Preparatory Study on Light Sources
for Ecodesign and/or Energy Labelling Requirements
('Lot 8/9/19').

Final report

Project Summary

Energy

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Project Summary

This study, assigned by the European Commission, prepares for a comprehensive review of the four existing ecodesign and energy labelling regulations for Light Sources (‘Lot 8/9/19’) in the European Union [1]. It aims at setting more ambitious targets, removing flaws and possibly unifying the existing regulations into one or two improved pieces of legislation.

The study ran from January 2014 to October 2015, and was structured according to the MEErP [2] methodology with 8 Tasks (0 to 7). Stakeholders have been consulted during two meetings and their information and comments have been taken into account.

Task 0: Assignment, Methodology and First screening

A summary of the context is provided, including a description of the existing regulations regarding Light Sources. The assignment, project structure, planning and team for the study are presented. In the first screening, the initial scope of the study is chosen very wide: “The study regards all light sources, lamps, ballasts and lamp control gears according to the definitions provided in the Task 0 report ”.

Task 1: Scope, Standards and Legislation

Typology of light sources on the EU-market and relevant parameters are presented. Special Purpose Lamps and other exemptions have been analysed. They account for 70-80 TWh/a [3] of EU-28 electricity consumption in 2013. The lack of accurate, verifiable definitions is identified as a barrier for effectiveness of market surveillance. The initial scope is slightly reduced (Figure 1), mainly on the basis of the eligibility criteria of art. 15 of the Ecodesign Framework Directive 2009/125/EC, and a proposal for further reduction is presented to the stakeholders and the Commission.

A study of the many available standards related to lighting products (measurement, safety, other) led to the identification of several potential issues for mandates to European Standardization Organisations, such as:

- accelerated testing for lumen maintenance & life,
- dimmer compatibility (ongoing, expected 2018),
- colour rendering metrics across lamp types,
- cost-effective solutions for testing of directional lamps,
- practical tests for special purpose lamps and other exemptions,
- generally accepted methods for testing and calculation of flickering.

Minimum efficacy requirements exist in almost all parts of the world. An international comparison concludes that the EU has the broadest scope, is the most stringent and

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[1] Commission Regulation (EC) No 244/2009 of 18 March 2009, OJ L76/3, 24.3.2009 (non-directional household lamps)
Commission Regulation (EC) No 245/2009 of 18 March 2009, OJ L76/17, 24.3.2009 (fluorescent lamps without integrated ballast, high intensity discharge lamps, ballasts and luminaires able to operate such lamps)
Commission Regulation (EU) No 1194/2012 of 12 December 2012, OJ L342/1, 14.12.2012 (directional lamps, light emitting diode lamps and related equipment)
Commission Delegated Regulation (EU) No 874/2012 of 12 July 2012, OJ L258/1, 26.09.(energy labelling of electrical lamps and luminaires)
as amended by successive regulations

[2] 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

[3] Excluding lighting on means of transport, backlighting for electronic displays, and lamps integrated into products that are already subject of separate ecodesign measures.

covers most lamp types, while energy labels and information requirements for light sources are very comprehensive. Yet, most recently, Japan has announced more ambitious targets.

Task 2: Markets

In 2013 a total of 2.1 billion light sources was sold in EU-28 (Figure 2)of which 62% in the residential sector and 38% in the non-residential sector. The installed stock in 2013 was around 11 billion units and is continuously increasing (Figure 3). The total consumer expense for lighting in 2013 was around 65 billion euros [4], corresponding to 0.4% of the EU-28 GDP.
Data regarding ballasts show a > 60% sales share for electronic ballasts in 2010.

Together with the parameters from Task 3, all data have been collected and processed in the very comprehensive 'Model for European LIght Sources Analysis' (MELISA) (Figure 5). Model input and output have been extensively checked against other available data sources.

Task 3: Users

Task 3 reports annual operating hours, useful lifetimes, installed power (W) and capacity (lm), and efficacy. In 2013 the installed lighting capacity was 10.8 Tlm and the total installed power 304 GW [5], estimated to correspond to 11 W/m^2 in the residential sector and 8.7 W/m^2 in the indoor non-residential sector.

Electric energy consumption for lighting amounted to 382 TWh/a in 2013 (including ballasts, controls, standby and special purpose lamps), which is around 14% of the EU-28 total. The share of the residential sector is 93 TWh/a (24%), with energy density estimated in 467 kWh/household/a or 4.3 kWh/m^2/a. The non-residential sector accounts for 289 TWh/a (76%) with an estimated energy density of 13.4 kWh/m^2/a for the indoor applications.

Other issues addressed in Task 3 are:

- More efficient lighting (LED) is estimated to lead (on average) to 0.1°C colder rooms in 2020 due to the lower heating contribution of light sources.
- As regards health aspects of light sources, in general there is no reason for concern, but in some cases there are reports on issues related to blue-light hazard, glare and photo-biological safety.
- At end-of-life, according to European waste handling statistics, 30% of the discharge lamps and 5% of the other lighting equipment is separately collected, of which 75-80% is recycled or re-used. All other lighting products end up in the main waste stream.
- There are problems with dimming of 'dimmable' LED lamps, but data lack as regards the size of the problem. A cautious estimate is that 50% of the households has on average 1 phase-cut dimmer installed, and some of these may encounter problems. A new dimmer-lamp compatibility standard is expected by 2018.

Task 4: Technology

The technological aspects of all types of lamps are discussed, with a focus on LED technology. The 2014/2015 LED lighting products have an average efficacy of 89 lm/W

[4] Fixed 2010 euros, including 20% VAT for the residential sector. Total expense for acquisition, installation, use (electricity cost) and maintenance. Excluded: special purpose lamps, lighting controls and standby.
[5] Tlm = Tera-lumen (10^12), GW = Giga-Watt (10^9)

and an average price of 23 euros/klm. The future projections up to 2030 for LED efficacy and LED prices are shown in Figure 6 and Figure 7. LED prices are rapidly coming down, efficacies are still going up, and quality is improving. These developments, and the penetration of LEDs in the light source market, are much faster than could be expected in 2007-2009 when the studies for the current regulations were made.

