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Real-time, evidence-based policy making – critical for decisions on rapidly evolving technologies

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Abstract

Phasing out incandescent lighting has been widely acknowledged as one of the most cost-effective, surest ways to achieve rapid energy savings in mature and emerging markets. In 2009, Europe adopted an ecodesign policy measure on non-directional lighting to phase out incandescent lamps over a six year period. This policy measure established a gradual market transition toward higher efficiency lamps, with the final stage of this regulation originally scheduled to take effect in September 2016. That final stage was designed to remove mains-voltage halogen lamps from the European market, promoting more efficient technologies. But the adopted measure has concerned some industry stakeholders who are calling for a delay or abolishment of the final stage. Some governments, citing consumer concerns, have called for a delay as well. European Commission's DG Energy commissioned a review study on the feasibility of Stage 6 that was published in June 2013. The review study included a projection of LED replacement lamp price and performance based on the best information available at that time. But in the year following its publication, innovation in LED products far exceeded expectations, and performance levels that the review study anticipated in 2018 to 2020 can already be found in 2014. Recalling how television innovation far outpaced expectations and resulted in Ecodesign measures that failed to move the market, it became clear that in order for policy makers to make an informed decision for lighting products, some new evidence was needed. Thus, a new testing study was conducted, purchasing 170 clear LED replacement lamps from vendors across Europe and testing them in the lighting laboratory of the Swedish Energy Agency. The performance of these current products on the market will help inform policy makers, enabling them to decide whether to keep, delay or abolish the final stage of the lighting regulation. This case study for lighting demonstrates how evidence-based data is needed for products experiencing a rapid technological improvement curve, as technical and market forecasts can quickly become outdated. The paper highlights the need for resources and capacity within governments to act quickly in response to developments such as these, noting that significant energy saving opportunities may be lost if policy-making is based on outdated information.

Introduction

Europe adopted an ecodesign policy measure in 2009 on non-directional household lamps that was designed to phase out incandescent technology over a six year period. This policy measure established a gradual market transition toward higher efficiency lamps through a series of six steps, with the final step ("Stage 6") of this regulation scheduled to take effect in September 2016. The regulation, EC No 244/2009, bifurcated the incandescent lighting market into frosted and clear lamps, and set different energy efficiency requirements for frosted and clear replacement lamps. The intention of the policy measure was that frosted incandescent lamps would be replaced with compact fluorescent lamps (A-class energy label) and clear incandescent lamps would be replaced by halogen lamps (C/D-class energy label) in steps 1 through 5. Then, in September 2016, the final step of 244/2009 would phase out mains-voltage halogen lamps and require B-class halogen lamps.

Stage 6 would phase-out of mains voltage halogen lamps (C/D-class) in favour of B-class halogens, compact fluorescent lamps (CFLs) and LED lamps, of which there are models on the market in 2014 in the A, A+ and A++ classes. But this adopted measure has concerned some industry stakeholders who are calling for a delay or abolishment of the final stage. Some governments, citing consumer concerns, have called for a delay as well. Thus, DG Energy commissioned a review study on the feasibility of Stage 6 that was published in June 2013. The review study investigated the technological progress of LED lighting, and included a projection of replacement lamp price and performance which was based on the best information available at that time.

However, in July 2014 the authors of this paper found that the price and performance being claimed by LED lamps in the European market were much faster than had been anticipated in the June 2013 review study. Therefore, this study was conceived to ascertain the performance of LED retrofit lamps in 2014 relative to what had been expected a year earlier. The very rapid evolution of LED technology meant that the forecast prepared and published in June 2013 was no longer a valid basis for making a policy decision and new evidence was needed. In this context, it became clear that in order for policy makers to make an informed decision, some new evidence was needed and thus this LED testing study was initiated.

In September, an email was sent to all the members of the European Commission's lighting Consultation Forum to inform them that this study was commencing. This email message conveyed the parties organising the study, the reason it was being done, the methodology that would be followed and the fact that the test results would be made public. A copy of that email appears in Annex A of the November 2014 test report. [1]

On 5 November, the European Commission completed its Interservice Consultation process and published its draft proposal for a revision to EC No 244/2009, which was issued to the World Trade Organisation for review. These amendments concern Regulation (EC) No 244/2009 with regard to ecodesign requirements for non-directional household lamps and Regulation (EU) No 1194/2012 with regard to ecodesign requirements for directional lamps, light emitting diode lamps and related equipment. Among other revisions, the proposal contains a modification to 244/2009 that would delay the effective date of Stage 6 by two years, to September 2018.

Two weeks later, the authors of this study published the report on which this paper has been based – "Test Report – Clear, Non-Directional LED Lamps – A test report prepared for the European Commission and the Consultation Forum on the performance of clear LED lamps in the European Market in the third quarter of 2014." [1]

European market

In a recent publication, the IEA 4E Mapping & Benchmarking Annex published an update to their European domestic lighting market study. [2] This update, published in September 2014, includes lamp sales data that is tracked at the retail level by the market research agency, GfK. These data are reproduced in Figure 1 for mains-voltage incandescent lamps and their replacements – mains voltage halogen, integrally ballasted CFL and LED lamps.

