL T8h BC : this is the base case described in the Task 4 report, par. 5.3. It represents the EU-28 average LFL T8 halo-phosphor lamp. For this lamp the EcoReport presented in Task 5 was used. Note that this reference option is no longer on the market, but there is still a small installed stock.

- LFL T8t BC : this is the base case described in the Task 4 report, par. 5.4. It represents the EU-28 average LFL T8 tri-phosphor lamp. For this lamp the EcoReport presented in Task 5 was used.

- LED 2015: this option represents the average LED retrofit tube for an LFL T8 existing in this moment. The average characteristics identified in table 1 of the Task 4 report have been used, i.e. 109 lm/W and 18.21 euros/klm. The EcoReport for 1000 lm LEDs as presented in the Task 5 report has been used, but scaled to the 2400 lm flux of the LFL T8h BC reference lamp (see details below).

- LED 2020: this option represents the average LED retrofit tube for an LFL T8 that is expected to exist in 2020, based on the projections of the Task 4 report, i.e. 175 lm/W and 7.5 euros/klm. The same EcoReport has been used as for LED 2015, but adapting power and product price.

Remarks and explanations:

- Different from par. 3.1, the LFL T8t HE- and XL-options are not included here. Consequently there is no price-comparison problem, and the original BC-prices have been maintained, both for the T8h and T8t option.

- The data for the LFL T8t BC- and LED-options presented here are not identical to those presented in par. 3.1, because here the LFL T8t or LED-tube is used as a substitute for T8h, which has a different mix of residential and non-residential stock, and consequently different annual operating hours, different electricity rate, and different average VAT %.

- For all options, the same operating hours per year (1398 h/a) and the same luminous flux (2400 lm) as the base case have been assumed, implying that no rebound effect has been applied [29].

- The LED lifetime of 20,000 hours is assumed to be representative for a reduction of the installed luminous flux to 90% of the initial value (comparable to the T8-options). The declared L70 lifetimes for LED tubes are usually much longer.

- The energy consumption by external control gears has been added in the current analysis by dividing the EcoReport results (that are without this energy) by the control gear efficiency. For the LFL T8h BC this efficiency is 80% (magnetic control gear), while for all other options it is 91% (electronic gear or LED control gear). Stand-by energy, if any, is NOT included.

[29] See par. 5.4.5 in the Task 4 report for remarks regarding the lumen equivalence between LFL and LED tubes.

Table 4 provides a summary of the most relevant input and output data. For additional input data see the Task 5 report (EcoReports) and references therein.

The LCC per Mlmh and the electricity consumption in kWh per Mlmh are also shown graphically in Figure 5. The LED 2020 option has the lowest energy consumption and the lowest cost per Mlmh. Of the currently available options, the LED 2015 has the lowest energy consumption per Mlmh, but the LCC per Mlmh is slightly higher than for the LFL T8 tri-phosphor option.

The bottom part of Table 4 (see also Figure 6) shows the cumulative consumer expenditure over the useful lifetime for each option. Values for year 0 are purchase and installation cost. Each following year the amount increases by the running costs (electricity, repair and maintenance).

Figure 6 indicates that current (2015) average LED tubes for LFL T8 replacement do not pay back when compared to T8 halo-phosphor lamps, within the lifetime of the latter. Note that the LED 2015 curve in the graph is based on the average price from table 1 in the Task 4 report (18.21 euros/klm). Taking the lowest price from the same table (11.31 euros/klm), the LED 2015 curve would shift downwards by approximately 17 euros, and would then have approximately the same cumulative expenditure as the LFL T8h BC after its 6 year lifetime.

Substituting a T8 halo-phosphor lamp five years from now, an investment in a LED 2020 tube will have a payback time of 2.5 - 3 years as compared with the T8 tri-phosphor option. It can be deducted from the graph that this payback time is sensitive to increases in purchase and installation costs (shift the LED 2020 curve slightly up). On the other hand, these curves assume lumen equivalence, while using LED tubes it may be possible to install less lumen (directionality of the light, possibility to remove optical losses, see Task 4 report), and that would imply lower electricity costs (smaller slope for the curve).

As regards the comparison between LFL tri-phosphor lamps and LED-substitutes, see further remarks in par. 3.1.

Table 4 Summary of design options for LFL T8 halo-phosphor: input data, results over product lifetime, results per Mega-lumen-hour (Mlmh), and cumulative consumer expenditure up to option useful lifetime. In this table, electricity includes the control gear.

		LFL T8h BC	LFL T8t BC	LED 2015	LED 2020	
Operating hours	h/yr	1398	1398	1398	1398	
Capacity	lm	2400	2400	2400	2400	
Useful life (hours)	h	8000	13000	20000	20000	
Useful life (years)	yr	5.7	9.3	14.3	14.3	
Power	W	32.0	30.0	22.0	13.7	
Efficacy	lm/W	75	80	109	175	
Product price	euros	8.5	8.5	44.2	18.2	
Installation costs	euros	5.8	5.8	5.8	5.8	
Repair & Maint. Costs	euros/life	1.2	2.0	3.1	3.1	
Electricity rate	euros/kWh	0.138	0.138	0.138	0.138	
Mercury content	mg	8	3	0	0	
CRM indicator	mg Sb eq.	11	32	240	240	
o/w REE	mg Sb eq.	0	28	0.06	0.06	
EoL recycling	%	74%	76%	85%	85%	
Total weight	g	169	169	461	461	
Results per product over lifetime						
Electricity (incl. CG)	kWh/life	320	429	484	301	
Electricity cost	euros/life	44.2	59.1	66.8	41.6	
Life cycle cost	euros/life	59.7	75.4	119.9	68.7	
Results per Mlmh						
Electricity (incl. CG)	kWh/Mlmh	16.7	13.7	10.1	6.3	
Electricity cost	euros/Mlmh	2.30	1.90	1.39	0.87	
Purchase cost	euros/Mlmh	0.44	0.27	0.92	0.38	
Installation cost	euros/Mlmh	0.30	0.18	0.12	0.12	
Repair & Maint. cost	euros/Mlmh	0.06	0.06	0.06	0.06	
Total costs per Mlmh	euros/Mlmh	3.11	2.42	2.50	1.43	
Consumer expenditure						
purchase & installation	euros	14.29	14.29	49.99	23.98	
annual running costs	euros/year	7.93	6.58	4.88	3.12	
Cumulative consumer expenditure						
Year 0	euros	14	14	50	24	
1	euros	22	21	55	27	
2	euros	30	27	60	30	
3	euros	38	34	65	33	
4	euros	46	41	70	36	
5	euros	54	47	74	40	
6	euros	62	54	79	43	
7	euros		60	84	46	
8	euros		67	89	49	
9	euros		73	94	52	
10	euros			99	55	
11	euros			104	58	
12	euros			109	61	
13	euros			113	65	
14	euros			118	68	
15	euros					

REE= Rare earth elements, in particular from phosphors, see Task 5 report; CRM= Critical raw materials; CG= Control gear; Mlmh= Mega-lumen-hours (e.g. 500 lm over 2000 h or 1000 lm over 1000 h)

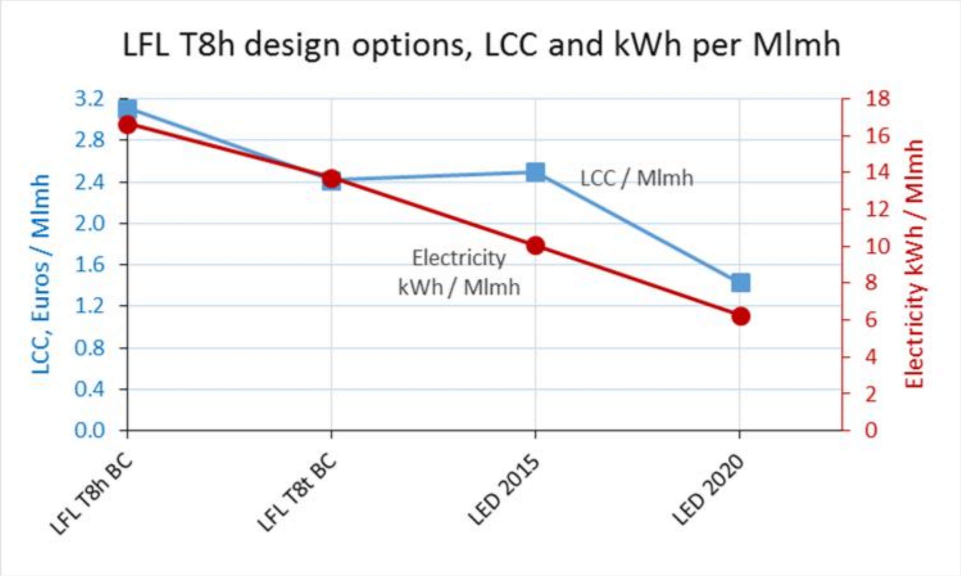

Figure 5 Design options for LFL T8 halo-phosphor lamps: life cycle cost (LCC, in euros/Mlmh, blue line with square markers, axis left) and electricity consumption (in kWh/Mlmh, red line with round markers, axis right). See Table 4 for underlying data.

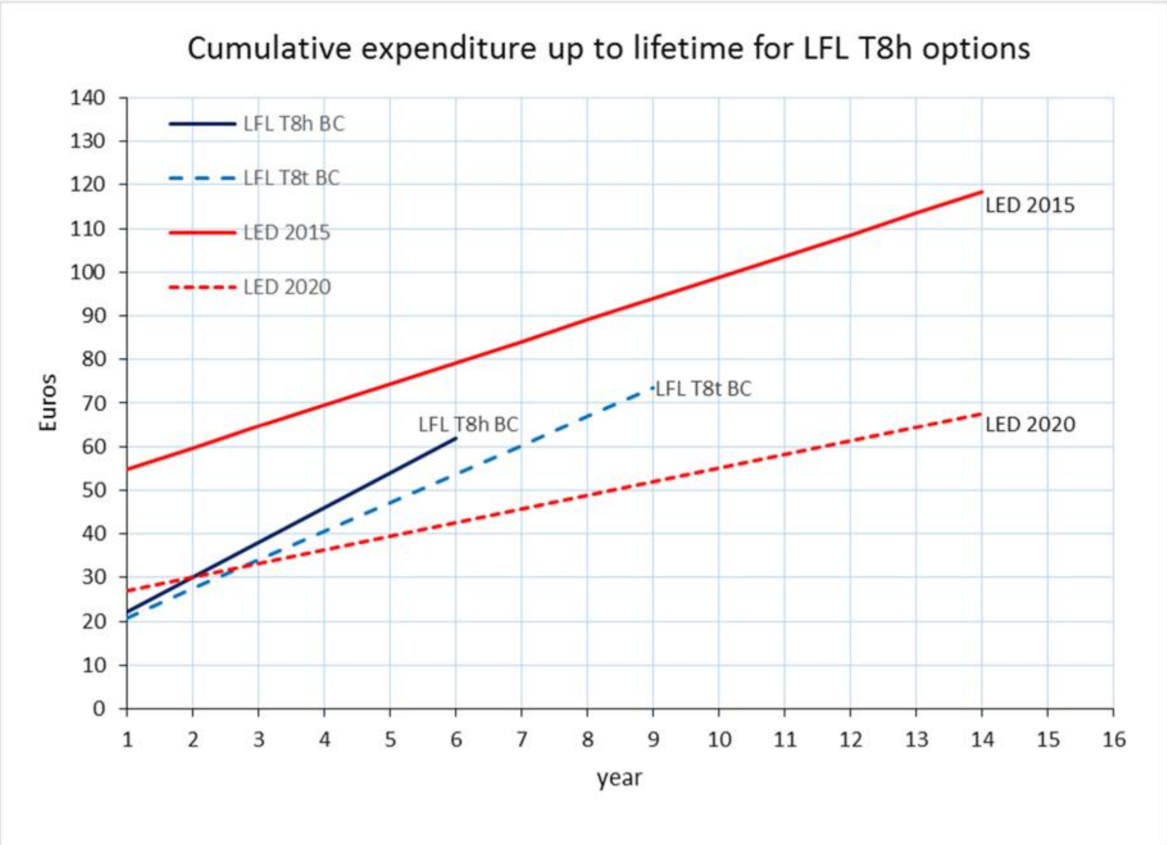

Figure 6 Cumulative consumer expenditure (fixed 2010 euros) for the design options for LFL T8 halo-phosphor lamps, up to their lifetime. Values for year 0 include purchase and installation. Each following year the amount increases by the running costs (electricity, repair and maintenance). See Table 4 (bottom part) for underlying data.

3.4. LFL T12

Design options considered:

- LFL T12 BC : this is the base case described in the Task 4 report, par. 5.2. It represents the EU-28 average LFL T12. For this lamp the EcoReport presented in Task 5 was used. Note that this reference option is no longer on the market, but there is still a small installed stock.

- LFL T8t BC : this is the base case described in the Task 4 report, par. 5.4. It represents the EU-28 average LFL T8 tri-phosphor lamp. For this lamp the EcoReport presented in Task 5 was used.

- LED 2015: this option represents the average LED retrofit tube for an LFL T8 existing in this moment. The average characteristics identified in table 1 of the Task 4 report have been used, i.e. 109 lm/W and 18.21 euros/klm. The EcoReport for 1000 lm LEDs as presented in the Task 5 report has been used, but scaled to the 2400 lm flux of the LFL T8h BC reference lamp (see details below).

- LED 2020: this option represents the average LED retrofit tube for an LFL T8 that is expected to exist in 2020, based on the projections of the Task 4 report, i.e. 175 lm/W and 7.5 euros/klm. The same EcoReport has been used as for LED 2015, but adapting power and product price.

Remarks and explanations:

- Different from par. 3.1, the LFL T8t HE- and XL-options are not included here. Consequently there is no price-comparison problem, and the original BC-prices have been maintained, both for the T12 and T8t option.

- The data for the LFL T8t BC- and LED-options presented here are not identical to those presented in par. 3.1, because here the LFL T8t or LED-tube is used as a substitute for T12, which has a different mix of residential and non-residential stock, and consequently different annual operating hours, different electricity rate, and different average VAT %.

- For all options, the same operating hours per year (1623 h/a) and the same luminous flux (2450 lm) as the base case have been assumed, implying that no rebound effect has been applied [30].

- The LED lifetime of 20,000 hours is assumed to be representative for a reduction of the installed luminous flux to 90% of the initial value (comparable to the T8-options). The declared L70 lifetimes for LED tubes are usually much longer.

- The energy consumption by external control gears has been added in the current analysis by dividing the EcoReport results (that are without this energy) by the control gear efficiency. For the LFL T12 BC this efficiency is 80% (magnetic control gear), while for all other options it is 91% (electronic gear or LED control gear). Stand-by energy, if any, is NOT included.

[30] See par. 5.4.5 in the Task 4 report for remarks regarding the lumen equivalence between LFL and LED tubes.

Table 5 provides a summary of the most relevant input and output data. For additional input data see the Task 5 report (EcoReports) and references therein.

The LCC per Mlmh and the electricity consumption in kWh per Mlmh are also shown graphically in Figure 7. The LED 2020 option has the lowest energy consumption and the lowest cost per Mlmh. Of the currently available options, the LED 2015 has the lowest energy consumption per Mlmh, but the LCC per Mlmh is slightly higher than for the LFL T8 tri-phosphor option.

The bottom part of Table 5 (see also Figure 7) shows the cumulative consumer expenditure over the useful lifetime for each option. Values for year 0 are purchase and installation cost. Each following year the amount increases by the running costs (electricity, repair and maintenance).

Figure 6 indicates that current (2015) average LED tubes for LFL T8/T12 replacement do not pay back when compared to LFL T12 and LFL T8t lamps, within the lifetime of the latter two. Note that the LED 2015 curve in the graph is based on the average price from table 1 in the Task 4 report (18.21 euros/klm). Taking the lowest price from the same table (11.31 euros/klm), the LED 2015 curve would shift downwards by approximately 17 euros, and would then have approximately the same cumulative expenditure as the LFL T12 after its 5 year lifetime.

Substituting a T12 lamp five years from now, an investment in a LED 2020 tube will have a payback time of 2.5 years as compared with the T8 tri-phosphor option. It can be deducted from the graph that this payback time is sensitive to increases in purchase and installation costs (shift the LED 2020 curve slightly up). On the other hand, these curves assume lumen equivalence, while using LED tubes it may be possible to install less lumen (directionality of the light, possibility to remove optical losses, see Task 4 report), and that would imply lower electricity costs (smaller slope for the curve).

As regards the comparison between LFL tri-phosphor lamps and LED-substitutes, see further remarks in par. 3.1.

Table 5 Summary of design options for LFL T12: input data, results over product lifetime, results per Mega-lumen-hour (Mlmh), and cumulative consumer expenditure up to option useful lifetime. In this table, electricity includes the control gear.

