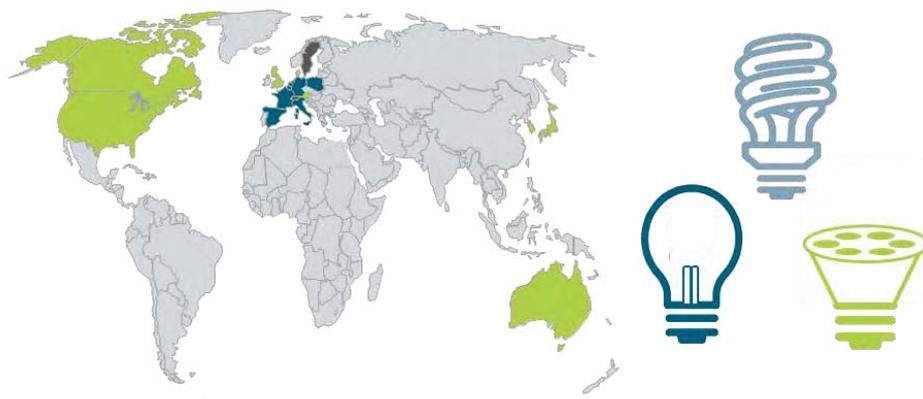




Technology: Lighting: Market Impact of 'Phase-out' Regulations



Participating countries:

Australia, Austria, Canada, Denmark, Japan, Republic of Korea, UK, USA

Other funding countries:

Netherlands, Switzerland, Sweden

Other regions covered:

EU

Updated Benchmarking Report

Impact of 'Phase-Out' Regulations on Lighting Markets

Issue Date: March 2015

For further information refer to <http://mappingandbenchmarking.iea-4e.org/matrix>

Issue date: March 2015





Summary for policy makers

Introduction

This benchmarking analysis has been undertaken as part of the IEA's Mapping and Benchmarking Activities under the Efficient End-use Electrical Equipment Implementing Agreement (4E). The analysis updates the results of the domestic lighting benchmarking published in July 2011¹ based on new data that gives insight into more recent market trends.

In many parts of the world the lighting market continues to go through a period of significant transition. This transition is a combination of 'regulations to phase-out inefficient lighting' and the market entrance of new products, in particular new types of LEDs. As with the previous report, the analysis will seek to:

- Compare the approach and stringency of the various 'phase-out' regulations² 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 efficacies* (efficiencies) of the new products entering the market which should indicate longer term efficiency improvements of the installed stock.
- Identify key areas of concern for policy makers, including areas where additional or modified policy intervention may be required in the future.

The products being investigated are restricted to those lamps applicable to the domestic sector (i.e. general service incandescent, halogen and compact fluorescent lamps (CFLs), and light-emitting diodes (LEDs)) but may include the sales of these lamps to other sectors.

Observations and recommendations for policy makers

Regulatory approaches and potential for harmonisation

At the macro level, the regulatory requirements to phase out inefficient lighting are broadly similar between all the countries/regions, i.e. the regulations are not technology specific; have exclusions that allow less efficient lamps to be sold in certain circumstances; are implemented incrementally over time; and have other mandatory performance characteristics in addition to efficacy.

However, more detailed investigation identifies some stark differences in the approaches taken to regulation. These can be grouped as differences in:

- The overall regulatory approach including the metrics used, the lamp types to which they are applied, and the approach to tolerances and allowances for declarations.

¹ Available at <http://mappingandbenchmarking.iea-4e.org/matrix?type=product&id=5>

² Primarily regulations related to non-reflector lamps.



- The stringency at which the required performance levels are set, and the associated phasing or speed at which the required actions come into force.
- The range of light outputs and products included in the regulations and the products exempted or requiring lower performance levels.

There is no evidence to date that such differences are adversely affecting individual markets or that suppliers are unable to meet the varying requirements. However, analysis indicates that the regulatory differences are potentially leading to significant variations in policy outcomes, with some countries/regions attaining significantly higher efficiency levels (and in many cases broader levels of performance) of installed lamps compared with those installed elsewhere.

However, as lighting products are the most globally traded product, with very little technical variation between markets, such a situation is difficult to understand given the general political consensus that harmonisation of product requirements brings significant economic benefits. Further, among the countries studied, test methods are already very closely aligned. Thus, the alignment of efficiency requirements between jurisdictions should be technically *relatively* simple.

Further, the alignment of the various 'scopes and exclusions' (e.g. general adoption of the requirement for CFL equivalent efficacies for all non-clear light sources, alignment of upper and lower lumen thresholds across national boundaries, etc.) is likely to:

- Enable the realisation of substantial additional energy savings. Adopting the most stringent performance requirements and product scopes *that are currently in place or will imminently come into force* in participant countries would result in an increase in the stringency of existing requirement of between 10-30% in most participating countries.
- Enable better supplier understanding and compliance with the requirements of regulations in all countries.
- Enhance the potential for local and cross border enforcement actions.
- Facilitate increased global trade and *potentially* reductions in cost to the consumer.

If such alignment results in the equivalent of saving just 1 W for each light bulb sold in the countries included in this study, that would have yielded additional savings of over 300 GWh/year or approximately 0.25 million tonnes/year of avoided CO₂ emissions,³ although this saving potential is actually likely to be *much* higher in these regions. Further, given the size of these trading blocs, such harmonisation would send a powerful signal to other countries on the levels of ambition possible, and the benefits in reduced energy consumption (and increased trade) from harmonisation.

While such alignment has clear benefits, and indeed there are ongoing efforts for alignment through activities such as the Australian-led efforts to harmonise CFL performance

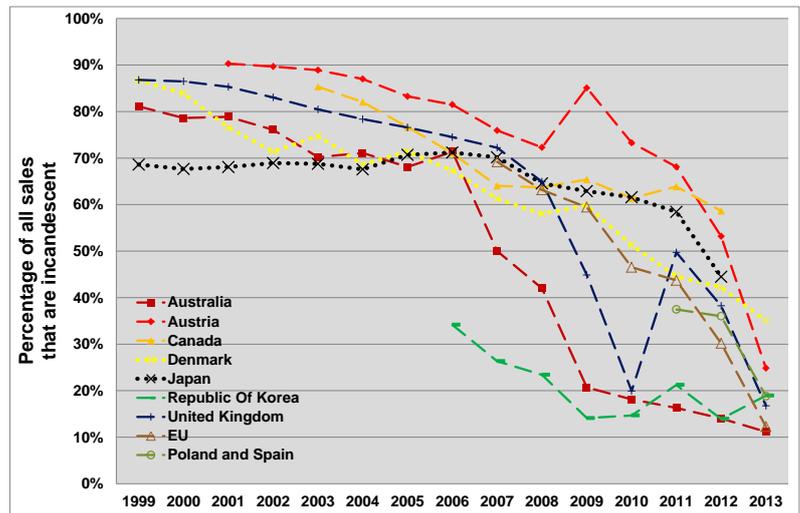
³ Assuming the 830 million lamps (estimated combined sales of lamps in countries studied in 2013) save 1 W and operate for an average of 1 hour per day for each day of the year. Average CO₂ emissions factor assumed to be 0.8kg of CO₂ per 1 kWh of electricity consumed.



requirements through the International Electrotechnical Commission (IEC), it is unlikely to be possible during the implementation of current regulatory requirements (not least due to the recent vote by the majority of the IEC standards committee to reject efforts at harmonisation of CFL performance requirements). Therefore, policy makers should remain aware of the opportunities for harmonisation when regulatory requirements are revised in the future and, in the short term, potentially focus on international efforts to align requirements for LEDs where there is less historical regulatory inertia, e.g. through adoption of recently developed International Commission on Illumination (CIE) and IEC test methods for LEDs and recommendations for performance measurements and levels from the IEA 4E SSL Annex. Other opportunities for collaboration and development of future regulation also exist, for example related to the monitoring and development of appropriate regulation for 'beyond illumination' lighting products mentioned below.

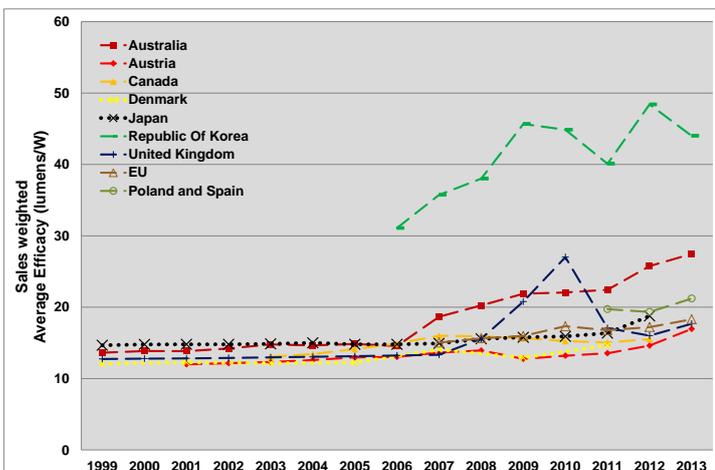
Impact of policies to remove inefficient lighting and associated issues for policy makers to consider

Following the very gentle fall in the pre-regulatory sale of incandescent lamps from 80-90% of all lamps sold in 1999 to 70-80% by 2007, the countries introducing mandatory regulation relatively recently (Australia in 2009 and the EU countries phased from 2009-12) have seen a precipitous fall in incandescent sales to between 11 and 25%⁴ of overall lamp sales. Early indications are that the Canadian market, where regulations only came into effect in 2014, seems to be following a broadly similar trajectory. The variations in the scope of regulations and their phased



introduction outlined above, as well as the political, culture and media landscapes in the different countries, have affected the speed and extent of the market transformation, but the overall impact is clear.

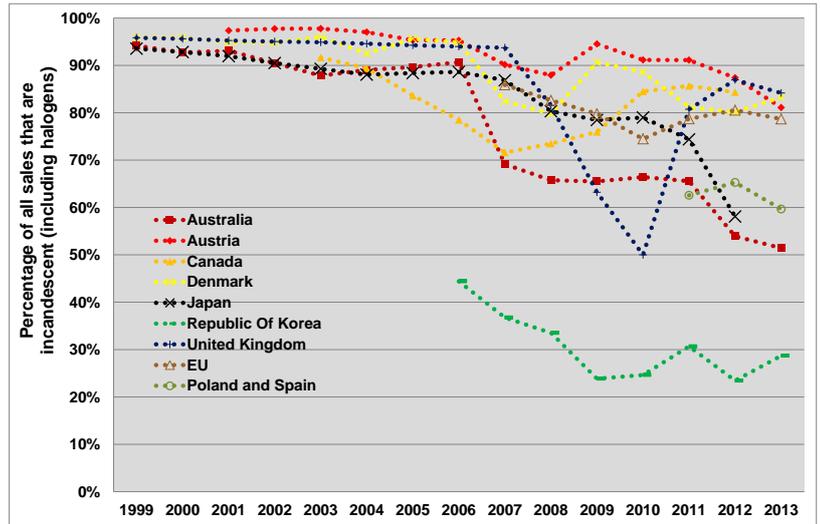
Nevertheless, given the significant falls in the sales of incandescent lamps, the widely anticipated increase in the average efficacy of new lamp sales has not been realised in the EU countries. Typically the increase in average efficacy of lamp sales has been



⁴ Sales of incandescents in Denmark were reported as 35% in 2013. However, a significant degree of modelling was required to create the Danish reported sales values and it is believed incandescent sales are likely to be over-reported and actual sales values are closer to those reported by other EU countries.

from 12-15 lm/W, to 17-20 lm/W. While this represents a 25-33% improvement in the efficiency of lamp sales, and the overall improvement in stock efficiency will be greater than this, it is relatively marginal compared with the potential savings available.

The reason for the relatively small increases in efficacy appears simply to be that consumers are migrating from the purchase of incandescent lamps to the purchase of marginally more efficient halogen products. The combined sales of incandescent and halogen lamps in EU countries moved from around 90% of all sales before the introduction of regulations, to 80% now. This is clearly not the major market movement to CFL and LED purchase which many regulators may have anticipated and factored into the original energy savings projections. In fact in the EU countries (and most likely Canada), there is a suggestion the consumer migration towards CFLs has actually stalled and current CFL sales are primarily replacing existing CFL stock that has failed.



Through their ongoing engagement with market stakeholders, Australia has fared significantly better with CFL sales still above 30% of the total market (50% when low voltage halogen lamps are excluded) with resulting overall market average efficacy of sales of 27 lm/W and rising. However, even here sales of mains voltage halogen lamps increased significantly following the 2009 introduction of regulations and have recently stabilised at around 25% of sales.

Further, while data on LED sales is uncertain, their penetration in all markets is apparently still limited at between 3 and 15% of total lamp sales, although typically around 5% of the market.

If the situation continues, policy makers in the EU, Canada and, most likely the USA and Australia, risk halogens becoming the new 'default' lamp of choice for consumers. Consequently, any later move to restrict the supply of halogen lamps may be met with the same negative consumer and media reaction seen in some countries during the initial removal of incandescent lamps. Therefore, policy makers in these countries may consider continuing the momentum of market evolution currently being experienced and *expected* by consumers rather than allowing the market to reach a new 'steady state' which will result in a stalling in improvements in stock efficiency.

While movement towards the levels of cross-border harmonisation mentioned above would be ideal, to address this immediate issue:



- EU policy makers may wish to minimise any possible delay in the introduction of the 2016 'Phase 6' regulations which, when implemented, will result in the removal of standard Halogen lamps from the market.
- Policy makers in other countries may wish to consider mirroring the approach set out in EU 2016 regulations, albeit with modifications to the timescales or scope to accommodate the particular issues experienced in their local market, for example with non-compatible dimmers/controls.
- US policy makers may seek to bring forward the implementation of the anticipated 2020 '45 lm/W average efficiency of lamps' regulations, and Canadian regulators may consider following a similar path.

While there is a degree of uncertainty in the data, the remarkable experience of Korea, indicates that such regular revision to lamp standards can result in major market movement. Regulation of incandescent lamps was first introduced in Korea in 2003 and these regulations have since been revised several times. This appears to have resulted in Korea having very high levels of CFL penetration (around 70% of sales) and average efficacies of new lamp sales above 40 lm/W.

Other policy action beyond regulation

Of the non-regulatory policy interventions, few appear to have sustained impact where there is not ongoing engagement with stakeholders. For example, historically Canada had relatively high levels of CFL sales due to the 'switch and save' programme (up to 30% of all sales in 2007). However, following the scaling-down of the programme, sales of CFLs in Canada have fallen to just 13% of all sales, close to the levels seen elsewhere. Similar occurrences have happened in the UK and in Denmark.

In contrast the ongoing industry/government engagements in Japan (the only country without any formal regulatory intervention) appear to have resulted in ongoing positive market change. However, there appears also to be a strong cultural element at play. In Japan, incandescent sales are only marginally higher than most EU countries in the last reporting year (2012) but this should be set against a background of Japan having a historically lower use of incandescents (broadly stable at 70% up to 2007). Further, Japanese manufacturers have entered into voluntary agreements to end production of incandescents and the Japanese government has issued voluntary administrative guidelines for promoting high efficiency CFLs, and in a later update, LEDs. These actions sit within a backdrop of an aggressive governmental promotional campaign (targeting both consumers and industry) focusing on national energy saving after the close down of nuclear reactors following the tsunami/ Fukushima nuclear power plant issue. So although there is no regulatory pressure within Japan there is a degree of cultural pressure to comply with overall government direction.

Hence, policy makers need to be aware that non-regulatory intervention is possible, but requires sustained, long term collaboration with stakeholders and actions appropriate to the local cultural environment.





Better market knowledge is needed

As a result of regulation and other policy intervention, plus the entrance of new products (particularly LEDs), all markets have changed. However, the specific evolution of individual markets is variable and rapidly altering. Unfortunately, the degree of granular market knowledge currently available to policy makers appears limited. On a basic level, such information is required to:

- Evaluate the impact of regulation and other policy and establish if original intent and expectation is being achieved, or whether modification to the regulatory framework or addition intervention is required.
- Identify areas where regulations are being flouted and/or circumvented as appears to be the case in the EU with the increase in sales of 'exempted' shock proof lamps as 'replacements' for traditional incandescents.
- Identify if individual products are meeting the required levels of efficiency and other performance parameters.

To some extent this is already occurring, with countries such as Australia conducting analysis of market imports by lamp type, in-store monitoring, and testing of products. Korea also requires annual reporting of sales of all labelled products and, under normal circumstances, the USA requires ongoing monitoring of products exempted from regulation. Unfortunately, in general it appears such market monitoring is rather ad-hoc and relies heavily on industry supplied data which is often aggregated and does not provide the granular detail necessary to facilitate the analysis of specific market trends; a problem made worse by a lack of sufficiently detailed and harmonised international customs/product codes.

Further, lamps are not a traditional 'appliance' and may be deployed in a range of sockets with very different usage patterns. These different operation patterns have a major impact on the practical life of products, which in turn impacts on both sales and the levels of energy and cost saving resulting from the regulatory intervention. Yet base knowledge of consumer application, and how this is changing over time, appears very limited in most markets.

Thus, it is likely the current limited knowledge of consumer usage patterns, combined with the restricted levels of ongoing market monitoring, is impacting policy makers' ability to understand and adjust policies to be appropriate to the evolving market. Unfortunately, this situation is likely to become worse rather than better as regulation is extended to increasing numbers of products.

Further, the market entrance of newer 'beyond illumination' products (giving additional functionality such as extended wifi capability or movement sensing) are likely to bring increasing energy use related to their extended functionality. Hence, there seems significant value in policy makers increasing levels of market supervision, monitoring and understanding of consumer activities to enable evaluation of existing regulation, and to develop timely strategies to refocus regulatory regimes as the market evolves.





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1. Introductions and cautions

1.1. Introduction

This document updates the results of the benchmarking of domestic lighting published in July 2011⁵ based on new data that gives insight into more recent market trends. As previously, the report seeks to analyse the ongoing transition of the lighting market occurring due to a combination of 'regulations to phase-out inefficient lighting', and the market entrance of new products, in particular LED lamps. The analysis updates previous findings which sought to:

- Compare the approach and stringency of the various 'phase-out' regulations being introduced by each 4E participant;
- Compare changes in the type of products entering each market which should indicate any major outcomes of the various policies implemented to date;
- Identify changes in the overall average efficiencies of the new products entering the market which will indicate longer term efficiency improvements of the installed stock; and
- Identify key areas of concern for policy makers, including areas where additional or modified policy intervention may be required in the future.