The data show that CFL sales peaked in 2010 and has been in decline ever since. In fact, CFL sales in 2013 were lower than they were in 2007, prior to the adoption of regulation EC No 244/2009. Meanwhile, mains voltage halogen lamp sales have grown by 477 % over that same time period. These sales data indicate that the non-directional household lamp regulation has failed to advance sales of CFLs, and instead has simply moved the European non-directional household lighting market from incandescent to halogen lamps.[1]

The actual market in 2013 contrasts sharply with the market forecasts prepared in 2009 for "Option 2 Clear B Slow" (the scenario selected by the Commission for regulation EC No 244/2009, see Figure 2), which had expected CFL sales to be 4 times larger than mains voltage halogen lamps in 2013. [3] The fact that actual CFL sales are one quarter of halogen sales in 2013 (see Figure 1) would mean that the European market is not on track to deliver the anticipated 39 TWh of electricity savings in 2020 that was anticipated from EC No 244/2009.

When making a comparison between the two graphs, it is important to focus on the relative shares of lamp types rather than the absolute numbers. This is because the GfK shipment data is reported to represent about 70 percent of seven large EU Member States while the 2009 lamp forecast used to calculate energy savings represents the whole EU market (100 % of sales in all Member States). There is a notable contrast in the relative share of halogen to CFL between the projected lamp sales data made in 2009 (Figure 1) and the actual GfK lamp shipment data published in 2014 (Figure 2).

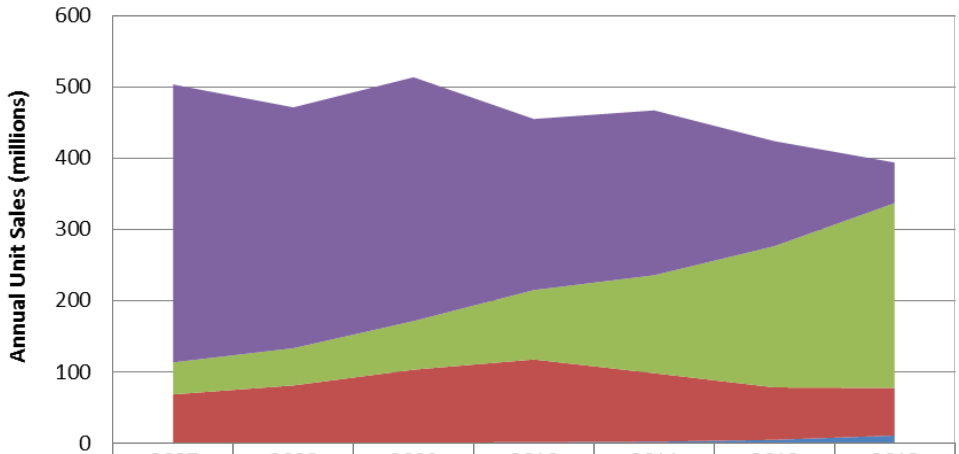
Furthermore, frosted incandescent lamp sales were estimated to be nearly three-quarters of sales in 2007 (clear incandescent was approximately one-quarter of sales). The analysis published in conjunction with the regulatory measure showed that a transition from frosted incandescent to CFLs was deemed cost effective for households and would result in significant energy savings in Europe. However, after four years in place, it appears that most of the frosted incandescent lamp sockets did not migrate to CFLs – instead, clear halogen lamp sales were 4 times larger than CFL sales in 2013. Therefore, the decision to keep clear halogen lamps on the European market seems to have slowed down the market adoption of energy-efficient lighting and undermined the energy savings objective from this regulatory measure.

It is therefore a concern that, in the light of this information about how the market responded to the policy measures (i.e. rejecting CFL lamps), any delay to Stage 6 of 244/2009 which would introduce energy-efficient lighting into Europe could further erode the anticipated energy savings and carbon emission reductions.

Collecting updated evidence

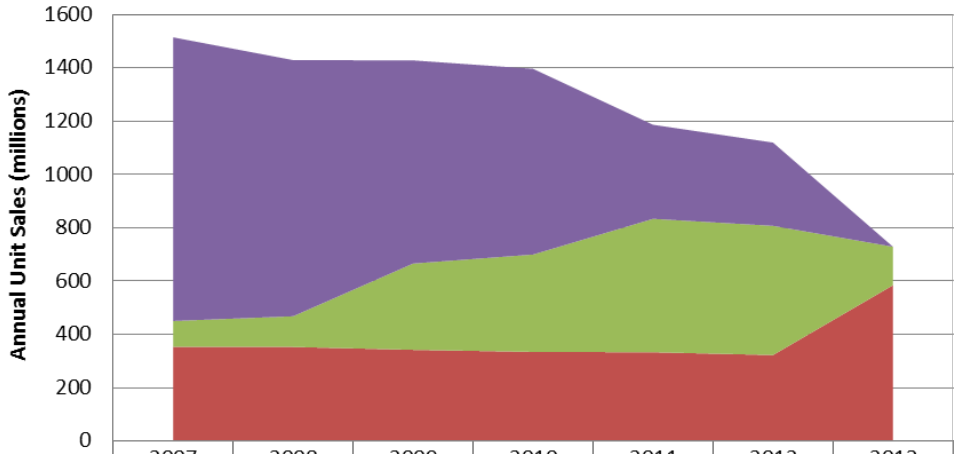
Given the importance of the decision on Stage 6, the Swedish and Belgian governments decided to work together with CLASP and eceee to conduct a study of clear LED lamps (with LED filaments or light guides) that were currently on the market in

1. Halogen lamps are approximately 20 % more efficient than incandescent lamps while CFLs are approximately 400 % more efficient. Thus, the allowance made for halogen mains voltage clear lamps has become a loop-hole that has undermined the original regulation and wiped out the anticipated savings.



