# Product Definition: Domestic Lighting Revision
## *September 2014*

The Mapping and Benchmarking of *'Phase-Out' Regulations on Lighting Markets*[1] was originally undertaken in 2011. This Benchmarking and associated national Mappings are currently being updated. This document (the product definition) on which the updated Mappings and Benchmarking are based remains broadly in line with the original product definition from 2011, but does contain significant modifications. In particular, this document now includes information on assumed product efficacies and lifetimes, and a summary of Terminology used (included as Appendix 1).

## 1 Introduction

Lighting is somewhat unusual among the products being addressed by the Mapping and Benchmarking Annex due to the large variety of individual product types and subgroups of colour, shape, light output, etc. Further, in many parts of the world the lighting market is going through a significant transitory phase, in part due to the introduction of new regulations "to phase-out inefficient lighting", and in part by the market entrance of new products (in particular LEDs). As a consequence, Annex participants have agreed that rather than examine the comparative efficiencies of *individual* products, the updated Benchmarking should again seek to:

- Compare the approach and stringency of the various 'phase-out' regulations[2] being introduced by each Annex participant and others;
- Compare changes in the *type* of products entering each market which should indicate any major outcomes of the various policy implementations to date;
- Identify changes in the overall *average efficiencies* (efficiencies) of the new products entering the market which should indicate longer term efficiency improvements of the installed stock;
- Establish if the outcomes and recommendations for the 2011 Benchmarking are still valid or whether evolving market conditions are resulting in unanticipated outcomes which may be of concern for policy makers, including areas where additional or modified policy intervention may be required in the future.

Such an approach is *broadly* in line with the approached used elsewhere in the Annex for the definition of individual products, ie based on "functionality" (in this case "illumination"), but taken one step further to include technologically very different products.

[1] Refer to http://mappingandbenchmarking.iea-4e.org/matrix?type=product&id=5
[2] Primarily regulations related to non-reflector lamps.

# 2 Product Scope

Products included within the lighting Mapping and Benchmarking activity are broadly defined by the following:

> *"Lighting products that perform the vast majority of illumination applications within the domestic (household) sector"*

Within this context, the specific lighting products that are to include within the scope of the Mapping and Benchmarking activity are grouped broadly as follows:

- Mains Voltage Incandescent Lamps
- Mains Voltage Halogen Lamps (separately single ended and double ended)
- Low Voltage (12V) Halogen Lamps
- Mains Voltage CFLs (separately Pin Based and Self-ballasted)
- Mains Voltage Linear Fluorescent Lamps (separately T5, T8 and T12)[3]
- LED Lamps (separately Retrofit and Dedicated)

In all cases the "product" is the lamp element only with the exception of self-ballasted CFLs and LEDs where the ballast/driver is almost universally sold as a single package with the lamp unit.

# 3 Metrics

In line with almost all testing methodologies and regulations worldwide, the energy used by the product is defined by:

| | |
|---|---|
| *Unit Power/Rating:* | *W (instantaneous power consumption of "new" products[4] under test conditions)* |

Note, the reporting power varies by jurisdiction. In some case rated power is reported, in others "verified" tested values are declared. However, within the context of the analysis, these differences have marginal impact on the outcomes and so rated and tested values are considered equivalent.

The efficacy (efficiency[5]) of the lamps will be defined as:

| | |
|---|---|
| *Unit Efficacy:* | *Lumen/Watt (where lumen output is measured for "new" products under local test conditions[6])* |

Total instantaneous lighting output provides a measure of the increase in the "lumens purchased" and hence an indication of the number of lamps replacing current failed lamps (which would result in a broadly unchanged total luminous output) and those leading to an increase in the total number of lamps installed. Total luminous output will be defined by:

| | |
|---|---|
| *Instantaneous Light Output:* | *The rated light output of a lamp or group of lamps (in lumens or lm), ie the Sum of [lamp efficacy] for all lamps under analysis* |

[3] It should be noted that, in 2011, data was collected on linear fluorescent tubes and reported in the Mapping documents, but was not subsequently used in preparation of the Benchmarking report. These lamps were excluded from the Benchmarking as, in those countries where data was reported, the penetration of linear fluorescent lamps in the domestic sector was low. It is anticipated that this will again be the case, but to maintain consistency with the 2011 reporting, where possible linear fluorescent data will again be presented in the Mapping documents.

[4] New product is defined as the point when a particular product would be tested for "initial values" under the local test condition, typically at 24-100 hours of aging.