LED retrofit lamps are available for most classical lamp types. Some (partial) exceptions are LEDs to replace LFL T5, high capacity HID-lamps and CFLni. Some LED-retrofits for halogen lamps with G9 or R7s cap may encounter lock-in problems in existing luminaires.

Task 4 also discusses OLED-lighting, Laser-diode lighting, Induction lighting, Plasma lighting and Smart lamps, but these have not been considered as separate base cases. In addition the packaging and material resources (bill-of-materials) are addressed.

Task 5: Environment & Economics (base case LCA and LCC)

Using the EcoReport-tool, the life cycle costs (LCC) and the environmental impacts (Figure 8) for all light source types have been determined. The LCC for average 2013 LED lighting products is 3.4 euros/Mlmh [6], which is 5 to 7 times lower than for filament lamps and 2 times lower than for CFL. In 2020 the LCC for LED is expected to decrease to 1.3 euros/Mlmh, i.e. significantly lower than for linear fluorescent and high-intensity discharge lamps.

The electricity consumption of light sources in 2013 was 265 TWh (excluding ballasts, controls, standby and special purpose lamps), which is 9.5% of the EU-28 total. Greenhouse gas emissions due to lighting products were 103 MtCO_2eq. (2% of EU-28 total). Mercury emissions due to the generation of electricity for lighting were 4.2 ton in 2013 (5.3% of EU-28 total). The mercury contained in lamps that reached their end-of-life in 2013 was around 2.1 ton (2.7% of EU-28 total).

Task 6: Design Options (Least Life-Cycle Costs and payback times)

The payback time for an investment in LED lighting products is 1-4 years [7]. These values are reached in 2015 for substitution of filament lamps (GLS, HL) by LEDs, and are projected to be reached in 2020 for substitution of discharge lamps (LFL, CFL, HID) (Figure 9).

Task 7: Scenario Analysis (Policy Options)

The Business-as-Usual (BAU) scenario includes the future effects of existing regulations and the expected trends in LED sales, efficacy and prices. It leads to 110 TWh/a of electric energy savings in 2030 as compared to 2015 (Figure 10, Figure 11).

The ECO-scenarios aim at a single new ecodesign regulation, technology neutral, with a single energy efficiency criterion for all types of lighting products (light source + control gear + other related devices if integrated). The scope is further clarified in Figure 1, Figure 12 and Figure 13).

The required energy efficiency is expressed as a maximum allowed power (Figure 14) that includes a bonus for low lumen lamps and for lamps with high colour rendering index (CRI). The target efficacy in this formula (70, 80 or 120 lm/W) is based on the

[6] Considering that different light sources have different lifetimes, for honesty of comparison, the life-cycle costs and energies have been normalized to a total light output of a million lumen-hours (Mlmh)

[7] In some cases payback times can be less than one year.

LLCC criterion, while the timing of measures considers the expected development of the affordability of LED lighting products, the ongoing work on the dimmer compatibility standard (2018), the need for recent investors in high-intensity discharge (HID) lamps and high-frequency T5 linear fluorescent lamps (LFL T5) to recuperate investments, and time for industry to prepare for the new requirements.

The proposal is completed with requirements regarding standby power, suitability for general purpose lighting, dimmability, power factor and colour consistency. Improvement of Market Surveillance is enabled, speeding up test procedures and removing ambiguities.

The ecodesign measures are combined with an improved energy labelling for lighting products (indicated as '+LBL' below), aimed mainly at increasing the visibility of the label (Figure 15).

The ECO-scenarios that have been analysed are:

- ECO70+LBL: P(on) ≤ (2 + Ø/ 70)*((CRI+240)/320) in 2020
- ECO80+120 (+LBL): P(on) ≤ (2 + Ø/ 80)*((CRI+240)/320) in 2020 (stage 1)
  P(on) ≤ (2 + Ø/120)*((CRI+240)/320) in 2024 (stage 2)
- ECO120+LBL [8]: P(on) ≤ (2 + Ø/120)*((CRI+240)/320) in 2020

The ECO120+LBL scenario is an approximate reference for the maximum savings that could be theoretically obtained, but its technical feasibility is uncertain. The ECO80+120+LBL has been selected by the European Commission for its draft regulation proposal to the Ecodesign Consultation Forum of December 2015.

The additional savings of the ECO-scenarios with respect to the BAU-scenario in 2030 are provided in Figure 10 and Figure 11. The ECO80+120+LBL scenario saves additional 61 TWh/a of electricity and 21 MtCO_2eq of greenhouse gas emissions. Without energy label improvement these savings drop to 43 TWh/a and 14 MtCO_2eq.

To obtain these savings, an investment in LED lighting products is required, leading to a peak in EU-28 total acquisition costs around 2020. This peak is higher when the measure is more ambitious (Figure 16): 19 billion euros for BAU and 26 billion euros for the ECO80+120+LBL scenario (+7 bn euros, +36%).
As a consequence, the EU-28 total annual consumer expense for lighting is higher for the ECO-scenarios than for the BAU-scenario up to 2022 (Figure 17). After that year the consumer reaps the benefits of the investments due to lower energy costs: in 2030 the total expenses are 76 billion euros in BAU and 62 billion euros for the ECO80+120+LBL scenario (-14 bn euros per year, -18%).

All documentation regarding the Light Sources study can be found on the project website http://ecodesign-lightsources.eu/documents .

[8] This is an approximate reference scenario for the maximum savings that could be theoretically obtained, but the technical feasibility of this scenario is uncertain.