		LFL T12 BC	LFL T8t BC	LED 2015	LED 2020	
Operating hours	h/yr	1623	1623	1623	1623	
Capacity	lm	2450	2450	2450	2450	
Useful life (hours)	h	8000	13000	20000	20000	
Useful life (years)	yr	4.9	8.0	12.3	12.3	
Power	W	35.0	30.6	22.5	14.0	
Efficacy	lm/W	70	80	109	175	
Product price	euros	8.5	8.5	45.1	18.6	
Installation costs	euros	5.8	5.8	5.8	5.8	
Repair & Maint. Costs	euros/life	1.4	2.3	3.5	3.5	
Electricity rate	euros/kWh	0.131	0.131	0.131	0.131	
Mercury content	mg	8	3	0	0	
CRM indicator	mg Sb eq.	15	32	245	245	
o/w REE	mg Sb eq.	0	28	0.06	0.06	
EoL recycling	%	75%	76%	85%	85%	
Total weight	g	254	169	470	470	
Results per product over lifetime						
Electricity (incl. CG)	kWh/life	350	438	494	308	
Electricity cost	euros/life	45.9	57.3	64.7	40.3	
Life cycle cost	euros/life	61.5	73.9	119.1	68.2	
Results per Mlmh						
Electricity (incl. CG)	kWh/Mlmh	17.9	13.7	10.1	6.3	
Electricity cost	euros/Mlmh	2.34	1.80	1.32	0.82	
Purchase cost	euros/Mlmh	0.43	0.27	0.92	0.38	
Installation cost	euros/Mlmh	0.29	0.18	0.12	0.12	
Repair & Maint. cost	euros/Mlmh	0.07	0.07	0.07	0.07	
Total costs per Mlmh	euros/Mlmh	3.14	2.32	2.43	1.39	
Consumer expenditure						
purchase & installation	euros	14.27	14.27	50.89	24.34	
annual running costs	euros/year	9.59	7.44	5.54	3.56	
Cumulative consumer expenditure						
Year 0	euros	14	14	51	24	
1	euros	24	22	56	28	
2	euros	33	29	62	31	
3	euros	43	37	68	35	
4	euros	53	44	73	39	
5	euros	62	51	79	42	
6	euros		59	84	46	
7	euros		66	90	49	
8	euros		74	95	53	
9	euros			101	56	
10	euros			106	60	
11	euros			112	63	
12	euros			117	67	
13	euros					

REE= Rare earth elements, in particular from phosphors, see Task 5 report; CRM= Critical raw materials; CG= Control gear; Mlmh= Mega-lumen-hours (e.g. 500 lm over 2000 h or 1000 lm over 1000 h)

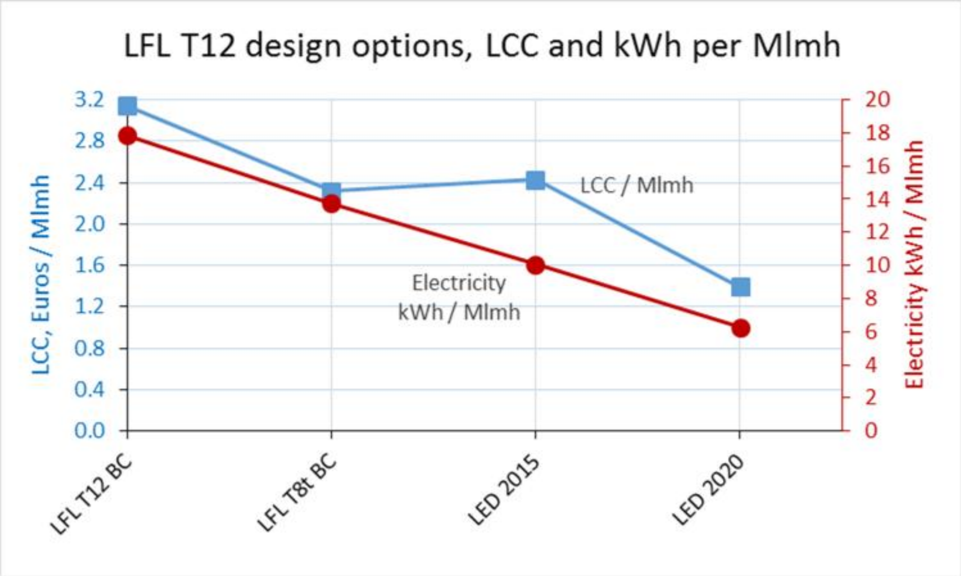

Figure 7 Design options for LFL T12 lamps: life cycle cost (LCC, in euros/Mlmh, blue line with square markers, axis left) and electricity consumption (in kWh/Mlmh, red line with round markers, axis right). See Table 5 for underlying data.

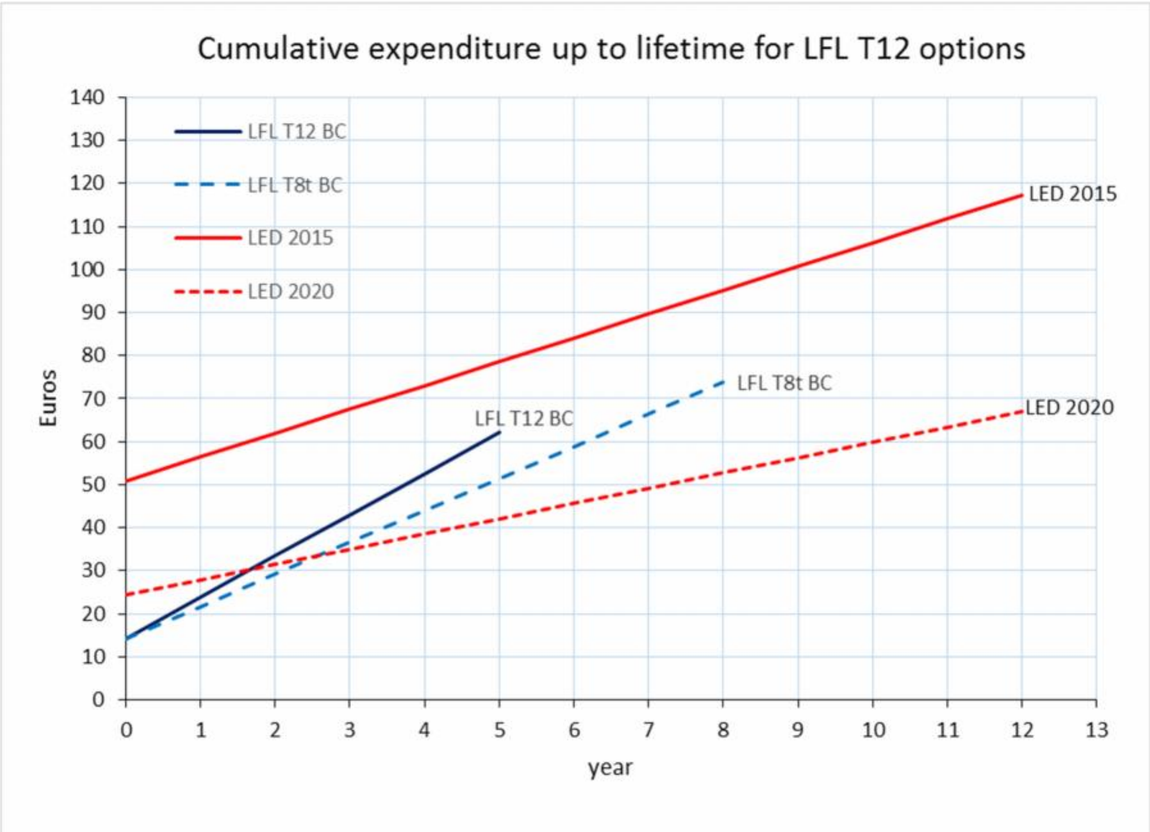

Figure 8 Cumulative consumer expenditure (fixed 2010 euros) for the design options for LFL 12 lamps, up to their lifetime. Values for year 0 include purchase and installation. Each following year the amount increases by the running costs (electricity, repair and maintenance). See Table 5 (bottom part) for underlying data.

3.5. Other linear fluorescent lamps (LFL X)

This base case covers all LFL types not included in the T12, T8h, T8t and T5 base cases. It includes older T5 types (4-13 W) and special fluorescent lamps, e.g. circular T9, T4 tubes, T6, T10 and others. The 2013 energy consumption of these lamps is around 3% of the total LFL energy, and this base case is therefore of minor importance for resources study and scenario analysis.

The older, low-wattage, T5 types (with G5 cap) are also known as TL mini lamps. In tertiary lighting they are frequently used in emergency lighting and exit signs. Special versions are on the market that fit well with battery operated applications. Due to their compact dimensions they were also used in small furniture and in portable lamps.

No design options have been identified in Task 4 (par. 5.6) for these lamps, except for a ballast optimization and replacement by a LED luminaire. Consequently no analysis of design options is presented for these lamps.

3.6. CFL without integrated ballast (CFLni)

Design options considered:

- CFLni BC: this is the base case described in the Task 4 report, par. 5.8. It represents the EU-28 average for compact fluorescent lamps without integrated ballast. For this lamp the EcoReport presented in Task 5 was used.

- LED 2015: this option has been derived from the EcoReport for the 1000 lm average 2015 LED retrofit lamp, but scaling all data to 633 lm. The approximate best 2015 efficacy-price combination for LED substitutes of CFLni was derived as 94 lm/W and 28.1 euros/klm excl. VAT [31].

- LED 2020: this is the same as LED 2015, but with efficacy and price adjusted according to the 2020 projections made in the Task 4 report, i.e. 175 lm/W and 7.50 euros/klm excl. VAT.

Remarks and explanations:

- For all options a flux of 633 lm and 1197 operating hours per year are applied. Considering that CFLni are already energy saving lamps, no additional rebound effect has been applied.

- For all options, the same mix between residential and non-residential sales has been used as defined in the Ecoreport for CFLni BC. This implies that all options have the same lamp installation cost, the same electricity rate, and the same effective VAT percentage included in prices and costs.

- Some of the LED lamps are plug-and-play, but others require a re-wiring of the luminaire and/or installation of a LED control gear. The control gear price is assumed to be included in the lamp price (usually packages are sold), but the installation cost for LEDs has been doubled to account for any additional operations.

Table 6 provides a summary of the most relevant input and output data. For additional input data see the Task 5 report (EcoReports) and references therein.

The LCC per Mlmh and the electricity consumption in kWh per Mlmh are also shown graphically in Figure 9. The LED 2020 option has the lowest energy consumption and the lowest cost per Mlmh. Of the currently available options, the LED 2015 option has the lowest energy consumption per Mlmh, and the lowest cost per Mlmh, but the latter is close to the cost of the base case.

The bottom part of Table 6 (see also Figure 10) shows the cumulative consumer expenditure over the useful lifetime for each option. Values for year 0 are purchase and installation cost. Each following year the amount increases by the running costs (electricity, repair and maintenance).

[31] For reference see table 29 notes 1 and 3 of the Task 4 report. There are lamps on the market with higher declared efficacy, but no price information was available for them.

Figure 10 and Table 6 show that a 2015 investment in a LED retrofit for CFLni does not pay back within the lifetime of the CFLni. This is mainly due to the high initial costs of the LEDs. A value of 28.1 euros/klm excl. VAT was used, but this value is uncertain because it is based on data of only 2 models. In general, retrofit LED lamps for CFLni are scarce on the market, and none of the major lamp suppliers now produces them.

If the LED 2020 option were already available, with the projected characteristics of 175 lm/W and 7.5 euros/klm excl. VAT, it would have a payback time around 3.5 years. This payback time depends heavily on the assumed 4.3 euros additional installation costs for LEDs (for re-wiring and LED control gear installation in some of the cases). Without these costs, the payback time would be around 1 year.

Table 6 Summary of design options for CFLni: input data, results over product lifetime, results per Mega-lumen-hour (Mlmh), and cumulative consumer expenditure up to option useful lifetime. Electricity by control gear included (91% efficiency)

		CFLni BC	LED 2015	LED 2020			
Operating hours	h/yr	1197	1197	1197			
Capacity	lm	633	633	633			
Useful life (hours)	h	10000	20000	20000			
Useful life (years)	yr	8.4	16.7	16.7			
Power	W	11.5	6.7	3.6			
Efficacy	lm/W	55	94	175			
Product price	euros	4.7	18.8	5.0			
Installation costs	euros	4.3	8.6	8.6			
Repair & Maint. costs	euros/life	10.7	21.5	21.5			
Electricity rate	euros/kWh	0.138	0.138	0.138			
Mercury content	mg	2	0	0			
CRM indicator	mg Sb eq.	21	63	63			
o/w REE	mg Sb eq.	17	0.02	0.02			
EoL recycling	%	74%	85%	85%			
Total weight	g	98	121	121			
Results per product over lifetime							
Electricity (incl. CG)	kWh/life	126	148	79			
Electricity cost	euros/life	17.4	20.4	11.0			
Life cycle cost	euros/life	37.1	69.4	46.1			
Results per Mlmh							
Electricity (incl. CG)	kWh/Mlmh	20.0	11.7	6.3			
Electricity cost	euros/Mlmh	2.76	1.61	0.87			
Purchase cost	euros/Mlmh	0.73	1.49	0.40			
Installation cost	euros/Mlmh	0.68	0.68	0.68			
Repair & Maint. cost	euros/Mlmh	1.70	1.70	1.70			
Total costs per Mlmh	euros/Mlmh	5.87	5.48	3.64			
Consumer expenditure							
purchase & installation	euros	8.97	27.48	13.67			
annual running costs	euros/year	3.37	2.51	1.94			
Cumulative consumer expenditure							
Year 0	euros	9	27	14			
1	euros	12	30	16			
2	euros	16	32	18			
3	euros	19	35	19			
4	euros	22	38	21			
5	euros	26	40	23			
6	euros	29	43	25			
7	euros	33	45	27			
8	euros	36	48	29			
9	euros		50	31			
10	euros		53	33			
11	euros		55	35			
12	euros		58	37			
13	euros		60	39			
14	euros		63	41			
15	euros		65	43			

REE= Rare earth elements, in particular from phosphors, see Task 5 report; CRM= Critical raw materials; CG= Control gear; Mlmh= Mega-lumen-hours (e.g. 500 lm over 2000 h or 1000 lm over 1000 h)

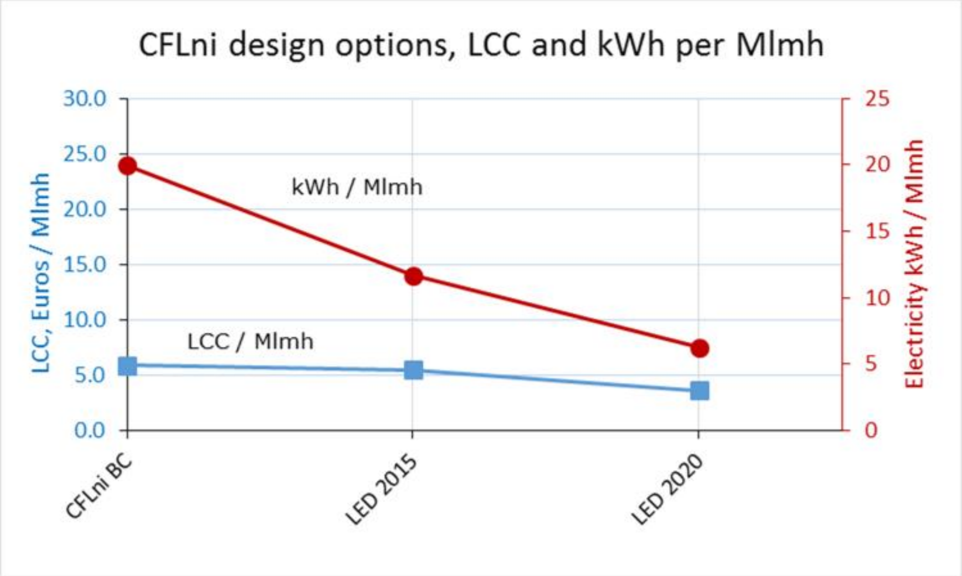

Figure 9 Design options for CFLni: life cycle cost (LCC, in euros/Mlmh, blue line with square markers, axis left) and electricity consumption (in kWh/Mlmh, red line with round markers, axis right). See Table 6 for underlying data.

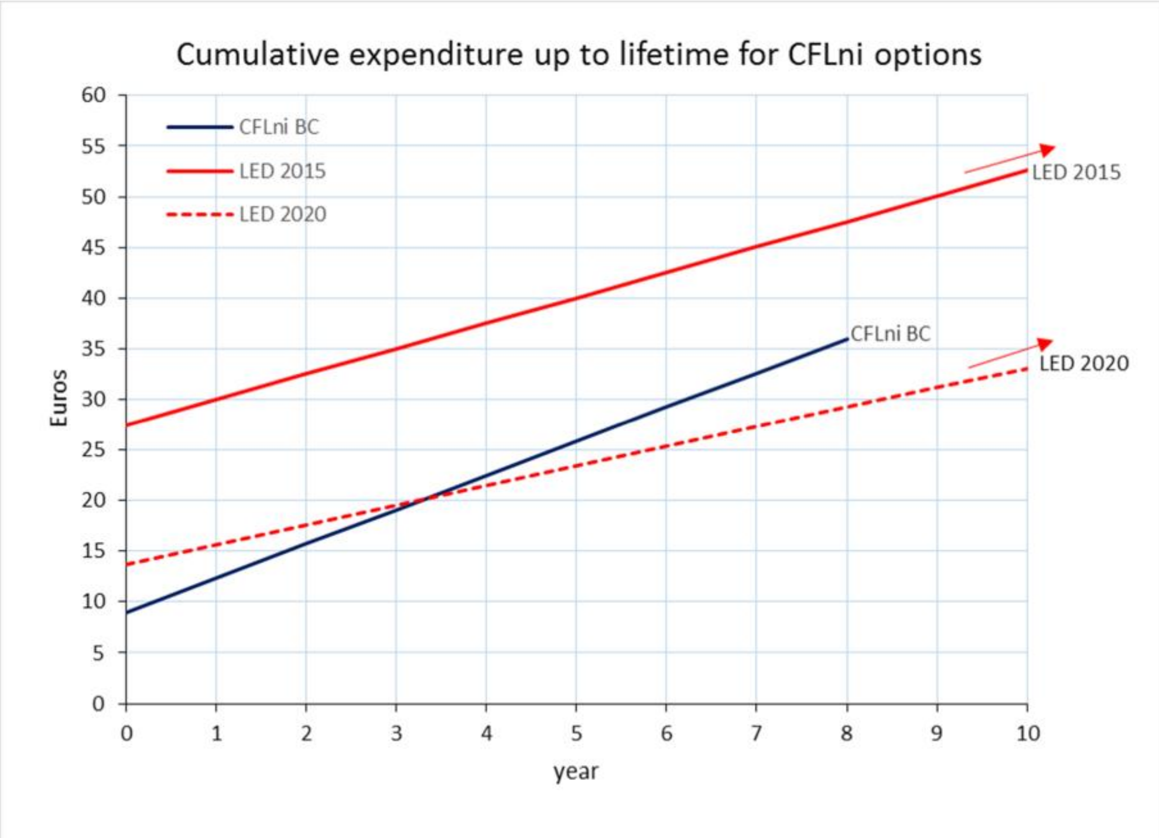

Figure 10 Cumulative consumer expenditure (fixed 2010 euros) for the design options for CFLni, up to their lifetime. Values for year 0 include purchase and installation. Each following year the amount increases by the running costs (electricity, repair and maintenance). See Table 6 (bottom part) for underlying data.