The analysis is based on Country Mappings which contain summaries of all source material received from individual countries referenced in this benchmarking (Australia, Austria, Canada, Denmark, Japan, Republic of Korea, United Kingdom, USA and the EU⁶).⁷ Again, the products being investigated have been restricted to those applicable to the domestic sector (i.e. general service incandescent, halogen, compact fluorescent and LED lamps) but include the sales of these products to other sectors.⁸

⁵ Available at <http://mappingandbenchmarking.iea-4e.org/matrix?type=product&id=5>

⁶ Represented by data from Austria, Belgium, France, Germany, Great Britain, Italy and the Netherlands, and separately, as Poland and Spain.

⁷ To view individual country mappings please refer to:

<http://mappingandbenchmarking.iea-4e.org/matrix?type=product&id=5>

⁸ In almost all participant countries it is not possible to distinguish the sale of 'domestic lamps' that are for use in the home environment from those sold for use in industrial and commercial applications. Further, in almost all cases where policy has been applied to limit sales of less efficient lamps and stimulate sales of more efficient alternatives, the policies have been applied irrespective of actual end use sector. Therefore *all* general service incandescent, halogen, compact fluorescent and LED lamps have been considered as 'domestic'. Further, while the majority of country mappings include information on linear and circular fluorescent tubes the extensive use of these products in the domestic environment is limited to a very few countries, only one of which is included in the study. Therefore fluorescent tubes have been excluded from the benchmarking to avoid unnecessary confusion in interpretation of results. For more details of the approach taken to data collection and analysis, please refer to lighting product definition:

<http://mappingandbenchmarking.iea-4e.org/matrix?type=product&id=5>





1.2. Important cautions for interpreting and using mapping and benchmarking information

Considerable efforts have been made to ensure the integrity of the data supplied and the subsequent data manipulation and analysis. The approach to the analysis is detailed in the Lighting Product Definition,⁹ but readers must also be aware of the variation in the reliability of each of the results presented. To provide readers with an indication of this reliability, all results have been graded based on a standard 'Framework for Grading Mapping and Benchmarking Outputs' as shown in Annex 1.¹⁰ As with other benchmarking reports, these gradings are based on a robust, illustrative and indicative scale. However, given the degree of modelling required in all cases, no individual data set or overall comparative benchmarking is graded higher than indicative. Summaries of the individual gradings are shown in Figure 1 with a more detailed breakdown provided in Annex 2.

Figure 1. Grading of data and benchmarking by country/region.

Country	Policy information	Mapping data	Benchmarked data	Efficacies
Australia	Robust	<ul style="list-style-type: none"> All data Indicative except LEDs and double ended halogen which are Illustrative 	<ul style="list-style-type: none"> All data Indicative except LEDs and double ended halogen which are Illustrative 	<ul style="list-style-type: none"> Indicative
Austria	Robust	<ul style="list-style-type: none"> All data Indicative 	<ul style="list-style-type: none"> All data Indicative 	<ul style="list-style-type: none"> Indicative
Canada	Robust	<ul style="list-style-type: none"> All data Indicative 	<ul style="list-style-type: none"> All data Indicative 	<ul style="list-style-type: none"> Indicative
Denmark	Robust	<ul style="list-style-type: none"> All data Illustrative 	<ul style="list-style-type: none"> All data Illustrative 	<ul style="list-style-type: none"> Illustrative
Japan	Robust	<ul style="list-style-type: none"> All data Illustrative 	<ul style="list-style-type: none"> All data Illustrative 	<ul style="list-style-type: none"> Illustrative
Korea	Robust	<ul style="list-style-type: none"> Majority of data Indicative All halogen data Illustrative 	<ul style="list-style-type: none"> Majority of data Indicative All halogen data Illustrative 	<ul style="list-style-type: none"> Indicative
UK	Robust	<ul style="list-style-type: none"> All data Indicative 	<ul style="list-style-type: none"> All data Indicative 	<ul style="list-style-type: none"> Indicative
USA	Robust	<ul style="list-style-type: none"> Not available 	<ul style="list-style-type: none"> Not available 	<ul style="list-style-type: none"> Not available
EU	Robust	<ul style="list-style-type: none"> All data Indicative 	<ul style="list-style-type: none"> All data Indicative 	<ul style="list-style-type: none"> Indicative

⁹ Refer to <http://mappingandbenchmarking.iea-4e.org/matrix?type=product&id=5>

¹⁰ This grading framework has been used for all IEA 4E Mapping and Benchmarking analyses. However, the slightly different analysis used in this Benchmarking document (i.e. examining the overall market trends across multiple product types) means the grading framework is not entirely appropriate. Thus expert opinions have been used to grade the outputs for likely reliability using the Framework as a conceptual template only.





Further, readers should be aware of a number of specific limitations within the analysis and important caveats associated with the results. These limitations and caveats are described in detail in Annex 3.

Definitions of Terminology used in this benchmarking document are provided in the Lighting Product Definition.¹¹

¹¹ Refer to <http://mappingandbenchmarking.iea-4e.org/matrix?type=product&id=5>



2. Comparison of regulatory approaches and other policy actions

2.1. Observations: regulatory approaches

2.1.1. Regulatory approaches to the 'phase-out' of inefficient lighting

With the exception of Japan,¹² in all countries where information is reported the *primary* policy action in place is the mandatory 'phase-out' of the least efficient lighting products in the market. Figure 2 gives an overview of the stringency and timings of the various 'phase-out' regulations¹³ in these countries.¹⁴

At the macro level, the regulatory requirements are very similar between all the countries/regions, e.g. the regulations are not technology specific;¹⁵ have exclusions that allow less efficient lamps to be sold in certain circumstances; are implemented incrementally over time; and have other mandatory performance characteristics in addition to efficacy. However, more detailed investigation identifies some stark differences in the approaches taken. These differences may be grouped into the following categories:

- The overall regulatory approach to defining performance levels.
- The stringency at which the required performance levels are set and the associated phasing or speed at which the required actions come into force.
- The range of light outputs and products included in the regulations.
- The products exempted or requiring lower performance levels.
- Tolerances and allowances.

All these variations are likely to have an influence on the policy outcomes in each market and so are investigated individually below.

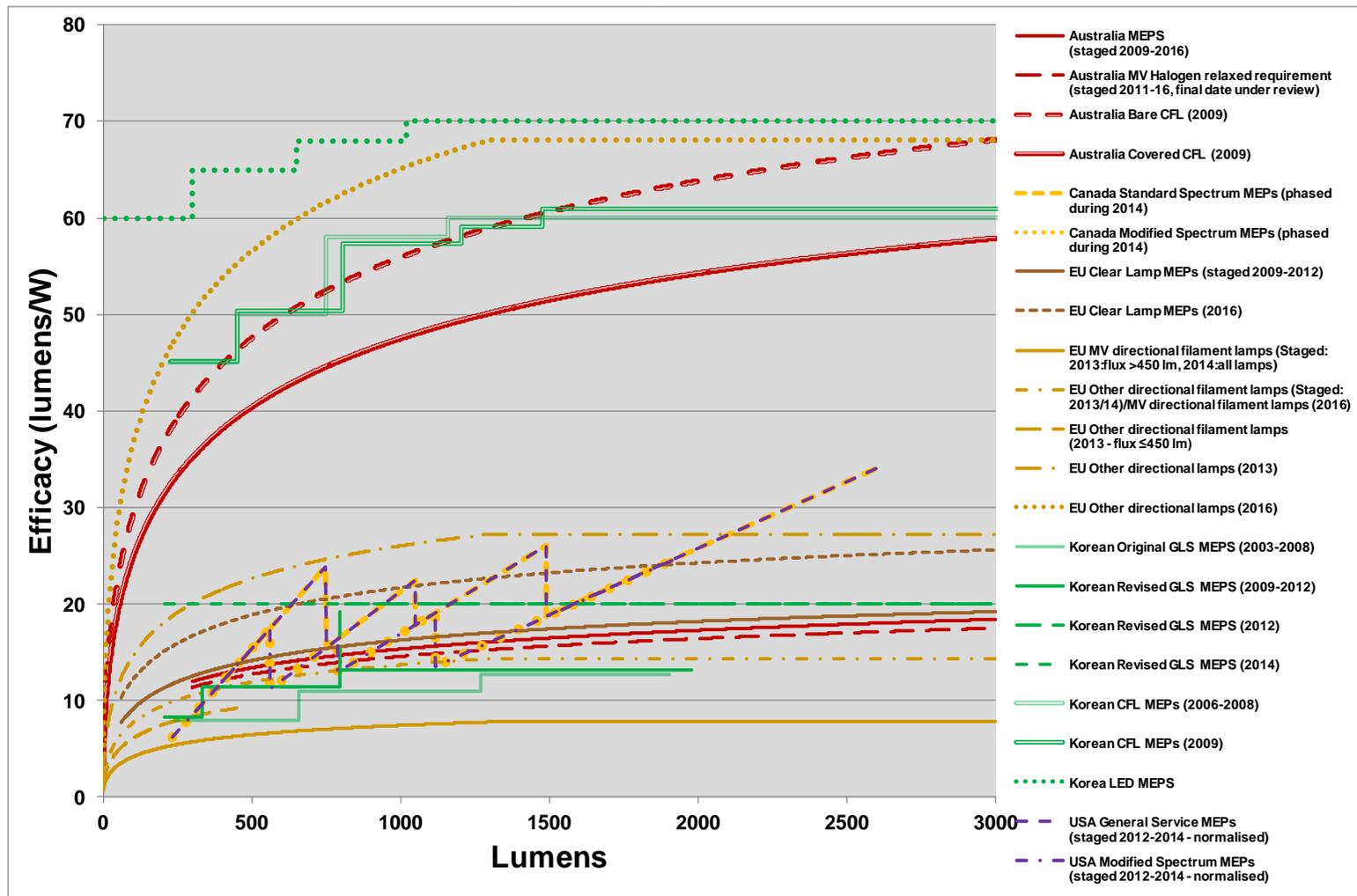
¹² A number of non-regulatory interventions have been made in Japan as described in Section 3.3.

¹³ Note that the USA has an additional requirement that new rules must be in place by 2017 (for implementation no later than 2020) that set a minimum average efficacy of 45 lm/W. Should such a rule not be put in place, a default requirement of 45 lm/W becomes mandatory on *all* non-reflector Incandescent lamps. However, this requirement has been excluded from the graphic as the likely requirements of the regulations are not currently clear, and the rule making is not anticipated to begin prior to 2014. Please refer to the USA country mapping at <http://mappingandbenchmarking.iea-4e.org/matrix?type=product&id=5>

¹⁴ Note that the graphic has been normalised for voltage variations. Refer to the Lighting Product Definition for details at: <http://mappingandbenchmarking.iea-4e.org/matrix?type=product&id=5>

¹⁵ While it is the case that all countries included in the study (with the exception of Japan) have adopted a regulatory approach to phase-out, all have used a non-technology specific approach (noting Australia does have an import restriction on tungsten filament 'general service' shaped lamps, but the majority of Australian regulations are technology neutral). However, this is not the case for *all* countries. For example, China has simply mandated the prohibition of import and sales of 'incandescent lamps' which can broadly be interpreted as 'traditional tungsten filament lamps'.

Figure 2. Normalised overview of the stringency and timings of the various 'phase-out' regulations in the countries reported.



Note: The scope of each regulation is very detailed. For specific information refer to national mappings.



2.1.2. Overall regulatory approach to required performance levels

The overall regulatory approach varies between jurisdictions in two distinct ways. Firstly, while in all markets regulators are striving for technology neutral standards, two broad approaches are being used to set minimum requirements:

- By lamp type or group, e.g. filament lamps, halogen lamps, CFL, LED etc.
- By the type of lighting service provided e.g. 'omni-directional' lamps, 'clear lamps' or 'non-clear lamps' and 'directional' lamps.

There are benefits to both of these approaches. Regulating by lamp type enables clear regulatory definitions and hence is relatively simple to implement and enforce. Further, it allows for definition of non-efficiency performance standards (start-time, colour, lifetime, etc.) that are appropriate to a particular technology such that consumer satisfaction is maximised. However, such an approach is limited as it requires regulation of all possible product derivatives and has the potential for alternative technologies to develop and circumvent the regulation. Alternatively, regulating by the type of light service leaves the market to deliver solutions that meet efficiency requirements in a manner most acceptable to consumers. However, while on a basic level it is easy to define (e.g. all products must meet a certain efficacy requirement), it is more challenging for the regulator to specify non-efficacy parameters without risking the possibility that the supply of a certain technology is restricted or the best outcomes are not achieved for some technologies. This can make the resulting regulation difficult for suppliers to understand, for compliance bodies to enforce and potentially results in lower levels of consumer satisfaction.

In practice almost all jurisdictions use a hybrid where a minimum efficacy requirement is set for all lamps providing a particular service, but with differing additional performance requirements based on the particular lamp type.¹⁶ The EU presents the clearest example of this approach where, for example, mains voltage directional filament lamps, 'other' (i.e. non-mains voltage) directional filament lamps and non-filament directional lamps are defined separately to allow for maximisation of performance of reflector lamps based on halogen and CFL/LED technologies within the service limitation of each lamp type.

The second difference in approach is the metrics through which minimum efficacy requirements are set. Although worded slightly differently in each jurisdiction, there are three primary regulatory approaches being used, as shown in Figure 3, Figure 4 and Figure 5 below.

¹⁶ Note that while the general service may be similar other lamp functions may vary. Hence there may be requirement to maintain the various lamp types on the market rather than simply setting MEPS at a level in line with the most efficient lamp type. For example, mains voltage and LED reflector lamps in principle provide the same lighting service and LEDs are often, although not always, more efficient. However, until recently LED lamps were unable to provide sufficient lumen output for a number of applications and often were not compatible with supporting control gear. Hence, in such circumstances, there would be a need to maintain halogen lamps on the market, but the setting of differential performance requirements allows the efficiency of halogen and LED lamps to be maximised where they are purchased.



Figure 3. Regulation by maximum wattage for a given lumen range (Canada/USA) as declared.

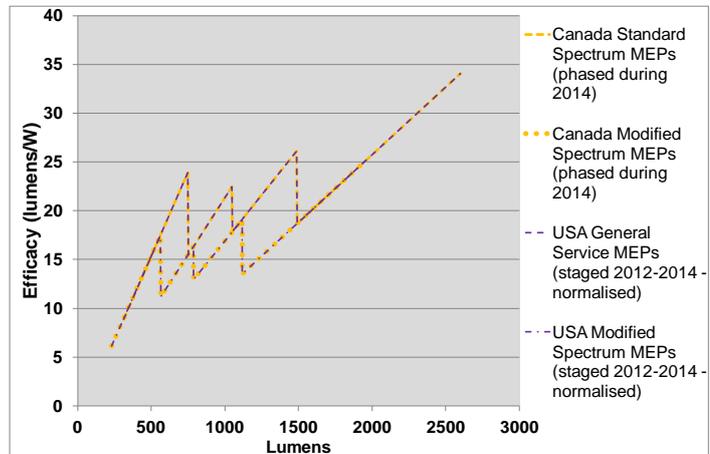


Figure 4. Regulation by minimum efficacy required for a given power/lumen range (Republic of Korea).

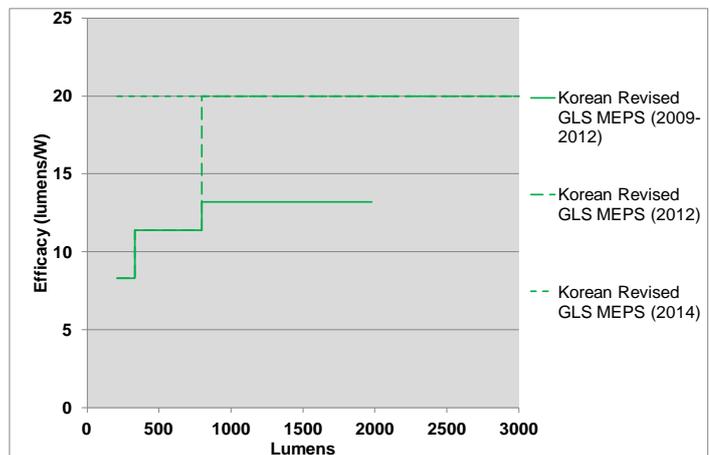
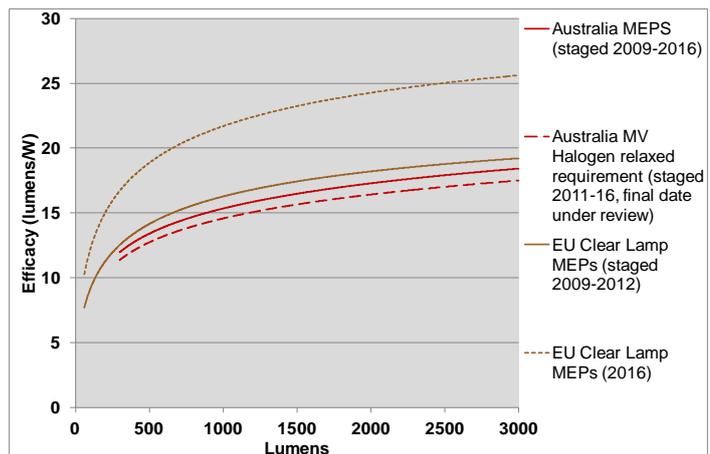


Figure 5. Regulation by continuous curve based on lumen output (Australia, EU member states).



Again, each approach has its own merits. In particular, the ‘maximum wattage for a given lumen range’, and the ‘minimum efficacy for a given power range’ are very easy to understand. Although paraphrasing the regulations slightly, examples of each are:

- Maximum wattage for a given lumen range:** For lamps that provide x-y rated lumens of light output, the maximum wattage shall be no greater than z watts;



- **Minimum efficacy for a given power range:** For lamps between x-y watts rated power, the minimum efficacy shall be z lumens/watt.

This simplicity makes it relatively easy for manufacturers, retailers, regulators and other market actors to understand and apply. However, this approach risks 'bin jumping' or 'lamp rerating' (both explained in Annex 4) which may result in lower lighting output leading to consumer dissatisfaction or, perversely, increased efficiency levels but with higher net electricity consumption. Further, as lamps of a particular type tend to become more efficient as their size (light output or wattage) increases, there is the likelihood that not all the potential savings will be captured.

The third approach, adopted by Australia and the EU, uses a continuous curve to describe the minimum efficacy requirement for any given light output. While this approach is more complex for stakeholders to understand, apply and enforce, it increases the likelihood of capturing all potential energy savings and removes the risks of bin jumping and lamp rerating. Hence, although it is more complicated, policy makers may wish to consider using a continuous curve to define the minimum efficacy requirements.