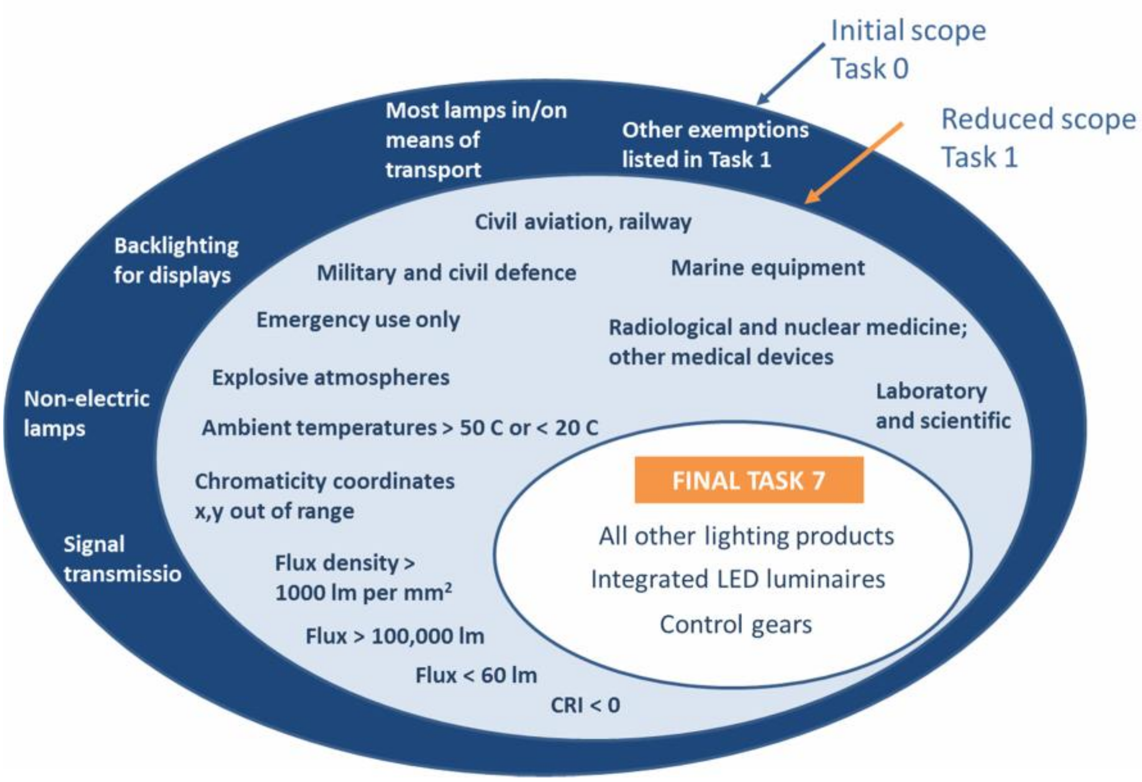


Figure 1 Reduction of the scope during the study. The final (Task 7) scope proposed for the new regulation regards all lighting products not exempted in the two outer ellipses.

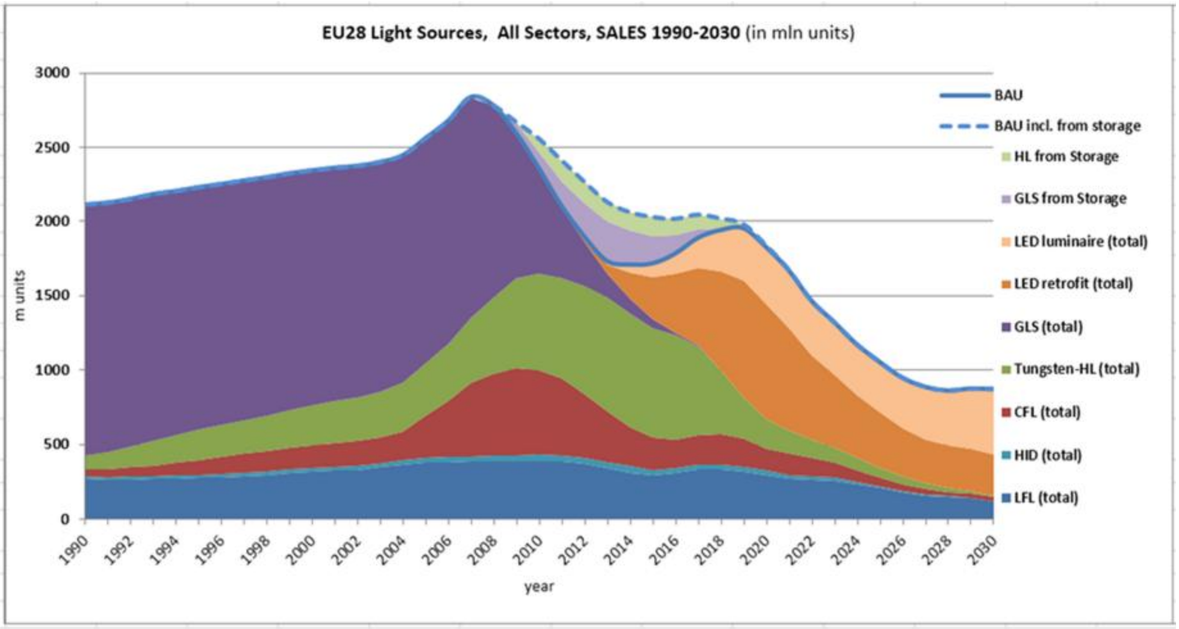


Figure 2 Sales volumes of light sources from the MELISA model, EU-28 totals over the period 1990-2030 (millions of units). In 2013 a total of 2.1 billion units were sold in EU-28 of which 62% in the residential sector. In 2030 this is predicted to decrease to 0.9 billion (Business-as-Usual scenario).