3.7. High-pressure mercury lamps (HPM)

Design options considered:

- HPM BC : essentially, this is the base case described in the Task 4 report, par. 5.17. It represents the EU-28 average HPM-lamp. For this lamp the EcoReport presented in Task 5 was used, but it has been slightly adapted, referring to an actually existing lamp [32].

- HPS retrofit: this is the first improvement option identified in the Task 4 report par. 5.17.2, i.e. a high-pressure sodium lamp especially designed as a retrofit for HPM, and operating on the same ballast. Data are based on an actually existing reference lamp [33].

- HPS BAT replacement: this is the second improvement option identified in the Task 4 report par. 5.17.2. It is a high-pressure sodium lamp with better efficacy and lifetime (intended as BAT) than the retrofit-option above, but it requires replacement of the existing ballast and ignitor. Data are based on an actually existing reference lamp [34].

- LED 2015: as explained in the Task 4 report, there are few LED retrofit lamps for HID-lamps on the market. This option is inspired by a mix of two existing retrofit lamps [35]. The EcoReport for 1000 lm LEDs as presented in the Task 5 report has been used, but scaled to the 12000 lm flux of the HPM BC reference lamp (see details below), and using efficacy and price from the reference LED lamps.

- LED 2020: this option represents the average LED replacement for an HPM-lamp that is expected to exist in 2020, based on the projections of the Task 4 report, i.e. 175 lm/W and 7.5 euros/klm. However, considering that the 2015 version has a price around 10 euros/klm (among the lowest for all LEDs), the projected 2020 price of 7.5 euros/klm has been reduced to 5 euros/klm. Except for efficacy and price, this option is the same as LED 2015.

Remarks and explanations:

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[32] As a reference, the following lamp was used: Philips HPL-N 250W 542 Cool White E40 HG
http://download.p4c.philips.com/l4bt/3/332443/mercury_vapor_standard_332443_ffs_aen.pdf
Power and lifetime are the same as for the BC of Task 4, but luminous flux and efficacy are slightly higher. Prices are the average of three on-line sales' sites.

[33] As a reference, the following lamp was used: Philips SON H 220W/220 E40 220V (indicated as replacement for 250 W HPM lamp) http://download.p4c.philips.com/l4bt/3/323223/son_h_323223_ffs_aen.pdf Prices are the average of four on-line sales' sites.

[34] As a reference, the following lamp was used: Philips MASTER SON APIA Plus Xtra 150W E40 1SL
http://download.p4c.philips.com/l4bt/3/344246/master_son_apia_plus_xtra_344246_ffs_aen.pdf Prices are the average of six on-line sales' sites.

[35] CroLED® E40 120W LED Lampe , 624LEDs 2835 SMD Leuchtmittel , Weiß Licht Birne Leuchte , 6500K 10800LM
http://www.amazon.de/Leuchtmittel-Hochleistung-Beleuchtung-AC100-240V-Strahler/dp/B00T5YPBM4/ref=sr_1_1?ie=UTF8&qid=1432489508&sr=8-1&keywords=croled+120+W+E40+led+lampe#productDetails and
MLLG-GI-LED-RETRO-150 http://www.myledlightingguide.com/150w_led_retro_unit___13500_lumens-details.aspx
See also Task 4 report table 44 ref 6 and 7

- The lifetime of the reference lamp for the BC-option (8000 h) corresponds to a maintenance of 80% of the originally installed luminous flux (considering the combination of LSF and LLMF).
  For the HPS retrofit option the same 80% of maintained flux is reached after 9000 h, but the documentation also states that both LSF and LLMF are 90% after 12,000 h. The latter value has been taken as lifetime for this option.
  For the HPS BAT option, LSF=99% and LLMF=94% after 20,000 h is declared. This has been used as lifetime for the option.
  For one of the LED reference lamps an L70 lifetime of 70,000 h is declared. Nothing is specified for the other lamp. In order to have a lumen maintenance condition comparable to the other options, a lifetime of 32,000 h has been estimated.

- For all options, the same operating hours per year (4000 h/a) have been used.

- For the HPM BC and LED-options the same luminous flux of 12,000 lm has been used, but higher fluxes (19,000 and 17,500) have been applied for the HPS-options. The motivation for this lies in the different colour and CRI for the HPS-lamps, see also the Task 4 report [36].

- The energy consumption by external control gears has been added in the current analysis by dividing the EcoReport results (that are without this energy) by the control gear efficiency. For the HPM BC and HPS retrofit options this efficiency is 83%, for the HPS BAT option 88%, and for the LED options 91%. Stand-by energy, if any, is NOT included.

- For the HPS BAT and LED options, additional costs have been considered for the control gear and its installation. For HPS BAT the costs for ballast and ignitor have been identified in the Task 4 report as 38 euros. The costs for installation of the new control gear and related re-wiring have been taken identical to the original installation costs, i.e. 9.25 euros. The same total cost of 47.25 euros has been applied for the LED options. These costs are not present in the underlying EcoReports, but have been added separately a posteriori.

Table 7 provides a summary of the most relevant input and output data. For additional input data see the Task 5 report (EcoReports) and references therein.

The LCC per Mlmh and the electricity consumption in kWh per Mlmh are also shown graphically in Figure 11. The LED 2020 option has the lowest energy consumption and the lowest cost per Mlmh. Of the currently available options, the HPS BAT has the lowest energy consumption per Mlmh, and the lowest cost per Mlmh.

The bottom part of Table 7 (see also Figure 12) shows the cumulative consumer expenditure over the useful lifetime for each option. Values for year 0 are purchase price (lamp and control gear) and installation costs (including re-wiring where applicable). Each following year the amount increases by the running costs (electricity, repair and maintenance).

[36] The HPS retrofit lamp with 220W and 19,000 lm is publicized as substitute for a 250 W HPM-lamp, even if the latter has far lower flux.

Compared to the HPM base case, the HPS retrofit option has a payback time around 1 year and the HPS BAT option slightly above 1 year, but lifetimes for the HPS options are longer.

An investment in a 2015 LED retrofit lamp has a payback time of 2 years with respect to HPM BC, 2.5 years with respect to HPS retrofit, and approximately 5 years with respect to HPS BAT. It should be recalled however, that the availability on the market of the LED retrofit option for HID-lamps is scarce, and that its characteristics are therefore uncertain.

The LED 2020 option, when it will become available with the projected characteristics, has payback times of less than 1 year compared with all classic technology options.

In addition note from Table 7 that LED lamps offer advantages as regards the absence of mercury [37]. On the other hand, LED lamps are still significantly heavier than the HID-lamps they aim to substitute and thus consume more material resources.

[37] The high LED value for the total CRM indicator (1199) derives from the use of Germanium, but as observed in the Task 5 report this value is probably excessive, because not all LEDs use this material.

Table 7 Summary of design options for HPM-lamps: input data, results over product lifetime, results per Mega-lumen-hour (Mlmh), and cumulative consumer expenditure up to option useful lifetime. In this table, electricity includes the control gear.

		HPM BC	HPS retrofit	HPS BAT	LED 2015	LED 2020
Annual operating hours	h/yr	4000	4000	4000	4000	4000
Capacity	lm	12000	19000	17500	12000	12000
Useful life (hours)	h	8000	12000	20000	32000	32000
Useful life (years)	yr	2.0	3.0	5.0	8.0	8.0
Power	W	250	220	154	133	69
Efficacy	lm/W	48	86	114	90	175
Product price	euros	10.5	25.6	39.2	115.3	57.6
Installation costs	euros	9.3	9.3	9.3	9.3	9.3
Repair & Maint. Costs	euros/life	12.3	18.5	30.8	49.3	49.3
Electricity rate	euros/kWh	0.119	0.119	0.119	0.119	0.119
Mercury content	mg	38	18	18	0	0
CRM indicator	mg Sb eq.	116	218	218	1199	1199
o/w REE	mg Sb eq.	4	1	1	0.29	0.29
EoL recycling	%	68%	74%	74%	85%	85%
Total weight	g	252	215	215	2303	2303
Results per product over lifetime						
Electricity (incl. CG)	kWh/life	2410	3181	3500	4689	2411
Electricity cost	euros/life	286.7	378.5	416.5	557.9	286.9
Life cycle cost	euros/life	318.8	431.8	543.0	779.0	450.4
Results per Mlmh						
Electricity (incl. CG)	kWh/Mlmh	25.1	14.0	10.0	12.2	6.3
Electricity cost	euros/Mlmh	2.99	1.66	1.19	1.45	0.75
Purchase cost	euros/Mlmh	0.11	0.11	0.11	0.30	0.15
Installation cost	euros/Mlmh	0.10	0.04	0.03	0.02	0.02
Repair & Maint. cost	euros/Mlmh	0.13	0.08	0.09	0.13	0.13
Total costs per Mlmh	euros/Mlmh	3.32	1.89	1.55	2.03	1.17
Consumer expenditure						
purchase & installation	euros	19.7	34.8	48.4	124.52	66.88
annual running costs	euros/year	149.54	132.34	89.47	75.91	42.03
CG price and installation	euros			47.25	47.25	47.25
Cumulative consumer expenditure						
Year 0	euros	20	35	96	172	114
1	euros	169	167	185	248	156
2	euros	319	299	275	324	198
3	euros		432	364	399	240
4	euros			454	475	282
5	euros			543	551	324
6	euros				627	366
7	euros				703	408
8	euros				779	450
9	euros					

REE= Rare earth elements, in particular from phosphors, see Task 5 report; CRM= Critical raw materials; CG= Control gear; Mlmh= Mega-lumen-hours (e.g. 500 lm over 2000 h or 1000 lm over 1000 h)

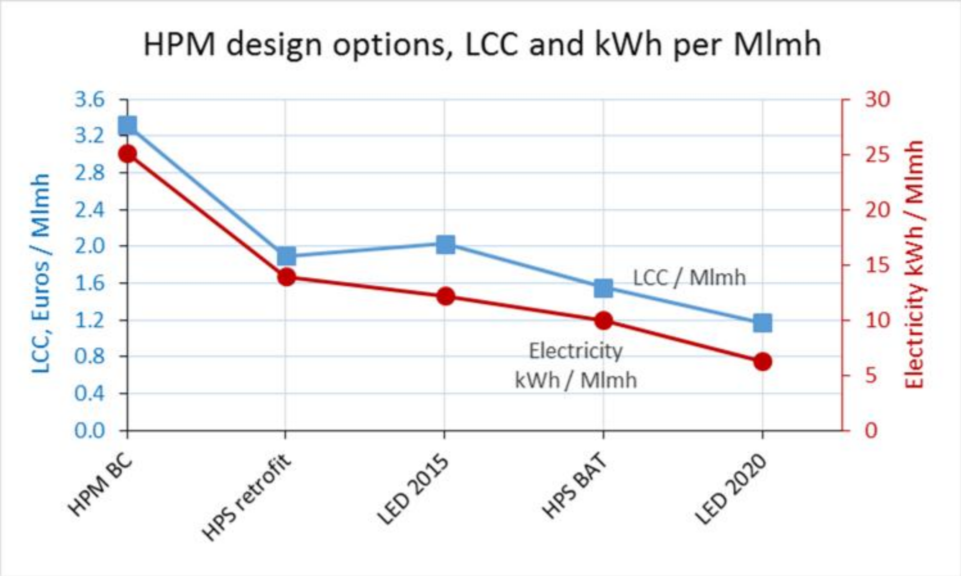

Figure 11 Design options for HPM lamps: life cycle cost (LCC, in euros/Mlmh, blue line with square markers, axis left) and electricity consumption (in kWh/Mlmh, red line with round markers, axis right). See Table 7 for underlying data.

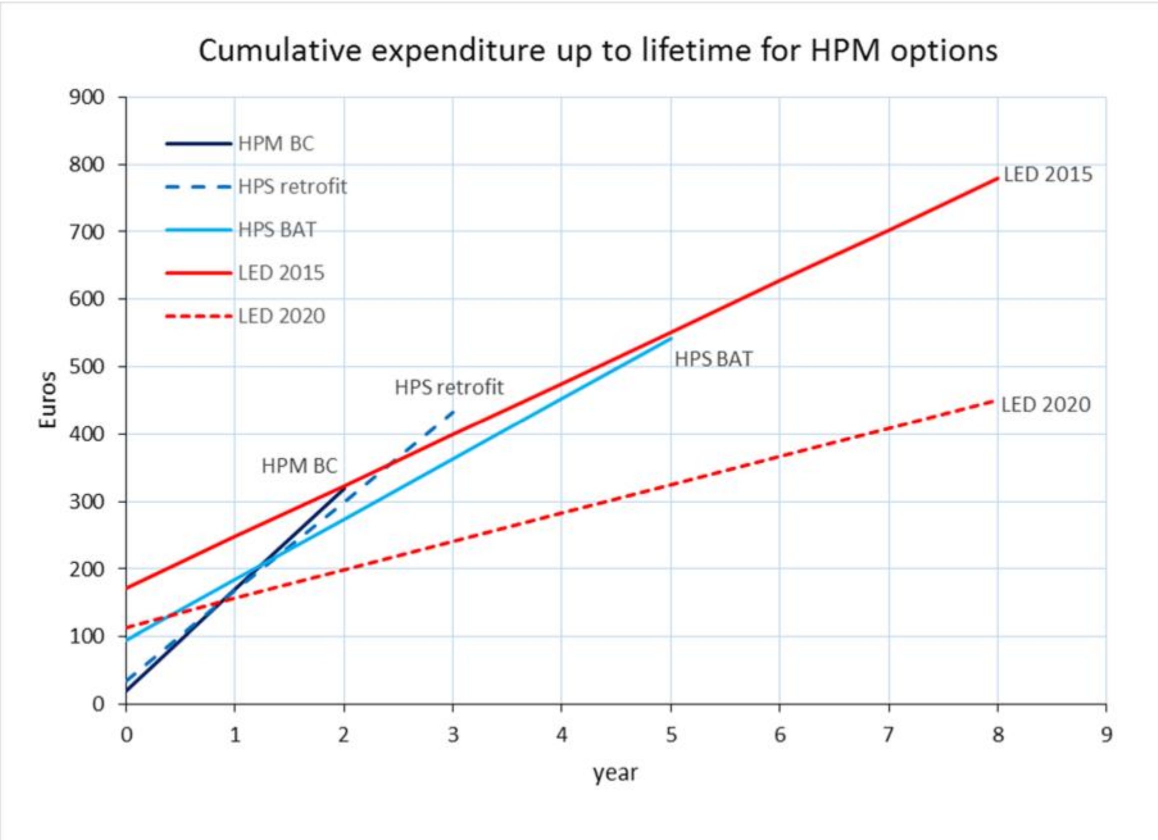

Figure 12 Cumulative consumer expenditure (fixed 2010 euros) for the design options for HPM lamps, up to their lifetime. Values for year 0 include purchase and installation. Each following year the amount increases by the running costs (electricity, repair and maintenance). See Table 7 (bottom part) for underlying data.

3.8. High-pressure sodium (HPS) and metal-halide lamps (MH)

Design options considered:

- HPS BC: this is the base case described in the Task 4 report, par. 5.18. It represents the EU-28 average HPS-lamp. For this lamp the EcoReport presented in Task 5 was used.
- HPS BAT replacement: this is the same lamp used as replacement for HPM in par. 3.7, but power and price have been adapted from the original 17,5000 lm to the 13,300 lm of the base case. Replacement of the existing ballast and ignitor has been assumed, see remarks in par. 3.7.
- MH BC: this is the base case described in the Task 4 report, par. 5.19. It represents the EU-28 average MH-lamp. For this lamp the EcoReport presented in Task 5 was used.
- MH BAT: this is an improved metal-halide lamp, with better efficacy and lifetime than the MH base case. Actually existing lamps have been used as a reference for efficacy, lifetime and price [38].
- LED 2015: this is the same lamp as used for HPM-replacement in par. 3.7, but slightly scaled from 12,000 lm to 13,300 lm. See remarks there.
- LED 2020: this is the same lamp as used for HPM-replacement in par. 3.7, but slightly scaled from 12,000 lm to 13,300 lm. See remarks there.

Remarks and explanations:

- As regards the lifetime for the MH BAT option: these lamps have a good LSF (> 97% up to 16k h), but a relatively bad lumen maintenance (respectively 88%, 85%, 82% and 80% after 8k, 12k, 16k and 20k hours). On this basis a lifetime of 12,000 h was selected for use in the analysis.
  See par. 3.7 for remarks on the lifetimes of the other options.
- For all options, the same operating hours per year (4000 h/a) have been used.
- In this case, nearly the same luminous flux has been assumed for all options (13,300 or 13,120 lm). Considering the difference in light colour and in CRI between HPS-lamps on the one hand and MH- and LED-lamps on the other hand, this may be penalizing for the latter lamp types, for which a lower flux would be sufficient to be equivalent with the HPS-lamps. See also par. 3.7, where such a flux difference has been applied in the comparison.