[5] For lighting, the "efficiency" of the product is normally referred to as the efficacy as it is technically not the ratio of energy input to output.

[6] The definition of "Wattage" used in regulations between jurisdictions. In general, the wattage normally refers to the rated/unit power of the product. But in some jurisdictions, the efficacy of the product is measured based on actual power consumption under test.

Total lifetime lighting output provides a measure of the "total lifetime lumens purchased" and hence an indication of the number of lamps requiring replacement in the future, ie the higher the total lifetime lighting output of lamps purchase, the longer the period before replacement is required. Total lifetime lighting output will be defined by:

| | |
|---|---|
| *Total Lifetime Light Output:* | *The lifetime light output of a lamp or group of lamps (in lumens or lm), ie the Sum of [lamp efficacy x lamp lifetime[7]] for all lamps under analysis* |

# 4 Wattage buckets, standard efficacy tables, standard lifetimes and normalisation of lamps on differing voltages

To undertake the required analysis, it is necessary to know sales of the various lamp types within each market, the wattages and efficacies of these lamps, and the lamp lifetimes Within the limited resources of the 4E mapping and benchmarking, gaining accurate reporting of data on each of these variables for all lamps would be impossible, even if such data were available. However, rather than a comparison of the performance of individual lamp types, the goal is to seek comparisons across the *entire* market, i.e. to compare the overall changes in lamp selection by type and size and the resulting impact on *market efficiency*. Therefore, 'standard' efficacies and lifetimes for various types and wattages of lamps have been established. This is appropriate because the degree of variation in average efficacies and lifetimes between lamps of a specific voltage and wattage range within each individual country (and indeed between countries) is very small compared with the difference in efficacies and lifetimes between lamp types. Hence, a number of standard wattage 'buckets' have been created for each lamp type and, for a specific year, an average efficacy has been used for lamps of the same voltage within the same wattage bucket. Similarly, an average lifetime has been used for each lamp type across all markets. These assumptions were agreed by a pool of lighting experts from three continents in the 2011 Benchmarking analysis, and have been verified for the 2014 Benchmarking.

## 4.1 Wattage buckets and assumed average wattage per bucket

Globally, the majority of lamps are rated by wattage.[8] For specific lamp types, the majority of lamps sold are from a number of discrete wattages, e.g. in Europe, traditional GLS incandescent lamps have normally been sold at 25 W, 40 W, 60 W, 75 W and 100 W. These discrete wattages vary between lamp types and between countries.

[7] Note that the lifetime used will be the rated lifetime of the lamp. Traditionally, most jurisdictions lamp lifetime as median life of a batch of lamps. However, increasingly this definition is being modified by predictive lifetime assessment of LEDs, and the adoption of none-modal lifetime by the EU and (for CFLs) as part of the new IEC 60969 standard. However, in each jurisdiction, the definition remains broadly stable and so, although the lifetime light output measure will not provide a definitive guide to the number of lamp replacement required at any point in the future, it will provide an indication of the direction and degree of change in annual number of lamps purchased.

[8] Recently there has been a move in many markets to require the labelling (and in some cases mandatory rating) of lamps by their lumen output. However, in the majority of markets, this change has been very recent and typically lamps will still display rated wattage as part of mandatory safety requirements. As the 2014 Mapping and Benchmarking exercise seeks time series data, which in some cases date back to 1996, the data collection and subsequent data analysis is based on rated lamp wattage.

Further, these discrete wattages account for the majority of, but not all, sales; some lamps are sold at intermediate wattages. However, it is possible to capture sales of all lamps by using these discrete wattages to create 'wattage buckets'. Typically these buckets have the discrete wattages for a particular lamp type as their upper limit, with the lower limit set immediately above the preceding discrete wattage (using our European example above, the wattage range for incandescent lamps may be set at $x \geq 25$ W; 25 W$>x \geq 40$ W; 40 W$>x \geq 60$ W; etc). This has been the approach adopted by, with the discrete wattages defined as follows.