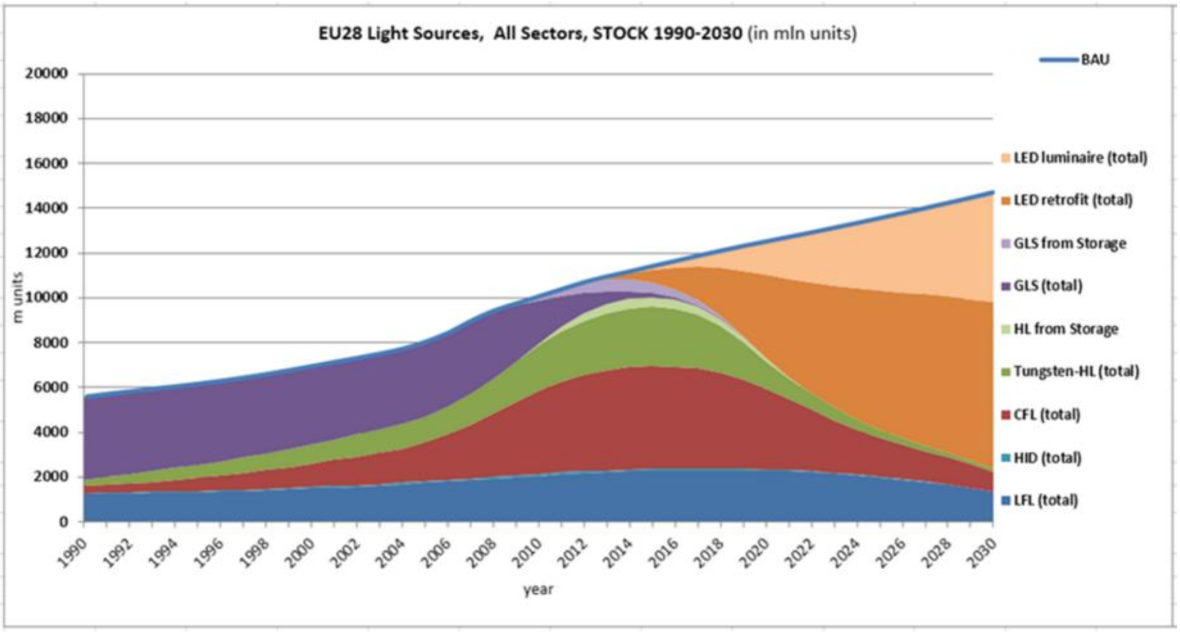


Figure 3 Installed Stock of light sources from the MELISA model, EU-28 totals over the period 1990-2030 (millions of units). In 2013 a total of 11 billion units were installed in EU-28 of which 60% in the residential sector. In 2030 this is predicted to increase to 15 billion (Business-as-Usual scenario).

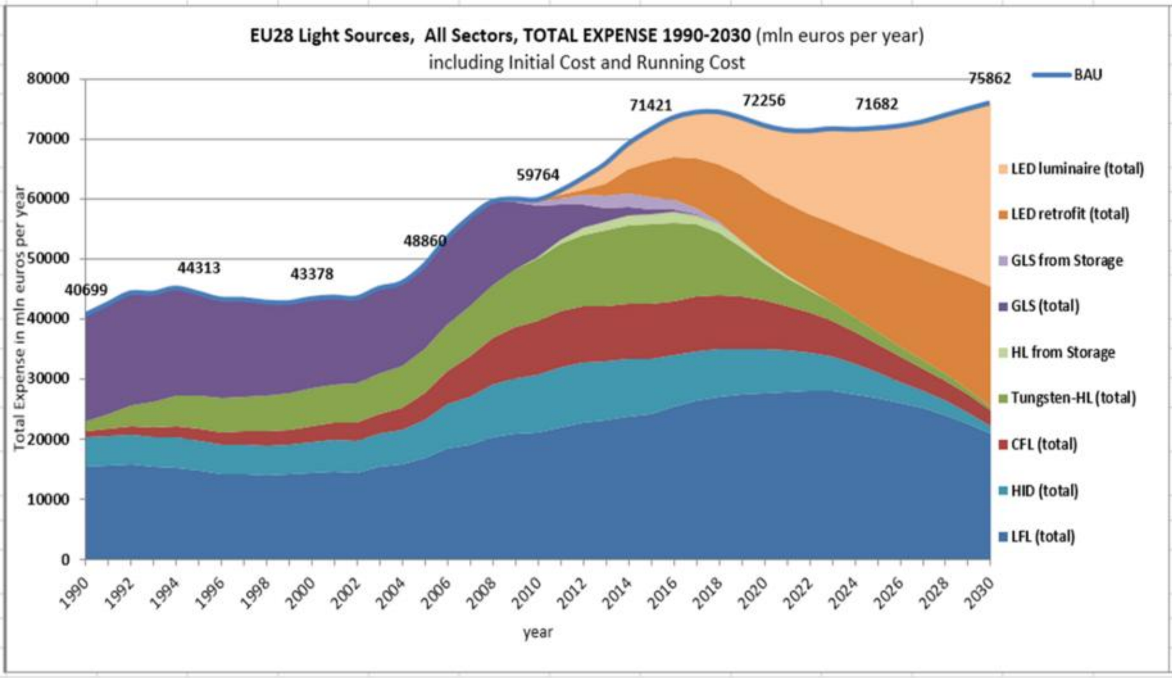


Figure 4 Annual Total Consumer Expenditure for the acquisition, installation and operation of light sources, from the MELISA model, EU-28 totals over the period 1990-2030 (millions of fixed 2010 euros, incl. VAT). Special purpose lamps, controls and standby are excluded. In 2013 the total expenditure was around 65 billion euros, or 0.4% of the EU-28 GDP. The residential share was 43%, i.e. 118 euros/household/year. (Business-as-Usual scenario for 2013-2030).