[38] As a reference, the following lamps were used: Philips MASTER CityWhite CDO-ET Plus 150W/828 E40 and the lamp of the same family with power of 100 W.
http://download.p4c.philips.com/l4bt/3/322972/master_citywhite_cdo-et_322972_ffs_aen.pdf
100 W: 9400 lm, 100 lm/W, 2890 K, 87 Ra, price approx.. 10% less than for 150 W lamp
150 W: 15100 lm, 106 lm/W, 2830 K, 85 Ra, price 41.26 euros excl. VAT from on-line sales' sites
Average data for 13120 lm lamp: 104 lm/W, price of 150 W lamp minus 5%

- The energy consumption by external control gears has been added in the current analysis by dividing the EcoReport results (that are without this energy) by the control gear efficiency. For both BC options this efficiency is 83%, for both BAT options 88%, and for the LED options 91%. Stand-by energy, if any, is NOT included.
- For the HPS BAT and LED options, additional costs have been considered for the control gear and its installation. See remarks in par. 3.7.

Table 8 provides a summary of the most relevant input and output data. For additional input data see the Task 5 report (EcoReports) and references therein.

The LCC per Mlmh and the electricity consumption in kWh per Mlmh are also shown graphically in Figure 13. The LED 2020 option has the lowest energy consumption and the lowest cost per Mlmh. Of the currently available options, the HPS BAT has the lowest energy consumption per Mlmh, and the lowest cost per Mlmh. The MH BAT option has the same costs and slightly higher energy consumption. Note that this comparison assumes lumen equivalence, and that this is penalizing for MH- and LED-lamps (see remarks above).

The bottom part of Table 8 (see also Figure 14) shows the cumulative consumer expenditure over the useful lifetime for each option. Values for year 0 are purchase price (lamp and control gear) and installation costs (including re-wiring where applicable). Each following year the amount increases by the running costs (electricity, repair and maintenance).

The data confirm MH BAT and HPS BAT as the best currently available options. The MH BAT option has the advantage of lower costs, while the HPS BAT option has the advantage of a longer useful lifetime.
Currently available LEDs (which are scarce on the 2015 market) have higher costs compared to all classic technology options, but it is recalled that underlying LED characteristics are uncertain.
The LED 2020 option, when it will become available with the projected characteristics, has a payback time of 1-2.5 years compared to the various classic technology options.

In addition note from Table 8 that LED lamps offer advantages as regards the absence of mercury [39]. On the other hand, LED lamps are still significantly heavier than the HID-lamps they aim to substitute and thus consume more material resources.

[39] The high LED value for the total CRM indicator (1199) derives from the use of Germanium, but as observed in the Task 5 report this value is probably excessive, because not all LEDs use this material.

Table 8 Summary of design options for HPS- and MH-lamps: input data, results over product lifetime, results per Mega-lumen-hour (Mlmh), and cumulative consumer expenditure up to option useful lifetime. In this table, electricity includes the control gear.

		HPS BC	HPS BAT	MH BC	MH BAT	LED 2015	LED 2020
Operating hours	h/yr	4000	4000	4000	4000	4000	4000
Capacity	lm	13300	13300	13120	13120	13300	13300
Useful life (hours)	h	12000	20000	8000	12000	32000	32000
Useful life (years)	yr	3.0	5.0	2.0	3.0	8.0	8.0
Power	W	140.0	124.3	160.0	126.2	147.8	76.0
Efficacy	lm/W	95	107	82	104	90	175
Product price	euros	27.0	37.2	27.0	40.0	127.8	63.9
Installation costs	euros	9.3	9.3	9.3	9.3	9.3	9.3
Repair & Maint. costs	euros/life	18.5	30.8	12.3	18.5	49.3	49.3
Electricity rate	euros/kWh	0.119	0.119	0.119	0.119	0.119	0.119
Mercury content	mg	18	18	10	10	0	0
CRM indicator	mg Sb eq.	218	218	26	26	1329	1329
o/w REE	mg Sb eq.	1	1	0	0	0.32	0.32
EoL recycling	%	74%	74%	76%	76%	85%	85%
Total weight	g	215	215	160	160	2552	2552
Results per product over lifetime							
Electricity (incl. CG)	kWh/life	2024	2825	1542	1720	5197	2673
Electricity cost	euros/life	240.9	336.2	183.5	204.7	618.4	318.0
Life cycle cost	euros/life	295.6	460.7	232.1	272.5	852.0	487.7
Results per Mlmh							
Electricity (incl. CG)	kWh/Mlmh	12.7	10.6	14.7	10.9	12.2	6.3
Electricity cost	euros/Mlmh	1.51	1.26	1.75	1.30	1.45	0.75
Purchase cost	euros/Mlmh	0.17	0.14	0.26	0.25	0.30	0.15
Installation cost	euros/Mlmh	0.06	0.03	0.09	0.06	0.02	0.02
Repair & Maint. cost	euros/Mlmh	0.12	0.12	0.12	0.12	0.12	0.12
Total costs per Mlmh	euros/Mlmh	1.85	1.73	2.21	1.73	2.00	1.15
Consumer expenditure							
purchase & installation	euros	36.25	46.44	36.25	49.25	137.01	73.13
annual running costs	euros/year	86.46	73.40	97.92	74.40	83.46	45.92
CG price and install.	euros		47.25			47.25	47.25
Cumulative consumer expenditure							
Year 0	euros	36	94	36	49	184	120
1	euros	123	167	134	124	268	166
2	euros	209	240	232	198	351	212
3	euros	296	314		272	435	258
4	euros		387			518	304
5	euros		461			602	350
6	euros					685	396
7	euros					769	442
8	euros					852	488
9	euros						

REE= Rare earth elements, in particular from phosphors, see Task 5 report; CRM= Critical raw materials; CG= Control gear; Mlmh= Mega-lumen-hours (e.g. 500 lm over 2000 h or 1000 lm over 1000 h)

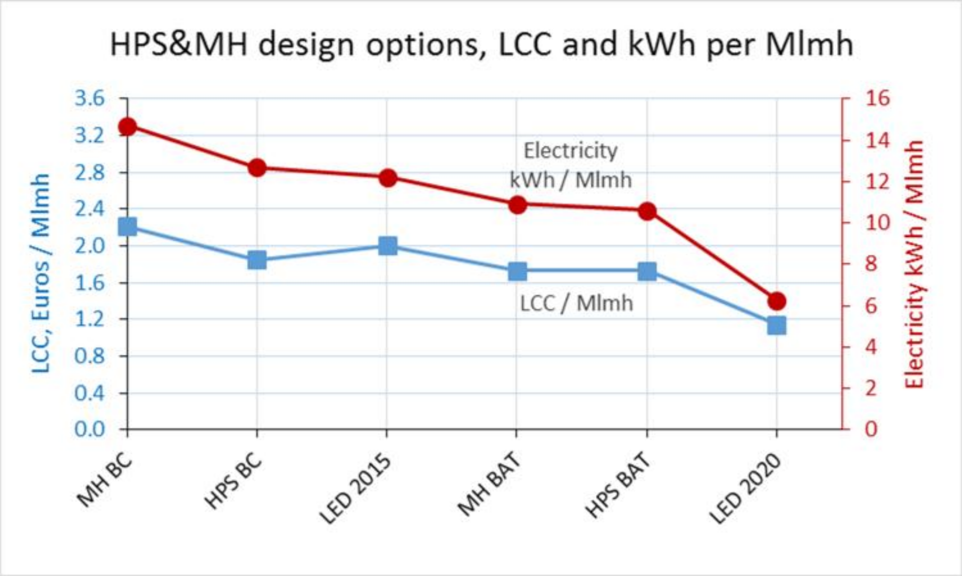

Figure 13 Design options for HPS- and MH-lamps: life cycle cost (LCC, in euros/Mlmh, blue line with square markers, axis left) and electricity consumption (in kWh/Mlmh, red line with round markers, axis right). See Table 8 for underlying data.

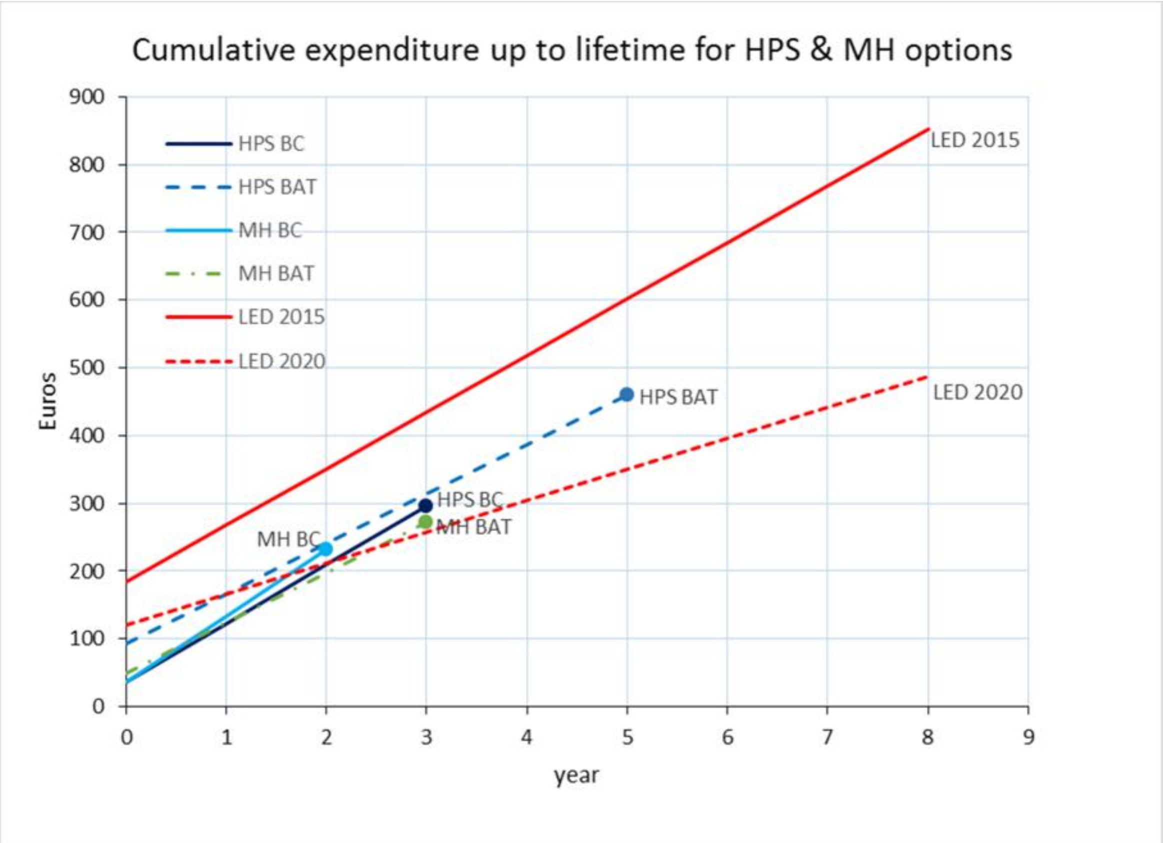

Figure 14 Cumulative consumer expenditure (fixed 2010 euros) for the design options for HPS- and MH-lamps, up to their lifetime. Values for year 0 include purchase and installation. Each following year the amount increases by the running costs (electricity, repair and maintenance). See Table 8 (bottom part) for underlying data.

3.9. Mains voltage non-directional lamps (GLS X, HL MV E, CFLi)

Design options considered:

- GLS X: this is the base case described in the Task 4 report, par. 5.16. It represents the EU-28 average non-reflector non-halogen filament lamps. For this lamp the EcoReport presented in Task 5 was used.
- HL MV E: this is the base case described in the Task 4 report, par. 5.13. It represents the EU-28 average mains voltage halogen lamp with E14 or E27 cap. Although this base case also contains some reflector lamps, here the non-directional lamps are addressed. For this lamp the EcoReport presented in Task 5 was used.
- CFLi: this is the base case described in the Task 4 report, par. 5.7. It represents the EU-28 average compact fluorescent lamp with integrated control gear. For this lamp the EcoReport presented in Task 5 was used.
- LED 2015: this option has been derived from the EcoReport for the 1000 lm average 2015 LED retrofit lamp, but scaling all data to 550 lm. The average 2015 characteristics presented in table 1 of the Task 4 report for LED filament lamps have been used, i.e. 109 lm/W and 24.80 euros/klm excl. VAT.
- LED 2020: this is the same as LED 2015, but with efficacy and price adjusted according to the projections made in the Task 4 report, i.e. 175 lm/W and 7.50 euros/klm excl. VAT.

Remarks and explanations:

- For the GLS X and HL MV E options, the original base cases have been slightly modified, adapting the power to correspond to 500 lm. For these options 450 operating hours per year are assumed.
  For the CFL and LED options, 550 lm and 500 h/a have been used in the analysis, thus applying a 10% rebound effect for both parameters.

Table 9 provides a summary of the most relevant input and output data. For additional input data see the Task 5 report (EcoReports) and references therein.

The LCC per Mlmh and the electricity consumption in kWh per Mlmh are also shown graphically in Figure 15. The LED 2020 option has the lowest energy consumption and the lowest cost per Mlmh. Of the currently available options, the LED 2015 option has the lowest energy consumption per Mlmh, and the lowest cost per Mlmh.

The bottom part of Table 9 (see also Figure 16) shows the cumulative consumer expenditure over the useful lifetime for each option. Values for year 0 are purchase price and installation costs. Each following year the amount increases by the running costs (electricity, repair and maintenance).

An investment in 2015 LEDs will not pay back within the lifetime of the GLS X and MV HL E options, but imagining a 2nd purchase for these lamps at the end of their lifetime, the payback time of the LEDs is around 3.5-4 years. This payback time depends mainly on the initial costs of the LEDs, and less on their efficacy. The LED 2015 curve is based on the average 2015 price for a LED filament lamp of 24.80 euros/klm. Using the lowest price from table 1 in the Task 4 report (10.33 euros/klm), the LED 2015 curve in Figure 16 would shift down over circa 8 euros, reducing the payback time to approximately 2 years.

When compared to the CFLi option, the LED 2015 option still has a long payback time, longer than the 12 year lifetime of the CFLs. Using lowest 2015 LED prices, this time would reduce to 8-9 years.

If the LED 2020 option would already be available, with the projected characteristics of 175 lm/W and 7.5 euros/klm, it would have a payback time of less than 1 year.

Table 9 Summary of design options for MV NDLS lamps with 500 lm and 450 h/a: input data, results over product lifetime, results per Mega-lumen-hour (Mlmh), and cumulative consumer expenditure up to option useful lifetime.

		GLS X	HL MV E	CFLi	LED 2015	LED 2020	
Operating hours	h/yr	450	450	500	500	500	
Capacity	lm	500	500	550	550	550	
Useful life (hours)	h	1000	1500	6000	20000	20000	
Useful life (years)	yr	2.2	3.3	12.0	40.0	40.0	
Power	W	52.6	41.7	10.0	5.0	3.1	
Efficacy	lm/W	9.5	12	55	109	175	
Product price	euros	0.8	2.5	5.1	15.8	4.8	
Installation costs	euros	0.4	0.4	0.4	0.4	0.4	
Repair & Maint. costs	euros/life	0.4	0.6	2.2	7.4	7.4	
Electricity rate	euros/kWh	0.177	0.177	0.177	0.177	0.177	
Mercury content	mg	0	0	2	0	0	
CRM indicator	mg Sb eq.	2	1	17	55	55	
o/w REE	mg Sb eq.	0	0	13	0.01	0.01	
EoL recycling	%	70%	70%	76%	85%	85%	
Total weight	g	86	83	119	106	106	
Results per product over lifetime							
Electricity (incl. CG)	kWh/life	53	63	60	101	63	
Electricity cost	euros/life	9.3	11.1	10.6	17.9	11.1	
Life cycle cost	euros/life	10.9	14.6	18.3	41.4	23.7	
Results per Mlmh							
Electricity (incl. CG)	kWh/Mlmh	105.3	83.3	18.2	9.2	5.7	
Electricity cost	euros/Mlmh	18.63	14.75	3.22	1.62	1.01	
Purchase cost	euros/Mlmh	1.62	3.39	1.54	1.43	0.43	
Installation cost	euros/Mlmh	0.74	0.49	0.11	0.03	0.03	
Repair & Maint. cost	euros/Mlmh	0.82	0.81	0.67	0.67	0.67	
Total costs per Mlmh	euros/Mlmh	21.81	19.44	5.54	3.76	2.15	
Consumer expenditure							
purchase & installation	euros	1.18	2.91	5.45	16.15	5.14	
annual running costs	euros/year	4.38	3.50	1.07	0.63	0.46	
Cumulative consumer expenditure							
Year 0	euros	1.2	2.9	5.4	16.2	5.1	
1	euros	5.6	6.4	6.5	16.8	5.6	
2	euros	9.9	9.9	7.6	17.4	6.1	
3	euros		13.4	8.7	18.0	6.5	
4	euros			9.7	18.7	7.0	
5	euros			10.8	19.3	7.5	
6	euros			11.9	19.9	7.9	
7	euros			12.9	20.6	8.4	
8	euros			14.0	21.2	8.8	
9	euros			15.1	21.8	9.3	
10	euros			16.1	22.5	9.8	
11	euros			17.2	23.1	10.2	
12	euros			18.3	23.7	10.7	
13	euros				24.4	11.2	
14	euros				25.0	11.6	
15	euros				25.6	12.1	

REE= Rare earth elements, in particular from phosphors, see Task 5 report; CRM= Critical raw materials; CG= Control gear; Mlmh= Mega-lumen-hours (e.g. 500 lm over 2000 h or 1000 lm over 1000 h)

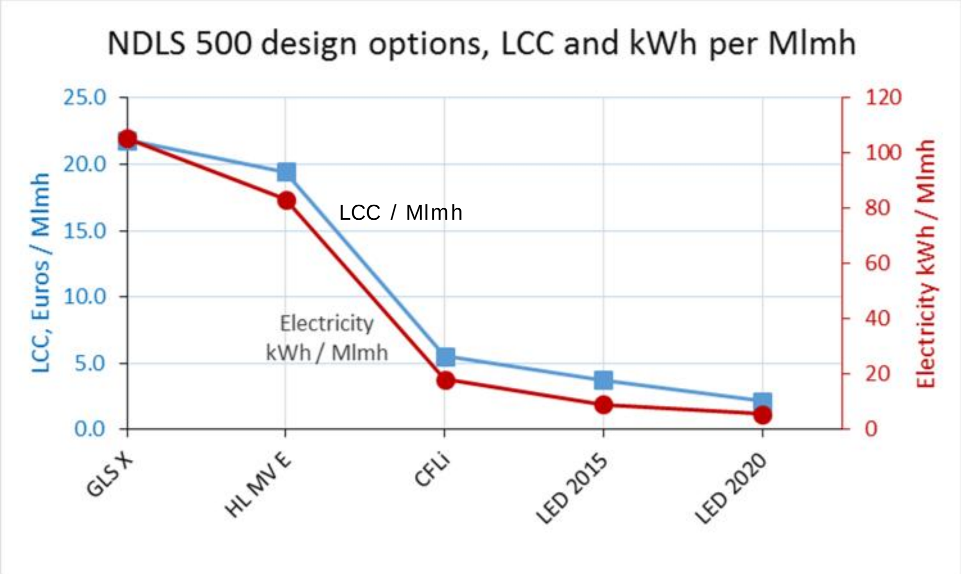

Figure 15 Design options for MV NDLS lamps with 500 lm and 450 h/a: life cycle cost (LCC, in euros/Mlmh, blue line with square markers, axis left) and electricity consumption (in kWh/Mlmh, red line with round markers, axis right). See Table 9 for underlying data.

