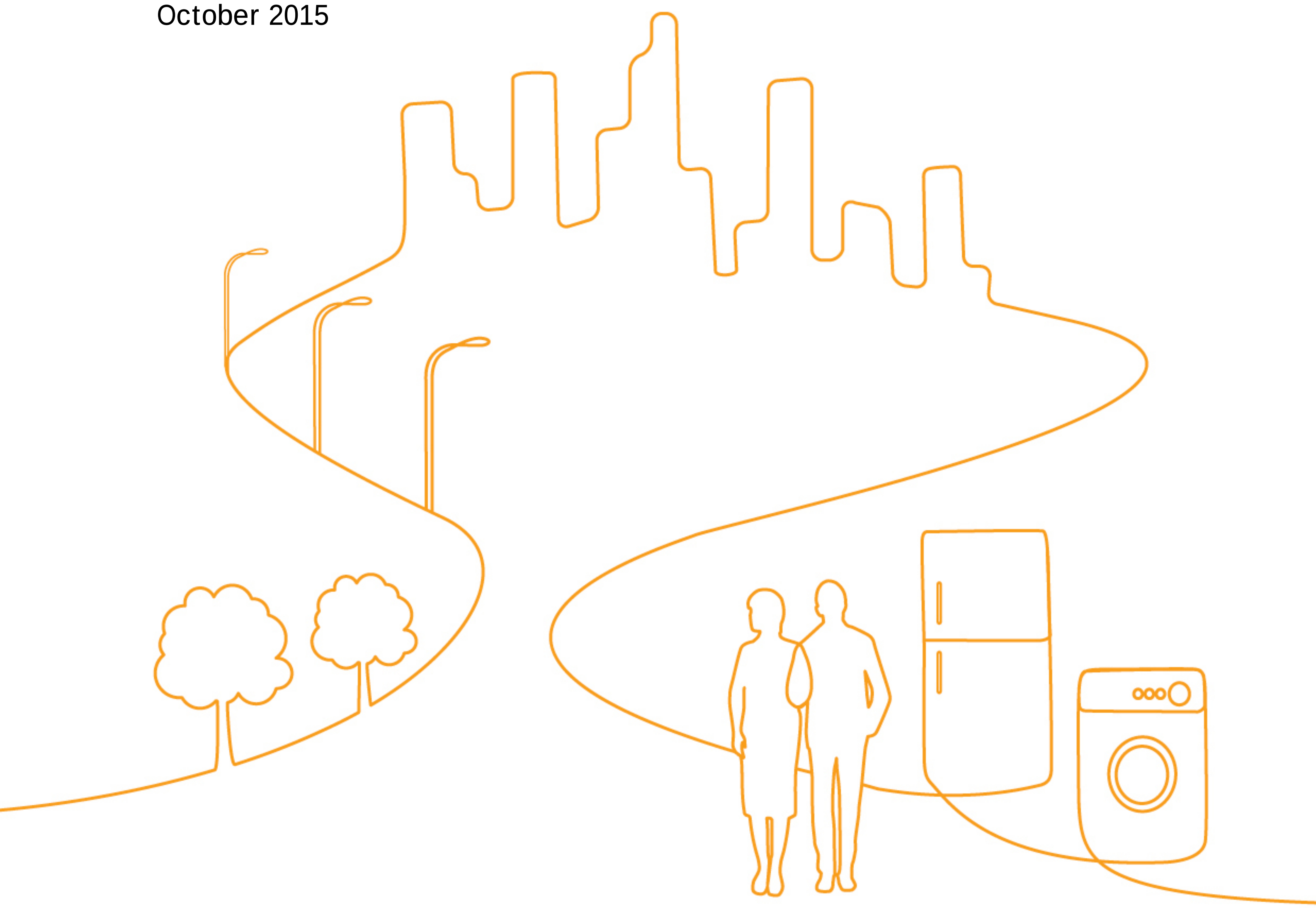
Mapping & Benchmarking of General Service Lamps

Final Report

October 2015



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Executive Summary

Lighting is responsible for 15% of electricity use around the world and for approximately 6% of total annual global greenhouse gas emissions (UNEP, 2015). To reduce this impact, many governments have phased out the least-efficient lamps. Many more are now working to facilitate a transition to more cost effective, energy efficient lighting options.