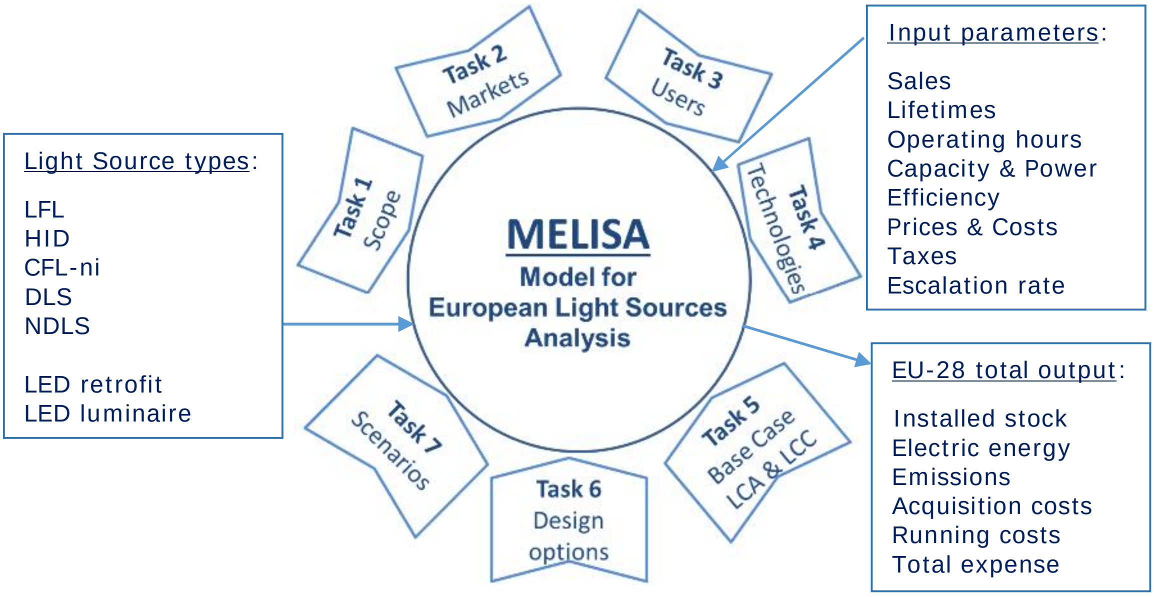
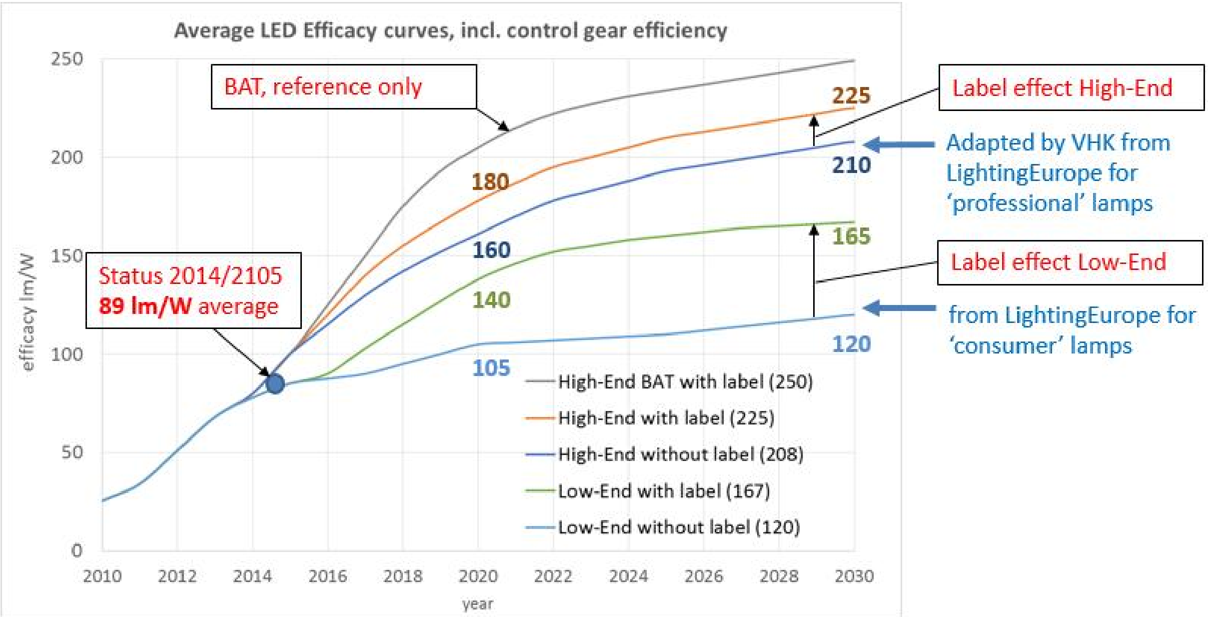
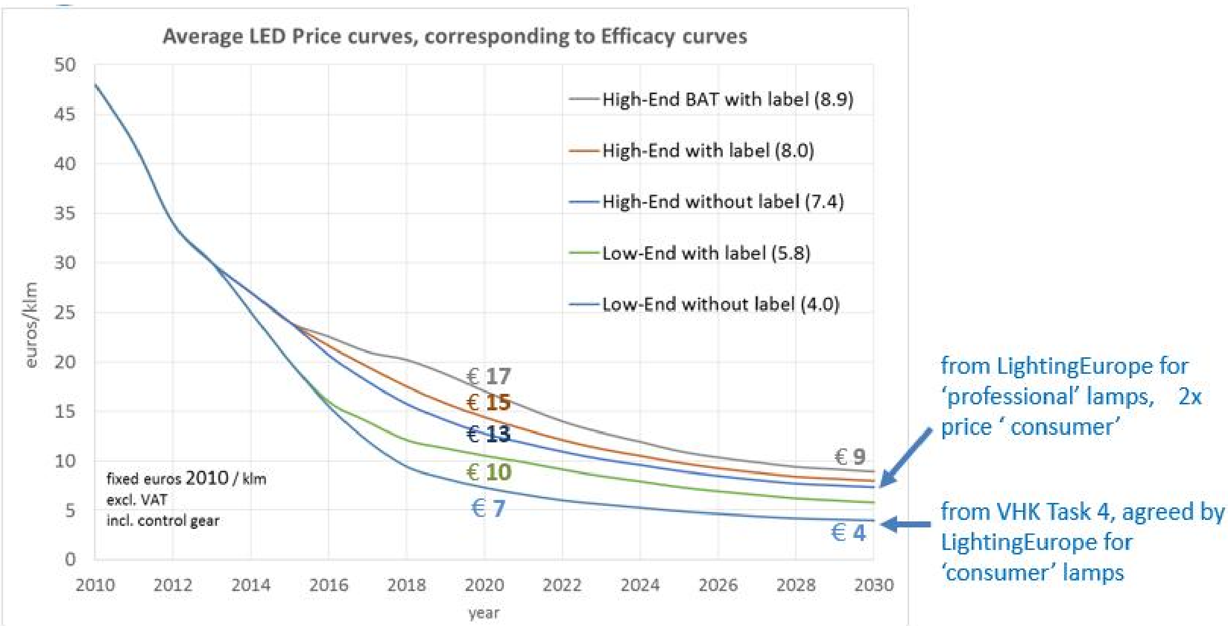


Figure 5 Model for European Light Sources Analysis (MELISA). Covers all general purpose light source types over the period 1990-2030. This model was originally developed and presented in Task 2 and further developed in Task 7 for the scenario analyses.
LFL= linear fluorescent lamp; HID = high-intensity discharge lamp; CFL = compact fluorescent lamp with ('i') or without ('ni') integrated ballast; DLS = directional light source (incandescent or halogen filament lamps); NDLS = non-directional light source (filament lamps and CFLi); LED = light-emitting diode



High-End = LED replacing LFL, CFLni, HID-lamps in non-residential sector.
Low-End = LED replacing GLS, HL, CFLi in all sectors and LFL, CFLni in residential.