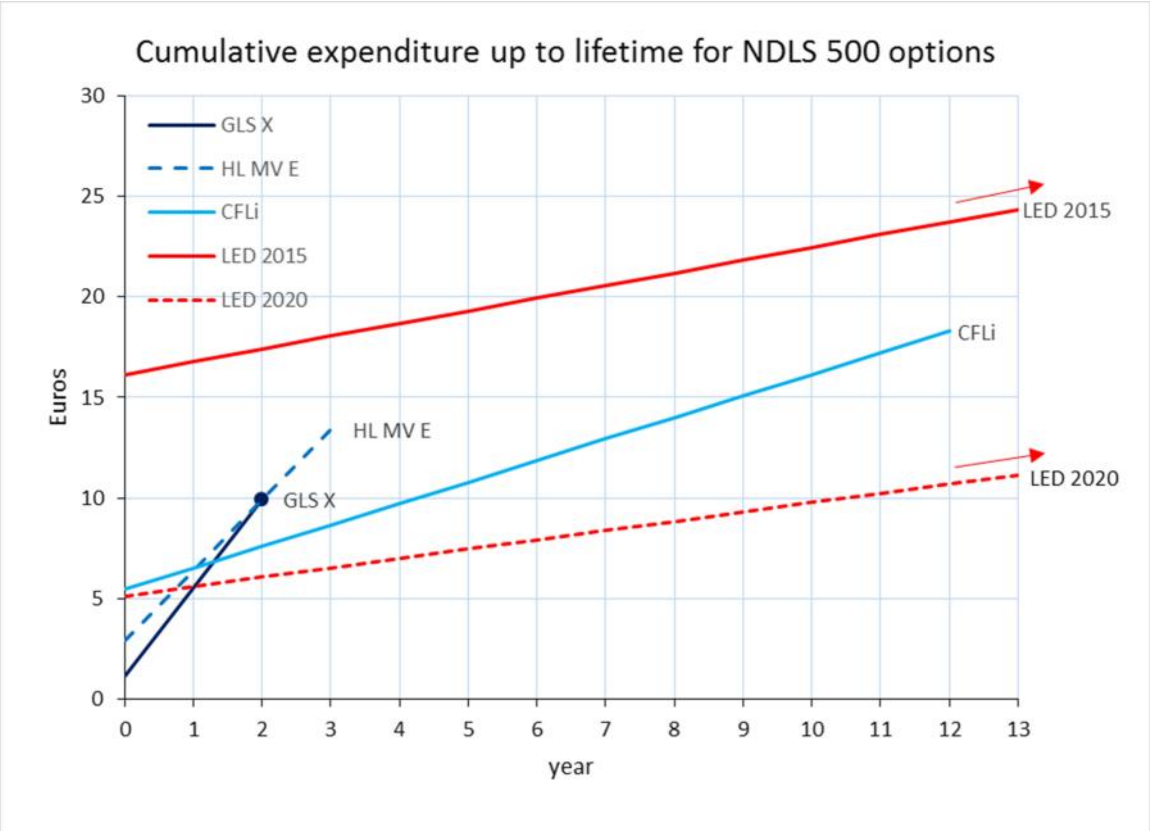

Figure 16 Cumulative consumer expenditure (fixed 2010 euros) for the design options for MV NDLS lamps with 500 lm and 450 h/a, up to their lifetime. Values for year 0 include purchase and installation. Each following year the amount increases by the running costs (electricity, repair and maintenance). See Table 9 (bottom part) for underlying data.

3.10. Mains voltage directional lamps (GLS R, HL MV X)

Design options considered:

- GLS R: this is the base case described in the Task 4 report, par. 5.15. It represents the EU-28 average for non-halogen reflector filament lamps. For this lamp the EcoReport presented in Task 5 was used, but adapted as indicated below.
- HL MV X: this is the base case described in the Task 4 report, par. 5.14. It represents the EU-28 average 'other' mains voltage halogen lamps, which are mainly PAR-lamps and reflector lamps with GU10 cap. For this lamp the EcoReport presented in Task 5 was used, but adapted as indicated below.
- LED 2015: this option has been derived from the EcoReport for the 1000 lm average 2015 LED retrofit lamp, but scaling all data to 500 lm. The approximate best 2015 efficacy-price combination for MV DLS LED retrofit lamps was derived as 100 lm/W and 22.50 euros/klm excl. VAT [40] [41].
- LED 2020: this is the same as LED 2015, but with efficacy and price adjusted according to the 2020 projections made in the Task 4 report, i.e. 175 lm/W and 7.50 euros/klm excl. VAT.

Remarks and explanations:

- For the GLS R and HL MV X options, the original base cases have been slightly modified, adapting the power to correspond to 450 lm [41] [42]. For these options 450 operating hours per year are assumed.
  For the LED options, 500 lm and 500 h/a have been used in the analysis, thus applying a 10% rebound effect for both parameters.
- In addition, the purchase prices for the GLS R and HL MV X base cases, have been adapted to the values derived from the MV DLS market assessment: 8.28 euros/klm excl. VAT for GLS R, and 15 euros/klm for HL MV X.

Table 10 provides a summary of the most relevant input and output data. For additional input data see the Task 5 report (EcoReports) and references therein.

The LCC per Mlmh and the electricity consumption in kWh per Mlmh are also shown graphically in Figure 17. The LED 2020 option has the lowest energy consumption and the lowest cost per Mlmh. Of the currently available options, the LED 2015 option has the lowest energy consumption per Mlmh, and the lowest cost per Mlmh.

The bottom part of Table 10 (see also Figure 18) shows the cumulative consumer expenditure over the useful lifetime for each option. Values for year 0 are purchase price and installation costs. Each following year the amount increases by the running costs (electricity, repair and maintenance).

[40] For reference see table 1 of the Task 4 report and underlying data. There are some lamps on the market with higher efficacy, but they also have higher prices.
[41] The luminous flux used here for directional lamps is the total flux, not the flux in a 90˚ or 120˚ cone.
[42] This is the approximate average flux derived from the MV DLS market assessment performed by the study team

Figure 18 shows that an investment in MV DLS LEDs has a payback time of approximately 2 years when compared with GLS R or MV HL X options (imagining a 2nd purchase for GLS R at the end of its lifetime). This payback time depends mainly on the initial costs of the LEDs, and less on their efficacy. The LED 2015 curve is based on the median 2015 price for a MV DLS LED retrofit lamp of 22.50 euros/klm. Using the lowest price from table 1 in the Task 4 report (9.72 euros/klm), the LED 2015 curve in Figure 18 would shift down over circa 6 euros, reducing the payback time to less than 1 year.

If the LED 2020 option would already be available, with the projected characteristics of 175 lm/W and 7.5 euros/klm, it would be immediately convenient.

Table 10 Summary of design options for MV DLS lamps with 450 lm and 450 h/a: input data, results over product lifetime, results per Mega-lumen-hour (Mlmh), and cumulative consumer expenditure up to option useful lifetime.

		GLS R	HL MV X	LED 2015	LED 2020		
Operating hours	h/yr	450	450	500	500		
Capacity	lm	450	450	500	500		
Useful life (hours)	h	1000	1500	20000	20000		
Useful life (years)	yr	2.2	3.3	40.0	40.0		
Power	W	47.4	37.5	5.0	2.9		
Efficacy	lm/W	9.5	12	100	175		
Product price	euros	4.3	7.8	13.0	4.3		
Installation costs	euros	0.4	0.4	0.4	0.4		
Repair & Maint. costs	euros/life	0.4	0.6	7.4	7.4		
Electricity rate	euros/kWh	0.177	0.177	0.177	0.177		
Mercury content	mg	0	0	0	0		
CRM indicator	mg Sb eq.	2	1	50	50		
o/w REE	mg Sb eq.	0	0	0.01	0.01		
EoL recycling	%	70%	70%	85%	85%		
Total weight	g	121	80	96	96		
Results per product over lifetime							
Electricity (incl. CG)	kWh/life	47	56	100	57		
Electricity cost	euros/life	8.4	10.0	17.7	10.1		
Life cycle cost	euros/life	13.5	18.8	38.5	22.2		
Results per Mlmh							
Electricity (incl. CG)	kWh/Mlmh	105.3	83.3	10.0	5.7		
Electricity cost	euros/Mlmh	18.63	14.75	1.77	1.01		
Purchase cost	euros/Mlmh	9.59	11.58	1.30	0.43		
Installation cost	euros/Mlmh	0.82	0.55	0.04	0.04		
Repair & Maint. cost	euros/Mlmh	0.91	0.90	0.74	0.74		
Total costs per Mlmh	euros/Mlmh	29.95	27.78	3.85	2.22		
Consumer expenditure							
purchase & installation	euros	4.68	8.19	13.40	4.71		
annual running costs	euros/year	3.96	3.17	0.63	0.44		
Cumulative consumer expenditure							
Year 0	euros	4.7	8.2	13.4	4.7		
1	euros	8.6	11.4	14.0	5.1		
2	euros	12.6	14.5	14.7	5.6		
3	euros		17.7	15.3	6.0		
4	euros			15.9	6.5		
5	euros			16.5	6.9		
6	euros			17.2	7.3		
7	euros			17.8	7.8		
8	euros			18.4	8.2		
9	euros			19.0	8.6		
10	euros			19.7	9.1		
11	euros			20.3	9.5		
12	euros			20.9	10.0		
13	euros			21.5	10.4		
14	euros			22.2	10.8		
15	euros			22.8	11.3		

REE= Rare earth elements, in particular from phosphors, see Task 5 report; CRM= Critical raw materials; CG= Control gear; Mlmh= Mega-lumen-hours (e.g. 500 lm over 2000 h or 1000 lm over 1000 h)

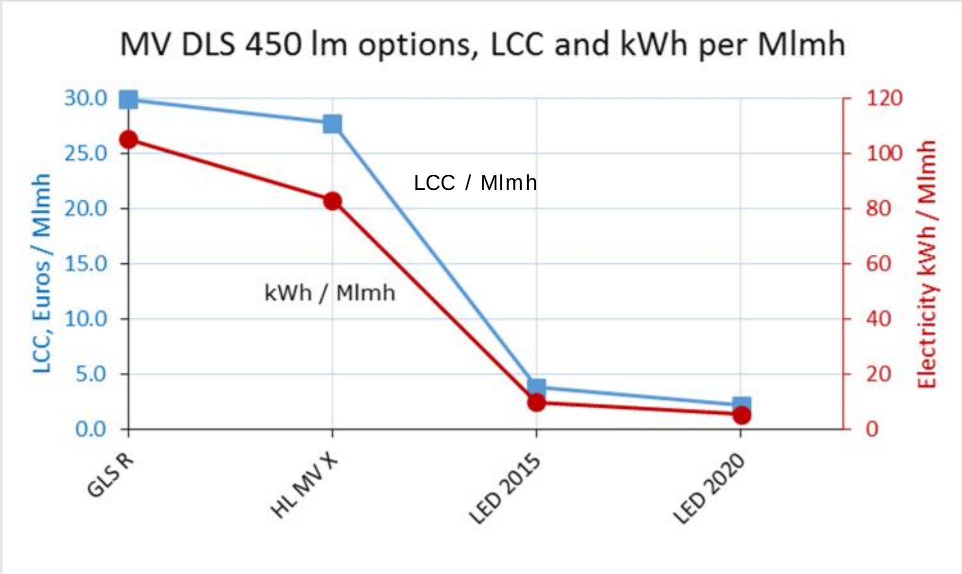

Figure 17 Design options for MV DLS lamps with 450 lm and 450 h/a: life cycle cost (LCC, in euros/Mlmh, blue line with square markers, axis left) and electricity consumption (in kWh/Mlmh, red line with round markers, axis right). See Table 10 for underlying data.

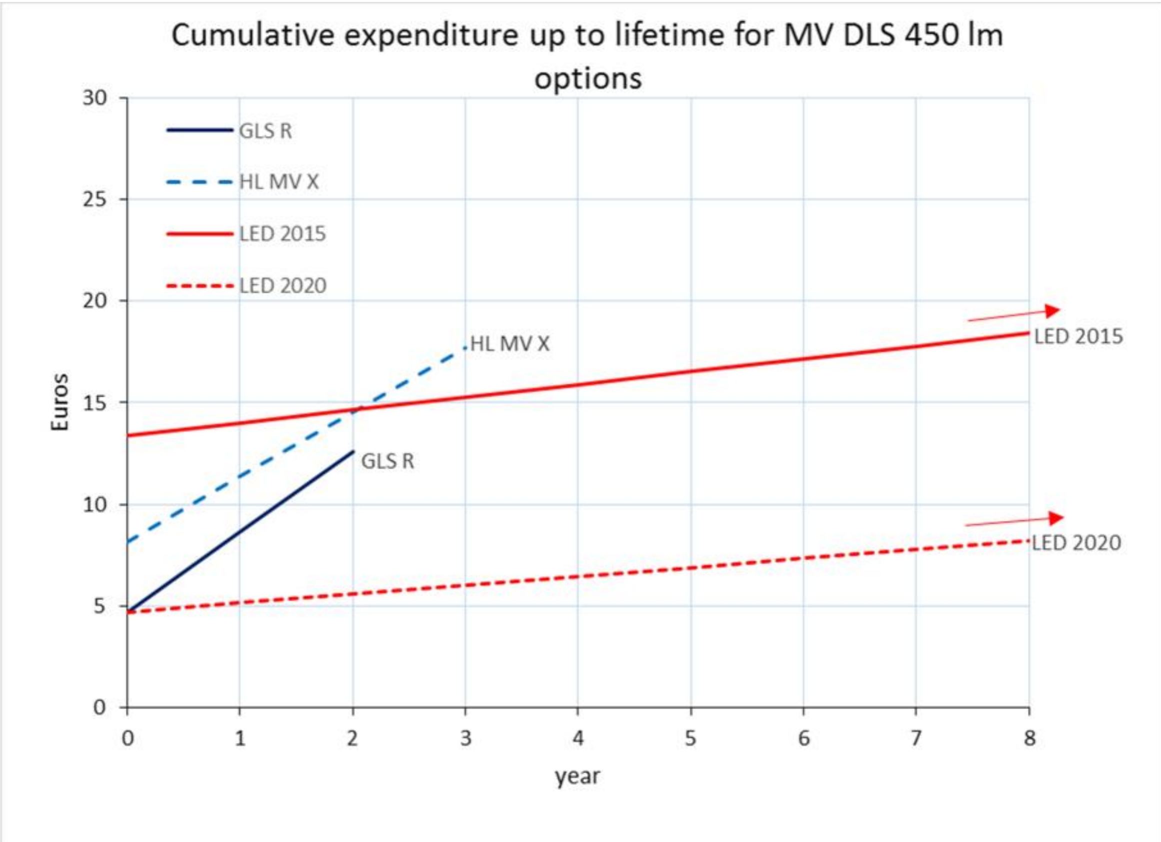

Figure 18 Cumulative consumer expenditure (fixed 2010 euros) for the design options for MV DLS lamps with 450 lm and 450 h/a, up to their lifetime. Values for year 0 include purchase and installation. Each following year the amount increases by the running costs (electricity, repair and maintenance). See Table 10 (bottom part) for underlying data.

3.11. Low voltage halogen reflector lamps (HL LV R)

Design options considered:

- HL LV R BC: this is the base case described in the Task 4 report, par. 5.9. It represents the EU-28 average for low voltage halogen reflector lamps (typically MR16 with GU5,3 cap). For this lamp the EcoReport presented in Task 5 was used.

- HL LV R BAT: this option is based on an actually existing reference lamp [43] that has improved efficacy and lifetime with respect to the BC, but higher price. It is intended to represent the BAT option, when maintaining halogen technology (i.e. without switching to LED). For this lamp the same EcoReport as the BC was used, but with adapted efficacy, lifetime and price.

- LED 2015: this option has been derived from the EcoReport for the 1000 lm average 2015 LED retrofit lamp, but scaling all data to 540 lm. The approximate best 2015 efficacy-price combination for LV DLS LED retrofit lamps was derived as 87 lm/W and 22.30 euros/klm excl. VAT [44] [45].

- LED 2020: this is the same as LED 2015, but with efficacy and price adjusted according to the 2020 projections made in the Task 4 report, i.e. 175 lm/W and 7.50 euros/klm excl. VAT.