2.1.3. Stringency and timing of regulatory requirements

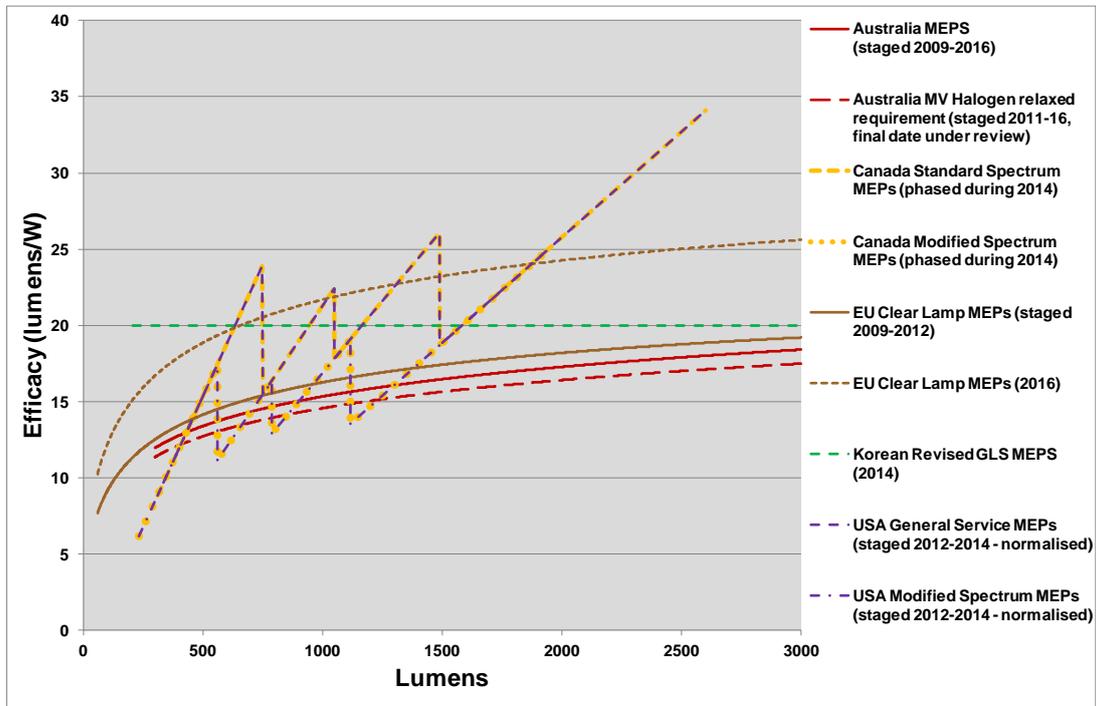
The original 2011 benchmarking report for lighting compared stringency broadly based on lamp type as it was relatively simple to translate the limited number of regulations in place at the time. However, there are now more regulations based on the type of lighting service provided and so, in this report, regulations are compared based on lighting service. Hence, graphical comparisons of the comparative stringency of regulations are presented for 'clear lamps', 'non-clear lamps' and 'reflector lamps'. As a result, some regulations targeting specific lamp types appear on multiple graphs.

Figure 6 shows the overall stringency of requirements (i.e. the minimum performance levels) for all known current and future regulations for 'omni-directional clear lamps' in reporting countries¹⁷ (primarily incandescent and halogen lamps, although potentially the new generation of LED 'filament strip' lamps may fall under this designation). The different approaches to regulation are clearly evident, maximum wattage, minimum efficacy and continuous curve for the Canada/USA, Korea and Australia/EU respectively. As can be seen, this leads to significant differences in the stringency of efficacy requirements for any given lumen output. This difference in stringency is further compounded over time as the phasing (or staging) of the introduction of regulations varies significantly.¹⁸

¹⁷ Note that the USA has an additional requirement that mandates new regulations must be in place by 2017 (for implementation no later than 2020). These regulations are required to ensure a minimum average efficacy of 45 lm/W of all lamps sold. Should such a rule not be put in place, a default requirement of 45 lm/W becomes mandatory on *all* non-reflector incandescent lamps. However, this requirement has been excluded from the graphic as the likely requirements of the regulations are not currently clear, and the rule making has not yet formally commenced. Please refer to the USA country mapping at <http://mappingandbenchmarking.iea-4e.org/matrix?type=product&id=5>

¹⁸ Note that phasing is happening in two ways. Firstly there is the phasing of the introduction of regulations over time (e.g. the introduction of the EU regulations between 2009-2012 for various lamp sizes). The second is the phasing of the increased stringency of the overall requirement. Again using the EU as an example, this is the

Figure 6. Overall stringency of requirements for all known current and future regulations for ‘omni-directional clear lamps’ in reporting countries.



Taken together, the national variations lead to some fundamental differences in the most recent regulations. The most noticeable difference is the move to the 2016 performance requirements in the EU (often referred to as Phase 6 regulations, implementation of which is currently under review¹⁹) which are between 39 and 41% more stringent than those currently being imposed in Australia up to the same date²⁰ (although Australian regulations are also currently under review with options to progressively phase-out halogen lamps where efficient alternatives exist). However, because of the varying approaches to regulation, the 2016 EU regulations are not the most stringent in all cases, with Korean regulations being as much as 32% higher for lamps of a light output lower than 650 lumens. For brighter lamps, the minimum energy performance standards (MEPS) in Canada and the USA are up to 35% more stringent for lamps of a light output higher than 1900 lumens as well as being marginally more stringent at a number of lower lumen outputs. While there are some differences in the scope of lamps captured within the various regulations these are *relatively* minor. Given there is technically very little variation in the lamps supplied to the different markets (other than mains voltage filament lamps), it is difficult to see why there are such significant variations in the performance requirements. This is particularly the case given that

‘step’ between the requirements in 2009-12 and those from 2016 onward. For clarity, the benchmarking primarily addresses the second type of phasing.

¹⁹ It should be noted that the EU Phase 6 requirements are currently being reviewed. There is some concern that clear lamps that meet the specified efficacy requirements may not be available for all applications. The recent market entry of ‘filament LEDs’ makes this less likely. However, there remains the possibility that implementation of Phase 6 may be delayed by 1-4 years.

²⁰ At time of writing (in 2014) the Australia 2009-16 and EU 2009-12 clear lamp requirements are functionally identical when local approaches to tolerances and allowances are taken into account.



there are very few reported cases of suppliers failing to deliver appropriate lighting solutions that are compliant with all the various regulations around the world.²¹ As such, policy makers may wish to consider an internationally harmonised requirement which takes into account the most stringent requirements in current national legislations across the entire lumen range.

Figure illustrates a similar range of minimum efficiency requirements for omni-directional non-clear lamps including CFLs. Both Australia and Korea have specific and robust efficacy and performance requirements for CFLs. The European Union set their 2009 minimum requirement for non-clear lamps more broadly (i.e. lighting products that do not provide a point source illumination²² including ‘pearl’ or ‘frosted’ lamps). This EU requirement is technology neutral, but has the effect of requiring all non-clear lamps to be of an efficacy equivalent to a covered CFL.²³ The logic of this approach is that CFLs (and more recently LEDs) provide an excellent non-point-source lighting service and therefore the efficiency of all lamps providing the service should be at least to that of CFL/LEDs.²⁴ While non-point-source lamps have limited penetration in many markets, when next reviewing regulatory requirements, policy makers may still wish to consider a switch in regulation to this ‘non-clear’ lamp approach as there are significant potential savings to be made with no apparent adverse consequences. However, whether applied only to CFLs or all non-clear lamps, once again there are significant differences in the efficacy requirements among the different countries, and opportunities for harmonisation in the future. Further, where not already used, policy makers may wish to consider a realignment of requirements to a continuous curve broadly in line with the peak of Korean requirements, hence capturing the improvements in CFL and LED performance since most regulations were originally made.²⁵ This would generate substantial additional savings for all countries and reduce the burden of compliance on manufacturers.

Figure shows the MEPS for directional lamps. This is particularly interesting as the incrementally phased EU regulations illustrate the anticipated improvements in product performance in the near term, i.e. a movement from basic incandescent reflector lamps to halogen, and then to LED. There are some indications that these transitions are occurring naturally in some markets. However, adoption by other countries of efficacy requirements similar to those soon to become effective in the EU will accelerate this transition from halogen lamps (discussed in the following Section 3) and ensure higher levels of market penetration of more efficient products.

²¹ It should be noted that there are currently ongoing discussion on whether the EU 2016 regulations may require delay in implementation due to limitations on ability of the market to supply compliant lamps, and there has also been one instance in Australia (mains voltage halogen lamps) where regulations were relaxed as no compliant lamps were made available to the market.

²² For precise definition of a non-clear lamp please refer to the EU mapping sheet at <http://mappingandbenchmarking.iea-4e.org/matrix?type=product&id=5>

²³ Australia also regulated non-clear lamps, but not at a level that is equivalent to CFL efficacies.

²⁴ It is worth noting that the additional minimum performance requirements (for example related to lifetime, colour, lumen maintenance, etc) are similar in Australia, the EU and Korea.

²⁵ As evidenced by the ongoing upward revisions to the Canadian/USA Energy Star specifications for CFLs and elsewhere.



Figure 7. Overall stringency of requirements for all known current and future regulations for 'omni-directional non-clear lamps' and CFLs in reporting countries.

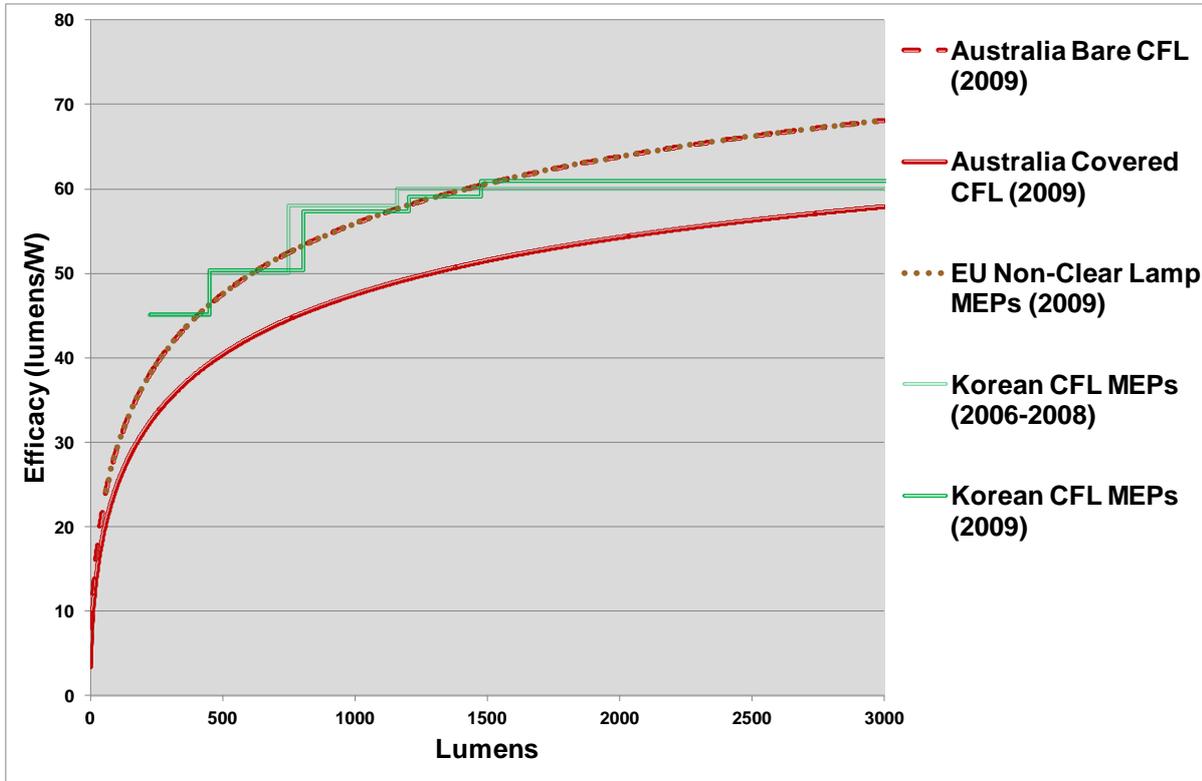
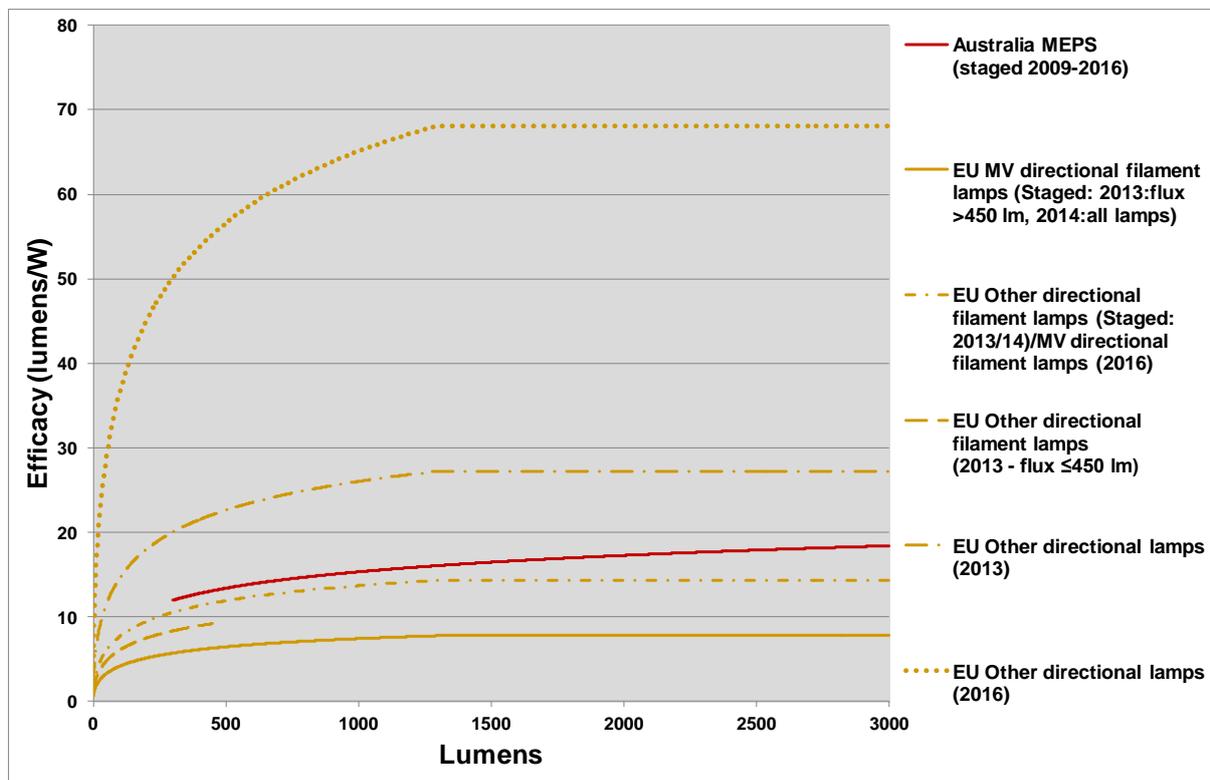


Figure 8. Overall stringency of requirements for all known current and future regulations for 'directional lamps' in reporting countries.

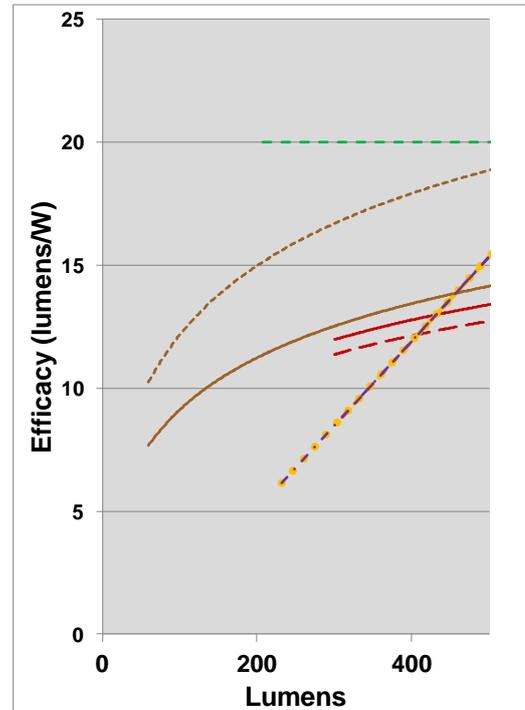


2.1.4. Variation in the scope of regulatory requirements

As noted earlier, there is variation in the way that regulations define exactly which lamps are captured by the scope of the MEPs.

The first significant difference is that almost all regulations have a limited minimum and maximum range in terms of lumen output or power, i.e. the regulations do not apply to 'small' or 'large' lamps. Figure 7 shows an expanded view of the lower limits for minimum efficiency for regulated clear lamps. At this lower end, the regulations encompass lamps greater than 25 W (approximately 300 lm) in Australia down to 60 lm (approximately 7 W standard incandescent) in the EU member states. A similar situation exists for the upper end of the regulations where the limits are 2,600 lm in Canada and the USA, 3,000 lm in Korea, and 12,000 lm in the EU lamp types. Further, upper and lower limits to MEPs may entice consumers currently using lamps near those limits to switch to slightly larger or smaller lamps, thereby bypassing the regulatory requirements. Given that these lamps perform the same functions in all locations, this would appear to be a further opportunity for international harmonisation to align the upper and lower thresholds of regulatory scope.

Figure 7. Expanded view of lower limit of clear lamp regulations.



The second significant difference in the scope of regulation is the types of lamps excluded from the regulation, typically for specialist applications, e.g. lamps designed for airport runways, lamps for appliances, etc. These exemptions are often due to cultural, historical and technical differences²⁶ and as a result, vary between regulations. In principle, such variations should be of no concern if appropriate for local conditions. However, such differences create two potential risks:

- 1) At the detailed level, the exclusions are very different across the countries studied. Such difference has the *potential* to cause confusion for suppliers. This confusion may lead to the inadvertent supply of non-compliant lamps to some markets and/or the unnecessary restriction of supply of certain lamp types to other markets.
- 2) There is a potential that exemptions may lead some suppliers to alter the technical specification, or in some cases just the declared lamp type or application, of their products to be compliant with the regulations. There is some evidence that such exploitation is currently occurring in the EU where 'shock-proof' lamps are excluded

²⁶ For example, the historical and technical barriers that sometimes arise are amply demonstrated by a particular sort of dimmer switch in very common use in Australia but also seen in North America. This dimmer relies on current leakage which means the majority of CFLs will not operate on the circuit.



from regulation. However, evidence suggests 16 million such shock-proof lamps were sold as 'general domestic service' replacements in the EU in 2012²⁷.