| Lamp Type | Wattage Ranges | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Main Voltage Incadescents | 0-25 | 26-40 | 41-60 | 61-75 | 76-100 | >100 | | | | |
| Mains Voltage Halogens (single ended) | 0-17 | 18-20 | 21-28 | 29-43 | 44-53 | 54-73 | >73 | | | |
| Mains Voltage Halogens (double ended) | 0-100 | 101-150 | 151-200 | 201-250 | >250 | | | | | |
| Low Voltage (12V) Halogens | 0-34 | 35-38 | 39-50 | 51-100 | >100 | | | | | |
| Mains Voltage Pin Based CFLs | 0-3 | 4-5 | 6-7 | 8 | 9-11 | 12-13 | 14-15 | 16-20 | 21-25 | >25 |
| Mains Voltage Self-Ballasted CFLs | 0-3 | 4-5 | 6-7 | 8 | 9-11 | 12-13 | 14-15 | 16-20 | 21-25 | >25 |
| Mains Voltage Linear Flourescent Tubes (T5) | 0-28 | 29-50 | >50 | | | | | | | |
| Mains Voltage Linear Flourescent Tubes (T8) | 0-24 | 25-27 | 28-31 | >31 | | | | | | |
| Mains Voltage Linear Flourescent Tubes (T12) | 0-33 | 34-40 | >40 | | | | | | | |
| Retrofit LED Lamps | 0-1 | 1-2 | 2-4 | 4-8 | 8-11 | 12-14 | 15-20 | >20 | | |
| Dedicated LED Lamps | 0-1 | 1-2 | 2-4 | 4-8 | 8-11 | 12-14 | 15-20 | >20 | | |

For analysis, the *average* wattages of all lamps sold within a bucket is assumed to be the top of the range (the discrete wattage), less 5% of the range.[9] This 5% reduction recognises that the majority of lamp sales will be at the discrete wattage, whilst taking into account the significantly lower wattage lamp sales of wattages across the remainder of the bucket range.

## 4.2 Lamp efficacies

### 4.2.1 Efficacies of 220-250 V lamps

To analyse the information received on lamps, it is necessary to know the efficacy of lamps (lumens/watt)[6]. For a specific wattage, these efficacies will vary between lamps within the same market, and potentially more so between markets. Further, given wattage buckets are being used, the efficacies of lamps at the lower end of the wattage range of the bucket will typically be lower than the efficacy of lamps at the higher wattage range of the bucket.[10] However, the efficacy variation between individual lamps and of lamps of the same voltage within a bucket is far outweighed by the differences between lamp types. Hence it is reasonable to use an average efficacy for each wattage bucket.

In the 2011 Benchmarking report, average efficacies of new lamps (in 2010) in each wattage bucket (at 220-250 V) were created based on a combination of actual test data of lamps purchased in Australia, China and Europe, and where test data was not available, by a review of manufacturer declared efficacies for a range of lamps in those buckets. These average 2010 lamp efficacies for 220-250V are shown in the table below.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Main voltage incandescent (W) | 0-25 | 26-40 | 41-60 | 61-75 | 76-100 | >100 | |
| *2010 (efficacy)* | *8.7* | *10.2* | *11.8* | *12.5* | *13.5* | *14.8* | |
| Mains voltage halogens (single ended) (W) | 0-17 | 18-20 | 21-28 | 29-43 | 44-53 | 54-73 | >73 |
| *2010 (efficacy)* | *11.5* | *11.9* | *12.0* | *13.5* | *15.0* | *17.3* | *18.5* |
| Mains voltage halogens (double ended) (W) | 0-100 | 101-150 | 151-200 | 201-250 | >250 | | |
| *2010 (efficacy)* | *16.0* | *17.5* | *17.8* | *19.0* | *20.0* | | |
| Low voltage (12 V) halogens (W) | 0-34 | 35-38 | 39-50 | 51-100 | >100 | | |
| *2010 (efficacy)* | *17.0* | *18.2* | *18.8* | *21.7* | *23.0* | | |

[9] For example, for a wattage rage 40 W> $x \geq 60$ W, the assumed *average* wattage of all lamp sales in that bucket will be 60 W – ((60-40) * 5%) = 59 W.

[10] Lamp of lower wattages are typically of lower efficacy than lamps of the same type with higher wattages.