Remarks and explanations:

- For the HL LV R options, the power corresponds to 490 lm, which is the one from the BC. The reference lamp for HL LV R BAT has 540 lm, but this has been scaled down to 490 lm for comparison purposes. For these options 450 operating hours per year are assumed.
  For the LED options, 540 lm and 500 h/a have been used in the analysis, thus applying a 10% rebound effect for both parameters.

- The energy consumption by external control gears (voltage transformers) has been added in the current analysis by dividing the EcoReport results (that are without this energy) by the control gear efficiency. For all options this efficiency is 94%; LED retrofit lamps are assumed to work on the same transformers as the low voltage halogen lamps that they replace.

Table 11 provides a summary of the most relevant input and output data. For additional input data see the Task 5 report (EcoReports) and references therein.

The LCC per Mlmh and the electricity consumption in kWh per Mlmh are also shown graphically in Figure 19. The LED 2020 option has the lowest energy consumption and

[43] The following lamp was used as a reference: Philips MASTERLine ES 30W GU5.3 12V 36D – 18136, http://www.lighting.philips.com/main/prof/lamps/halogen-lamps/lv-halogen-with-reflector/masterline-es/924895317101_EU/product 540 lm, 18 lm/W (lm in 90˚ cone), 5000 h up to 50% failures, average price 5.22 euros excl. VAT from 6 online sales' sites. Scaled down to 490 lm for comparison with BC lamp.

[44] For reference see table 31 note 5 of the Task 4 report. There are lamps with lower prices, but they also have lower efficacy.

[45] The luminous flux used here for LV directional lamps is the flux in a 90˚ cone.

the lowest cost per Mlmh. Of the currently available options, the LED 2015 option has the lowest energy consumption per Mlmh, and the lowest cost per Mlmh.

The bottom part of Table 11 (see also Figure 20) shows the cumulative consumer expenditure over the useful lifetime for each option. Values for year 0 are purchase price and installation costs. Each following year the amount increases by the running costs (electricity, repair and maintenance).

Figure 20 shows that an investment in LV DLS LEDs has a payback time of 4 - 4.5 years when compared with the HL LV R options. This payback time depends mainly on the initial costs of the LEDs, and less on their efficacy. The LED 2015 curve is based on a price of 22.30 euros/klm. Using the lowest price from table 1 in the Task 4 report (11.67 euros/klm), the LED 2015 curve in Figure 20 would shift down over circa 6 euros, reducing the payback time to 1 – 1.5 years.

If the LED 2020 option would already be available, with the projected characteristics of 175 lm/W and 7.5 euros/klm, it would have a payback time of 3 – 4 months.

Table 11 Summary of design options for HL LV R lamps: input data, results over product lifetime, results per Mega-lumen-hour (Mlmh), and cumulative consumer expenditure up to option useful lifetime. Electricity by control gear included (94% efficiency)

		HL LV R BC	HL LV R BAT	LED 2015	LED 2020		
Operating hours	h/yr	450	450	500	500		
Capacity	lm	490	490	540	540		
Useful life (hours)	h	2000	5000	20000	20000		
Useful life (years)	yr	4.4	11.1	40.0	40.0		
Power	W	35.0	27.2	6.2	3.1		
Efficacy	lm/W	14	18	87	175		
Product price	euros	3.7	6.0	13.9	4.7		
Installation costs	euros	0.4	0.4	0.4	0.4		
Repair & Maint. costs	euros/life	0.8	2.1	7.4	7.4		
Electricity rate	euros/kWh	0.177	0.177	0.177	0.177		
Mercury content	mg	0	0	0	0		
CRM indicator	mg Sb eq.	1	1	54	54		
o/w REE	mg Sb eq.	0	0	0.01	0.01		
EoL recycling	%	70%	70%	85%	85%		
Total weight	g	60	60	104	104		
Results per product over lifetime							
Electricity (incl. CG)	kWh/life	74	145	132	66		
Electricity cost	euros/life	13.2	25.6	23.4	11.6		
Life cycle cost	euros/life	18.0	34.1	45.1	24.1		
Results per Mlmh							
Electricity (incl. CG)	kWh/Mlmh	76.0	59.1	12.2	6.1		
Electricity cost	euros/Mlmh	13.45	10.46	2.16	1.08		
Purchase cost	euros/Mlmh	3.73	2.47	1.29	0.43		
Installation cost	euros/Mlmh	0.38	0.15	0.03	0.03		
Repair & Maint. cost	euros/Mlmh	0.84	0.84	0.68	0.68		
Total costs per Mlmh	euros/Mlmh	18.40	13.92	4.17	2.23		
Consumer expenditure							
purchase & installation	euros	4.03	6.42	14.32	5.06		
annual running costs	euros/year	3.15	2.49	0.77	0.48		
Cumulative consumer expenditure							
Year 0	euros	4.0	6.4	14.3	5.1		
1	euros	7.2	8.9	15.1	5.5		
2	euros	10.3	11.4	15.9	6.0		
3	euros	13.5	13.9	16.6	6.5		
4	euros	16.6	16.4	17.4	7.0		
5	euros		18.9	18.2	7.4		
6	euros		21.4	18.9	7.9		
7	euros		23.9	19.7	8.4		
8	euros		26.3	20.5	8.9		
9	euros		28.8	21.2	9.3		
10	euros		31.3	22.0	9.8		
11	euros		33.8	22.8	10.3		
12	euros			23.5	10.8		
13	euros			24.3	11.2		
14	euros			25.1	11.7		
15	euros			25.9	12.2		

REE= Rare earth elements, in particular from phosphors, see Task 5 report; CRM= Critical raw materials; CG= Control gear; Mlmh= Mega-lumen-hours (e.g. 500 lm over 2000 h or 1000 lm over 1000 h)

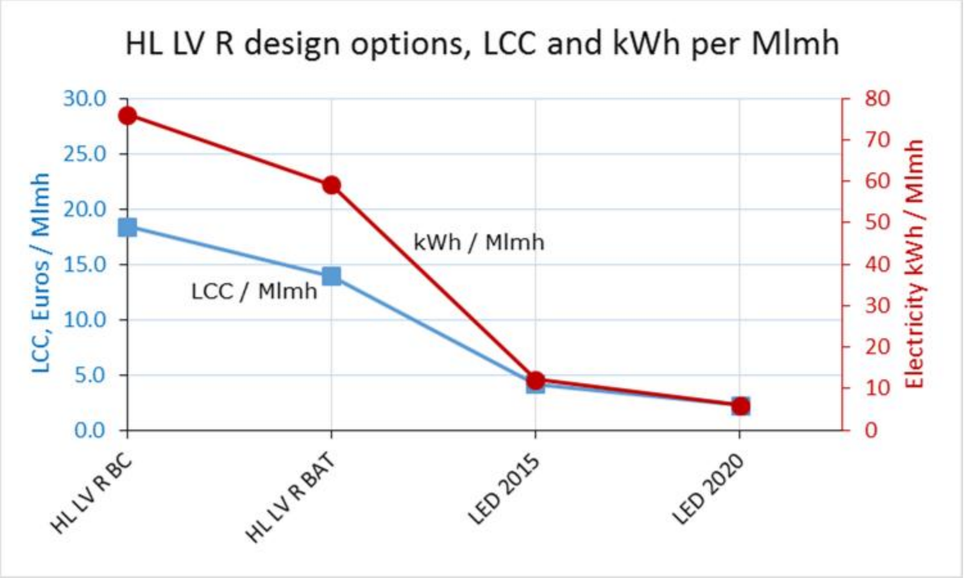

Figure 19 Design options for HL LV R lamps: life cycle cost (LCC, in euros/Mlmh, blue line with square markers, axis left) and electricity consumption (in kWh/Mlmh, red line with round markers, axis right). See Table 11 for underlying data.

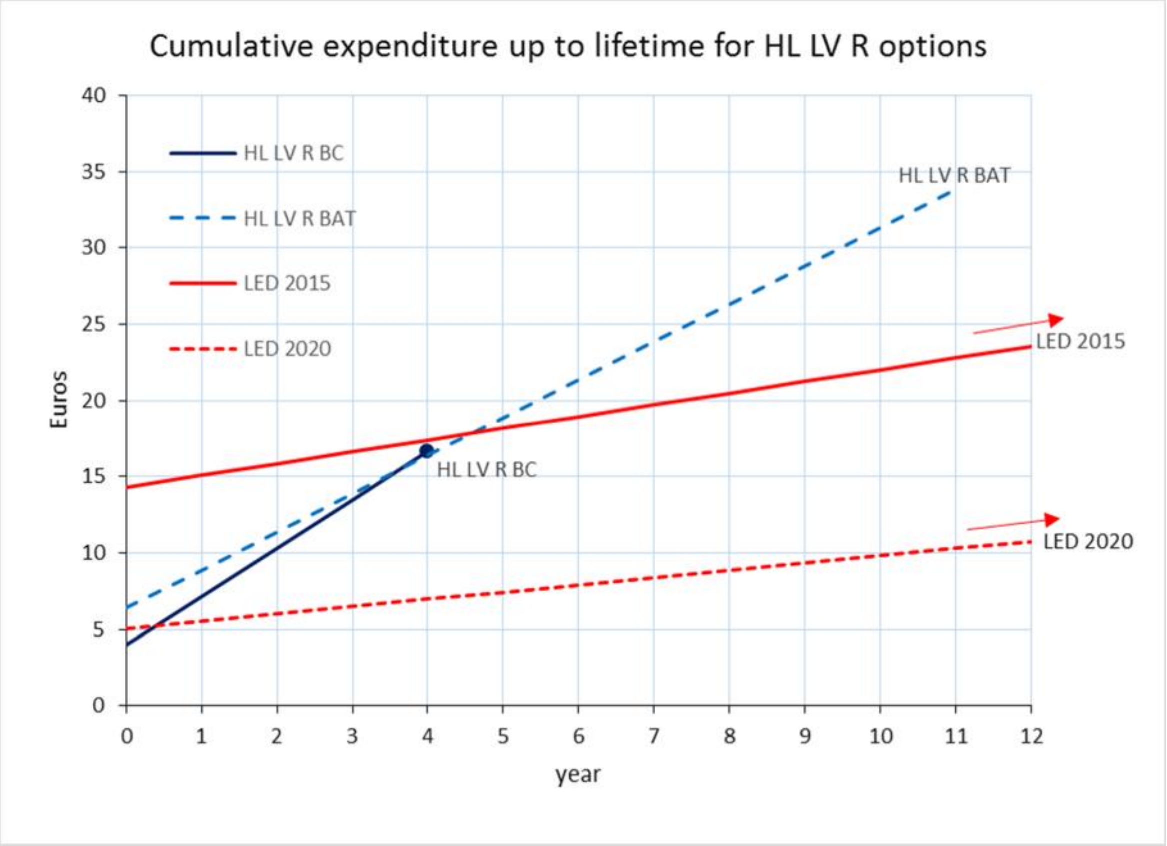

Figure 20 Cumulative consumer expenditure (fixed 2010 euros) for the design options for HL LV R lamps, up to their lifetime. Values for year 0 include purchase and installation. Each following year the amount increases by the running costs (electricity, repair and maintenance). See Table 11 (bottom part) for underlying data.

3.12. Low voltage halogen capsules (HL LV C)

Design options considered:

- HL LV C BC: this is the base case described in the Task 4 report, par. 5.10. It represents the EU-28 average for low voltage halogen capsules (with G4 or GY6.35 cap). For this lamp the EcoReport presented in Task 5 was used [46].

- HL LV C BAT1: this option is based on an actually existing reference lamp [47] that has improved efficacy and price with respect to the average of the BC. It is intended to represent a BAT option, when maintaining halogen technology (i.e. without switching to LED). For this lamp the same EcoReport as the BC was used, but with adapted efficacy and price.

- HL LV C BAT2: this option is based on an actually existing reference lamp [48] that has improved efficacy and lifetime with respect to the average of the BC, but a higher price. It is intended to represent a BAT option, when maintaining halogen technology (i.e. without switching to LED). For this lamp the same EcoReport as the BC was used, but with adapted efficacy, lifetime and price.

- LED 2015: this option has been derived from the EcoReport for the 1000 lm average 2015 LED retrofit lamp, but scaling all data to 540 lm. The approximate best 2015 efficacy-price combination for LV LED capsules was derived as 100 lm/W and 10 euros/klm excl. VAT [49].

- LED 2020: this is the same as LED 2015, but with efficacy and price adjusted according to the 2020 projections made in the Task 4 report, i.e. 175 lm/W and 7.50 euros/klm excl. VAT.

Remarks and explanations:

- For the HL LV C options, the power corresponds to 490 lm, which is the one from the BC. The reference lamps for HL LV C BAT have 630 or 500 lm, but this has been scaled down to 490 lm for comparison purposes. For these options 450 operating hours per year are assumed.
  For the LED options, 540 lm and 500 h/a have been used in the analysis, thus applying a 10% rebound effect for both parameters.

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[46] Based on new gathered information, the efficacy of 14 lm/W used in the base case seems pessimistic as an average, it could be a lower bound. The price around 3 euros/piece used for the base case could be reasonable, as a mix of shop prices (higher) and on-line prices (lower) and as a mix of low-efficacy-low-life capsules (on-line price around 1 euro) and high-efficacy-high-life capsules (on-line prices from 3 to 6 euros).

[47] The following lamp was used as a reference: Osram Halostar 35W 12V GY6.35, http://www.osram.com/osram_com/products/lamps/halogen-lamps/halostar/halostar-star55566/index.jsp 630 lm, 18 lm/W, 2000 h rated life, average price 0.80 euros excl. VAT from 4 online sales' sites. Scaled down to 490 lm for comparison with BC lamp.

[48] The following lamp was used as a reference: Osram HALOSTAR PRO 25 W 12 V GY6.35 (also referred to as ECO), http://www.osram.com/osram_com/products/lamps/halogen-lamps/halostar/halostar-pro/index.jsp 500 lm, 20 lm/W, 4000 h rated life, average price 3.85 euros excl. VAT from 6 online sales' sites. Scaled down to 490 lm for comparison with BC lamp.

[49] For reference see table 33 note 6 of the Task 4 report.

- The energy consumption by external control gears (voltage transformers) has been added in the current analysis by dividing the EcoReport results (that are without this energy) by the control gear efficiency. For all options this efficiency is 94%; LED retrofit capsules are assumed to work on the same transformers as the low voltage halogen capsules that they replace.

Table 12 provides a summary of the most relevant input and output data. For additional input data see the Task 5 report (EcoReports) and references therein.

The LCC per Mlmh and the electricity consumption in kWh per Mlmh are also shown graphically in Figure 21. The LED 2020 option has the lowest energy consumption and the lowest cost per Mlmh. Of the currently available options, the LED 2015 option has the lowest energy consumption per Mlmh, and the lowest cost per Mlmh.

The bottom part of Table 12 (see also Figure 22) shows the cumulative consumer expenditure over the useful lifetime for each option. Values for year 0 are purchase price and installation costs. Each following year the amount increases by the running costs (electricity, repair and maintenance).

Figure 22 shows that an investment in LV LED capsules has a payback time of just over 1 year when compared with the HL LV C BC and BAT2 options, and of approximately 3 years when compared with the HL LV C BAT1 option. This payback time depends mainly on the initial costs of the LEDs, and less on their efficacy. The LED 2015 curve is based on a price of 10 euros/klm. Using the median price from table 10 in the Task 4 report (32 euros/klm), the LED 2015 curve in Figure 22 would shift upwards over circa 12 euros, increasing the payback times to 4.5 – 7 years.
Due to its higher initial cost, the HL LV C BAT2 option (higher efficacy and lifetime) is economically not convenient with respect to the BAT1 option. The main advantage of the BAT2 option is that the need for substitution is less frequent, which makes it adequate in particular for positions where a replacement is difficult.

If the LED 2020 option would already be available, with the projected characteristics of 175 lm/W and 7.5 euros/klm, it would be immediately convenient when compared to the HL LV C BC and BAT2 options, and have a payback time of slightly less than 2 years when compared with the BAT1 option.