Countries are taking various approaches to limit such impacts. For example, the USA has a mandatory system that re-examines the exemption given to particular lamp types if sales of those lamps reach twice the levels projected during the original rule making process. However, no system appears fool-proof and the best approach seems to be to maximise the scope of legislation wherever possible, and to remain vigilant to the possibility that these issues may arise. This vigilance is particularly important during the current market and technology transition where LEDs have the potential to merge the traditional lamp, fitting/luminaire and supporting structure or other functionality into a single unit. For example, consider a new 'LED lamp' that has integral dimming/colour variation functions, integrated movement sensitivity, and data carrying/wifi relay capacity; is this still a 'lamp'? And if so, in what state should the light output and energy consumption be measured. Regulators are going to have to be far sighted and define future regulations in a much more general form to capture the sheer variety of products that may enter the market, and have structures developed so that when an anomaly occurs, revision of scope is possible. Ideally these actions should be taken at the international level (e.g. through the International Electrotechnical Commission (IEC) or intergovernmental bodies such as the 4E) to ensure that short term responses at the national level do not hamper longer term alignment as is currently the case.

One final note on the inclusions and exemptions relating to the European Union. The EU now requires higher lamp survivability than the international norm in test methodologies of modal failure (i.e. at least 70% of lamps of a particular model must reach the rated lifetime when tested rather than the more typical 50% international norm). However, this higher survivability requirement is closer to something the consumer is likely to expect based on the lifetime declaration. Policy makers may wish to consider similar requirements across a range of performance parameters so that consumer satisfaction is maintained as they transition to the new, potentially unfamiliar, lamp types required by the regulations.

2.1.5. Tolerances, allowances and declarations

As noted above, the Australia 2009-16 and EU 2009-12 clear lamp requirements are functionally identical. However, the less stringent interpretations of tolerances and allowances in the EU has the net effect of EU regulation appearing to be at a higher performance level. Such differences in regulation only increase the chances of misinterpretation and resulting non-compliance by suppliers (or increased costs to suppliers in meeting the different regulatory requirements). While such differences in the approach to tolerances and allowances is often an historical artefact within national regulatory regimes, and so may be challenging to alter, there again seems value in regulators seeking to resolve unnecessary differences in interpretation at an international level.

²⁷ Refer to the EU Mapping Document downloadable from mappingandbenchmarking.iea-4e.org/shared_files/643/download.



2.1.6. Other policy actions supporting improved lighting efficiency

Although the primary focus of this benchmarking is the regulatory policy interventions related to the phasing out of inefficient lighting products, a number of other policy actions are currently (or have been) in place that will have an effect on the apparent outcomes of the regulatory policies. In particular, most countries have strong promotional, labelling, financial support mechanisms and/or building codes which have directly or indirectly supported the adoption of higher efficiency products (in particular CFLs and more recently LEDs).²⁸

In addition the UK voluntary agreement²⁹ with retailers to phase-out most inefficient domestic lighting between 2007-2010, i.e. slightly in advance of the requirements adopted by most other EU member states, appears to have *initially* offset a negative market movement elsewhere (see Sections 3.2 and 3.3) until the approach was forced to be abandoned.

Japan has a number of non-regulatory policies in place for domestic lighting, the flagship being its 'Top Runner' programme. The Top Runner programme attempts to identify the most efficient product on the market at a particular time. An agreement is then reached with industry on a future deadline where all (national) manufacturers must achieve a sales weighted fleet average efficiency for that product equal to, or better than, the best product in the base year. As an example, a target has been set for the fiscal year of 2017, by which time the sales average luminous efficacy of daylight, daylight white, and white LEDs should exceed 110 lm/W, and that of warm white and extra white should exceed 98.6 lm/W. Previously, Japanese manufacturers entered into a voluntary agreement to end incandescent lamp production from 2008 onwards and the Japanese government issued voluntary administrative guidelines for promoting high efficiency CFLs, and in a later update LEDs, replacing incandescent lamps by 2012.

A number of countries have had programmes to distribute free (or at greatly reduced cost) energy efficient lamps. Canada ran the 'switch and save' promotion of CFLs from the mid-2000's. In Australia, the energy regulatory authorities in some states give mandatory efficiency targets to electricity suppliers, some of whom have used schemes that replace incandescent lamps with CFLs and more recently LEDs to achieve savings. Similarly, utilities in the UK distributed 224 million CFLs between 2008-2010 as part of their CERT (Carbon Emission Reduction Targets). However, most of these activities appear to have stopped or been significantly reduced by changes to the ways that energy savings from such programmes are calculated. In the UK, the reason for the revised approach is reasonable evidence that lamps distributed this way do not all end up in use, although the extent of this is unknown. In Australia the remaining programmes require the installation of the product in-situ and removal of the inefficient lamps to address this issue.

²⁸ Although they are excluded from the scope of this study, it is worth noting that many countries/regions have had highly successful programmes targeting fluorescent tubes. Many countries are in the process of banning the sale of T12 tubes (Korea did so before 2007). Further, market penetration of T5 tubes is rapid in a number of markets.

²⁹ Between 2008-2010 utilities in the UK also distributed 224 million CFLs as part of the CERT (Carbon Emission Reduction Targets).

2.1.7. Metrics for enforcement and impact

One final issue that is of relevance to all regulatory regimes is the metrics used for enforcement and the measurement of the impact of the regulations. Clearly when enforcing regulations in the market place it is the *actual measured* efficacy of the *individual* lamp that is being imported, or sold, that is of importance. However, when considering the *impact* on the market, the *average efficacy of all lamps* sold is the most appropriate measure, not the *average of the sum of lamp efficacies*.³⁰ While a true indication of impact requires knowledge of usage patterns and the lamps being replaced, considering the *average efficacy of all lamps* sold gives an indication of the likely direction of changes in *consumption* (by taking into account potential changes in consumer preference for the size/power of the lighting products they are selecting). The average of all lamp efficacies sold provides almost no useful indication of market impact.

2.2. Key issues for policy makers

Despite the large variety of sizes, shapes, colours, caps, etc., lamps are *the* most globally traded energy consuming product. However, while on the very broadest level the regulatory approaches to the phase-out of inefficient lighting products across borders are similar, at a more detailed level there are major differences in the scope of products captured by the regulations, and in the definitions of efficiency and other performance parameter requirements. Given the global picture of the supply, and the evidence to date that almost all regulatory requirements that have been introduced could be met by suppliers, the alignment of efficiency requirements between jurisdictions should be technically *relatively* simple if the political environment were to allow this approach (with necessary amendments to account for local conditions/tolerance interpretations). Similar opportunities exist through the alignment of the various 'scopes and exclusions', e.g. general adoption of the requirement for CFL equivalent efficacies for all non-clear light sources, alignment of upper and lower lumen thresholds across national boundaries, etc. Such an alignment of requirements is likely to:

- Enable the realisation of substantial additional energy savings. Simply adopting the most stringent performance requirements and product scopes *that are currently in place or will imminently come into force* in participant countries is estimated to result in an increase in the stringency of existing requirement of between 10-30% in most participating countries.
- Enable better supplier understanding and compliance with requirements of regulations in all countries.
- Enhance the potential for local and cross border enforcement actions;
- Facilitate increased global trade and *potentially* reductions in cost to the consumer.

³⁰ Equation one: *Average efficacy of all lamp = (sum of all lumens sold)/(sum of all wattages sold)*. Equation two: *Average of the sum of lamp efficacies = (sum of efficiencies of all lamps sold)/(sum of lamp sold)*. Equation one results in lamps with higher wattages (and hence energy consumption) having a greater impact on the overall resulting average efficacy. Equation two gives equal weighting to all lamps irrespective of consumption.



If such alignment results in the equivalent of saving just 1 W for each light bulb sold in the countries included in this study, that would have yielded additional savings of over 300 GWh/year or approximately 0.25 million tonnes/year of avoided CO₂ emissions.³¹ However, this saving is actually likely to be *much* higher in these regions. Further, given the size of these trading blocs, such harmonisation would send a powerful signal to other countries on the levels of ambition possible, and the benefits in reduced energy consumption (and increased trade) from harmonisation.

There are ongoing efforts for international alignment through activities such as the Australian-led efforts to develop internationally agreed CFL performance standards in the IEC, however these are proving challenging, with, for example, the majority of voting representatives in the IEC lighting standards committee voting against a proposal for harmonised CFL performance levels. Further, due to the difficulty in revising regulations in a number of jurisdictions, such harmonisation of action outlined above is unlikely to be possible during the implementation of current regulatory requirements. However, policy makers should remain aware of the opportunities when local requirements are revised in the future (policy makers currently undertaking revisions may wish to take particular note of the USA requirement that new rules must be in place by 2017 that will set a minimum average efficacy of 45 lm/W for all lamp sales).

A more immediate opportunity is presented as test methods and regulatory requirements are developed for LEDs. International coordination of action at this early stage of market penetration (such as the recently developed CIE and IEC test methods for LEDs, recommendations for performance measurements and levels from the IEA 4E SSL Annex and elsewhere³²) has the potential to yield dramatic benefits for the consumer through wider choice of high quality products and for reductions in emissions in the medium term. Further, there appears significant value in international cooperation to monitor and develop appropriate and coordinated responses to the introduction of 'beyond illumination' products that may integrate functions such as dimming/colour variation functions, movement sensitivity, and data-carrying/wifi relay capacity, etc. To deal with these issues, policy makers will need to be far sighted and define future regulations in a much more general form to capture the sheer variety of products that may enter the market; and undertaking this task on a coordinated international basis is likely to limit potential future problems associated with lack of harmonisation.

At the very least, policy makers should be aware of the issues that could affect the desired outcomes of their policies as they become effective in local markets. At present it appears that technical compliance with regulations should be relatively easy in all regions. However, policy makers may wish to put in place performance requirements (or other policies such as

³¹ Assuming the 830 million lamps (estimated combined sales of lamps in countries studied in 2013) save 1 W and operate for an average of 1 hour per day for each day of the year. Average CO₂ emissions factor assumed to be 0.8 kg of CO₂ per 1 kWh of electricity consumed.

³² Other similar actions are being supported by the UNEP/GEF En.Lighten Project, APEC, ASEAN, etc. However, there appear to be opportunities for further collaboration/harmonisation between these activities.





the US's ENERGY STAR endorsement programme) that ensure consumers have access to replacement products of appropriate quality and functionality.

Finally, to ensure they have a good understanding of the market and are in a position to react to inappropriate market movements, most policy makers would benefit from enhanced market monitoring activities to quickly identify if:

- There is a significant increase in sales of lamps falling outside the lower or upper lumen or wattage limits of the regulations. This would indicate consumers are switching to smaller or larger lamps rather than adopting the more efficient alternatives as intended by the regulations;
- There is a significant increase in the sales of lamps that are excluded from regulations, or that are subject to relaxed requirements (e.g. modified spectrum lamps or shock-proof lamps). Such an increase in sales is *likely* to indicate suppliers are bringing products to market that are modified in some way (either technically or by declaration) thus enabling the sale of existing products that confound the intent of the policy;

Where policy makers are unable to monitor the impact on actual consumption in their market through full stock models, they may wish to do so through monitoring of the efficacy of sales. However, in this case, it is important to do so through the monitoring the *average efficacy of all lamps sold*, not the *average of the sum of lamp efficacies*.³³

³³ The (sum of all lumens sold)/(sum of all wattages sold) **not** the (sum of efficiencies of all lamps sold)/(sum of lamp sold). This is because in the first equation lamps with higher wattages (and hence energy consumption) have a greater impact on the overall resulting average efficacy, rather than all lamps having equal weighting irrespective of consumption, as is the case in the second equation.



3. Impact of regulations on lamp sales and implications for policy makers

3.1. Observations

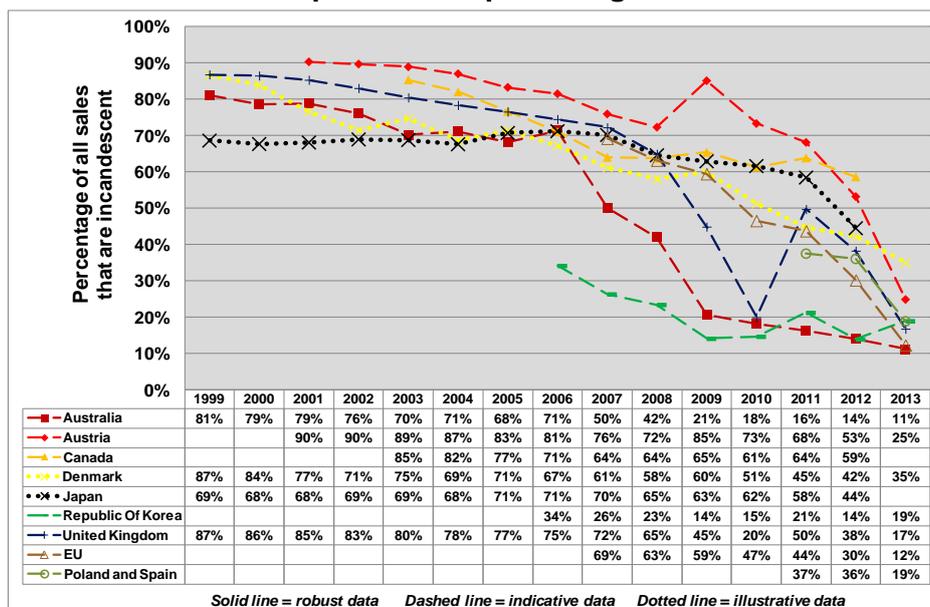
As stated in the introduction, the key objectives for examining time series lighting sales data in the target countries/regions are to look for any indications of major outcomes of the various policies implemented to date; to identify changes in the overall average efficiencies of the new products entering the market; and to identify key areas of concern for policy makers, including areas where additional or modified policy intervention may be more effective in the future.

The use of sales data remains the best metric for examining the immediate market impact of regulatory changes. However, as detailed in Annex 3 and Annex 5, the use of sales data as the basis for analysis has limitations and, in transient markets, these limitations become more exaggerated over time. Therefore, before proceeding to the following analysis of impacts, readers are encouraged to review these Annexes which provide more details of the limitations of the approach and resulting outcomes.

3.2. Impact of regulatory interventions on the sales of incandescent lamps³⁴

As illustrated by Figure 8, where mandatory regulation has been introduced to curtail sales of inefficient lamps, the reaction of the market has been substantial, with major falls in the sales of incandescent lamps.

Figure 8. Incandescent lamp sales as a percentage of all sales of domestic lamps.



³⁴ In line with the rest of the document, the term 'incandescent lamps' is used to describe all types of tungsten lamps (both reflector and non-reflector) not encapsulated by a halogen filled capsule. For full definitions please refer to http://mappingandbenchmarking.iea-4e.org/shared_files/611/download

Following the very gentle fall in in the pre-regulatory sale of incandescent lamps from 80-90% of all lamps sold in 1999 to 70-80% by 2007, the countries introducing mandatory regulation relatively recently (Australia in 2009 and the EU countries phased from 2009-12) have seen a precipitous fall in incandescent sales to between 11 and 25%³⁵ of overall lamp sales. There is obviously a degree of variation in the speed of these falls due to:

- The specific phase out regulations coming into effect (phasing, exemptions, ability to sell existing stock after regulations come into force, etc.).
- Variations in cultural attachment to incandescent lamps and the ease of transition of consumers to alternative products.
- The political background and media coverage related to the introduction of the regulations, Austria and the UK being two examples where there was strong negative media reaction to the introduction of the regulations and there is evidence of stockpiling of incandescent lamps by both consumers and retailers, hence delaying the full short term impact of the regulation³⁶ (the original 2011 benchmarking document gives more details of the 'backlash' to the regulations and associated stockpiling of Incandescent lamps in Austria).

However, the overall trend is clear and ongoing as illustrated by Figure 9 which shows the reductions in sales of incandescents in the EU as the restrictions on various wattages come into force over time.

In Korea, the only other country where regulations were in force prior to 2012, there is no data preceding 2006 so it is not possible to reliably comment on the reason for its relatively low incandescent sales in this first reporting year.³⁷ However, it does seem reasonable to note that Korea began regulating the efficiency of incandescent lamps much earlier than other countries (2003) and although this initial level was not particularly stringent, those regulations have been revised twice in the interim. This does seem to suggest that regular revision to standards may be as influential as the actual performance requirement itself. Further, by 2014, Korean regulations will be the most challenging in the world for smaller

³⁵ Sales of incandescents in Denmark were reported as 35% in 2013. However, a significant degree of modelling was required to create the Danish reported sales values and it is believed incandescent sales are likely to be over-reported and actual sales values are closer to those reported by other EU countries.

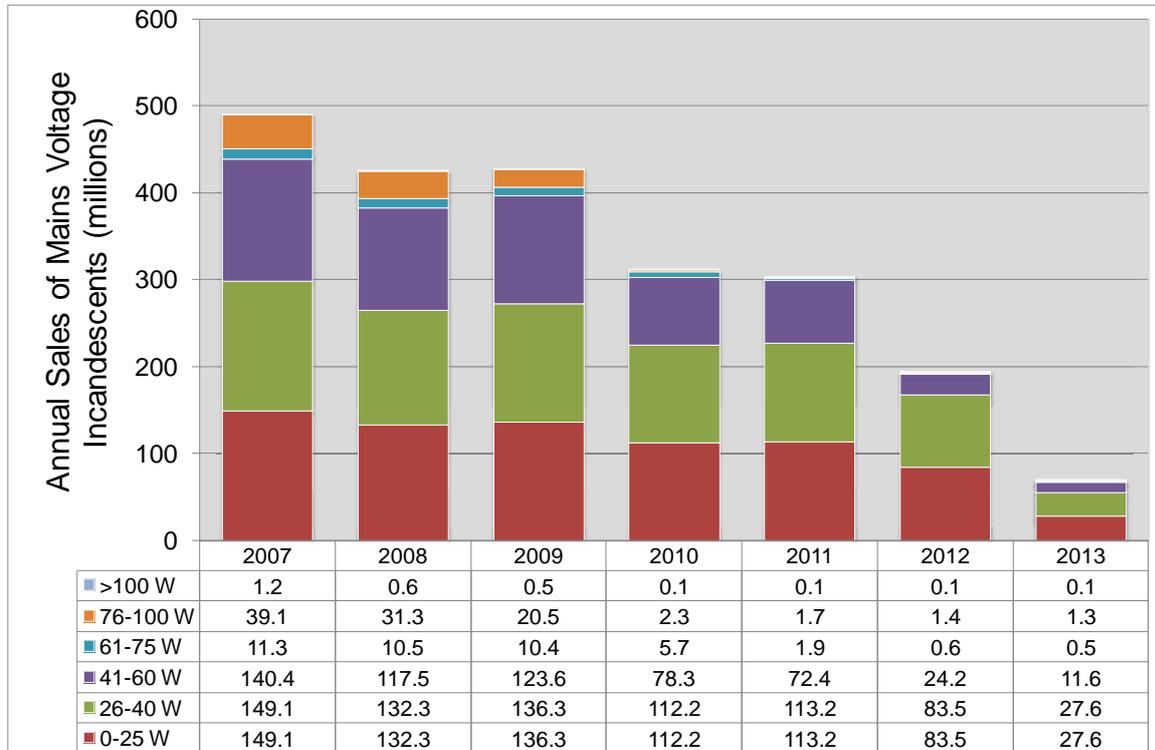
³⁶ Sales of incandescents in the UK appear particularly volatile. However, the apparent 'pre-regulation' falls in incandescent lamp sales from 2008 to 2010 were the result of a combination of a voluntary agreement with retailers to restrict the sale of incandescents in advance of the EU wide regulations, and very high levels of CFL distribution via various other UK policy initiatives (the high levels of CFL giveaways resulting in the *percentage* of incandescents appearing to fall dramatically although the actual quantity of sales fell less precipitously). However, the expiry of the agreement and the end of the giveaway programmes resulted in the UK reverting to trend above the EU average. This negates the apparent finding in the 2011 report which postulated the voluntary agreement in the UK avoided the stockpiling experienced in Austria (refer to the UK national mapping for more details at http://mappingandbenchmarking.iea-4e.org/shared_files/641/download).