	2007	2008	2009	2010	2011	2012	2013
MV Incandescents	389.9	337.9	342.1	240.1	231.3	147.4	57.0
MV Halogens (single-end)	44.9	52.2	68.2	97.3	137.4	198.0	259.4
MV Self-Ballasted CFLs	68.5	80.8	102.3	116.0	96.0	73.6	66.6
Retrofit LED Lamps	0.2	0.5	1.1	1.7	2.5	5.0	11.0

Figure 1. GfK shipment estimate of Non-Directional Mains-Voltage Lamps, 2007–2013 (Austria, Belgium, France, Germany, Great Britain, Italy and the Netherlands) [1].



	2007	2008	2009	2010	2011	2012	2013
MV Incandescents	1064.4	961	762.2	696.7	353	312.5	0
MV Halogens (single-end)	97.4	115.2	323.8	365.3	500.5	484.7	144.6
MV Self-Ballasted CFLs	353	353.1	342.3	334.6	333.2	322.7	584.6
Retrofit LED Lamps							

Figure 2. Lot 19 Impact Assessment Shipments Projection of Non-Directional Mains-Voltage Lamps for all of Europe, 2007–2013 [1].

Europe (in August/September 2014). The Swedish government offered to make its in-house testing laboratory available for the project. This laboratory was established in 2013 in cooperation with the UNEP Collaborating Global Efficient Lighting Centre in Beijing. The main activity of this laboratory is for conducting testing as part of on-going market surveillance activities in Sweden to ensure compliance with the European Commission's ecodesign lighting product regulations; however for this study, it was decided that these tests would not be market surveillance tests due to limitations on sample size and schedule. Thus, the results of this study should only be viewed as interim findings that offer indicative performance information for a few models of clear LED Lamps to European market surveillance authorities. This may help authorities better target their compliance and enforcement procurement practices.

METRICS MEASURED

The Swedish Energy Agency's laboratory conducted a range of tests on the samples of lamps procured for this study. The study looked at how the tested lamps compared to the requirements of EU No 1194/2012, although the sample size and procurement practices may not be aligned with procedures followed by the Swedish Market Surveillance Authority. The following is a list of tests conducted, although some of the tests are not yet complete – such as lumen maintenance and colour shift at 6,000 hours – as these will take about a year. However, the

Table 1. Metrics Measured by the Swedish Energy Agency on the Sample of Lamps Purchased [1].

Recorded physical information	Light and colour quality
• Test Lamp Identification Number	• Chromaticity x
• Manufacturer Name	• Chromaticity y
• Model Number	• Correlated colour temperature (CCT)
• Width, Length and Weight	• Colour rendering index* and individual scores for CRI01 through CRI16
	• Minimum measured Duv (negative values are below Planck)
Steady-state operation	• Maximum measured Duv
• Voltage (V)	• MacAdam centre x
• Current (mA)	• MacAdam centre y
• Power (Watts)	• Colour consistency – within six MacAdam steps?* (yes/no)
• Luminous flux (lumens)	• Number of MacAdam ellipses containing all points?
• Efficacy (lm/W)	• Gamut Point
• Power factor*	
• Lamp max temperature, °C	**Lifetime**
• Flicker index	• Premature failure rate to 1,000 hours*
• Percent flicker	• Switching cycles* – 30 second on + 30 second off
	• Lumen maintenance at 1,000, 2,000, 4,000 and 6,000 hours
Dimmer compatibility (only for 'dimmable' lamps)	• Colour shift at 1,000, 2,000, 4,000 and 6,000 hours
• Leading edge dimmer (ELKO 400GLI)	• Lamp survival factor at 6,000 hours* – tests are on-going
• Trailing edge dimmer (ELKO 315GLE)	• Lumen maintenance at 6,000 hours* – tests are on-going

** Test parameters marked with a (*) are regulated quantities under EU No 1194/2012.*

interim results are presented in this paper. Test metrics in Table 1 that are marked with a star (*) are the ones required by the European regulation EU No 1194/2012.

In addition to these, CLASP (who managed the procurement of the lamps) also recorded the prices paid and the sources from which the samples were obtained for the study. These data were used to help plot the current price and performance of LED lamps relative to the projected performance given in Table 2 of the VHK/VITO technical review published in June 2013. [4]

LAMP SELECTION AND PROCUREMENT

All of the lamps purchased for this study were procured through on-line retailers and websites, and prices and performance thus reflect what normal consumers would encounter in the market place. Figure 3 shows the countries from which the lamps were sourced from retailers located in Belgium, France, Germany, the Netherlands, Sweden, and the United Kingdom.