Table 12 Summary of design options for HL LV Capsules: input data, results over product lifetime, results per Mega-lumen-hour (Mlmh), and cumulative consumer expenditure up to option useful lifetime. Electricity by control gear included (94% efficiency)

		HL LV C BC	HL LV C BAT1	HL LV C BAT2	LED 2015	LED 2020	
Operating hours	h/yr	450	450	450	500	500	
Capacity	lm	490	490	490	540	540	
Useful life (hours)	h	2000	2000	4000	20000	20000	
Useful life (years)	yr	4.4	4.4	8.9	40.0	40.0	
Power	W	35.0	27.2	24.5	5.4	3.1	
Efficacy	lm/W	14	18	20	100	175	
Product price	euros	3.1	0.9	4.5	6.3	4.7	
Installation costs	euros	0.4	0.4	0.4	0.4	0.4	
Repair & Maint. costs	euros/life	0.8	0.8	1.6	7.4	7.4	
Electricity rate	euros/kWh	0.177	0.177	0.177	0.177	0.177	
Mercury content	mg	0	0	0	0	0	
CRM indicator	mg Sb eq.	1	1	1	54	54	
o/w REE	mg Sb eq.	0	0	0	0.01	0.01	
EoL recycling	%	70%	70%	70%	85%	85%	
Total weight	g	18	18	18	104	104	
Results per product over lifetime							
Electricity (incl. CG)	kWh/life	74	58	104	115	66	
Electricity cost	euros/life	13.2	10.3	18.5	20.3	11.6	
Life cycle cost	euros/life	17.4	12.4	24.9	34.3	24.1	
Results per Mlmh							
Electricity (incl. CG)	kWh/Mlmh	76.0	59.1	53.2	10.6	6.1	
Electricity cost	euros/Mlmh	13.45	10.46	9.41	1.88	1.08	
Purchase cost	euros/Mlmh	3.11	0.95	2.28	0.58	0.43	
Installation cost	euros/Mlmh	0.38	0.38	0.19	0.03	0.03	
Repair & Maint. cost	euros/Mlmh	0.84	0.84	0.84	0.68	0.68	
Total costs per Mlmh	euros/Mlmh	17.78	12.62	12.72	3.18	2.23	
Consumer expenditure							
purchase & installation	euros	3.42	1.30	4.83	6.63	5.07	
annual running costs	euros/year	3.15	2.49	2.26	0.69	0.48	
Cumulative consumer expenditure							
Year 0	euros	3.4	1.3	4.8	6.6	5.1	
1	euros	6.6	3.8	7.1	7.3	5.5	
2	euros	9.7	6.3	9.4	8.0	6.0	
3	euros	12.9	8.8	11.6	8.7	6.5	
4	euros	16.0	11.3	13.9	9.4	7.0	
5	euros			16.1	10.1	7.4	
6	euros			18.4	10.8	7.9	
7	euros			20.7	11.5	8.4	
8	euros			22.9	12.2	8.9	
9	euros			25.2	12.9	9.3	
10	euros				13.6	9.8	
11	euros				14.3	10.3	
12	euros				14.9	10.8	
13	euros				15.6	11.2	
14	euros				16.3	11.7	
15	euros				17.0	12.2	

REE= Rare earth elements, in particular from phosphors, see Task 5 report; CRM= Critical raw materials; CG= Control gear; Mlmh= Mega-lumen-hours (e.g. 500 lm over 2000 h or 1000 lm over 1000 h)

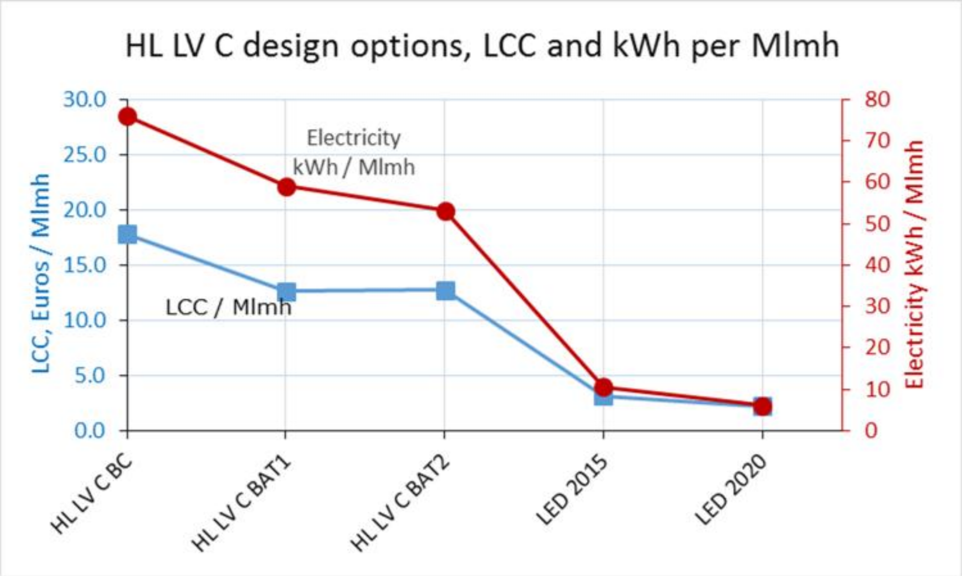

Figure 21 Design options for HL LV Capsules: life cycle cost (LCC, in euros/Mlmh, blue line with square markers, axis left) and electricity consumption (in kWh/Mlmh, red line with round markers, axis right). See Table 12 for underlying data.

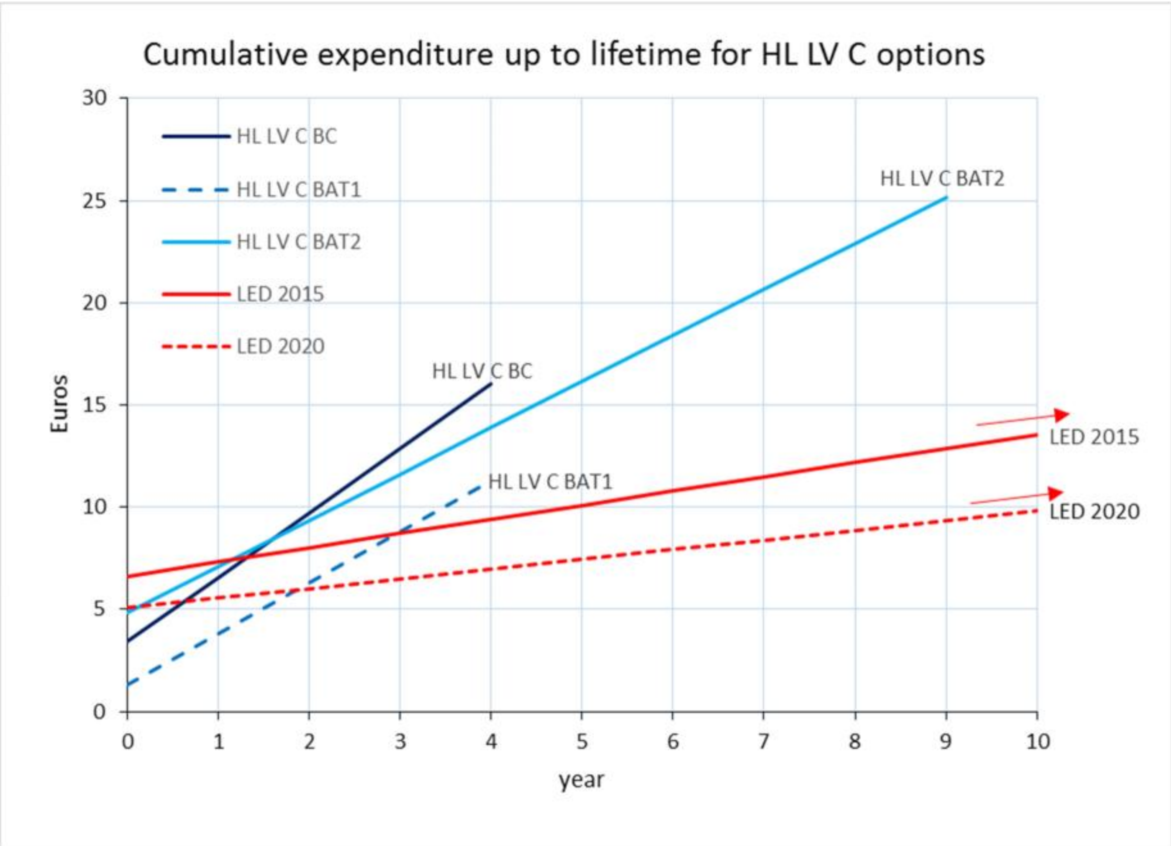

Figure 22 Cumulative consumer expenditure (fixed 2010 euros) for the design options for HL LV Capsules, up to their lifetime. Values for year 0 include purchase and installation. Each following year the amount increases by the running costs (electricity, repair and maintenance). See Table 12 (bottom part) for underlying data.

3.13. Mains voltage halogen capsules (HL MV C)

Design options considered:

- HL MV C: this is the base case described in the Task 4 report, par. 5.11. It represents the EU-28 average for mains voltage halogen capsules (with G9 cap). For this lamp the EcoReport presented in Task 5 was used.

- LED 2015: this option has been derived from the EcoReport for the 1000 lm average 2015 LED retrofit lamp, but scaling all data to 460 lm. The approximate best 2015 efficacy-price combination for MV LED capsules was derived as 96 lm/W and 11.15 euros/klm excl. VAT [50].

- LED 2020: this is the same as LED 2015, but with efficacy and price adjusted according to the 2020 projections made in the Task 4 report, i.e. 175 lm/W and 7.50 euros/klm excl. VAT.

Remarks and explanations:

- For the HL MV C option, the power corresponds to 420 lm. For this option 450 operating hours per year are assumed.
  For the LED options, 460 lm and 500 h/a have been used in the analysis, thus applying a 10% rebound effect for both parameters.

- No BAT option using halogen technology has been identified in Task 4.

Table 13 provides a summary of the most relevant input and output data. For additional input data see the Task 5 report (EcoReports) and references therein.

The LCC per Mlmh and the electricity consumption in kWh per Mlmh are also shown graphically in Figure 23. The LED 2020 option has the lowest energy consumption and the lowest cost per Mlmh. Of the currently available options, the LED 2015 option has the lowest energy consumption per Mlmh, and the lowest cost per Mlmh.

The bottom part of Table 13 (see also Figure 24) shows the cumulative consumer expenditure over the useful lifetime for each option. Values for year 0 are purchase price and installation costs. Each following year the amount increases by the running costs (electricity, repair and maintenance).

Figure 24 shows that an investment in MV LED capsules has a payback time of approximately 1 year. This payback time depends mainly on the initial costs of the LEDs, and less on their efficacy. The LED 2015 curve is based on a price of 11.15 euros/klm. Using the average price from table 1 in the Task 4 report (22.3 euros/klm), the LED 2015 curve in Figure 24 would shift upwards over circa 5 euros, increasing the payback times to approximately 3 years. Note that LED retrofits for MV halogen capsules may have slightly larger dimensions and that this may cause lock-in problems in some luminaires.
If the LED 2020 option would already be available, with the projected characteristics of 175 lm/W and 7.5 euros/klm, it would be immediately convenient.

[50] For reference see table 35 note 3 of the Task 4 report.

Table 13 Summary of design options for HL MV Capsules: input data, results over product lifetime, results per Mega-lumen-hour (Mlmh), and cumulative consumer expenditure up to option useful lifetime. Electricity by control gear included (94% efficiency)

		HL MV C BC	LED 2015	LED 2020			
Operating hours	h/yr	450	500	500			
Capacity	lm	420	460	460			
Useful life (hours)	h	1500	20000	20000			
Useful life (years)	yr	3.3	40.0	40.0			
Power	W	35.0	4.8	2.6			
Efficacy	lm/W	12	96	175			
Product price	euros	3.7	5.9	4.0			
Installation costs	euros	0.4	0.4	0.4			
Repair & Maint. costs	euros/life	0.6	7.3	7.3			
Electricity rate	euros/kWh	0.177	0.177	0.177			
Mercury content	mg	0	0	0			
CRM indicator	mg Sb eq.	1	46	46			
o/w REE	mg Sb eq.	0	0.01	0.01			
EoL recycling	%	70%	85%	85%			
Total weight	g	19	88	88			
Results per product over lifetime							
Electricity (incl. CG)	kWh/life	53	96	53			
Electricity cost	euros/life	9.3	17.0	9.3			
Life cycle cost	euros/life	13.9	30.6	21.0			
Results per Mlmh							
Electricity (incl. CG)	kWh/Mlmh	83.3	10.4	5.7			
Electricity cost	euros/Mlmh	14.75	1.84	1.01			
Purchase cost	euros/Mlmh	5.81	0.64	0.43			
Installation cost	euros/Mlmh	0.59	0.04	0.04			
Repair & Maint. cost	euros/Mlmh	0.97	0.80	0.80			
Total costs per Mlmh	euros/Mlmh	22.12	3.32	2.28			
Consumer expenditure							
purchase & installation	euros	4.03	6.28	4.37			
annual running costs	euros/year	2.97	0.61	0.42			
Cumulative consumer expenditure							
Year 0	euros	4.0	6.3	4.4			
1	euros	7.0	6.9	4.8			
2	euros	10.0	7.5	5.2			
3	euros	12.9	8.1	5.6			
4	euros		8.7	6.0			
5	euros		9.3	6.4			
6	euros		9.9	6.9			
7	euros		10.5	7.3			
8	euros		11.1	7.7			
9	euros		11.7	8.1			
10	euros		12.4	8.5			
11	euros		13.0	8.9			
12	euros		13.6	9.4			
13	euros		14.2	9.8			
14	euros		14.8	10.2			
15	euros		15.4	10.6			

REE= Rare earth elements, in particular from phosphors, see Task 5 report; CRM= Critical raw materials; CG= Control gear; Mlmh= Mega-lumen-hours (e.g. 500 lm over 2000 h or 1000 lm over 1000 h)

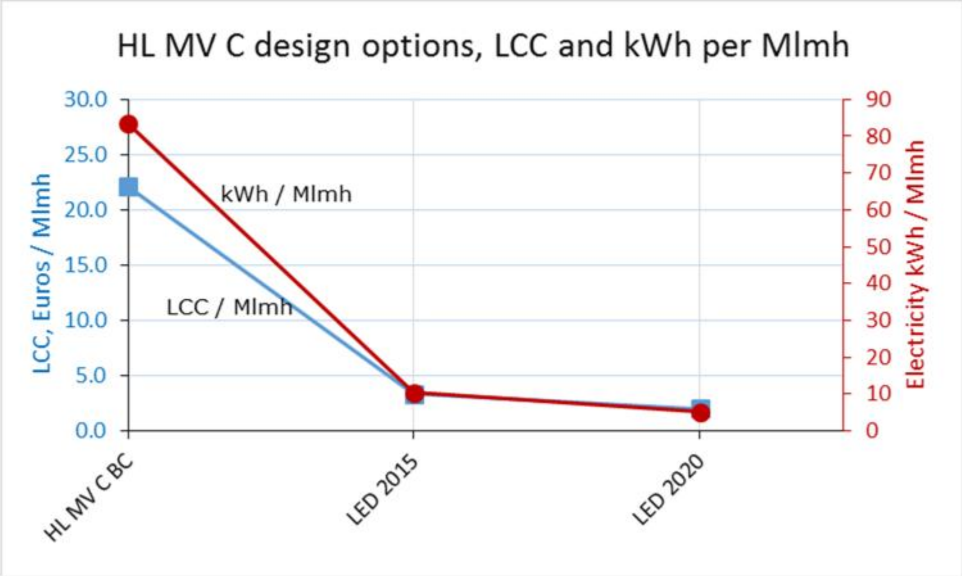

Figure 23 Design options for HL MV Capsules: life cycle cost (LCC, in euros/Mlmh, blue line with square markers, axis left) and electricity consumption (in kWh/Mlmh, red line with round markers, axis right). See Table 13 for underlying data.

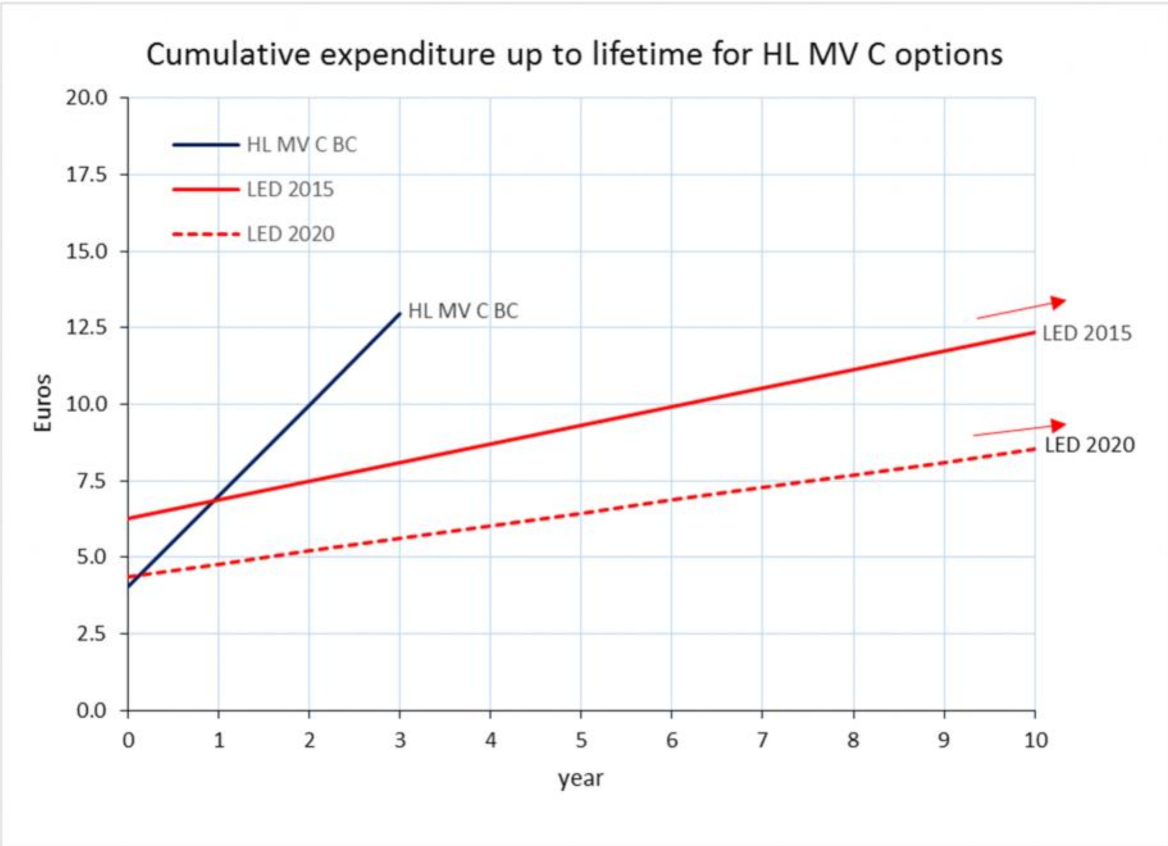

Figure 24 Cumulative consumer expenditure (fixed 2010 euros) for the design options for HL MV Capsules, up to their lifetime. Values for year 0 include purchase and installation. Each following year the amount increases by the running costs (electricity, repair and maintenance). See Table 13 (bottom part) for underlying data.

3.14. Double-ended linear halogen lamps with R7s cap (HL MV L)

Design options considered:

- HL MV L BC: this is the base case described in the Task 4 report, par. 5.12. It represents the EU-28 average for mains voltage double-ended linear halogen lamps with R7s cap. For this lamp the EcoReport presented in Task 5 was used [51].