³⁷ It is likely that the actual proportion of incandescent lamps sold in Korea is somewhat over-reported as there is limited market data on sales of halogen lamps which, if significant, could significantly further reduce the proportion of incandescent lamps sold Korea. However, this would also have a similar effect in lowering the percentage of CFLs and LEDs sold into the market which, overall, would lead to a reduction in the reported average efficacy of all sales. However, despite this limitation in the data, there is reasonable evidence that Korean data is *broadly* correct and that the associated analysis is valid.



sized (the most inefficient) incandescent lamps, continuing to send a clear and strong message to the marketplace.

Figure 9. Sales volumes of incandescent by wattage in the EU (2007-2013).



There are interesting differences in the two countries where there have been no regulations, or where they are only recently coming into force:

- Prior to the regulatory interventions elsewhere, sales of incandescents in Canada were falling more rapidly than in most other countries. From 2003-2008 sales of incandescents had fallen from 85% to just 54% of all lamp sales. This significant fall aligns closely with the 2004 launch by National Resources Canada (and its partners - primarily utilities) of 'switch and save', a major national promotional campaign targeted at encouraging consumers to switch to CFLs. From 2008 this reduction in the sales of incandescents has slowed, and there is some evidence to suggest a minor backlash to the 2014 introduction of regulations lamps as shown by the slight increase in the proportion of incandescent sales in 2011.³⁸
- Japan, the only reporting country with no formal regulations restricting incandescent lamp sales, had a proportion of incandescent sales only marginally higher than most EU countries in the last reporting year (2012). However, this should be set against a background of Japan having a historically lower use of incandescents (broadly stable

³⁸ Although on the evidence available it is impossible to discount the possibility that this is simply a result of a proportion of consumers that had switched to CFL being disappointed with product performance and now switching back to alternative products.

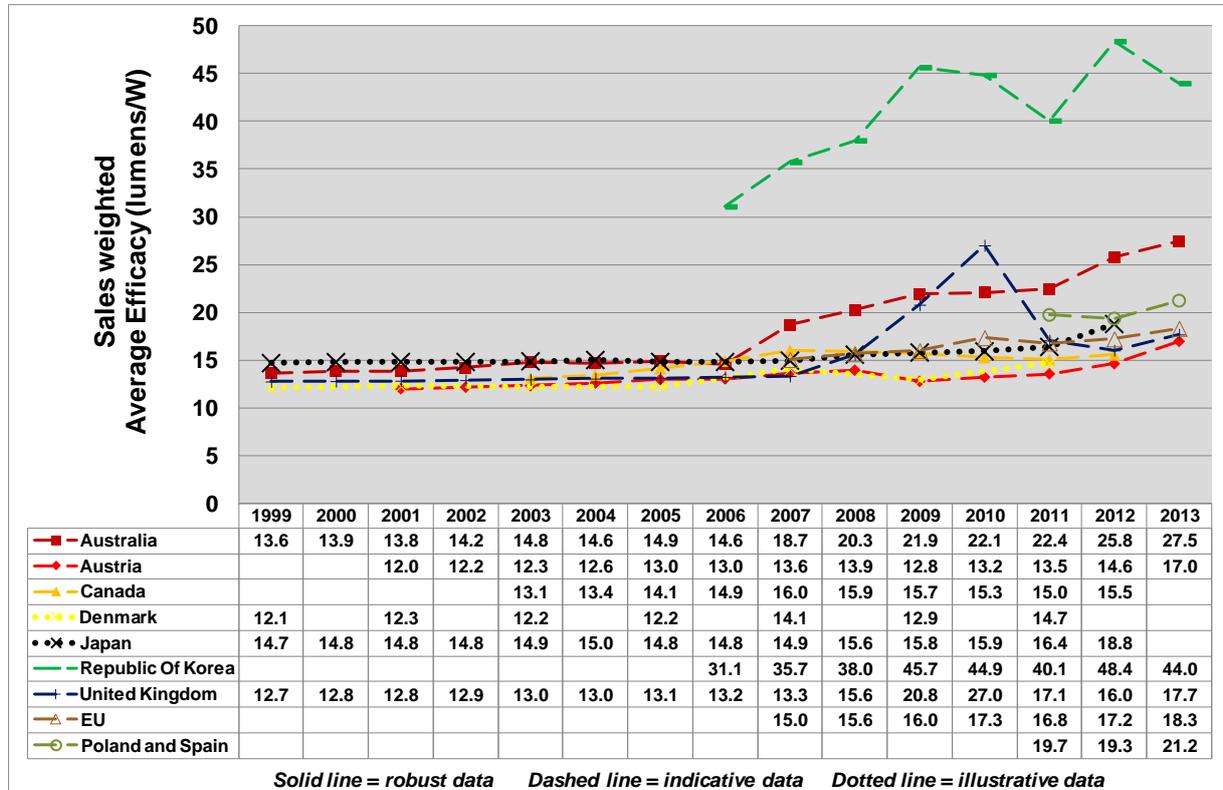


at 70% up to 2007). Further, Japanese manufacturers entered into a voluntary agreement to end incandescent lamp production from 2008 onwards (although imports were still legal, which explains the continued sale of incandescent lamps) and the Japanese government issued voluntary administrative guidelines for promoting high efficiency CFLs, and in a later update LEDs, to replace incandescent lamps by 2012. The 2011 tsunami impact on the Fukushima nuclear power plant and the subsequent shutdown of other facilities has led to an aggressive governmental promotional campaign (targeting both consumers and industry) focusing on national energy saving which also appears to have played a part in the shift to more efficient lighting products.

3.3. Impact of regulatory interventions on the overall efficiency of lamps sold

Given the significant falls in the sales of incandescent lamps in all countries as a result of phase-out regulations (and other policy interventions), it might be anticipated that there would be a significant increase in the average efficacy (lamp efficiency) of new lamp sales as consumers migrate to the higher efficiency alternative products. However, as Figure 10 indicates, in most countries this increase is relatively minor.

Figure 10. Impact of regulatory and other policy interventions on the average sales weighted efficacy of annual lamp sales.



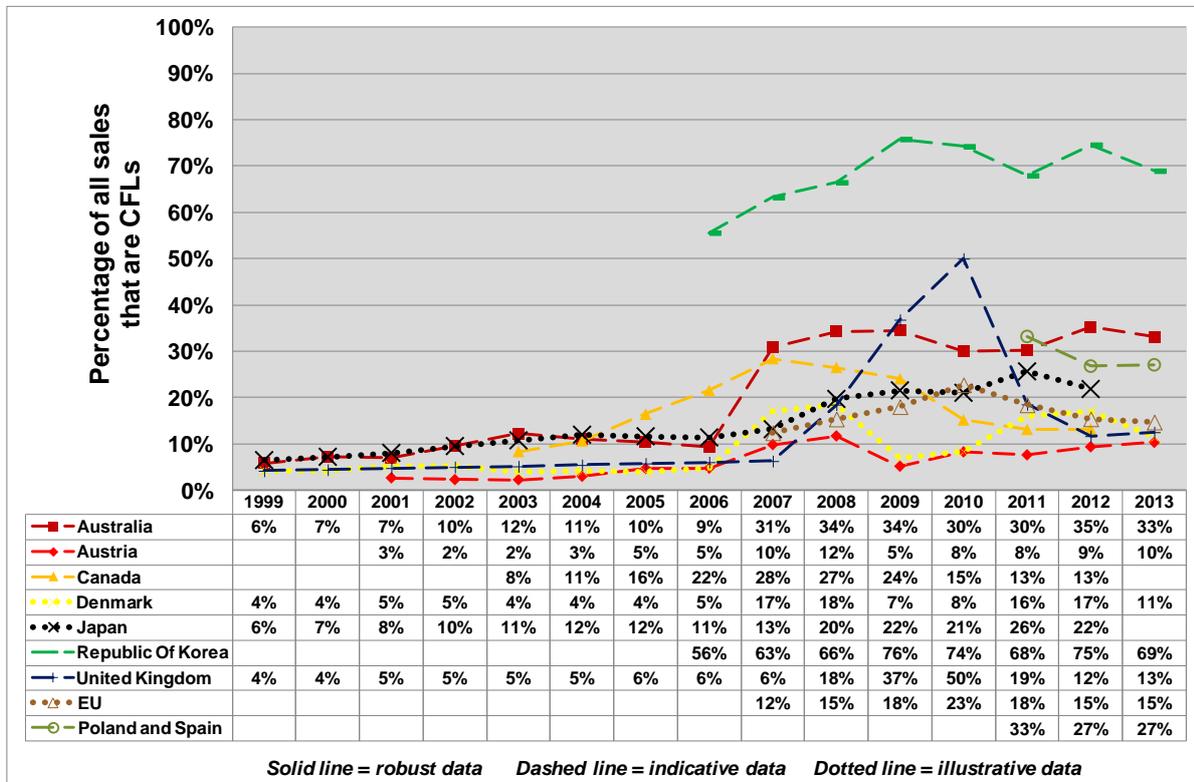
Australia and Korea are the only outliers. The Australian market has moved from annual average efficacy of sales of around 14 lm/W to over 27 lm/W and rising, and Korea has

achieved a quite astonishing average efficacy in the mid-40's lm/W³⁷. However, in the majority of countries, while there has been a noticeable increase in the average efficacy of lamps sold, this increase is relatively modest compared with the potential. Typically the increase has been from between 12-15 lm/W to 17-20 lm/W. While in itself this represents a 25-33% improvement in efficacy which should be applauded, it was widely anticipated by policy makers that as incandescent lamps were withdrawn from the market, there would be much greater increases in efficiency as consumers adopted CFLs and LEDs (with efficacy of around 60 lm/W and increasing).

3.3.1. Sales of CFLs, LED and halogen lamps

The apparent lack of market movement to CFL and LED lamps is borne out by Figure 11 and Figure 13 which show the percentage of sales attributable to CFLs and LEDs³⁹ respectively, with Figure 12 showing percentage of sales that are combined single and double ended halogen lamps (readers are once more referred to the cautions given in Annex 3 regarding interpretation of the reported data, particularly those related to the proportion of lamp sales by type not directly equating to equivalent changes in stock due to differing lamp lifetimes) .

Figure 11. CFL (pin based and integrated ballasts) sales as a percentage of all sales of domestic lamps.



³⁹ As stated earlier, due to the relatively recent entrance of LEDs to the market, and the higher percentage of LED lamp sales being made through non-traditional channels, the reporting of LED sales is considered somewhat unreliable in almost all countries.

Figure 13. LED sales as a percentage of all sales of domestic lamps.

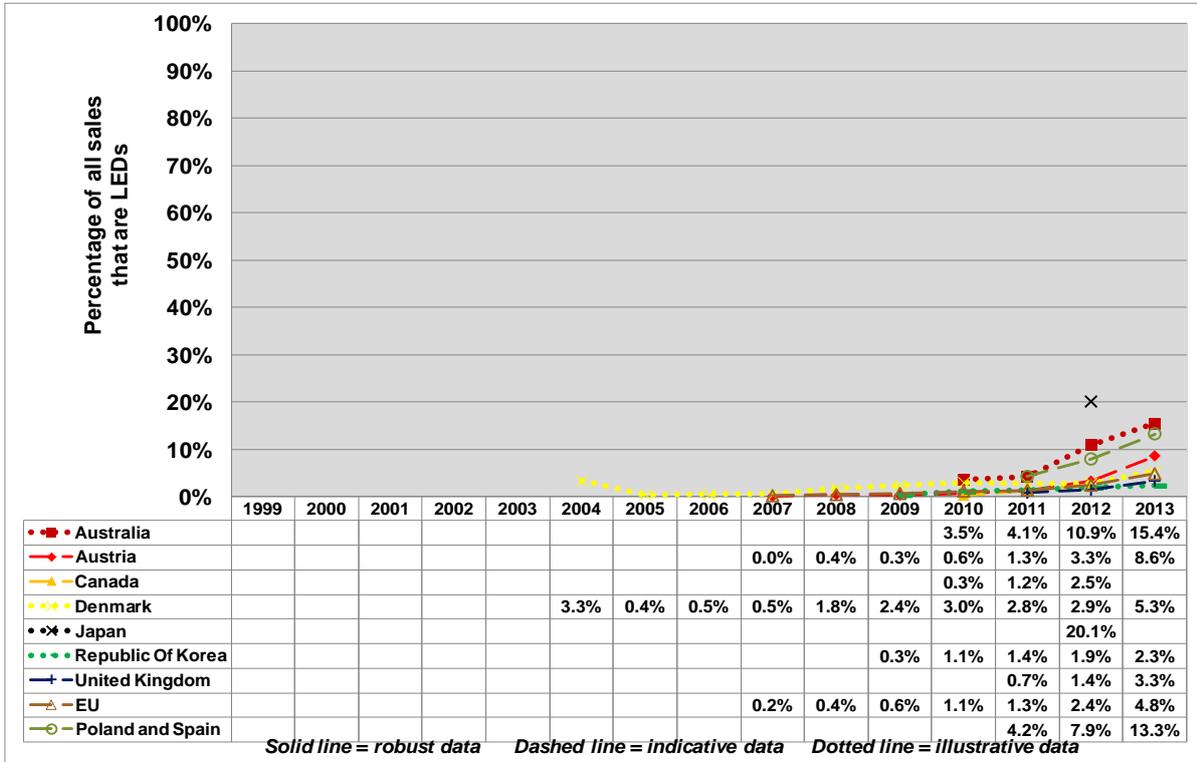
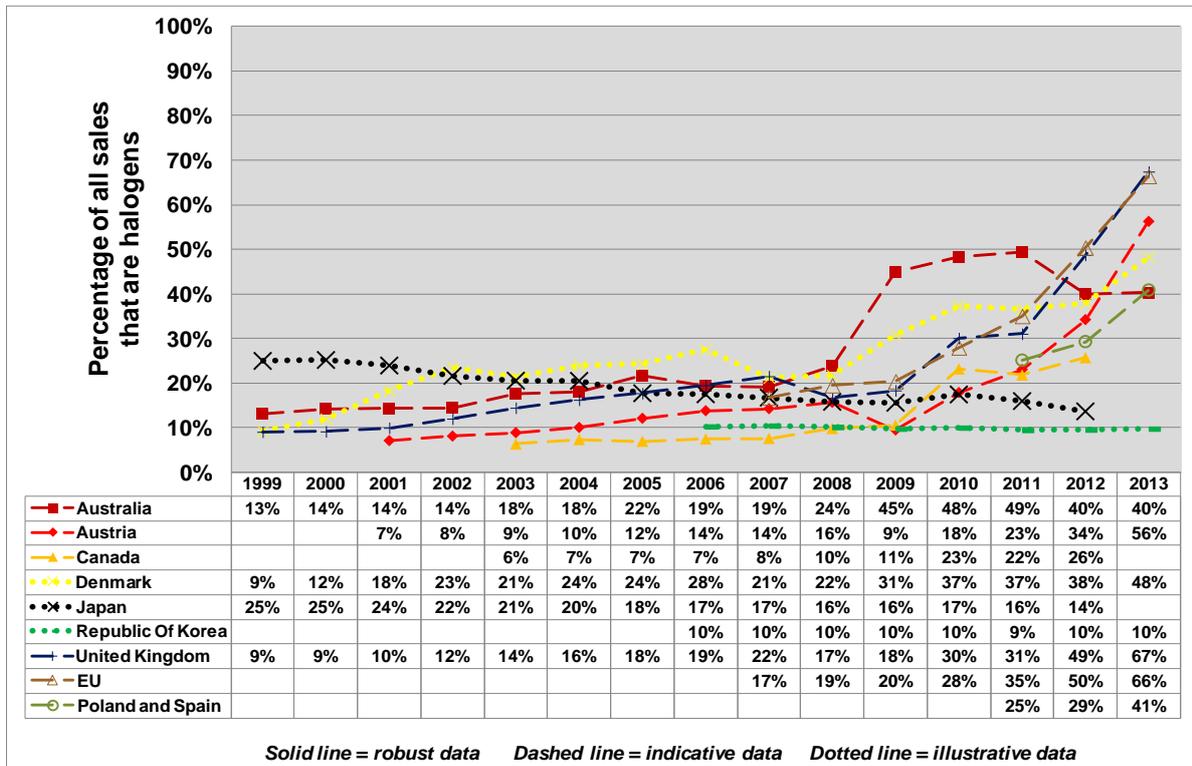


Figure 12. Halogen (single and double ended, mains and low voltage) sales as a percentage of all sales of domestic lamps.





It is clear that one of the primary reasons for the impressive average efficacy seen in Korean lamp sales³⁷ is the high levels of adoption of CFLs. Similarly, the outperformance of other markets by Australia is also related to *relatively* high levels of CFLs which have remained above 30% of all lamp sales since the run-up to the announcement of phase-out in 2007.⁴⁰

However, it is equally clear that in the EU countries, after brief turbulence in sales around the time of initial announcement and initiation of inefficient lamp phase-out, the proportion of CFL sales are beginning to stabilise at approximately 10-15% of all lamp sales,⁴¹ only marginally higher than the levels before the phase-out commenced. Hence, the sales of CFLs are not leading to a significant increase in overall efficacy of lamp sales. In fact much of the most recent increase in efficacy is attributable to the entrance of LEDs which are taking 3-9% of the market in the EU countries (with Spain/Poland being the outliers in the EU with LED penetration of 13% for unknown reasons). Further, the 10-15% of CFL sales in most EU countries in 2013 is based on a lower total number of lamps sold than prior to the regulatory intervention, i.e. the absolute number of sales of CFLs has not risen by the same proportion.⁴² This may indicate that even the small movement towards CFLs has actually stalled and the sales levels now seen are primarily replacement lamps for failed CFLs rather than a migration to CFLs from lower efficiency lamp types.