Due to some comments that were raised by stakeholders in 2013 about the lack of replacement products that could offer a 'sparkle' effect in decorative fixtures and luminaires such as those which incorporate refractive glass and crystal, this study sought to identify and source LED lamps that offered a clear glass envelope where the LED emitting part of the light could create this effect. There were two general types of clear LED lamps on the European Market at this time:

1. a clear optical light guide, such as the lamps produced by IKEA, Philips and OSRAM and
2. LED filament lamps, such as those sold by Maplin (UK), Wholesale Lighting (UK) and Vosla (DE).

Both types of LED lamps offer consumers the benefit of creating a 'sparkle' effect when installed in those luminaires that interact optically with the lamp. Table 2 provides a list of all the lamps purchased for this study, the price paid and the normalised price per 500 lumens of measured light output. This normalised price was selected to comparable with the cost of LED lamps reported in the VHK/VITO technical review. [4]

It should be stressed again that the testing conducted under this study cannot be interpreted as enforcement testing of the products, the sample sizes were not sufficient. These test results should be seen as indicative of the actual performance of those lamps tested and the main purpose was to assess how fast the technology has been evolving. However, the test results may also be used by market surveillance authorities to help better target their own respective sampling and testing programmes for lighting.

Sample of test results

This section provides the test results from one of the 17 models of LED lamps tested, and then shows two graphs from the section which compared the test results across all of the lamps tested (i.e., including the one halogen lamp model that was measured to provide a reference point). All of the test results, including more detailed reports can be found in the full report. [1]

VOSLA LIGHT BULB CLEAR, 5.5 W

This sample of lamps was purchased from Vosla's on-line retail shop based in Germany. As shown in the photos, this is an LED filament lamp which has six filaments in each lamp. Furthermore, the combination of the filaments and a gas filling with a high thermal conductivity obviates the need for the typical aluminium heat sink found in other LED lamps. The product is marketed as having good quality light, and this is reflected in the measured results of 91 CRI and an R09 (red) of 60.1. The lamps have an efficacy rating typical of the LED filament lamps at this time, but they are more expensive than some of the other lamps in this study. The packaging for these lamps includes an EU energy label with an A+ rating and a guide for CCT

scale. These lamps were purchased in August 2014 for €34.50, or €28.42 per 500 lumens including VAT, and there has been a substantial change in price – the lamps are now selling for €15.00 per lamp, or €12.36 per 500 lumens just 5 months later.

SAMPLE OF COMPARISON OF KEY TEST RESULTS

Figure 5 shows the average efficacy in lumens per Watt of the sample of lamps tested (blue diamond) with an error bar that gives the minimum and maximum values observed for each of the 18 lamp models (that is, 17 models of LED lamp and 1 model of a halogen lamp, for a total of 180 lamps tested). The efficacy distribution pattern varied significantly for LED lamps. Those lamps that employed light guides tended to have slightly lower efficacy than some that emitted light directly from an LED filament. The three lamps with the highest variance in efficacy are #1 (Wholesale Lighting), #10 (NCC Licht) and #17 (Calex) – the same three lamps with the highest variance in measured power. The halogen lamp (#3) is shown with an efficacy of 12.8 lumens/Watt, which is 5 to 10 times lower than the LED lamps tested.

Figure 6 presents the mass (in grams) of the 18 lamps tested, compared to a red line which represents the weight of a standard 60 W incandescent lamp (28 grams). The halogen lamp (#3) is a slightly smaller lamp than the standard 60 W, thus it has a slightly lower mass. Many of the LED filament lamps have quite

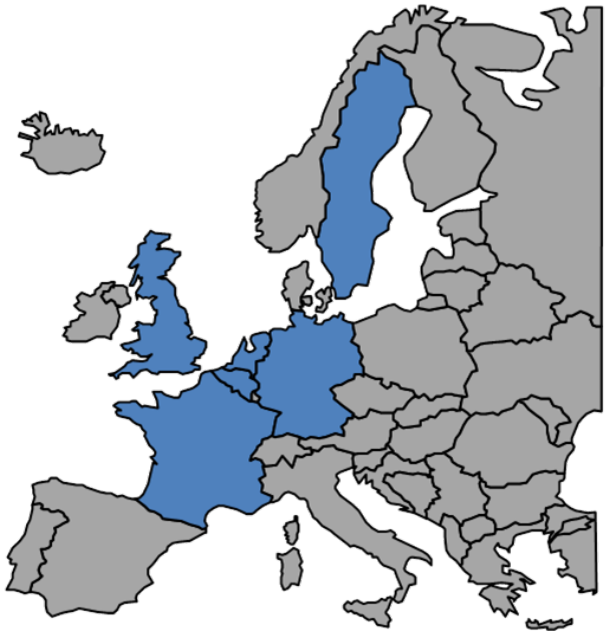


Figure 3. Map of Europe showing countries where LED lamps were procured [1].

Table 2. Lamps purchased, Prices paid in Aug/Sept 2014 and Price per 500 lumens of light* [1].