- HL MV L BAT: this option is based on actually existing reference lamps [52] that have improved efficacy and lifetime with respect to the average of the BC, but a higher price. It is intended to represent a BAT option, when maintaining halogen technology (i.e. without switching to LED). For this lamp the same EcoReport as the BC was used, but with adapted efficacy, lifetime and price.

- LED 2015: this option has been derived from the EcoReport for the 1000 lm average 2015 LED retrofit lamp, but scaling all data to 3300 lm. The approximate best 2015 efficacy-price combination for MV LED lamps with R7s cap was derived as 90 lm/W and 4.54 euros/klm excl. VAT [53].

- LED 2020: this is the same as LED 2015, but with efficacy and price adjusted according to the 2020 projections made in the Task 4 report, i.e. 175 lm/W and 7.50 euros/klm excl. VAT. However, considering that the 2015 price is already lower than the 2020 average projection over all LED lamp types, the 2015 4.54 euros/klm has been halved for the 2020 option [54].

Remarks and explanations:

- For the HL MV L options, the power corresponds to 3000 lm, which is the one from the BC. The reference lamps for HL MV L BAT have 3100 lm, but this has been scaled down to 3000 lm for comparison purposes. For these options 450 operating hours per year are assumed.
  For the LED options, 3300 lm and 500 h/a have been used in the analysis, thus applying a 10% rebound effect for both parameters.

Table 14 provides a summary of the most relevant input and output data. For additional input data see the Task 5 report (EcoReports) and references therein.

The LCC per Mlmh and the electricity consumption in kWh per Mlmh are also shown graphically in Figure 25. The LED 2020 option has the lowest energy consumption and the lowest cost per Mlmh. Of the currently available options, the LED 2015 option has the lowest energy consumption per Mlmh, and the lowest cost per Mlmh.

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[51] Based on new gathered information, the efficacy of 12 lm/W used in the base case seems pessimistic as an average. The BC lifetime of 1000 h is also low, but that was a choice motivated by the fragility of these lamps.

[52] The following lamp was used as a reference: HALOLINE PRO 160 W 230 V R7S (also referred to as ECO), http://www.osram.com/osram_com/products/lamps/halogen-lamps/haloline/haloline-pro/index.jsp 3100 lm, 19.4 lm/W, 2000 h rated life, average price 5.71 euros excl. VAT from 8 online sales' sites. Scaled down to 3000 lm for comparison with BC lamp. The Osram lamp characteristics are identical to those of 'Philips Plusline ES Small 118mm 2y 160W R7s 230V' and 'Sylvania Double Ended 118mm Eco 160W R7S 230'.

[53] For reference see table 37 note 12 of the Task 4 report. There are lamps on the market with higher declared efficacy, but they have higher initial costs.

[54] Note that the average over all LED lamps reduces from 23.4 euros/klm in 2015 to 7.5 euros/klm in 2020, which implies a 68% reduction.

The bottom part of Table 14 (see also Figure 26) shows the cumulative consumer expenditure over the useful lifetime for each option. Values for year 0 are purchase price and installation costs. Each following year the amount increases by the running costs (electricity, repair and maintenance).

Figure 26 and Table 14 show that an investment in MV LEDs with R7s cap has a payback time of just over 1 year when compared with the HL MV L BAT option, while it has a payback time of slightly less than 1 year when compared with the HL MV L base case. This payback time depends mainly on the initial costs of the LEDs, and less on their efficacy. The LED 2015 curve is based on a price of 4.54 euros/klm. Using the average price from table 1 in the Task 4 report (26.71 euros/klm), the LED 2015 curve in Figure 26 would shift upwards over circa 73 euros, increasing the payback times to approximately 4.5 – 8 years.

It is recalled that consumers wishing to substitute their halogen R7s lamp by a LED, should pay attention to the larger dimensions of the LED retrofit lamp: this may cause lock-in problems in some luminaires. See details in the Task 4 report, par. 5.12.

If the LED 2020 option were already available, with the used characteristics of 175 lm/W and 2.27 euros/klm excl. VAT, it would have a payback time of some months.

Table 14 Summary of design options for HL MV L lamps (R7s cap): input data, results over product lifetime, results per Mega-lumen-hour (Mlmh), and cumulative consumer expenditure up to option useful lifetime. Electricity by control gear included (94% efficiency)

		HL MV L BC	HL MV L BAT	LED 2015	LED 2020		
Operating hours	h/yr	450	450	500	500		
Capacity	lm	3000	3000	3300	3300		
Useful life (hours)	h	1000	2000	20000	20000		
Useful life (years)	yr	2.2	4.4	40.0	40.0		
Power	W	250.0	154.6	36.7	18.9		
Efficacy	lm/W	12	19.4	90	175		
Product price	euros	3.1	6.4	17.4	8.7		
Installation costs	euros	0.4	0.4	0.4	0.4		
Repair & Maint. costs	euros/life	0.4	0.4	7.4	7.4		
Electricity rate	euros/kWh	0.177	0.177	0.177	0.177		
Mercury content	mg	0	0	0	0		
CRM indicator	mg Sb eq.	4	4	330	330		
o/w REE	mg Sb eq.	0	0	0.08	0.08		
EoL recycling	%	70%	70%	85%	85%		
Total weight	g	30	30	633	633		
Results per product over lifetime							
Electricity (incl. CG)	kWh/life	250	309	733	377		
Electricity cost	euros/life	44.3	54.7	129.8	66.8		
Life cycle cost	euros/life	48.1	61.9	154.9	83.2		
Results per Mlmh							
Electricity (incl. CG)	kWh/Mlmh	83.3	51.5	11.1	5.7		
Electricity cost	euros/Mlmh	14.75	9.12	1.97	1.01		
Purchase cost	euros/Mlmh	1.02	1.07	0.26	0.13		
Installation cost	euros/Mlmh	0.12	0.06	0.01	0.01		
Repair & Maint. cost	euros/Mlmh	0.14	0.07	0.11	0.11		
Total costs per Mlmh	euros/Mlmh	16.03	10.32	2.35	1.26		
Consumer expenditure							
purchase & installation	euros	3.42	6.78	17.74	9.06		
annual running costs	euros/year	20.10	12.41	3.43	1.85		
Cumulative consumer expenditure							
Year 0	euros	3.4	6.8	17.7	9.1		
1	euros	23.5	19.2	21.2	10.9		
2	euros	43.6	31.6	24.6	12.8		
3	euros		44.0	28.0	14.6		
4	euros		56.4	31.5	16.5		
5	euros			34.9	18.3		
6	euros			38.3	20.2		
7	euros			41.8	22.0		
8	euros			45.2	23.9		
9	euros			48.6	25.7		
10	euros			52.0	27.6		
11	euros			55.5	29.4		
12	euros			58.9	31.3		
13	euros			62.3	33.2		
14	euros			65.8	35.0		
15	euros			69.2	36.9		

REE= Rare earth elements, in particular from phosphors, see Task 5 report; CRM= Critical raw materials; CG= Control gear; Mlmh= Mega-lumen-hours (e.g. 500 lm over 2000 h or 1000 lm over 1000 h)

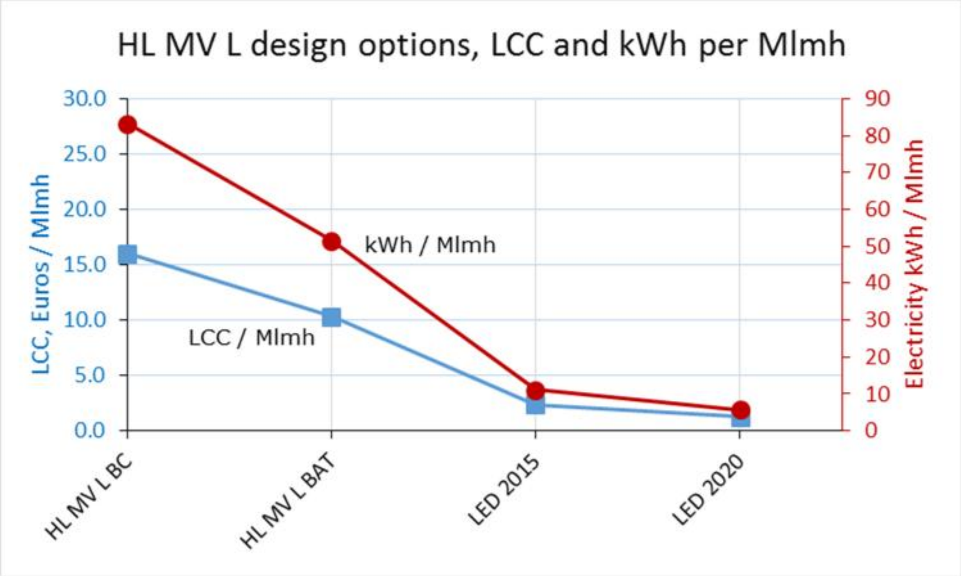
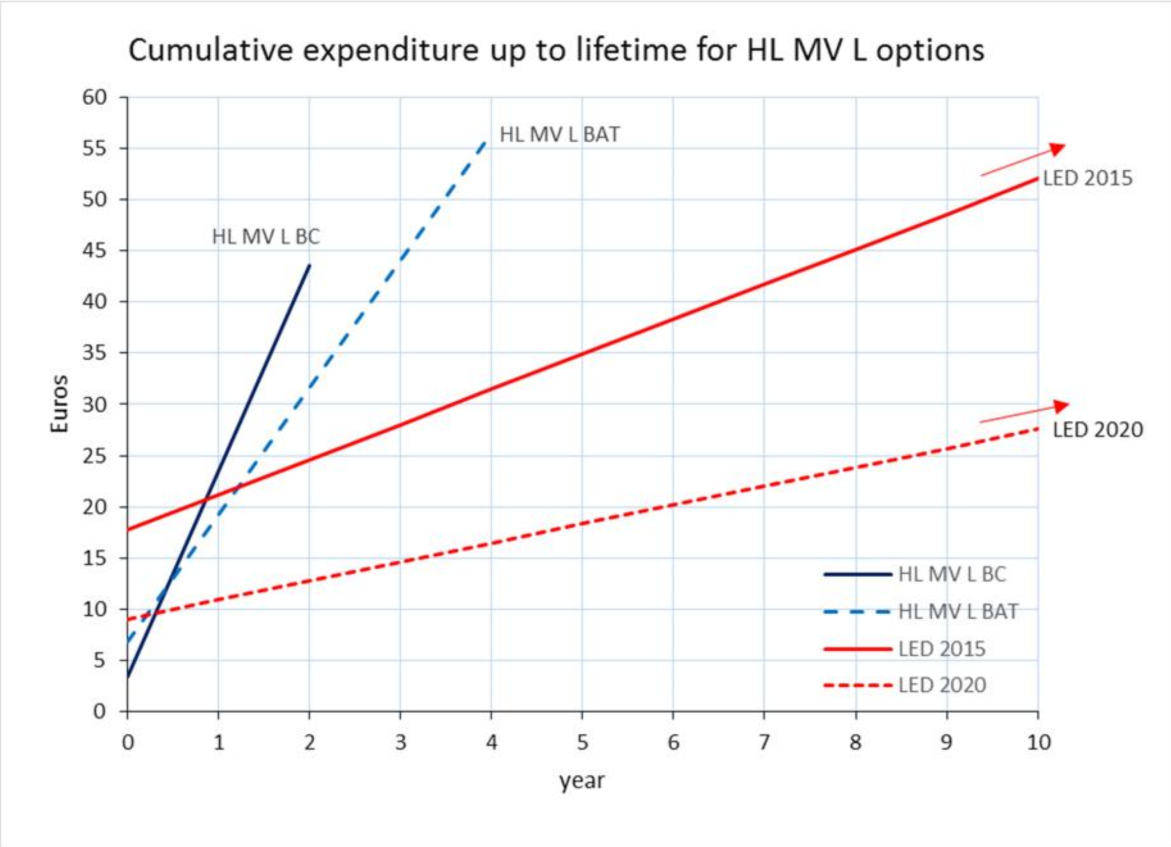


Figure 25 Design options for HL MV L lamps (R7s cap): life cycle cost (LCC, in euros/Mlmh, blue line with square markers, axis left) and electricity consumption (in kWh/Mlmh, red line with round markers, axis right). See Table 14 for underlying data.



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Acronyms

a	Annum, year
BAT	Best Available Technology
BC	Base Case (as used in MEErP)
BNAT	Best Not (yet) Available Technology
BoM	Bill Of Materials
CCT	Correlated Colour Temperature
CFL	Compact fluorescent lamps
CFLi	CFL with integrated ballast
CFLni	CFL without integrated ballast
CG	Control Gear
CRI	Colour Rendering Index
CRM	Critical Raw Material (see EcoReports)
DLS	Directional light sources
E14, E27	Screw-type lamp caps for general purpose lamp
EC	European Commission
ECG	Electronic Control Gear
EEI	Energy Efficiency Index
EoL	End-of-Life
ErP	Energy related Product
EU	European Union
G4, GY6.35	Low-voltage halogen lamp types, 2 pin cap, single ended
G9	Mains-voltage halogen lamp, 2-pin cap, single ended
GLS	General Lighting Service (a.k.a. incandescent lamp)
h	Hour
HE	High efficiency
HF	High Frequency
Hg	Mercury
HID	High-Intensity Discharge
HL	Halogen
HO	High output
HPM	High-Pressure Mercury
HPS	High-Pressure Sodium
klm	Kilo lumen (see lm)
LCC	Life Cycle Cost
LE	LightingEurope (lighting manufacturers association)
LED	Light Emitting Diode
LFL	Linear Fluorescent Lamp
LLCC	Least Life Cycle Cost
LLMF	Lamp Lumen Maintenance Factor
lm, Φ	Lumen, unit of luminous flux Φ
LV	Low Voltage (typical 12V)

L70	Lifetime, lumen output decreased to 70% of original value
max	maximum
MELISA	Model for European Light Sources Analysis
MEErP	Methodology for Ecodesign of Energy-related Products
MF	Maintenance Factor
MH	Metal Halide
min	minimum
Mlmh	Mega-lumen-hours
mn / mln	Million (10^6)
MV	Mains Voltage (typical 230V)
NDLS	Non-directional light sources
par	paragraph
-R	Reflector
R7s	Mains voltage linear halogen lamp, double ended
R9	Saturated red colour used as rendering reference
Ra	Colour rendering index, unit
REE	Rare Earth Element
ref	reference
TWh	Tera Watt hour (10^12)
V	Volt
VHK	Van Holsteijn en Kemna
VITO	Vlaamse Instelling voor Technologisch Onderzoek
W	Watt
XL	Extra long lifetime
yr	year

Annex A. Statement of contractor on right to delivered result

I, Dirk Fransaer, representing the “Consortium of VITO NV, VHK BV, Viegand & MaagØe ApS, Wuppertal Institute for Climate, Environment and Energy GmbH, and ARMINES”, party to the contract ‘Preparatory Study on Lighting Systems for Ecodesign and/or Energy Labelling Requirements (‘Lot 8/9/19’), specific contract No. ENER/C3/2012-418 LOT1/07/SI2.668526 implementing framework contract No. ENER/C3/2012-418-Lot 1’, warrant that the Contractor holds full right to the delivered Task 6 report of the ‘Preparatory Study on Lighting Systems for Ecodesign and/or Energy Labelling Requirements (‘Lot 8/9/19’)’, which is free of any claims, including claim of the creators who transferred all their rights and will be paid as agreed within 30 days from the receipt of confirmation of acceptance of work.

Mol, Belgium,
Date:
Signature:

Dirk Fransaer
Managing Director VITO NV

Annex B. Description of MEErP Task 6

The MEErP [55] prescribes the following topics to be addressed in Task 6, Design Options:

From MEErP part 1 (general):

Task 6 Identifies 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 monetary Life Cycle Costs is relevant to indicate whether design solutions might negatively or positively impact the total EU consumer's expenditure over the total product life (purchase, running costs, etc.), while taking into account for the purchase price development the manufacturers' R&D and investment costs. The distance between the LLCC and the BAT indicates – in a case a LLCC solution is set as a minimum target - the remaining space for product-differentiation (competition). The BAT indicates a medium-term target that would probably more subject to promotion measures than restrictive action. The BNAT indicates long-term possibilities and helps to define the exact scope and definition of possible measures.

From MEErP part 1 (specific):

6 DESIGN OPTIONS

6.1 Options

Identify and describe (aggregated clusters of) design options to be taken into account (from Task 4, typically 4 to 8 design options are appropriate)

6.2 Impacts

Assess quantitatively the environmental improvement per option using the EcoReport tool. Compare the outcomes and report only on impacts that change significantly with the design options.

6.3 Costs

Assess/ estimate price increase due to implementation of these design options, either on the basis of prices of products on the market and/or by applying a production cost model with sector-specific margins.

6.4 Analysis LLCC and BAT

- 6.4.1 Rank the individual design options by LCC (e.g. option 1, option 2, option 3;
- 6.4.2 Determine/ estimate possible positive or negative ('rebound') side effects of the individual design measures;
- 6.4.3 Estimate the accumulative improvement and cost effect of implementing the ranked options simultaneously (e.g. option 1, option 1+2, option 1+2+3, etc.), also taking into account the above side-effects;
- 6.4.4 Rank the accumulative design options; draw LCC-curves (1st Y-axis= LLCC, 2nd Y-axis= impact (e.g. energy), X-axis= options); identify the Least Life Cycle Cost (LLCC) point and the point with the Best Available Technology (BAT);

6.5 Long-term targets (BNAT) and systems analysis

Discussion of long-term technical potential on the basis of outcomes of applied and fundamental research, but still in the context of the present product archetype;

[55] MEErP 2011, Methodology for Ecodesign of Energy-related Products, part 1: Methods and part 2: Environmental policies and data, René Kemna (VHK) November 28th 2011

Discussion of long-term potential on the basis of changes of the total system to which the present archetype product belongs: Societal transitions, product-services substitution, dematerialisation, etc.