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Mains voltage pin based CFLs (W) | 0-3 | 4-5 | 6-7 | 8.0 | 9-11 | 12-13 | 14-15 | 16-20 | 21-25 |
| *2010 (efficacy)* | *50.0* | *51.5* | *59.0* | *62.0* | *65.2* | *69.0* | *72.0* | *66.9* | *74.2* |
| Mains voltage self-ballasted CFLs (W) | 0-3 | 4-5 | 6-7 | 8.0 | 9-11 | 12-13 | 14-15 | 16-20 | 21-25 |
| *2010 (efficacy)* | *40.0* | *50.0* | *51.1* | *52.2* | *56.4* | *56.0* | *57.5* | *62.5* | *61.4* |
| Mains voltage linear fluorescent tubes (T5) (W) | 0-28 | 29-50 | >50 | | | | | | |
| *2010 (efficacy)* | *87.8* | *94.0* | *94.0* | | | | | | |
| Mains voltage linear fluorescent tubes (T8) (W) | 0-24 | 25-27 | 28-31 | >31 | | | | | |
| *2010 (efficacy)* | *67.2* | *73.0* | *79.1* | *84.4* | | | | | |
| Mains voltage linear fluorescent tubes (T12) (W) | 0-33 | 34-40 | >40 | | | | | | |
| *2010 (efficacy)* | *73.0* | *74.0* | *75.0* | | | | | | |
| Retrofit LED lamps (W) | 0-1 | 1-2 | 2-4 | 4-8 | 8-11 | 12-14 | 15-20 | >20 | |
| *2010 (efficacy)* | *48.0* | *49.6* | *51.2* | *54.4* | *56.0* | *57.6* | *60.0* | *64.0* | |
| Dedicated LED lamps (W) | 0-1 | 1-2 | 2-4 | 4-8 | 8-11 | 12-14 | 15-20 | >20 | |
| *2010 (efficacy)* | *60.0* | *62.0* | *64.0* | *68.0* | *70.0* | *72.0* | *75.0* | *80.0* | |

For almost all lamps, efficacy has been improving over time. This improvement varies significantly between lamps. For example, the improvement in LED efficacies has been rapid in recent years, while incandescent lamps have improved very slowly. This improvement in efficacy over time has been accounted for by assuming an average annual improvement in efficacy for each lamp type as detailed in the table below[11].

| Lamp type | Annual improvement in efficacy |
|---|---|
| Main voltage incandescent | **0.1%** |
| Mains voltage halogens (single ended) | **0.3%** |
| Mains voltage halogens (double ended) | **0.3%** |
| Low voltage (12V) halogens | **0.3%** |
| Mains voltage pin based CFLs | **0.6%** |
| Mains voltage self-ballasted CFLs | **0.6%** |
| Mains voltage linear fluorescent tubes (T5) | **0.3%** |
| Mains voltage linear fluorescent tubes (T8) | **0.2%** |
| Mains voltage linear fluorescent tubes (T12) | **0.1%** |
| Retrofit LED lamps | **10.0%** |
| Dedicated LED lamps | **10.0%** |

Efficacies of lamps in each wattage bucket in years preceding and following 2010 have been calculated by:

*Prior to 2010: Efficacy in year n-1 = Efficacy in year n x [1/(1+annual improvement in efficacy)]*
*After 2010: Efficacy in year n+1 = Efficacy in year n x (1+annual improvement in efficacy)*

### 4.2.2 Efficacies of 110-120 V lamps

For lamps with an integral or external electromagnetic/electronic control unit (e.g. CFLs, LEDs fluorescent lamps with ballasts, etc), there is very little difference in efficacies between 220-250 V lamps and 110-120 V lamps. Therefore the efficacy tables for each wattage bucket calculated for 220-250 V lamps are also used for 110-120 V lamps.

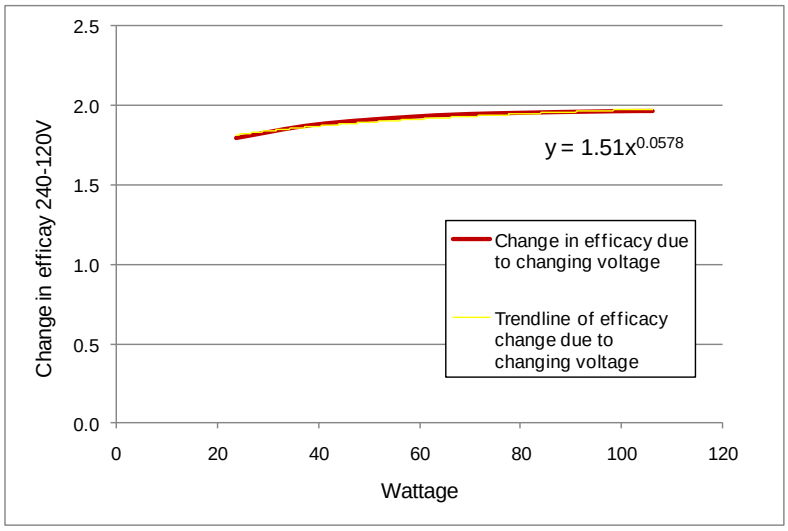
For lamps that use a filament to produce light (incandescent and halogen lamps) there is an inherent improvement in efficiency for lamps operating on lower voltages. Therefore, it is necessary to determine the efficacies to be used for filament lamps operating on 110-120 V.