#	Make / Model	Price each	Euros	€/500 lm
1	Wholesale Lighting / MS-B22-6W-OMNI	£14.62	€18.28	€15.29
2	Maplin "LED filament" / A15QF	£18.42	€23.03	€17.48
3	Osram Halogen Classic A ECO 64543 (46W)	£2.13	€2.66	€2.29
4	Lighting Ever "LED Filament" / 100047-WW-EU	£6.99	€8.74	€12.17
5	LED Connection "Classic LED bulb"	£12.49	€15.61	€18.31
6	IKEA LEDARE / 602.553.62	£6.00	€7.50	€6.30
7	Vosla GmbH (DE), vosLED-light bulb clear, 5.5W	(Germany)	€34.49	€28.42
8	LED Connection 8W warm white filament LED	£24.00	€30.00	€19.17
9	Panasonic "Nostalgic Clear" / LDAHV10L27CGBEP	(France)	€20.80	€13.12
10	NCC-Licht / LED Filament 6W warmweiß 2700K	(Germany)	€12.98	€9.18
11	LED24.cc / E27 LED Glühfaden Birne 8w 2700K	(Germany)	€16.95	€12.79
12	LED filament lampa E27 #338-71	52,00 SEK	€5.66	€6.16
13	LED filament lampa E27 #338-09 (candelabra)	106,00 SEK	€11.53	€20.21
14	Osram PARATHOM Classic A ADV 10W 827	£9.88	€12.35	€7.16
15	Philips "Clear LED bulb" – GLS 6W A60 E27 Clear	11.94	€14.93	€14.89
16	Led lampen direct (NL) / "Polaris 4 Watt"	(NL)	€9.50	€10.25
17	Calex (NL) "LED Filament GLS" / 474732	(BE)	€16.58	€14.46
18	Segula LED Lamp / E27 5.5W	(NL)	€41.95	€32.04
		Min:	€5.66	€6.16
		Max:	€41.95	€32.04

** The light output used to calculate the price/€500 is the measured average light for the sample of ten lamps purchased.*

Figure 4. Photographs of packaging and Vosla Clear LED lamp, 5.5 Watts [1].

Table 3. Summary of Test Results for Sample of Ten Units of Vosla Light Bulb Clear, 5.5 Watts [1].

Item	Quantity Declared	Quantity Measured	Units	Difference
Power	5.5	5.5	*Watts*	0 %
Light Output	550	607	*Lumens*	+10 %
Efficacy	100	109.8	*lm/W*	+10 %
CCT	2,700	2,761	*K*	+2 %
CRI	>90	91	*Ra*	+1 %
R09 (red)	–	60.1	*(Red)*	–
Max ellipse	–	4.6	*MacAdam steps*	–
Price paid	–	€28.42	*€/500 lm*	–
Nov. Price	–	€12.36	*€/500 lm*	*-56 %*
Website	http://www.vosla-shop.com/epages/64253153.sf/en_GB/?ObjectPath=/Shops/64253153/Products/50061			

similar weights to the standard 60 W incandescent – within 10 to 20 grams. At these weights, there is no risk that the LED replacement lamps would cause problems in existing fixtures and sockets due to the higher mass. There are a few LED lamps – notably #6, 9, 14 and possibly 15 which are heavier than the others – but all lamps are less than 160 grams, and the vast majority are less than 50 grams each.

Key questions answered

As stated in the email issued to all stakeholders of the European Commission's Consultation Forum, the overall objective of this work was to provide policy makers with current information about LED lamp performance. In so doing, six key questions were outlined in that September 2014 email [1] constituting the principal outcomes of this work. More detailed answers to these questions can be found in the full report, however brief summary answers are provided in the following text.

Q1: What is the current (winter 2013/14) cost and performance of clear LED lamps? How does this compare with the 2013 Impact Analysis from the Commission?

A1: The data for LED Lamps tested in this study have exceeded the expected progression of LED technology published in the VHK/VITO Report. Figure 7 shows the projections from the VHK/VITO Report on the Review of Stage 6 published in June 2013, presenting those projections as threshold lines of price and efficacy. The measured test results from this study are then superimposed on the graph, providing the sample average efficacies (n=10) of the clear LED lamps tested. Note that the halogen lamp is off the Y-axis scale due to its low efficacy. The figure has reversed the Y axis, so efficacy improves (and price is lower on the X-axis) as the products move toward the origin.

Table 4 presents the comparison between an estimate of the VHK/VITO Report forecast and the sample average from lamps purchased in August/September 2014.

The study found that current lamps are 11 % lower on price and 29 % higher on efficacy compared to a linearly-interpolated estimate from the VHK/VITO Technical Report.

Q2: Do they give an aesthetic pleasant light?