This Mapping and Benchmarking report was prepared to assist policymakers, program managers, and other stakeholders who are working to transition national and regional markets from inefficient incandescent and halogen lighting toward more energy-efficient, cost-effective alternatives including compact fluorescent lamps (CFLs) and light-emitting diodes-based lamps (LEDs).

To achieve this, 25 historical and contemporary data sets of CFL and LED products drawn from Australia, Cambodia, the EU, Lao PDR, Indonesia, the Philippines, Thailand, the USA and Vietnam were analyzed. The policy frameworks influencing the penetration of lamps into each market were also analyzed. Key findings and conclusions from the analysis are given below.

In all economies studied, CFLs are currently available with light output suitable for replacing incandescent GSL lamps up to and including 75W. Within the developed economies there is also demonstrable availability of 100W GSL equivalent CFLs. Despite limited demand for 100W replacement lamps in Asian economies, there is sufficient indirect evidence to suggest 100W equivalent lamps are also available in these economies. Further, evidence suggests that a high proportion of these GSL replacement CFLs achieve high levels of efficacy, have good color performance (defined by CRI) and, from the limited data available, exhibit satisfactory levels of lumen maintenance.

Thus, based on the evidence, CFLs that fully meet consumer expectations across all key performance parameters are available for all GSL-equivalent wattages from 25W to 100W in Australia, the EU, the USA, and in *most* Asian markets, with the possible exception of Cambodia. In fact, in almost all economies, there is scope to raise current performance requirements for CFLs to further enhance the consumer experience and/or maximize energy savings without significantly limiting the number and range of products available.

This outcome is not surprising, as evidence suggests CFLs are now a fully mature technology. Further, CFL markets are being widely protected through MEPS in 5 of the economies examined: Australia, Cambodia, the EU, the USA, and Vietnam. Several other economies examined have not implemented MEPS: Indonesia is currently implementing a new MEPS program, Thailand has a voluntary minimum standard, and the Philippines has mandatory comparative labeling. Additionally, almost all economies have extra policy support measures for CFL adoption. Thus, contrary to widely held perceptions, the developing economies represented typically have relatively comprehensive policy frameworks for CFLs, albeit not necessarily as well developed as elsewhere.

Nevertheless, in all markets analyzed, CFLs were available that failed to meet national requirements and/or internationally recognized norms of consumer acceptability, in some cases by substantial distances. Poor performance on efficacy was more evident among the lower-lumen-output lamps that are in demand in many Asian economies. However, the evidence demonstrates that technically there is no longer a need to accept these lower performing products, and in some markets, for example Australia, they are uncommon. The scarcity of poor quality products appears directly related to the presence of a strong policy support framework (in place in most economies, as noted above), coupled with ongoing and visible market surveillance/check-testing activities. In the majority of economies there is a need to strengthen market surveillance, particularly related to the lumen maintenance of products. It is critical to ensure lamps provide extended consumer-satisfying service, and hence remain installed, to yield the appropriate levels of economic and energy benefits.

Unfortunately, due to only slight differences in performance requirements between the economies, it is difficult to share market surveillance across borders. As a result, each economy bears the full cost of their surveillance programs, so they are often limited. International alignment of similar national CFL performance requirements offer the opportunity to share information on poor performing products. The inherent benefit is the shared market surveillance costs and resulting higher product quality at the national level. Such an alignment of performance requirements is relatively simple and has been attempted previously, as illustrated by the proposed IEC performance tiers referenced in this report. It is currently being pursued in some areas, for example among ASEAN members. However, efforts to internationally align performance requirements should be accelerated and widened. They could increase product quality and lower surveillance costs, and participating economies would benefit from the resulting increased trade and market competition, which should lower the prices of higher quality energy efficient lamps.

The situation for LEDs is more fluid, with very rapidly evolving products. In Australia, the EU, and the USA (very limited data on LED performance was available for Asian economies), products with sufficient light output to replace all omnidirectional incandescent GSL lamps up to and including 75W have been available for several years. However, significant numbers of LED replacements for the higher lumen output 100W GSL incandescent have only recently appeared in the U.S. market. In 2014, there was little evidence that these products had entered the Australia and EU markets. This lack of evidence is at least partly related to limitations on available data and, given the speed of product development, it seems likely 100W replacement products will now have entered most markets.