Figure 6 Current status and projection up to 2030 for the efficacy (lm/W) of LED lighting products. These curves have been used in Task 7 for the scenario analysis



Price curves apply to efficacy curves with same name,
i.e. price increases linearly with efficacy

Figure 7 Current status and projection up to 2030 for the prices (euros/klm) of LED lighting products. These curves have been used in Task 7 for the scenario analysis and are applied to LED products with the efficacy of the corresponding curve in Figure 6.

Parameter	EU-28 lamp-related	Share of EU-28 total (%)
Electricity	265 TWh *	9.5 % *
→ Primary Energy	2398 PJ	3.2 %
GHG emissions	103 Mt CO_2 eq.	2 %
Acidifying agents emission	455 kt SO_2 eq.	2 %
Other emissions to air		< 0.6 %
Emissions to water		< 0.1 %
Non-energy resources		< 0.1 %
End-of-Life Hg emissions	2.1 ton (end-of-life lamps)	
Use-phase Hg emission	4.2 ton (power plants)	
Total lamp-related Hg	6.3 ton (total lamp-related)	8 % (declining)
Critical raw materials	158 tons Sb equivalent	1.4 %
End-of-Life Lamp Waste	96 kt (light sources)	1 % of WEEE
	78 kt (packaging)	
Use-phase Lamp Waste	1.2 Mt (power plants solid waste)	
Total lamp-related Waste	1.4 Mt	0.04%

Figure 8 EU-28 Environmental Impacts of lighting products, as derived from the EcoReports in Task 5, compared to the EU-28 total impact of all products. * Excluded: impacts from ballasts/control gears, special purpose lamps, lighting controls and standby. Including those, electricity would be 382 TWh (44% higher). GHG = greenhouse gas emission; Hg = mercury; WEEE = Waste Electric & Electronic Equipment

Application Group (analysis conditions)	Available option with **lowest** **LCC/Mlmh**	Available option with **lowest** **kWh/Mlmh**	**Payback** for LED **2015** vs. best classic technology (years)	**Payback** for LED **2020** vs. best classic technology (years)
Linear fluorescent lamps (LFL) (approx. 2400 lm, 1400-2200 h/a)	Classic technology	LED 2015	maybe never	**3-4**
Compact fluorescent lamps (CFLni) (630 lm, 1200 h/a)	LED 2015	LED 2015	no pay back in CFLni life	**3.5**
High-intensity discharge lamps (HID) (12000-13000 lm, 4000 h/a)	Classic technology	Classic technology	maybe never	**1-2.5**
Directional (filament) lamps (DLS) (450 lm, 450 h/a)	LED 2015	LED 2015	**2**	**0-1**
Non-directional lamps (NDLS, incl. CFLi) (420-500 lm, 450 h/a) (3000 lm for R7s)	LED 2015	LED 2015	**3.5-4 (GLS, HL)** **>12 (CFLi)**	**0-2**

Figure 9 Least life-cycle cost design options and payback times for LED lighting products in 2015 and 2020. Results are valid only for the analysed conditions (reference lumen, operating hours per year), under the assumptions made, and for the prices and costs considered. NOT valid for every lighting situation, but indicative for the average EU-28 situation. LCC = Life-cycle cost; Mlmh = million lumen-hours of light output; kWh is kiloWatt-hour of electricity consumption

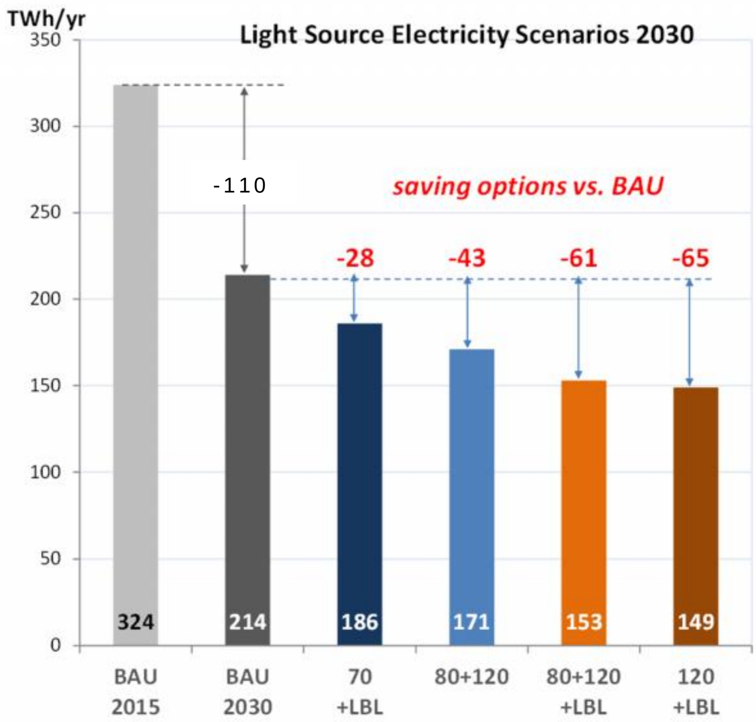


Figure 10 Annual electric energy savings (TWh/a) in the BAU-scenario between 2015 and 2030, and possible additional savings in 2030 depending on new Ecodesign and Energy Labelling measures.
(ECO)70, -80 and -120 indicate the target minimum efficacy requirement (Eff) in the maximum power requirement formula P_{on} < (2+flux/Eff)*((CRI+240)/320). ECO120 is an approximate reference for highest savings that could be theoretically obtained but technical feasibility of this scenario is uncertain. '+LBL' indicates introduction of label improvements (visibility, size) in addition to the ecodesign measure.