A2: The LED lamps tested in this study were found to have CCT values that were around 2700 K to 2900 K, which is consistent with the baseline technology they seek to replace (i.e., incandescent and halogen). The CRI value for most LED lamps exceeded 80 CRI (with a few exceptions, where the CRI was measured at 79). Two of the LED lamps tested

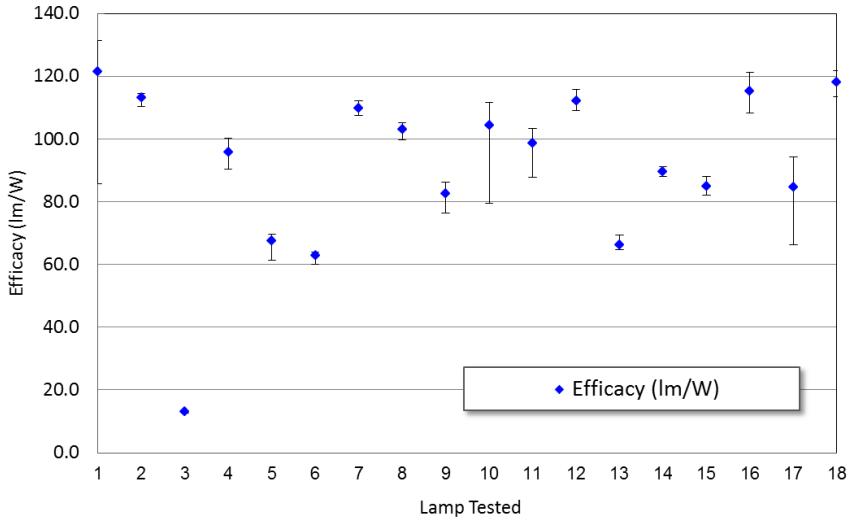


Figure 5. Distribution of Efficacy Measurements for Lamp Models Tested (lumens/Watt) [1].

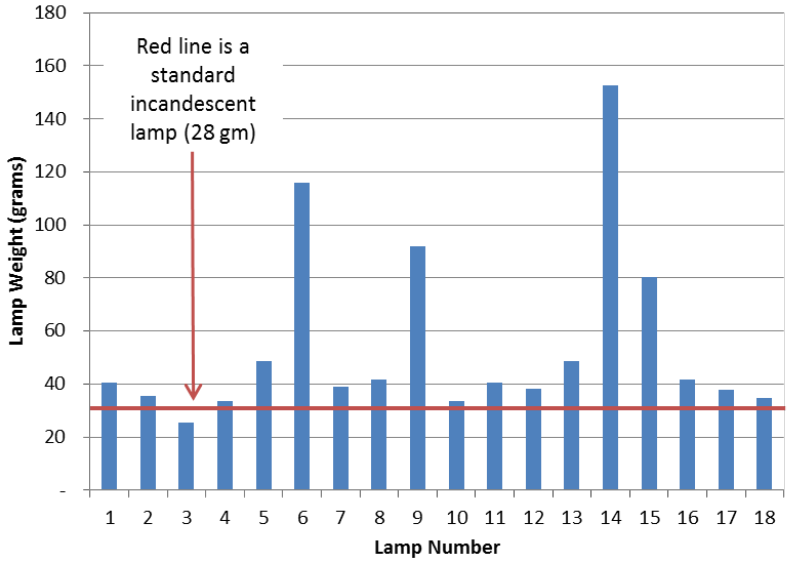


Figure 6. Weight of the lamps tested, compared to an Incandescent Lamp [1].

had CRIs values in the 90's (IKEA and vosLED). The flicker index and percent flicker of the lamps were measured and many lamps had no flicker. The lamps were also tested for their light distribution pattern, and there was a very good resemblance to the halogen reference lamp. Thus, it would appear that the LED Lamps can meet the optical requirements of luminaires currently using halogen lamps. For all of these reasons, it would appear that these clear LED lamps do offer consumers an aesthetic, pleasant light. An informal, limited review of website comments posted by customers who had purchased these LED filament lamps indicated that the early-adopters of LED filament lamps are satisfied.

Q3: Are the "dimmable" lamps compatible with leading edge and trailing edge dimmers?

A3: Of the LED lamps purchased for this test study, five of them were identified as 'dimmable' in the manufacturer literature. For those lamps that were labelled as 'dimmable', the LED lamps were tested on both a leading edge dimmer (ELKO 400GLI) and a trailing edge dimmer (ELKO 315GLE). Although these two dimmers do not represent all dimmers in Europe, they do represent two of the most common types found in the market. Table 5 presents the results of the testing of these five "dimmable" LED Lamps on the two dimmers.

The testing found that two of those lamps were able to be dimmed on both dimmers (#6 IKEA, #13 Star Trading). The other three lamps had issues with one of the dimmers. Lamp #5 from LED Connection was not compatible with the leading edge dimmer and Lamps #14 from OSRAM and #15 from Philips were not compatible with the trailing edge dimmer. Overall, the results indicate that the industry is working on better LED drivers to make them compatible with the main types in Europe, and there are still be some manufacturing/quality control issues to work out in production.