[11] Note that annual improvements are assumed to be the same percentage over time.

Three separate conversion methodologies created by experts[12] were identified for the conversion of 110-120 V *incandescent* lamps to their 220-240 V lumen equivalents. These conversions result in efficacy variations of between 1 and 3 lumens/watt over a range of lumen levels (typically the different methodologies result in efficacy differences reducing as lumen output increases, i.e. larger lamps have less variation). However, the derivation of these methodologies is not completely in the public domain and so not entirely transparent. Therefore, for the mapping and benchmarking work, a conversion has been developed based on an IEC standard (IEC 60064:2005).

IEC 60064:2005 provides minimum lumen values for given wattages at a range of voltages – thus these wattage and lumen values (and hence efficacies) can be considered comparable at each voltage. However, the table provides only a limited number of values based on minimum performance levels. To enable 120 V comparative efficacy values to be calculated for each 240 V wattage/efficacy combination used within the mapping and benchmarking analysis, manipulation of the data was required as follows:

The difference in efficacy values at various wattages shown in IEC 60064 of lamps for 120V and 240V are plotted below.




The trend line[13] shown allows a function to be derived which in turn is used to define the change in efficacy between 220-240 V[14] and 110-220 V for each of the wattage buckets used in this analysis.

Note that IEC 60064 proves equivalents for *incandescent* lamps. However, no similar equivalents have been identified for halogen lamps. Further, no conversion methodologies for halogen lamps have been identified elsewhere. Therefore the same conversion methodology used for incandescent lamps outlined above has been used for halogen lamps. While it is likely that this approach is valid as both lamp types rely on heated filament as the light source, it is *possible* that the conversion will be less valid for halogen lamps.

[12] Two conversions methodologies have been created by Ecos Consulting in the USA, and one by Navigant Consulting in the UK.
[13] The trendline has the following equation: Delta efficacy = 1.15 * wattage$^{0.0578}$ or y = 1.15 * x$^{0.0578}$
[14] Note that IEC 60064 gives slightly different efficacy values for 110 and 120 V, and for 220 and 240 V. However, these variations are *very* small and thus the 120 V and 240 V values have been used to define the efficacies for the ranges 110-120 V and 220-240 V respectively.

## 4.3 Lamp lifetimes

The individual lifetimes of lamps vary considerably between models of a particular type. Similarly there are variations in average lifetimes of lamps between geographical regions and over time. However, for the mapping and benchmarking analysis, 'standard lifetimes' have been used for each lamp types in all markets for all years.[15] These standard lifetimes used are given in the table below.

| Lamp type | Assumed lifetime (hours) |
|---|---|
| Main voltage incandescents | 1000 |
| Mains voltage halogens (single ended) | 1300 |
| Mains voltage halogens (double ended) | 1300 |
| Low voltage (12V) halogens | 1300 |
| Mains voltage pin based CFLs | 6000 |
| Mains voltage self-ballasted CFLs | 6000 |
| Mains voltage linear fluorescent tubes (T5) | 15000 |
| Mains voltage linear fluorescent tubes (T8) | 10000 |
| Mains voltage linear fluorescent tubes (T12) | 10000 |
| Retrofit LED lamps | 20000 |
| Dedicated LED lamps | 20000 |

# 5 Data requirements

To enable the most effective analysis of data and comparison between countries, the aim is to collect the following data:

## 5.1 For comparison of the stringency of "phase-out" regulations

a. Details of the regulations defining minimum product energy performance and the date at which the regulation (and any requirement) did or will come into force. For example, for Country X:

> *"Lamps sold within the market will have a minimum efficacy level of 15lm/watt. This regulation will apply to lamps with rated power above 100W on 1st January 2011 and for all lamps on 1st January 2012."*[16]

The primary information required is the specific regulatory requirements for product efficacy, the date these requirements come into force, and the test method(s) specified for compliance. However, where possible, the provision of other performance requirements (minimum lifetime, maximum lumen depreciation, requirements for colour temperature, etc) and the associated test methodology would be of significant value.