Obviously, as can be seen from Figure 12, the majority of the fall in the proportion of incandescent sales in the EU countries is actually being replaced by halogens. On the positive side, halogen lamps do have a higher efficacy than incandescent lamps, although only marginally so. Further, the increase in halogen lamp sales is smaller than the reduction in incandescent lamp sales as shown by Figure 14. So it is likely the overall efficiency of lamps installed in the EU is increasing at a higher rate than the efficiency of lamp sales (again refer to Annex 5).

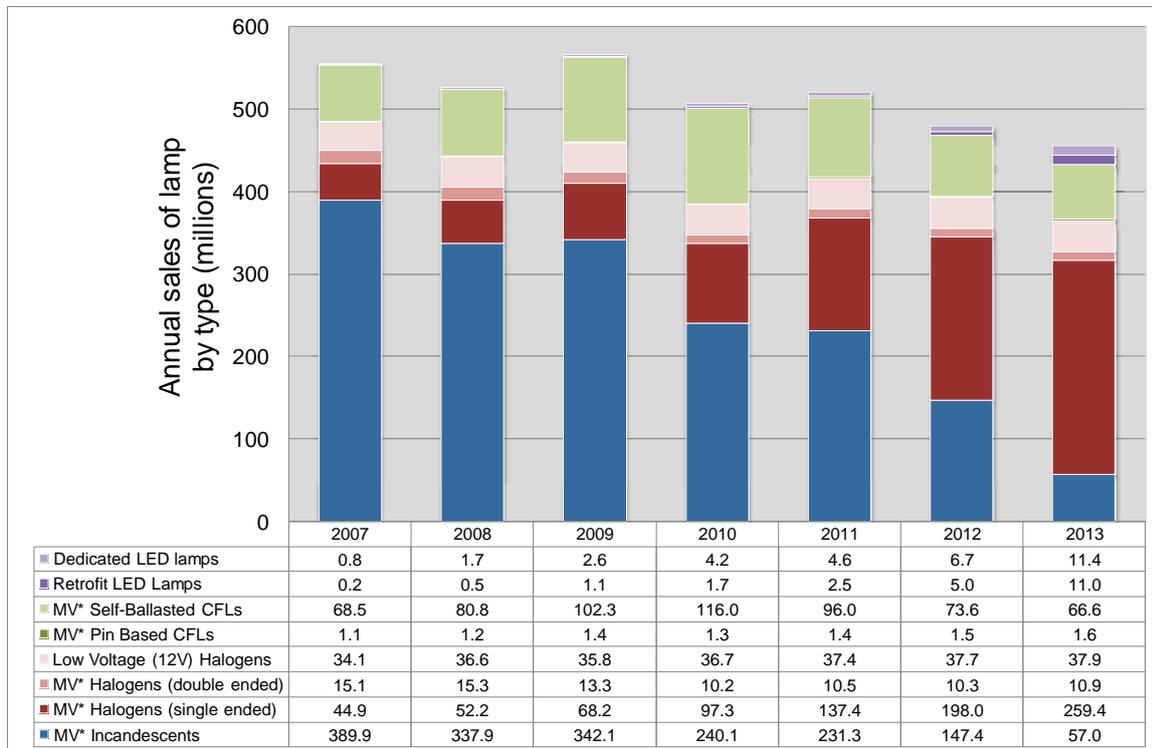
⁴⁰ It should be noted that a significant proportion of the reported CFL sales in Australia are the result of ongoing policy actions (e.g. white certificate programmes) at the State level. However, indications are that even without such interventions, sales of CFLs in Australia would still be at significantly higher levels than the majority of other reporting countries.

⁴¹ It should be noted the proportion of CFL sales in the combined Poland/Spain data is almost twice this level but unfortunately it has not been possible to establish the causes of this apparent anomaly.

⁴² For the reason why total sales of lamps are falling and the resultant CFL volumes are not rising as quickly as CFL sales as a percentage of the market, please refer to Annex 5. For specific details on CFL sales in individual countries, and the reduction of overall lamp sales, please refer to individual country mappings at: <http://mappingandbenchmarking.iea-4e.org/matrix?type=product&id=5>

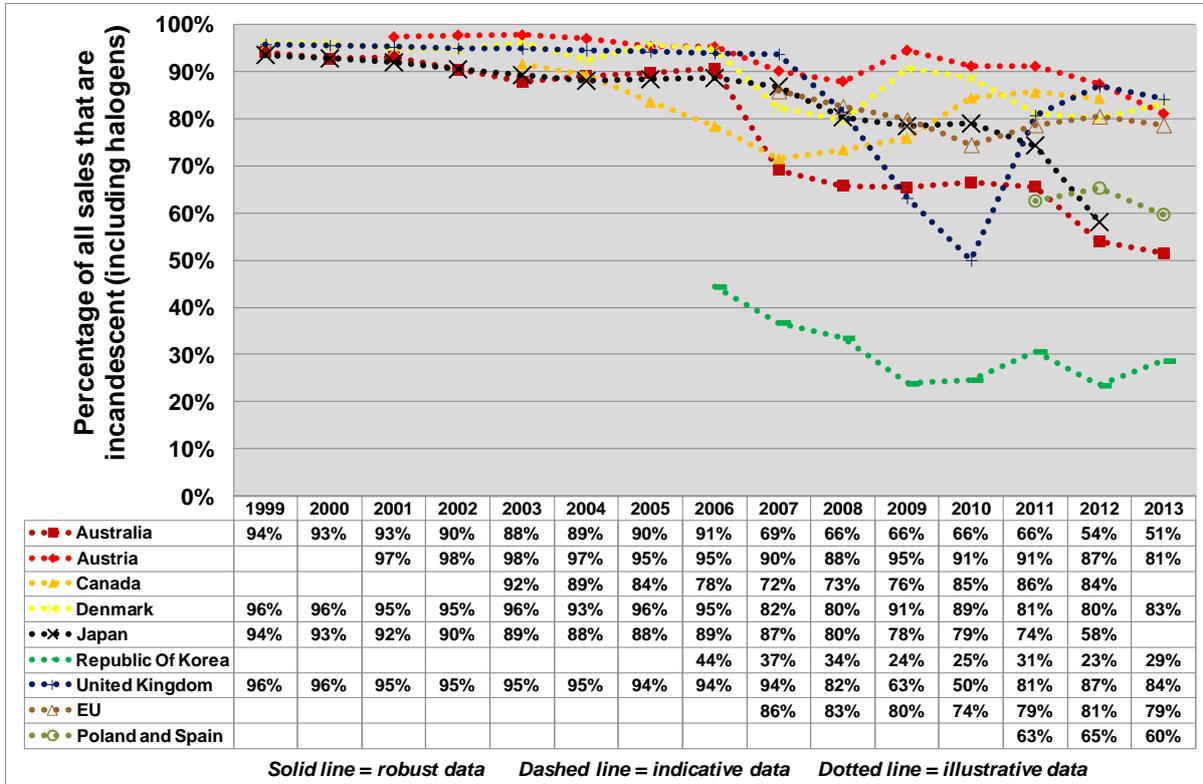


Figure 14. Sales of domestic lamps by type in the EU (2007-2013).



Nevertheless, as Figure 15 shows, following a brief period of turbulence during the initial introduction of the phase-out regulations, the combined sales of incandescents *and* halogens in most EU countries appears to be stabilising at around 80% of total sales (again with Poland/Spain being the outliers). While lower than the pre-phase-out average of above 90% of sales, this is still likely to be a concern for policy makers as it implies a core number of consumers are simply moving from incandescents to halogens. If the situation continues, in the relatively near term halogens are likely to become the new ‘default’ lamp choice for consumers, and any move to restrict the supply of halogen lamps may be met with the same negative consumer and media reaction seen in some countries during the initial removal incandescent lamps. Therefore, it is likely to be advantageous to continue the momentum of market evolution currently being experienced and expected by consumers rather than allowing the market to reach a new ‘steady state’ where improvements in stock efficiency will stall. EU policy makers may wish to factor this into their current consultations on the possible delay of the 2016 introduction of ‘Phase 6’ regulations which, when implemented will result in the removal of standard halogen lamps from the market. Further, as seen in Korea, regular revisions of targets pays dividends so, in the current review of lighting regulations within the EU (on energy-related products (ErP)) for lighting products, there is potential value in maintaining the momentum of change and adopting a still more ambitious target and mirroring the US commitment to average lamp sales of 45 lm/W by 2020.

Figure 15. Combined incandescent and halogen sales as a percentage of all sales of domestic lamps.

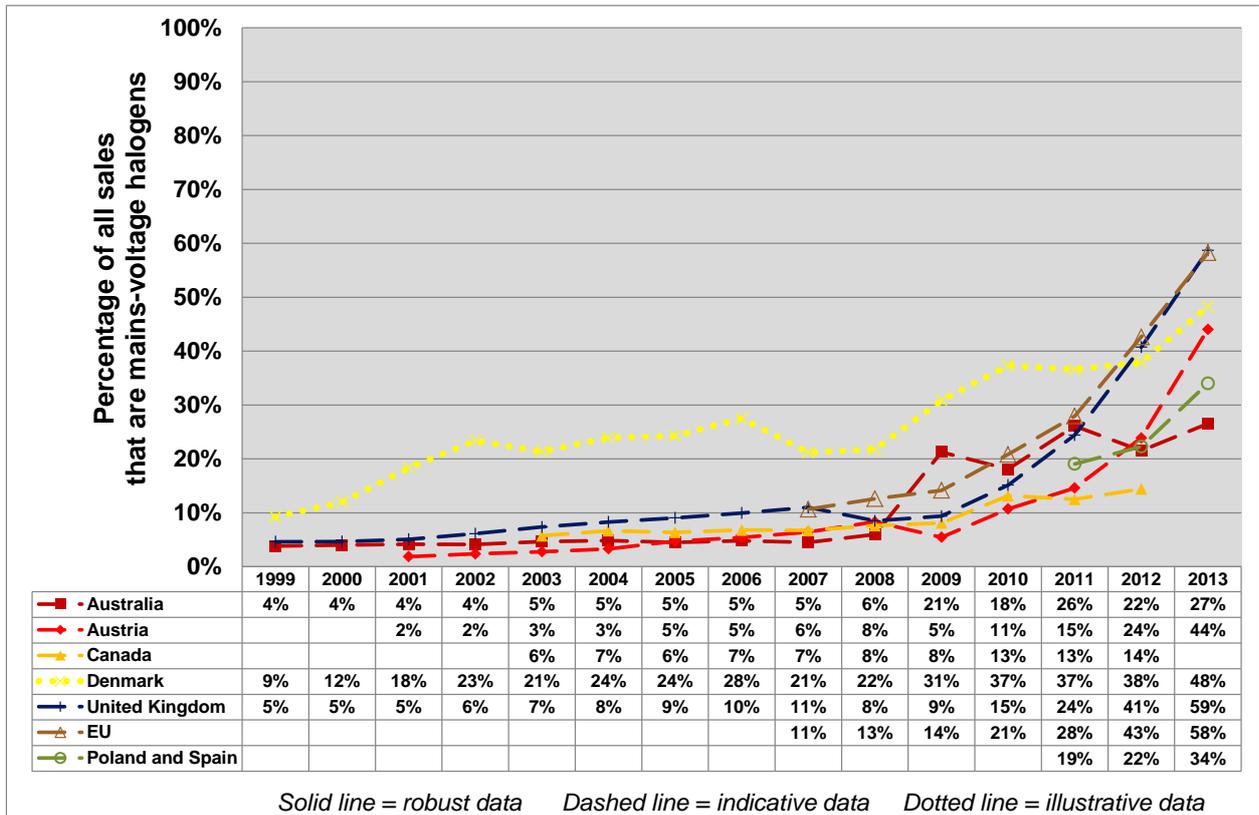


There seems to be a similar story developing in Canada. Although the full impact of phase-out is yet to be seen, it appears that CFL sales have fallen to a point where they are likely primarily to be replacements for failed CFLs rather than a move in installed stock, with the (currently relatively minor) falls in incandescent sales attributable to a migration to halogens. Further, while there is a degree of supposition needed, there seems a reasonable likelihood that as the phase-out schedule proceeds, the market is likely to continue to mirror the EU, with migration in sales to halogen rather than CFLs or (in the short term) LEDs. Further, Canada does not currently have an obvious future regulatory timetable like the EU or USA that will force the next step in lamp efficiency. Consequently, without additional action, the Canadian market may be stuck with halogens as the default consumer choice (and the resulting marginal increase in efficacy) for an extended period.

The Australian situation is slightly different. Following the introduction of phase-out regulations halogen sales spiked to 50% of all lamps sold (Figure 12), but more recently halogen sales have fallen back and appear to have stabilised at around 40%. However, this overall trend masks underlying market changes with increases in the proportion of mains voltage halogen lamps sales following the 2009 introduction of regulations (and recently stabilised at around 25% of sales (Figure 16)) being offset by recent falls in the sales of low voltage single ended halogen lamps (Figure 17) thought to be caused by market migration to

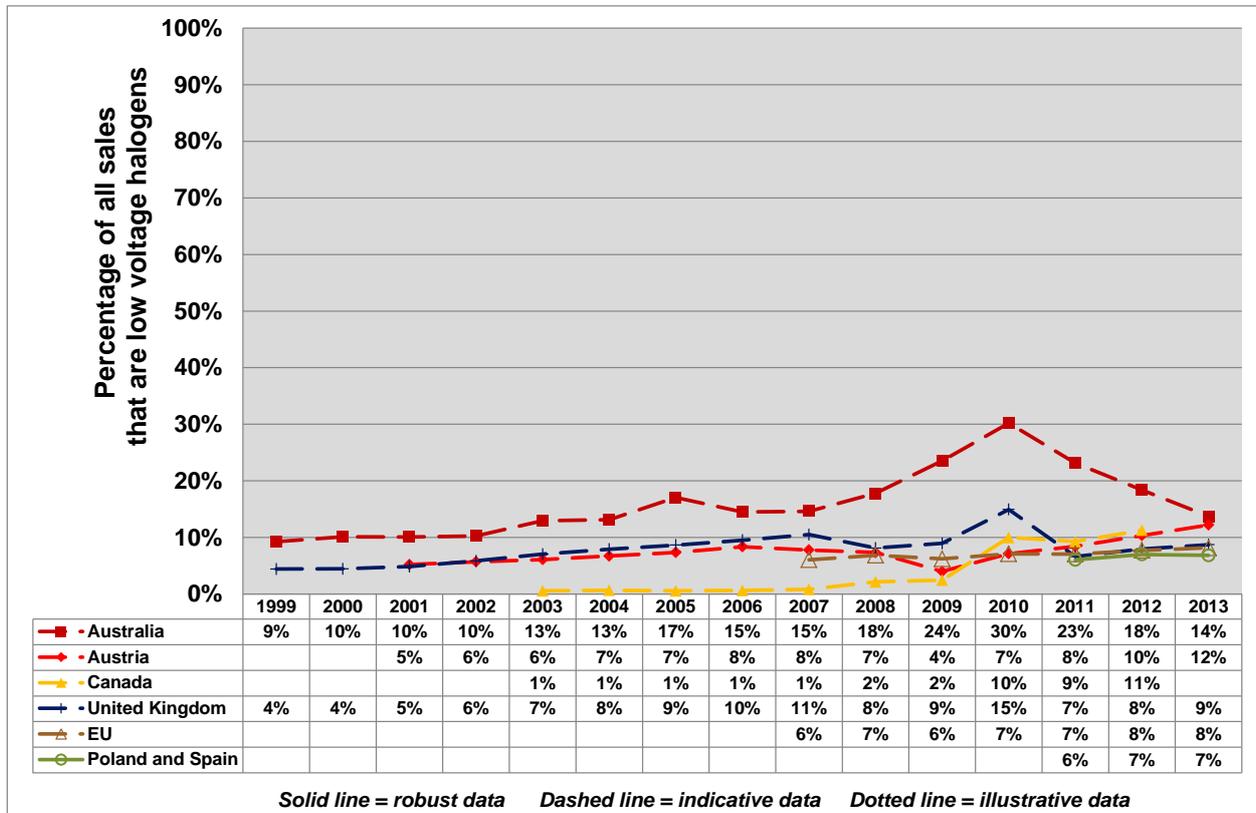
LEDs.⁴³ Nevertheless, at 50% of all sales, Australia has managed to maintain a lower level of combined incandescent and halogen sales than any country other than Korea, with CFL sales having stabilised around 30-35% (Figure 11). This has resulted in overall average efficacy of sales over 27 lm/W, almost 50% higher than most of the other countries following similar regulatory paths. While there is room for conjecture on the specific reason for this higher than average performance of Australia, it seems reasonable to suggest that the Australian regulators' engagement with the entire supply side chain (from original manufacturers as far afield as China and the EU, through to the major retailers in Australia) has been a major contributory factor; as has been the active development and supply of material for retailers to train staff and for use at point of sale (e.g. display boards on lamp equivalence, lifetimes, etc.).

Figure 16. Mains voltage halogen sales as a percentage of all sales of domestic lamps.



⁴³ It is worth noting that the potential trend towards low voltage halogen lamps identified in the 2011 benchmarking report has not materialised, with sales of low voltage halogen lamps having fallen back since the 2010 spike in both the UK and Australian. With the updated information now available, it appears the UK spike in the sales was due to a data anomaly, while the Australian spike was due to imports in advance of regulation, with the now stable sales servicing the higher level of low voltage halogen lamp installations in Australia.

Figure 17. Low voltage halogen sales as a percentage of all sales of domestic lamps.



3.3.2. Need for market monitoring and supervision for regulatory refinement and enforcement

One of the key outcomes from the benchmarking process was, not surprisingly, the remarkable changes in the type of lamps being purchased by consumers. In itself, this is an obvious statement, with the lamp switching resulting from the imposition of regulation and the market entry of LEDs. However, the specific evolution of individual markets is variable, and rapidly changing, as evidenced by the short lived increase in CFL sales in many markets, and the apparent spike in the sales of low voltage halogen lamps in Australia and the UK in 2010 which have now dissipated. Thus, it appears vitally important that regulators are in a position to monitor this ongoing market evolution to:

- Evaluate the impact of regulations and establish if original regulatory intent and expectation is being achieved, or whether modification or additions to the regulatory framework are required.
- Identify areas where regulations are being flouted and/or circumvented as appears to be the case in the EU with the increase in sales of shock-proof lamps as 'replacements' for traditional incandescents.
- Identify whether individual products are meeting the required levels of efficiency and other performance parameters.