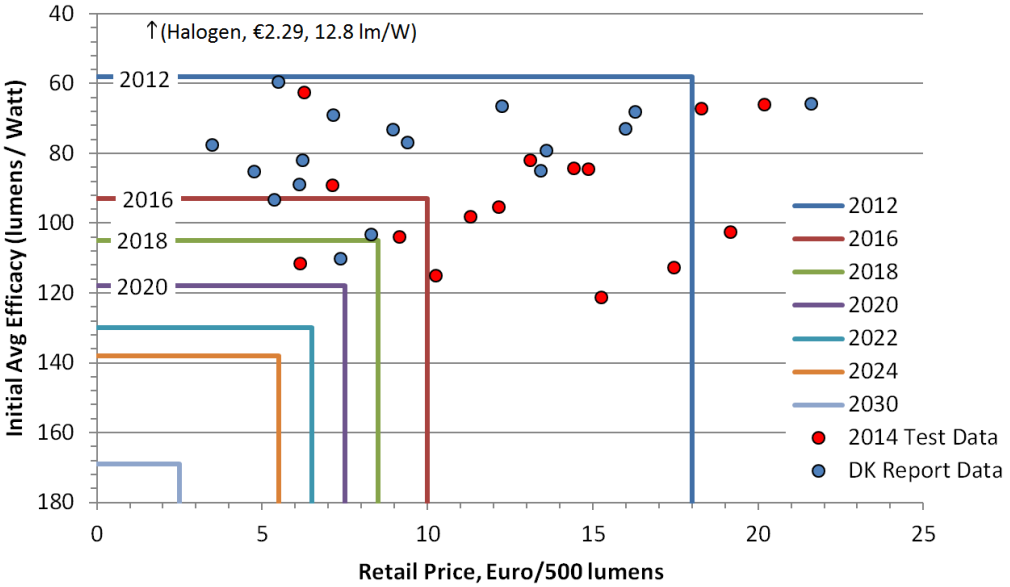


Figure 7. MV LED Non-Directional Retrofit LED Lamps; Projections from 2013 on price/performance and tested lamps from this study [1] and a Danish publication covering 2012-2014 lamp price/performance [9].

Table 4. Current Price and Efficacy of Mains-Voltage Retrofit LED Replacement Lamps [1].

Source of estimate	Price (Euro) per 500 lumens of light in 2014	Efficacy (lumens per watt) in 2014
VHK/VITO Report (June 2013)*	€14.00/500 lumen	76 lm/W
Test data average, this study	€12.52/500 lumen	98 lm/W
Difference, test data average in 2014 compared with VHK/VITO projected	11 percent lower	29 percent higher

** Note: the VHK/VITO June 2013 Stage 6 Review Report did not provide actual values for 2014, therefore the figures shown in this table are derived from linear interpolation between the 2012 and 2016 values.*

Q4: Do these lamps meet the LED quality requirements in EU No 1194/2012?

A4: In order to ensure that the manufacturers of these new high-performance, low-cost LED lamps are not sacrificing light quality aspects that are important to European consumers, the Swedish Energy Agency's test laboratory also conducted tests to investigate whether the lamps complied with the quality requirements for LED lamps under EU No 1194/2012. [5] The sample size (n=10) was not sufficiently large for market surveillance testing, therefore the findings should only be taken as indicative as to whether these lamps would meet the requirements. Furthermore, all of the tests are not complete (some require 6,000 hours of data), but most of those that are done the answer is 'yes', the new LED lamps do meet the quality requirements of EU No 1194/2012 – see Table 6[2].

Overall, the LED lamps were found to be compliant with the ecodesign requirements under 1194/2012, except for a few models which exceeded the six MacAdam[3] step limit and one model that experienced premature failure. At 1,000 hours, the LED lamps continued to perform very well with no changes over the 100 hours testing except for the Panasonic lamp (#9) which now measured within the colour consistency requirements (6.43 steps). As discussed in the previous report (and highlighted in comments from LightingEurope in December 2014), there were some issues associated with lamp packaging, however this project is focused on testing the quality of the lamps, not the packaging. Some importers did omit energy labels and one had developed their own energy label with an A+++ class (which does not exist in EU 874/2012). This labelling violation was reported to the UK NMO.

Q5: Are LED filament lamps reliable products for consumers?

A5: To assess reliability, the lamps were subjected to a switching-cycle test and an operational test which is ongoing, but so far has completed 200 hours of testing. In the future, the team collaborating on this study intends to publish additional test information on reliability at 3,000 hours

2. Colour consistency, 100 hours testing: In the November 2014 report [1], it was reported that three lamps failed the MacAdam steps, however the test results were reviewed again and if it was found that there was one deviating data point from the main grouped data and no other data points between the deviating point and the grouped data, the deviating point was removed from the MacAdam calculation since there was no other statistical confirmation from related data.

3. The six step Macadam requirement comes from ecodesign regulation EU No 1194/2012: when a light source is measured from multiple directions, all measurements x, y coordinates should be grouped within a 6 step Macadam ellipse.

Table 5. Dimmer Compatibility Check for Five "dimmable" LED Lamps.

Lamp	Description	Leading Edge (ELKO 400GLI)	Trailing Edge (ELKO 315GLE)
#5	LED Connection "Classic LED bulb"	No	Yes
#6	IKEA "LEDARE" / 602.553.62	Yes	Yes
#13	Star Trading LED filament lampa candelabra shape	Yes	Yes
#14	Osram PARATHOM Classic A ADV 10W 827	Yes	No
#15	Philips "Clear LED bulb" – GLS 6W A60 827 Clear	Yes	No

Table 6. Indicative Findings of Quality Requirements for LED Lamps [6].