[15] Note that 'standard' lamp lifetimes are based on an average of the lifetimes of lamps sold in 2010 as estimated by experts in the USA, Europe and Australia. Lamps in preceding years are *likely* to have shorter lifetimes and this has not been accounted for in the benchmarking.

[16] Clearly this is somewhat simplistic as almost all regulations are scaled based on rated power and/or product type. However the example if provided to give an *idea* of the desired information.

## 5.2 Information on New Product Sales

For as many years as possible between 1996-2010, the following information is requested:

a. Total sales **volumes** of products falling within individual lamp type and wattage bands defined in Figure 1 above (and where possible the total number of lamp sockets with that type of lamp installed);
b. Where the information in 2a) is not available, the percentage of total sales within the market for each lamp type defined in Figure 1 (and ideally the total number of lamp sales for all lamp types, the average installed wattage for each lamp type, and the total number of lamp sockets with that type of lamp installed).

## 5.3 Information required for Mapping and Benchmarking

a. Total number of socket in households;
b. Total number of households.

## 5.4 Additional Information Required for Other Analysis

a. Summary of all major policy actions (other than the “phase-out” regulations) over the period data is available including the times when policy were first considered, the time of formal announcement of the policy plans and the date when policy came into force;
b. Summary of major cultural issues that are thought to affect this product at the local level.

# Annex 1 Terminology used

The following lists some of the terminology used within this benchmarking document. It does not attempt to provide a full listing of all terminology, but rather to provide a summary of terminology most frequently used and/or terminology used in a context with a meaning that is less well known or different to its more common usage.

| | |
|---|---|
| CFL(s) | Compact Fluorescent Lamp(s). Covered CFLs are also sometimes referred to as 'look-alike CFLs'. |
| Clear lamp | Lamp with a transparent, or near transparent covering. |
| Efficacy | The efficiency of lighting as defined by rated light output divided by rated power input (lumen/watt or lm/W). |
| Efficacy tables | A table of global average efficacies (for the local voltage) broken down by lamp types, wattage groups and year used in the calculation of all efficacies displayed in the output graphs (refer to Wattage buckets, standard efficacy tables, standard lifetimes and normalisation of lamps on differing voltages. |
| GLS | General lighting service lamps. Refer to incandescent. |
| Incandescent lamp(s) | For the majority of this document, 'incandescent lamps' refers to all types of tungsten lamps (both reflector and non-reflector) *not* encapsulated by a halogen filled capsule. Depending on region, such lamps are normally referred to as one or more of the following, incandescent, GLS, golf ball, fancy round, candle, etc. In exception circumstances, all types of lamps defined above *plus* those in a halogen capsule are referred to as incandescent lamps – however, where this is the case it is clear stated in the text. |
| Instantaneous lighting output | The rated light output of a lamp or group of lamps (in lumens or lm). |
| LED(s) | Light Emitting Diode(s). LED is used within the document to denote lamps of all types similar to LEDs, e.g. including Organic Lighting Emitting Diodes (OLEDs). |
| Lifetime light output | Total light output of a lamp (or group of lamps) over its lifetime defined by rated light output of the lamp multiplied by the rated lamp lifetime. Expressed in lumen hours (lmh). |
| 'Look-alike' lamp | Refers to mains voltage, single ended halogen lamps and CFLs. |

| | |
|---|---|
| Low voltage, single ended halogen lamp | Typically 12 V lamps of either reflector variety or capsule. |
| Lumen | The measure of ‘quantity of light’, normally denoted by lm. |
| Mains voltage, double ended halogen lamp | Halogen lamps with two ends, most typically used in domestic environments to meet high-illumination needs (e.g. security/outdoor applications). |
| Mains voltage, single ended halogen lamp | A halogen lamp operating on domestic supply voltage (110-120 V or 220-240 V), with a single ended connection/cap. In the *majority* of cases these are reflector lamps or lamps which can be used as replacements for GLS incandescent lamp (also known as ‘halogen look-alike’). |
| Sales of [*lamp type(s)*] | The total sales of a single defined lamp type, or defined group of lamp types, within a particular country in a particular year. |
| Sales of [*lamp type(s)*] as a percentage of all lamp sales | The sales of a particular lamp type or group of lamp types as a percentage of all lamp sales in a particular country in a particular year. |