To some extent this is already occurring, with countries such as Australia conducting analysis of market imports by lamp type, in-store monitoring, and testing of products. Korea also requires annual reporting of sales of all labelled products and, under normal circumstances, the USA requires ongoing monitoring of products exempted from regulation.⁴⁴ Unfortunately, in general it appears such market monitoring is rather ad hoc and relies heavily on industry-supplied data which is often aggregated in a form and does not provide the granular detail necessary to facilitate the analysis of specific market trends.⁴⁵ Further, lamps are not a traditional 'appliance' and may be deployed in a range of sockets with very different usage patterns.⁴⁶ These different operation patterns have a major impact on the practical life of products, which in turn impacts on both sales and the levels of energy and cost saving resulting from the regulatory intervention. Yet base knowledge of consumer application, and how this is changing over time, appears very limited in most markets (noting that a number of countries do undertake consumer surveys and intrusive monitoring, but the former requires accurate reporting by consumers which research indicates is inaccurate for most lighting products, and the latter is generally an insufficient sample to be representative of the general market – although both are better clearly better than no information at all).

Thus, it is likely that the current limited knowledge of consumer usage patterns highlighted in Section 2, combined with the restricted levels of ongoing market monitoring is impacting policy makers' ability to understand and develop policies appropriate to the market. Unfortunately, this situation is likely to become worse rather than better as regulation is extended to increasing numbers of products. Further, the market entrance of newer 'beyond illumination' products (again highlighted in Section 2) is likely to bring increasing energy use related to their extended functionality. Hence, there seems significant value in policy makers increasing levels of market supervision, monitoring and understanding of consumer activities to enable evaluation of existing regulation, and to develop timely strategies to refocus regulatory regimes as the market evolves.

3.4. Key issues for policy makers

Where mandatory regulation has been introduced for a significant period to curtail sales of inefficient incandescent lamps (Australia, the EU and Korea), the reaction of the market has been substantial with precipitous falls in the sales of incandescent lamps to between 11 and 25% of total lamp sales in the most recent reporting years. Slight variations in the scope of regulations, and the political, culture and media landscapes in the different countries have affected the speed and extent of the market transformation, but the impact is clear. Based on

⁴⁴ In the case of 'phase-out' regulations this is not actually the case in the USA due to congressional action (refer to the USA mapping at <http://mappingandbenchmarking.iea-4e.org/matrix?type=product&id=5>)

⁴⁵ This is compounded by a lack of clarity in a number of international customs/product codes for lighting products, particularly at the sub-code level where international harmonisation at a national level is poor, hence hampering monitoring of product flows. The rapidly evolving LED market appears particularly problematic at present.

⁴⁶ For example a lamp in a living area may be providing primary illumination and be in operation for 4-6 hours a day, while a bedside lamp may operate just 10 minutes each day. If CFLs or LEDs are replacing living area lamps and halogens replacing bedside lamps this gives a very different energy outcome than the reverse situation, even if overall market sales of both lamps types are the same.





the limited data available following the later introduction of their regulations (in 2014), the Canadian market appears to be following a similar trend.

Nevertheless, given the significant falls in the sales of incandescent lamps, the widely anticipated increase in the average efficacy of new lamp sales has not been realised in the EU. Typically the increase in average efficacy of lamp sales has been from 12-15 lm/W, to 17-20 lm/W. While this represents a 25-33% improvement in the efficiency of lamp sales, it is relatively marginal relative to the potential savings available.

The reason for the relatively small increases in efficacy appears simply to be that consumers are migrating from the purchase of incandescent lamps to the purchase of marginally more efficient halogen products; the combined sales of incandescent and halogen lamps now being only slightly lower than at the time of intervention. This is clearly not the major market movement to CFL and LED purchase which many regulators may have anticipated and factored into original energy savings projections. In fact, in the EU countries (and most likely Canada), there is a suggestion the consumer migration towards CFLs has actually stalled and current CFL sales are primarily replacing existing CFL stock that has failed. Through their ongoing engagement with market stakeholders, Australia has fared significantly better, with CFL sales still above 30% of the total market (50% when low voltage halogen lamps are excluded), however, even here sales of mains voltage halogen lamps increased significantly following the 2009 introduction of regulations and have recently stabilised at around 25% of sales. Further, while data on LED sales is uncertain, their penetration of markets is apparently still limited at between 3 and 15% of total lamp sales.

If the situation continues, policy makers in the EU, Canada and, most likely the USA and Australia, risk halogens becoming the new 'default' lamp of choice for consumers. Consequently, any later move to restrict the supply of halogen lamps may be met with the same negative consumer and media reaction seen in some countries during the initial removal of incandescent lamps. Therefore, policy makers in these countries may consider continuing the momentum of market evolution currently being experienced and *expected* by consumers rather than allowing the market to reach a new 'steady state' where improvements in stock efficiency will stall. Should the overall harmonisation of actions proposed in Section 2.2 prove impractical:

- EU policy makers may wish to minimise any possible delay in the introduction of the 2016 'Phase 6' regulations which, when implemented, will result in the removal of standard halogen lamps from the market.
- Policy makers in other countries may wish to consider mirroring the approach set out in the EU 2016 regulations, albeit with modifications to the timescales or scope to accommodate the particular issues experienced in their local market, for example with non-compatible dimmers/controls.
- US policy makers may seek to bring forward the implementation of the anticipated 2020 '45 lm/W average efficiency of lamps' regulations, and Canadian regulators may consider following a similar path.





The remarkable experience of Korea (with average efficacies of new lamp sales above 40 lm/W), indicates that such a regular revision to lamp standards can result in major market movement.

It is interesting to note that among the non-regulatory policy interventions, few appear to have sustained impact where there is not ongoing engagement with stakeholders. For example, historically Canada had relatively high levels of CFL sales due to the 'switch and save' programme. However, following the scaling-down of the programme, sales of CFLs in Canada have returned to levels close to those seen elsewhere. In contrast, the ongoing industry/government engagements in Japan (the only country without formal regulatory intervention) and, to a lesser degree Australia, appear to have resulted in ongoing positive market change. However, there appears also to be a strong cultural element at play, particularly in Japan, where although there is no regulatory pressure, there is nonetheless a degree of cultural pressure to comply with overall government direction.

Finally it is important for policy makers to recognise that, in the majority of cases, the current restricted levels of market monitoring are likely to be limiting their ability to understand and appropriately react to ongoing market shifts. This shortage of information on the type of products in the market, the degree of adoption of these products and, as noted in Section 2.1.7, consumer usage patterns significantly increases the risk of original ongoing policy goals remaining unfulfilled. Therefore, policy makers may wish to consider significant strengthening of activities which can monitor new products entering the market and of programmes that provide much greater understanding of actual consumer application of these products.





Annex 1 Grading mapping and benchmarking outputs information

Considerable efforts have been made to ensure the integrity of the data supplied and the subsequent data manipulation and analysis. The generic approaches adopted are detailed in the Lighting Product Definition⁴⁷. However, to ensure readers are fully aware of the reliability of particular sets of data and any associated assumptions or transformations that have been necessary, the Annex has developed a 'Framework for Grading Mapping and Benchmarking Outputs' as described below.

Nevertheless, in this unusual case the benchmarking is looking at the entire lighting market within a specific country/region rather than an individual product group. Even in a smaller country, the lighting market will consist of several million individual purchases per year of items of varying type, colour, shape and light output, yet the typical cost of each product is just 1-5 \$/Euro. Therefore, it is impossible to track all purchases in any market and some degree of modelling and/or assumptions has been required for data submitted by all countries/regions (the specific country modelling and assumptions are reported in the individual country mapping sheets⁴⁸).

Further, in order to ensure comparability of data, a number of assumptions have been made which are detailed in the product definition. Hence the Framework is not entirely appropriate. Thus, expert opinions have been used to grade the outputs for likely reliability using the Framework as a conceptual template only.

Framework for grading mapping and benchmarking outputs

In order for the Mapping and Benchmarking Annex to provide transparency regarding the degree of 'reliability' that can be attributed to the results produced by the Annex, a framework has been developed that allows the *grading* of benchmarking outputs. This grading is based on a three part 'scale' of robust, indicative and illustrative. This scaling is applied to both the initial data input and any manipulations that are required to present the data in a consistent form in the country mappings, and to the subsequent manipulations of that data in order to make them comparable with datasets from other countries/regions during the benchmarking process. While expert opinion is used to formulate the specific grading allocated to individual data sets or outputs, this expert opinion is formed based on the following framework.

⁴⁷ Refer to: <http://mappingandbenchmarking.iea-4e.org/matrix?type=product&id=5>

⁴⁸ The specific modelling and/or assumptions that apply to an individual country or region are provided in the country-specific mapping sheets – see <http://mappingandbenchmarking.iea-4e.org/matrix?type=product&id=5>





Grading of data/mapping outputs

Robust – where typically:

- The data are largely representative of the full market and
- The data include at least a significant element of individual product data and
- The data are from known and reliable sources and
- Test methodologies are known and reliable and
- Any data manipulations are based on solid evidence and should not unduly distort results.

Conclusions from such datasets are as reliable as reasonably possible within boundaries of the Annex operation.

Indicative - where typically:

- Datasets may not be fully representative of the markets (but do account for a majority, ideally a known and understood majority) and/or
- Any data manipulation used includes some assumptions or unavoidable approximations that could unintentionally reduce accuracy.

Accuracy is, however, judged such that meaningful but qualified conclusions could be drawn.

Illustrative – where typically:

- One or more significant parts of a data set is known to represent less than a majority of the full market or
- Test methodologies used to derive data are not known or
- Test methodologies used to derive data are known but could lead to significant differences in outcome or
- Data manipulations for the analysis contain an element of speculation or significant assumption or
- Conflicting and equally valid evidence is available.

Rather than being rejected completely, perhaps because the flaws in the data are at least consistent, such data could provide some insight into the market situation and so are worth reporting, but results must be treated with caution.

Grading of comparison between country outputs (benchmarking)

Robust – where typically:

- The data sources being compared are each largely 'robust' and
- No data manipulations for benchmarking were necessary; or if manipulations were used they were based upon solid evidence and should not distort results.





Conclusions from comparisons within and between such datasets are as reliable as reasonably possible within boundaries outlined above.

Indicative - where typically:

- Datasets being compared are themselves only 'indicative' and/or
- Any data manipulation used for benchmarking includes some assumptions or unavoidable approximations that could unintentionally reduce accuracy and/or
- For any other reason(s) subsets of the data may not be strictly comparable which leads to some distortion.

However, accuracy is such that meaningful but qualified conclusions could be drawn.

Illustrative – where typically:

- One or more significant parts of the datasets are themselves 'illustrative' and/or
- Data manipulations for the benchmarking process contain an element of speculation or significant assumption.

Rather than being rejected completely, perhaps because the flaws in the data are at least consistent, such data could provide insight into the market situation and so are worth reporting, but results must be treated with caution.



Annex 2 Justification for data grading

Country	Policy information	Mapping data	Benchmarked data	Efficacies	Justifications - <i>see mapping reports for full details</i>
Australia	Robust	<ul style="list-style-type: none"> All data Indicative except LEDs and double ended halogen which are Illustrative 	<ul style="list-style-type: none"> All data Indicative except LEDs and double ended halogen which are Illustrative 	<ul style="list-style-type: none"> Indicative 	<ul style="list-style-type: none"> Projections supported by sales data with the exception of double ended halogens and LEDs
Austria	Robust	<ul style="list-style-type: none"> All data Indicative 	<ul style="list-style-type: none"> All data Indicative 	<ul style="list-style-type: none"> Indicative 	<ul style="list-style-type: none"> Data based on sales
Canada	Robust	<ul style="list-style-type: none"> All data Indicative 	<ul style="list-style-type: none"> All data Indicative 	<ul style="list-style-type: none"> Indicative 	<ul style="list-style-type: none"> Data based on sales
Denmark	Robust	<ul style="list-style-type: none"> All data Illustrative 	<ul style="list-style-type: none"> All data Illustrative 	<ul style="list-style-type: none"> Illustrative 	<ul style="list-style-type: none"> Sales data modelled which introduces significant levels of uncertainty.
Japan	Robust	<ul style="list-style-type: none"> All data Illustrative 	<ul style="list-style-type: none"> All data Illustrative 	<ul style="list-style-type: none"> Illustrative 	<ul style="list-style-type: none"> Japanese manufacturer data only (i.e. does not include imports). Data also required a number of assumptions to import into this analysis.
Korea	Robust	<ul style="list-style-type: none"> Majority of data Indicative All halogen data illustrative 	<ul style="list-style-type: none"> Majority of data Indicative All halogen data illustrative 	<ul style="list-style-type: none"> Indicative 	<ul style="list-style-type: none"> All data based on actual sales with the exception of halogen lamp sales which were estimated
UK	Robust	<ul style="list-style-type: none"> All data Indicative 	<ul style="list-style-type: none"> All data Indicative 	<ul style="list-style-type: none"> Indicative 	<ul style="list-style-type: none"> Data based on sales or modelled by outputs supported by a secondary, confidential data set
USA	Robust	<ul style="list-style-type: none"> Not available 	<ul style="list-style-type: none"> Not available 		
EU (and Poland/ Spain)	Robust	<ul style="list-style-type: none"> All data Indicative 	<ul style="list-style-type: none"> All data Indicative 	<ul style="list-style-type: none"> Indicative 	<ul style="list-style-type: none"> Data based on sales





Annex 3 Additional cautions for interpreting the results

As well as the country specific cautions described in Section 1.2, there are a number of limitations with the analysis and more general caveats of which readers should be aware of:

- Some reported sales data and associated analysis for years up to and including 2011 differs from the presented in the original benchmarking report published in June 2011. In all cases, this is because more reliable data has become available to Annex. For the specific details of the new data, please refer to the mapping reports for Australia, Denmark, Korea and the EU.
- The report presents data on the sales and average efficacies of new lamps sold within a particular year. However, all markets are currently in transition with consumers switching between lamp types as a result of a combination of policy actions and the market entrance of new lamp types. These different lamp types not only have differing efficacies, but also substantially different lifetimes. Such variations in lamp lifetimes mean that changes in the proportion of sales:
 - **Will not** lead to a directly proportional change in the installed lighting stock;
 - **Will not** lead to a proportional change in the efficacy of the stock.

Further, in times of major market transition, the longer the period over which annual market share of lamp types (see following bullet point) is used to observe market transformation, the less accurate it becomes as a proxy for long term changes to the efficacy of installed stock. However, given the apparent switch in lighting is from short lifetime (generally inefficient) lamps to longer lifetime (generally more efficient) lamps, the installed lamp stock will almost always have a higher average lifetime and higher average efficacy than the average of lamps sold with this difference increasing over time.

Hence, all reported proportions of sales and efficacies should be *treated as an indication of the direction, degree and speed of improvement of the efficacy of the installed lamp stock, not an absolute measure of this efficacy or penetration of a particular lamp type.*





- 100% reliable sales data are not available for any country.⁴⁹ Further, the reporting of absolute number of sales by category would make the outcomes of the benchmarking and associated graphics difficult to interpret. For example, a graphic which is scaled to show sales of Incandescent lamps in the USA would make the detailed analysis of similar sales in a much smaller country such as Denmark impossible. Therefore, the majority of the benchmarking refers to the sales of each lamp type within a country as a percentage of the overall sales of all lamps within that country, rather than absolute values for the sales of individual lamp types.
- The average efficacies presented for various lamp types and the markets as a whole are based on the equation:

$$\text{Average efficacy} = (\text{Sum of all lumens sold})/(\text{Sum of all wattages sold}).$$

As individual lamp efficacies vary, it is important to note that this will generally present a very different value than the equation used when analysing the average efficacy of most products, i.e.:

$$\text{Average efficiency} = (\text{Sum of efficiencies of all products sold})/(\text{Total number of all products sold}).$$

However, it is believed the first equation provides a more robust presentation of how sales are likely to impact on overall household and national energy consumption as they enter use⁵⁰.

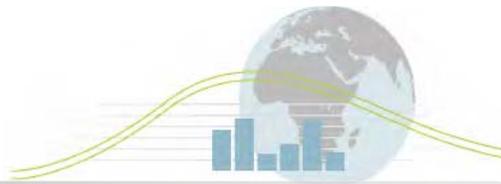
- The definitions of lighting products used in this analysis groups together somewhat dissimilar products. In particular, reflector and non-reflector lamps are grouped into the same categories, as are covered and bare CFLs.⁵¹ Similarly, lamps of differing colour temperatures and lifetimes are grouped. Such groupings are not 100% accurate as each variation will affect other lamp variables, in particular lamp efficacy. Further, the actual reporting of data differs slightly by country, for example, regulations in some jurisdictions allow reporting of “rated values” for power consumption, while others require “verified” tested values. Hence, given the particular assumptions and data manipulations used in the analysis, the reported average efficacies of product groups are likely to be slightly

⁴⁹ All countries have either used a degree of modelling to establish 100% market coverage, or have reported actual sales for a lower market proportion (e.g. the market coverage of the EU's reported data varies by country but is estimated to be 70% overall). However, within the context of this report and the use of percentage of sales, data are considered representative of the market (for detailed information on the data sets for each country, refer to individual country mappings at <http://mappingandbenchmarking.iea-4e.org/matrix?type=product&id=5>

⁵⁰ This is because in the first equation, lamps with higher wattages (and hence energy consumption) have a greater impact on the overall resulting average efficacy, rather than all lamps having equal weighting irrespective of consumption as is the case in the second equation.

⁵¹ Note that the efficiencies/losses associated with ancillary equipment (e.g. external ballasts and luminaires) are not included in the analysis.

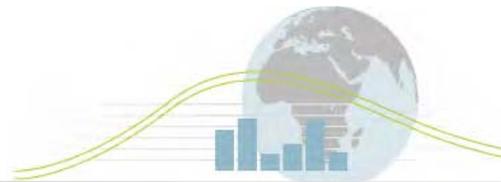




higher than the actual efficacies of products in the market. However, such variations are of limited magnitude relative to the variations between lamp types (i.e., between CFLs, low voltage halogens, incandescents, etc). Therefore the differences are believed to have little effect on the reliability of the overall outcomes of the benchmarking.

- Data from some countries/regions are either not available or have been grouped. For example, data from Korea group all types of halogen lamps (single ended and double ended, mains voltage, and low voltage). This leads to a slight reduction in the reliability of the outcomes related to these particular pieces of data, but again this is believed to have little effect on the reliability of the overall outcomes of the benchmarking.