impact	unit	absolute		relative vs. BAU 2030			
		BAU 2015	BAU 2030	ECO70+ LBL	ECO80+ 120	ECO80+ 120+LBL	ECO120 +LBL
Electricity	TWh/yr	324	214	-28	-43	-61	-65
GHG emissions	Mt CO_2 eq.	128	73	-10	-14	-21	-22
Acquisition costs	bn. euros	18.2	14.4	+0.8	-0.3	+1.1	+1.1
Energy costs	bn. euros	53.2	61.5	-7.4	-9.9	-14.9	-15.9
Total expenditure	bn. euros	71.4	75.9	-6.6	-10.2	-13.8	-14.7
Business revenu	bn. euros	10	8.6	+0.9	+0.2	+1.3	+1.3
Jobs (in+out EU)	000 jobs	199	172	+18	+4	+26	+26

Figure 11 Survey of savings in the BAU-scenario between 2015 and 2030, and possible additional savings in 2030 depending on new Ecodesign and Energy Labelling measures. (see Figure 10 for explanation of ECO-options)

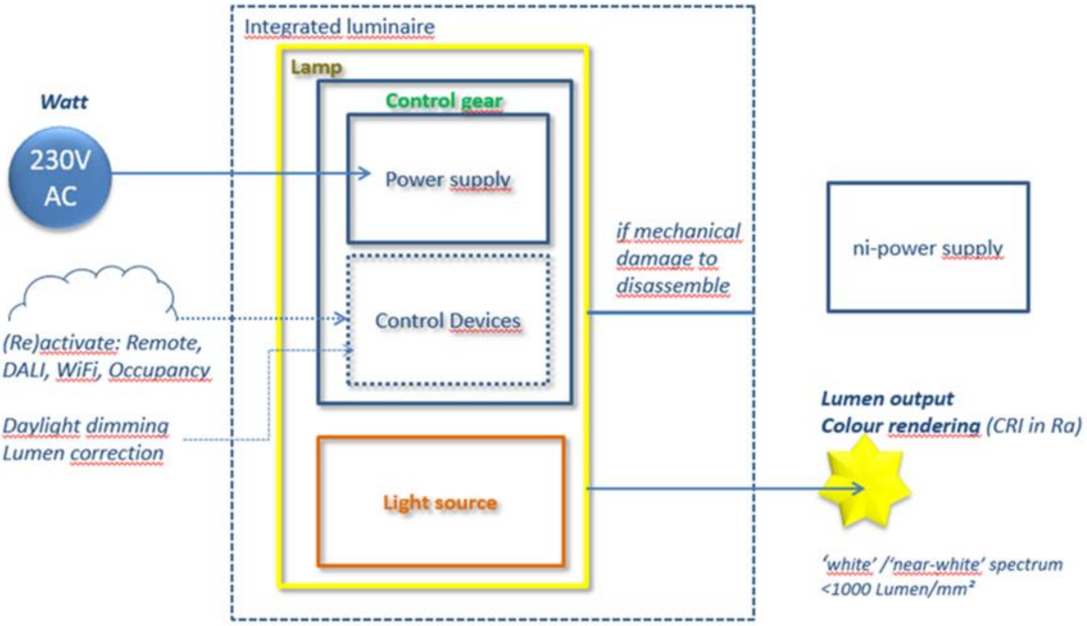


Figure 12 The subject of ecodesign measures is the mains-operated 'lighting product', intended as the combination of light source, ballast/control gear, and other integrated devices for control and communication where applicable. The scope is limited to products emitting 'white' or 'near white' light (Figure 13), with a flux between 60 and 100 000 lm, an emitter density below 1000 lm/mm^2, and a positive CRI. Products covered by other legislation, or related to safety and health, are excluded from the scope, see Figure 1.

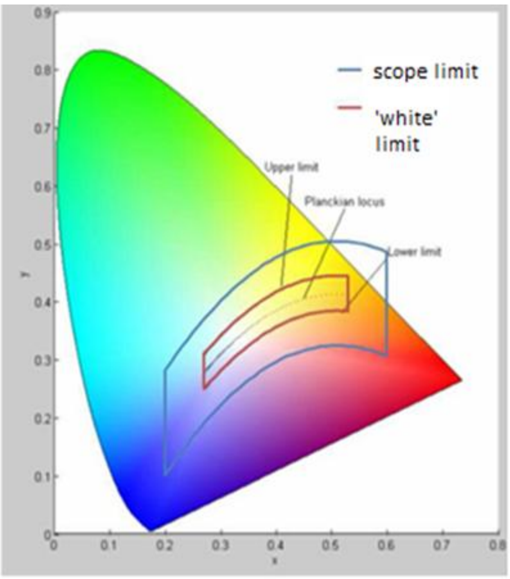


Figure 13 To be in the scope of the new proposed regulation, emitted light must satisfy:
$0{,}200 < x < 0{,}600$ and $-2{,}3172\,x^2 + 2{,}3653\,x - 0{,}2800 < y < -2{,}3172\,x^2 + 2{,}3653\,x - 0{,}1000$.

To be suitable for general purpose indoor lighting, emitted light must satisfy:
$0{,}270 < x < 0{,}530$ and $-2{,}3172\,x^2 + 2{,}3653\,x - 0{,}2199 < y < -2{,}3172\,x^2 + 2{,}3653\,x - 0{,}1595$.

This provides an easy to measure criterion for Market Surveillance and gives manufacturers the possibility to exclude IR (red, gold), UV (blue), grow lights (purple), collagen (pink), etc.