1194/2012 Requirement	100 hours testing	1,000 hours testing
Lamp survival factor at 6,000 h	200 h and 1,000 h aging and measurements complete. Technical 1,000 h report writing in progress. Lamps are in 2,000 h aging.	
Lumen maintenance at 6,000 h	Same as above.	
Switching cycles before failure	No failures in LED, but one failure in a halogen lamp.	
Starting time	Yes, all LED lamps passed.	
Lamp warm-up time to 95 %	Yes, all LED lamps passed.	
Premature failure at 1,000 h	n/a	One LED lamp (#11) failed; 2 lamps failed before 1,000 h.
Colour rendering index	After 100 hours, all LED lamps met the minimum requirement; two models were within the allowable tolerance.	After 1,000 hours, all LED lamps met the minimum requirement; two models were within the allowable tolerance.
Colour consistency	Most LED lamps met the six MacAdam step requirement, except #9 (Panasonic) and #17 (Calex) which exceeded the maximum 6 steps ±10 %.	After 1,000 hours, only one LED lamp (#17) exceeded the maximum 6 steps ±10 %.
Lamp Power Factor	All lamps met requirement.	

and 6,000 hours. All the LED lamps finished the switching cycle test successfully (one halogen lamp in the sample of ten failed the switching cycle test). While 3 of the 170 LED lamps tested were defective and did not operate out of the box (and thus could have been returned for a refund / replacement). Two individual LED lamps (both sample #11) failed during the burn-in. Lamp #12 had one unit fail during measurements, but all the other LED lamps so far have not have problems.[4] The longer-hour lifetime testing is continuing in parallel with the publication of this paper. The data gathered so far, show a mixed picture with LED filament lamps complying with switching-cycle tests, but one model showing premature failure above the Ecodesign threshold. This doesn't mean LED filament lamps are worse than other lamps; the halogen lamp also had difficulties in the switching-cycle test. For the consumer, the early failures should not pose a big problem, where they are covered by commercial or legal minimum product warranties.

Q6: What trends in price and performance of LED filament lamps have been observed in the last two years and what is expected in the future?

A6: Although LED filament technology was originally developed in 2008, it hasn't been a popular LED lamp type until more recently, in 2014. [1] The performance of LED filament lamps is linked to the performance of LEDs themselves, which it is shown in Chapter 2 are simply mounted in a chain under the phosphor coating of the filament. These emerging lamp designs have simplified the electronic drivers and the optics, resulting in an energy-efficient lamp which exceeds the price and performance that was envisaged in the VHK/VITO report. More specifically, the retail LED lamp price of these LED filament lamps is approximately 11 % lower than the forecast and efficacy is 29 % better. Given that the price and performance projection in the consultant's June 2013 report was one of the reasons the Commission decided to delay Stage 6 of EC No 244/2009 by 2 years [7], this study has shown that LED technology has already surpassed the product price and performance improvements by 3 to 5 years. In other words, to the extent that price and performance were key factors in the Commission's rationale for the delay, these factors would now no longer seem to be justified because the technological progress of LED lamps has exceeded expectations, surpassing the technology progression forecast. Indeed, as was shown by both this study and the recent study by Denmark, [8] there are LED lamps available now that can replace many halogen applications.

4. The verification procedure in Annex IV of EU/1194/2012 has a tolerance of maximum 1 failure out of every 20 lamps.

Conclusions

Some technologies covered under the ecodesign directive are experiencing a very rapid rate of technological evolution which can contribute to improvement in product performance as well as a reduction in cost. Recalling how innovation for televisions far outpaced expectations and resulted in Ecodesign measures that failed to move the market, it became clear that in order for policy makers to make an informed decision on Stage 6 of EC No 244/2009 for lighting products, some new evidence on price and performance of LED lamps was needed. LED technology is a rapidly evolving product, as has been confirmed by the test results presented in this paper. Findings have indicated an acceleration of 3–5 years over projections published only one year earlier based on the best available information.

Policy makers need current, accurate information in order to make decisions about mandatory standards and labelling for products. In Europe, policy makers are making a decision about whether to keep an ecodesign policy measure in place that will push the European market toward LED lamps in September 2016, or to delay that measure. At the time of this writing, the Commission has scheduled the decision to be taken on 17 April 2015, and thus it is imperative that current price and performance information is made available to these policy makers, to provide as much evidence as possible around the decision they will take. The authors will report back on the decision taken at the Summer Study in June.

This study represents an excellent case study for the importance of real-time information in policy making decisions. The LED lamps that are covered under the ecodesign directive are rapidly improving in performance and decreasing in price. In fact, a new study published in March 2015 [9] found that new products entering the European market in February 2015 have gone even further in terms of price reductions and performance improvements. This study found a five to eleven year acceleration in affordability of LED lamps, documenting actual prices of brand-name lamps around Europe [9].

Overall, the authors of this study believe that the data show LED products will be ready and available for mass consumption in September 2016. Consumers switching from halogen lamps will benefit from lighting electricity consumption reductions in excess of 80 %, while still enjoying the same light colour and quality, instant on, and other features they have come to expect.

References

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[2] IEA Mapping and Benchmarking report – Domestic Lighting Update, September 2014. See: http://mappingandbenchmarking.iea-4e.org/shared_files/609/download.

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[4] "NDLS STAGE 6 REVIEW – FINAL REPORT – Review study on the stage 6 requirements of Commission Regulation (EC) No 244/2009", by VHK (pl)/ VITO for the European Commission. Delft/Brussels, 14 June 2013.

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