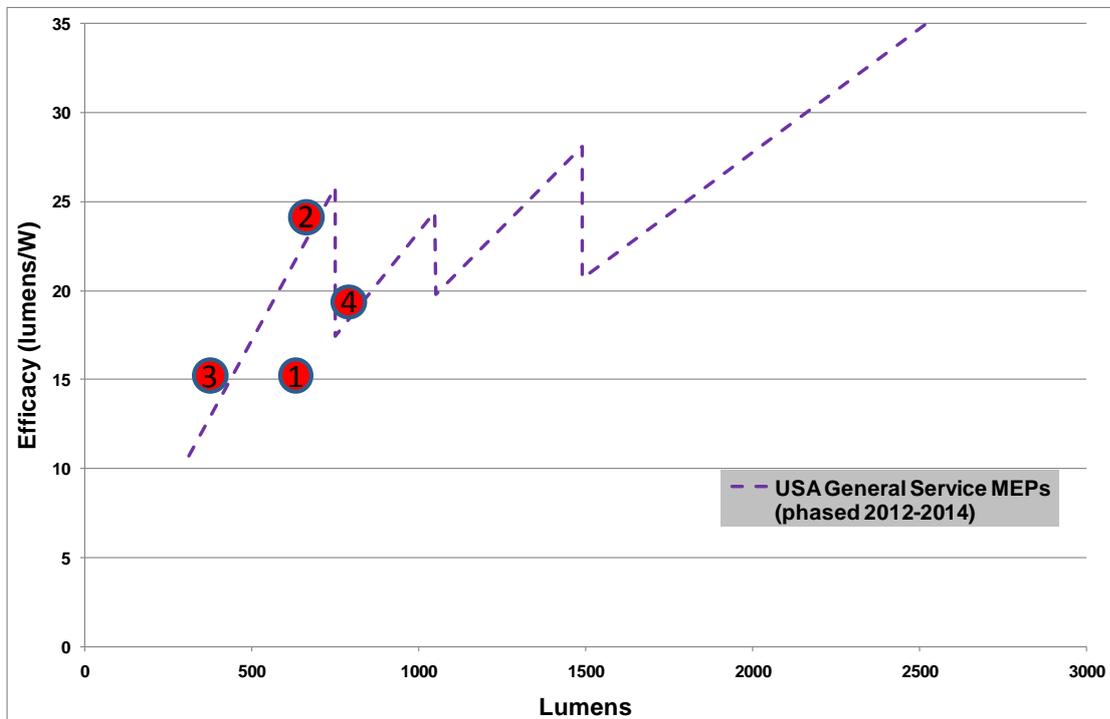
Annex 4 Overview of 'bin jumping' and 'lamp rerating'

As explained in Section 2.1.1, two of the three main approaches to regulation are the 'maximum wattage for a given lumen range' and the 'minimum efficacy for a given power range'. While these are very easy to understand, this approach risks 'bin jumping' or 'lamp rerating' which may result in lower lighting output leading to consumer dissatisfaction or, perversely, increased efficiency levels but with higher net electricity consumption. Further, as lamps of a particular type tend to become more efficient as their size (light output or wattage) increases, there is the likelihood that not all the potential savings will be captured. These two risks are explained in further detail below:

Risk 1: Bin Jumping: Increased Consumption vs Improved Efficacy

The risk of 'bin jumping' is most easily understood graphically. Consider a hypothetical 40 W lamp that is being sold prior to the implementation regulations in the USA. The lamp may have an efficacy of 15 lm/W and thus provide 600 lm of light output (point 1 in Figure 18).

Figure 18. Potential 'bin jumping' illustrated by US (maximum wattage) regulations.



As the implementation date of the regulations approaches, suppliers have three options:





- a. Remove the product from the market;
- b. Provide significant investment to improve the performance of the product (or develop a replacement) such that it maintains 600 lm light output and meets the 24+ lm/W regulatory requirement (point 2 on Figure 18);
- c. Provide minimal investment to slightly re-engineer the product and reduce the lighting output⁵² until the lamp complies with the efficacy requirement (point 3 on Figure 18).

There is anecdotal evidence to suggest some suppliers are choosing option c. which is the lowest cost option while still enabling the sale of the lamps. While this produces a compliant lamp, consumers that purchase this lamp as a replacement for the original now receive a significantly lower light output (in this case approximately 400 lm or a 33% reduction in the light output). It is likely a number of these consumers will not be happy with this lower lighting level and hence buy the lamp with the next highest lumen output (for example the lamp at point 4 on Figure 18). This does give a higher light output (approximately 800 lm) and may be a more efficient lamp than the original lamp (in this example 19 lm/W rather than the original 15 lm/W). However, ultimately such action confounds the original intent of the policy intervention as the lamp at point 4 actually *consumes* more energy than the original, in this case 42 W compared with the original 40 W.

Risk 2: Lamp Rerating

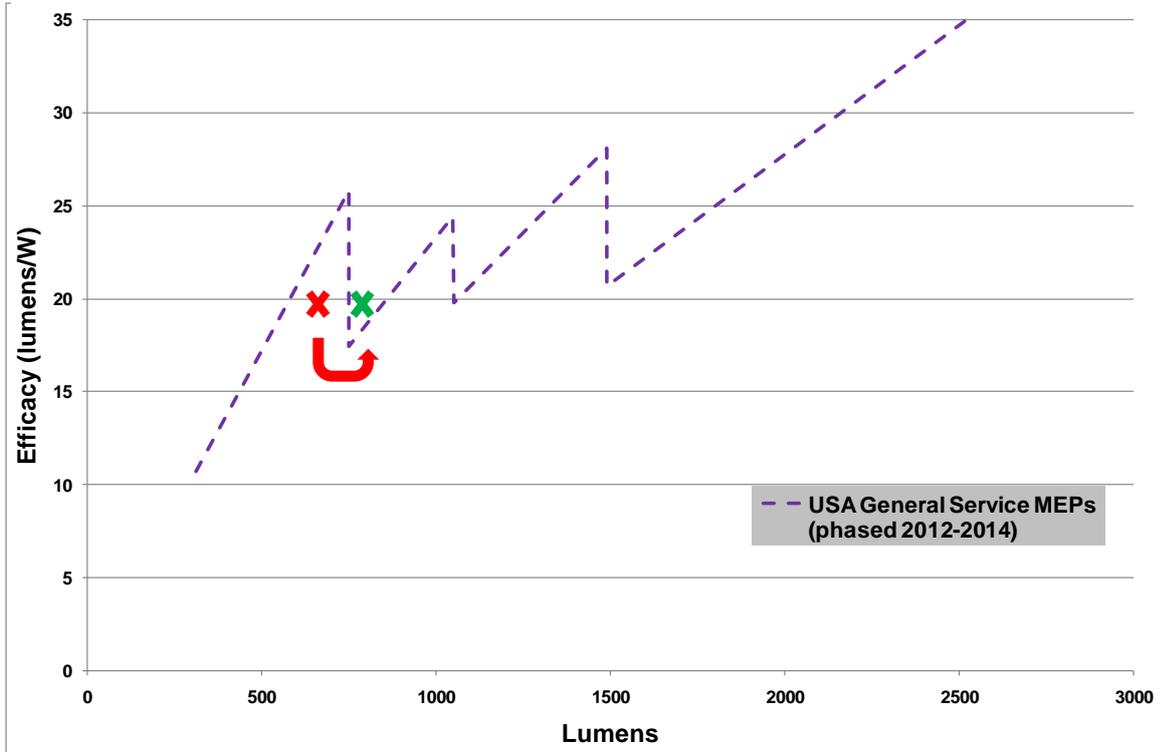
Lamp rerating has a similar outcome to bin jumping and is also most easily understood graphically. Figure 19 again shows the US (maximum wattage) regulations. Consider a lamp that has a rated lumen output (or equivalent wattage) denoted by the red cross on Figure 19. Such a lamp would not comply with forthcoming US regulations. However, simply by rerating the lamp to a slightly higher lumen output/wattage (illustrated by the arrow), the lamp would comply with the regulations as shown by the green cross.

⁵² Possibly through shortening of the filament length.





Figure 19. Potential issue with lamp rerating illustrated by US (maximum wattage) regulations.

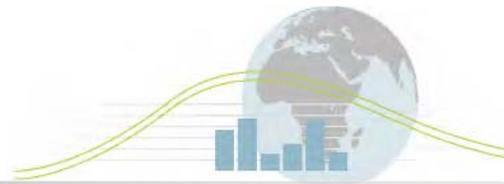


This rerating may be achieved ‘artificially’ by declaring a slightly higher rating if such an action would fall within the tolerances of the local test method or regulations. Alternatively, the lamp could be rerated by actually increasing the power consumption/lighting output of the lamp through slight re-engineering (typically by extending the length of the filament). In both cases a lamp that would have been deemed to be non-compliant in the USA would suddenly become compliant. If such compliance is achieved through re-engineering, this compliance is again achieved through the perverse outcome of consuming *more* energy⁵³.

Hence, although more complicated, policy makers may wish to consider using a continuous curve to define the minimum efficacy requirements. By doing so, savings are likely to be maximised and the risks of bin jumping or lamp rerating are eliminated. At the very least, policy makers should remain aware of the risks of bin jumping and lamp rerating and ensure the desired outcomes of existing regulations are not being eroded by suppliers rerating existing lamps.

⁵³ Note that such an outcome is less likely but still possible for regulations defined by a minimum efficacy requirement for a given power or lumen range.





Annex 5 Introduction to the Interpretation of Lamp Sales Data

The following introduction to the interpretation of lamp sales data, and the inherent limitations of the approach, are drawn from the 2011 benchmarking report⁵⁴. It is important to note that the UK sales data (and the interpretation of that sales data) presented below have been updated in the main body of the report. The original data and interpretation is maintained here simply for the purpose of explanation.

Changes in sales do not *necessarily* represent the equivalent change in stock as markets in most countries are in transition. This transition is causing consumers to switch between different lamp types and sizes, and the efficacy, performance and lifetime of the various lamp types is very different. To illustrate the complexity this introduces, consider a hypothetical example of a country with just 1,000 lamp sockets all of which are initially filled with Incandescent lamps (the initial stock):

- If the 1,000 installed Incandescent lamps have operational lives of 1 year, at the end of the first year when these lamps fail⁵⁵ consumers may replace the failed lamps with 900 Incandescent lamps of the same lifetime, plus 100 CFLs of equivalent light output but of 10 years operational life. In this first year, lamp sales match the change in the occupancy of the 1,000 sockets left vacant by the failed Incandescent, i.e. 100 CFLs and 900 Incandescent. Because of the equivalency of light output, total lighting levels remain the same.
- In the following year, given the 1 year operational lifetime of the Incandescent, all 900 will again fail, but no CFLs will fail (due to their 10 year operational lives). So, only 900 lamps will need replacing. If replacements follow the same ratio as year 1, i.e. 90% Incandescent and 10% CFL, then the sales will be 810 Incandescents and 90 CFLs. Thus the ratio of sales remains the same: the total delivered light output remains the same; but total sales have fallen by 10%. Penetration of CFLs in the stock has risen to 19%.
- All things remaining equal, sales in year 10 would be just 349 Incandescents and 40 CFLs but the level of lighting provided will still be the same.
- In year 11 the initial CFL purchased in year 1 would need replacing. However, by this time CFLs would be in place in 650 of the 1,000 sockets. Year 11 sales will be replacement of the 349 Incandescent lamps by 314 Incandescent lamps plus 35 CFLs; plus the original 100 CFLs from year 1. Throughout, light levels have remained constant, but lamp sales have been consistently falling until year 11 when there is a slight rise. Final installed stock at the end of year 11 is 314 Incandescent lamps, and 686 CFLs.

⁵⁴ Refer to <http://mappingandbenchmarking.iea-4e.org/matrix?type=product&id=5>

⁵⁵ Note that this example is hypothetical – lamp failures are obviously more complex in real life.





However, despite a very simple example with just two lamp types and detailed knowledge of how sales will develop over time, we have no knowledge of the actual usage patterns of the lamps, their rated wattages, etc. Thus we are not able to make projections on initial energy consumption of the stock or the likely future energy savings from the CFL installations. The best that can be achieved is an indication of the direction that stock efficiency will be taking (in this case clearly improving as CFLs replace Incandescent, but we do not know to what degree).

Unfortunately, the real life situation is significantly more complex than the example, and the data available in this analysis are limited to sales of lamps by type, some knowledge of the rated wattage of those sales, and estimates of lamp lifetime.⁵⁶ Therefore, how can these data inform our original aims of:

- Understanding whether there are any major outcomes of the various policy implementations to date; and
- Gaining an indication of longer term efficiency improvements of the installed stock?

Figure 20 shows a time series of the sales of different lamp types in the UK. As can be seen, total sales of lamps have been approximately stable for the last 10 years, with a slight fall in the last two reporting years. This is consistent with the increasing sales of CFLs in preceding years, just as in the example and this fall in total sales is likely to accelerate as the longer lifetime lamps begin replacing the shorter lifetime Incandescents.

However, from this limited information (plus information on the rated wattage of sales in the UK mapping document⁵⁷), we are able to learn the following:

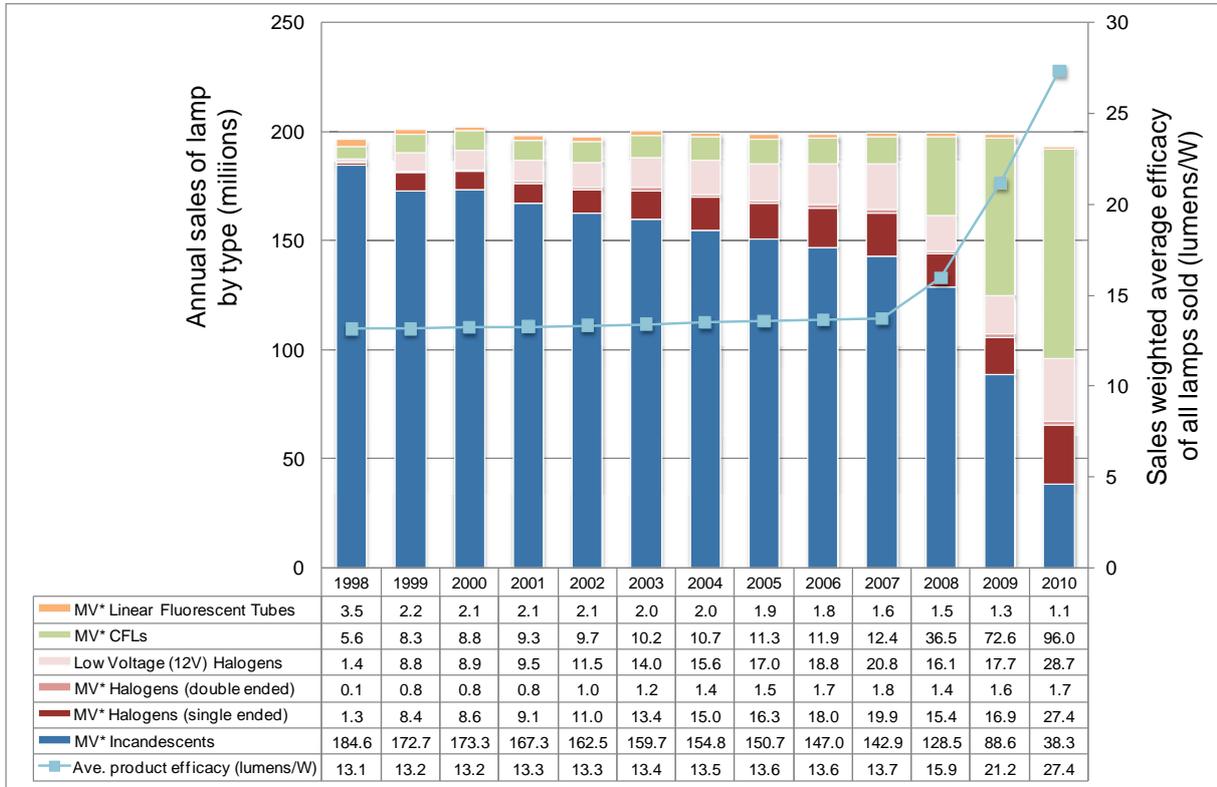
- **Lamp types:** In the years from 1998 to 2007 there is a gentle migration in sales from Incandescent lamps primarily to halogen (halogen sales growing from 1% to 22% of total annual sales), and a slower migration to CFLs (CFL sales growing from 3% to 6% of total annual sales). In 2008-2010, there is a marked shift in the pattern of lamp switching with the majority of movement from Incandescent to CFLs (CFL sales increasing from 6% of total sales in 2007 to 50% of total sales in 2010), with a continued, but slightly accelerated growth in the sales of halogens.

Figure 20. Time series sales of lamp types and sales weighted efficacy of lamps in the UK.

⁵⁶ Refer to the "Product Definition: Domestic Lighting Revision September 2014" at <http://mappingandbenchmarking.iea-4e.org/matrix?type=product&id=5>

⁵⁷ See <http://mappingandbenchmarking.iea-4e.org/matrix?type=product&id=5>





- Efficacy of lamp sales:** Between 2007 and 2010, this change in sales has resulted in an increase in the efficacy of lamps sold from 13.3 lm/W to 27 lm/W. This compares with a much smaller increase in efficacy of 12.5 lm/W to 13.3 lm/W over the longer 1998 to 2007 period.
- Timing and types of market changes in relation to policy intervention:** The pan-EU regulations restricting the sale of Incandescent lamps were formally announced in 2009 with initial restriction on the sale of larger inefficient lamps beginning in 2010. However, the UK government had reached a voluntary agreement with retailers to restrict the sale of inefficient lamps from 2007 onwards, in effect bring the entire European level timetable forward for the majority of retail outlets.

Given the strong alignment of the timing of policy action with significant changes in the market in the UK, it is reasonable to infer answers to our original questions as follows:

- Have there been any major outcomes of the various policy implementations to date?* The combined voluntary agreement and EU regulations have had a direct and robust impact on the UK market for lamps, with the sales weighted efficacy of lamps more than doubling compared with the business as usual path prior to the announcement of the voluntary agreement in 2007.





- *Is there an indication of longer term efficiency improvements of the installed stock?*
With some confidence it can also be asserted that the lamps being replaced in the stock will have a lower average efficiency than those recently purchased. This is evidenced by the relatively stable sales of lamp type (and their associated efficacy levels) prior to 2007, combined with the large number of relatively inefficient, short lifetime Incandescent lamps that constituted the majority of sales prior to 2007 (hence these inefficient lamps will be the majority of lamps being replaced in the post 2007 sales). Thus, the overall average efficacy of stock will be increasing at a rate more rapid than the increase in efficacy of sales, although by what rate is unknown.

[The main body of this report] follows the same logical approach to understanding whether there has been any impact of policy on the market. However, because of the large differences in the absolute number of total lamp sales between individual countries, [analysis is conducted on] the sales of each type of lamp as a percentage of total lamp sales in each market. This enables a comparison between countries of the changes in market share of individual lamp types over time. In parallel it is possible to analyse changes in average efficacy of sales and to provide detailed observations relating to individual countries where appropriate.