<u>Maximum power requirement formula</u>:

Power (on) ≤ (Constant + Flux/Target Efficacy)* CRI correction

- <u>Flux</u> is total luminous flux (not in cone) in Lumen Output
- <u>Target Efficacy</u> in Lumen Output / Mains Watt Input
  (for Lighting Product, including control gear)
- <u>Constant</u> = 2 W (proposed)
- Account for parasitic power of control- and network devices
- Account for fixed electrode losses in discharge lamps
- Allow lower efficacy for lower lumen lamps
- Makes result similar to square-root formula for EEI
- <u>CRI-correction</u> = (CRI+240)/320 (proposed)
- Bonus for high CRI lamps; penalty for low CRI lamps
- CRI=80→ 1.0; CRI=90→ 1.03; CRI=60→ 0.94; CRI=25→0.83

Figure 14 Explanation of the maximum power requirement formula that is used as the basis for the ECO-scenarios. Target efficacies of 70, 80 and 120 lm/W and combinations thereof have been analysed.

Figure 15 Increasing the effectiveness of the energy label for lighting products by requiring (at least) a coloured arrow with the label class to be directly visible to the consumer.

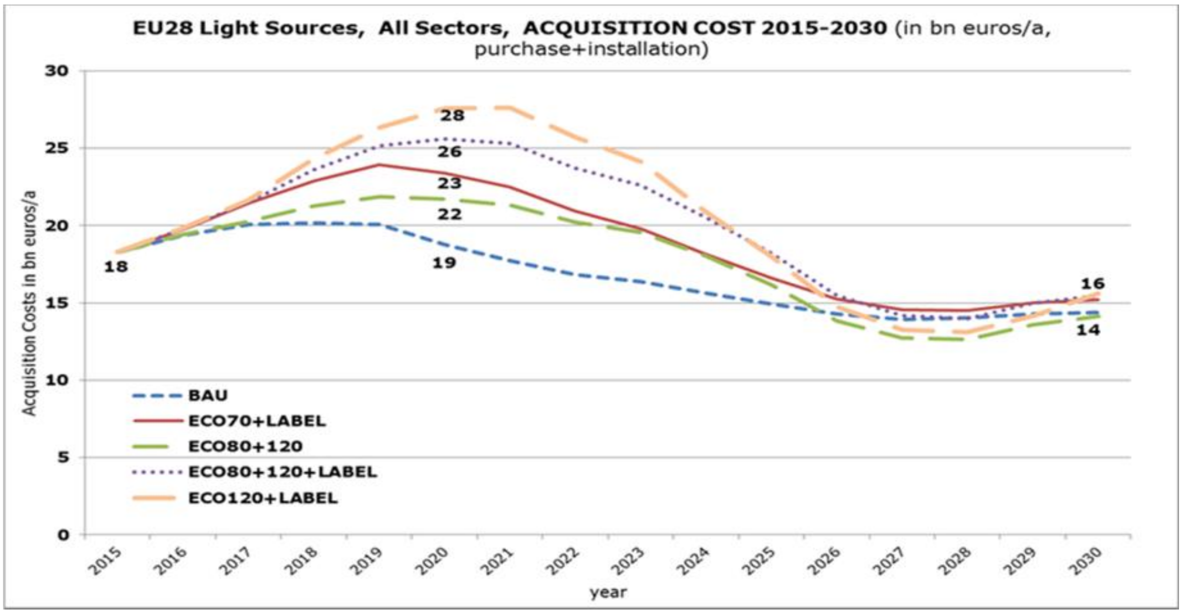


Figure 16 To obtain the savings of Figure 10 and Figure 11, an investment in LED lighting products is required. This leads to a peak in acquisition costs around 2020, that is higher when the measure is more ambitious.

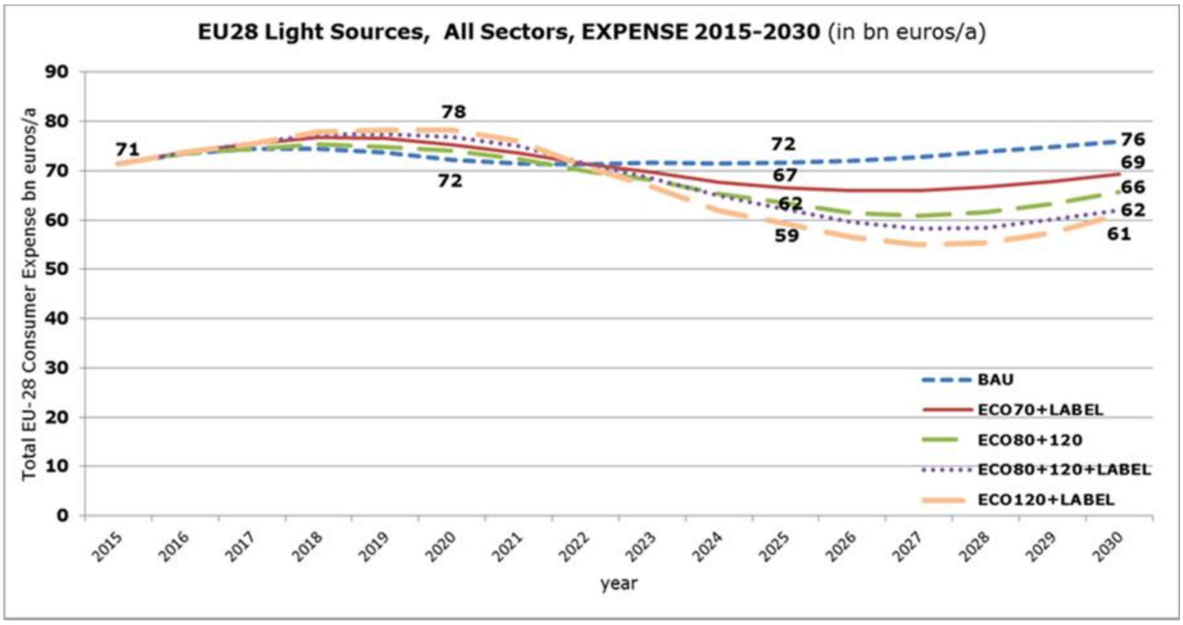


Figure 17 The total consumer expense for the ECO-scenarios is higher than the BAU scenario up to 2022 due to higher investments in LED lighting. After that year the lower energy costs related to LEDs become dominant and the consumer receives the benefits of its investment.