Of these three developed economies, the EU is the only one that considered all LED performance parameters with its MEPS. It is also the only economy where there is direct evidence that all available incandescent GSL replacement LEDs could be considered "of at least minimum quality" with respect to efficacy, i.e., performing above 50lm/W. However, in all three economies, lamp efficacies for any given lumen range are widely spread, with some LEDs now reaching efficacies in excess of 100lm/W. Thus, there is significant potential for the EU and the USA's premium Energy Star program to raise the efficacy requirements for LEDs across all lumen ranges to maximize the consumer and national energy saving without jeopardizing product availability. Obviously, in those economies where no current MEPS exist, the introduction of similar regulation or other policy support has the potential to rapidly yield high energy savings to the consumer and the overall economy by limiting the penetration of the lower efficacy products that are currently (or are likely to become) available in the market.

Further, across all three developed economies, there is evidence to suggest there are significant quality issues for color, with some LEDs showing CRI values below 70, and lumen maintenance, with some products achieving little more that 70% of their initial lumen output at 2,000 hours. The latter is significantly lower than the lumen maintenance requirements for CFLs in most economies and far below requirements for LEDs, where regulations exist. This is troubling, given that long lifetimes and the resulting economic benefits to consumers are key selling points used by policymakers to promote the adoption of high-efficiency lamps. Thus, the presence in the market of LEDs with poor lumen maintenance ultimately risks the slowing of overall market adoption of LEDs.

The existence of an extensive range of Energy Star qualified products demonstrates that LEDs are available that meet consumer expectations of quality across all key performance parameters. There is a strong expectation among the majority of policymakers worldwide that LEDs will soon penetrate all markets in significant quantities. They view LEDs as one of the primary products facilitating the transition to lower lighting energy consumption. It is critical to expand availability of high-quality products and protect markets from low-quality products. Thus, there is an urgent need in almost all economies to develop strong policy frameworks similar to those in place for CFLs (test methods, MEPS, premium product labeling, product registries, etc.) and to rigorously enforce compliance with those frameworks. However, the rapid evolution of LEDs makes the development of performance requirements on which such frameworks are based challenging (and expensive) to undertake at the national level, as is maintaining effective market supervision of the rapidly changing product landscape. Therefore the potential for international cooperation and alignment of performance requirements highlighted above is particularly important, e.g., through widespread adoption of the 4E SSL performance tiers. Further, given the relatively embryonic nature of most LED policy frameworks, such alignment should be easier than amending the embedded CFL frameworks.

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1. Introduction

Lighting is responsible for 15% of electricity use around the world and for approximately 6% of total annual global greenhouse gas emissions (UNEP, 2015). To reduce this impact, many governments have phased out the least-efficient lamps, and many more are working now to facilitate a transition to more cost-effective, energy-efficient lighting options.

This Mapping and Benchmarking report was prepared to assist policymakers, program managers, and other stakeholders who are working to transition national and regional markets from inefficient incandescent and halogen lighting toward more energy-efficient, cost-effect alternatives including compact fluorescent lamps (CFLs) and light-emitting diode-based lamps (LEDs). The report presents an extensive range of international data sets of omnidirectional general service lamps and conducts a robust comparative analysis on product performance.

The report seeks to answer the following key questions:

- Which omnidirectional LED and CFL products are available to replace incandescent lamps, and how is this availability changing over time?
- Are these CFL ad LED lamps of good quality, and does this quality differ internationally?
- Which governments have performance requirements that apply to CFL and LED lamps, and how do they compare?
- For those economies with regulatory requirements, what are the current levels of compliance and does this differ internationally?

In order to address each of these key questions in detail, this mapping and benchmarking report is structured as follows:

Section 2: Data Availability, Quality and Limitations – this chapter details the sources and content of the product performance data sets, the limitations on the analysis, and the caveats readers should be aware of when reviewing the findings and conclusions presented in this report;

Section 3: Policy Frameworks - this chapter provides a comparative summary of the national regulatory policies in place for transitioning markets away from incandescent lighting and ensuring quality LEDs and CFLs are offered in the market;

Section 4: Product Availability, Quality and Compliance - this chapter addresses how energy-efficient replacement lamps are changing over time, in terms of efficacy, light quality and other critical metrics, as well as the current rates of compliance in the markets where CFLs and LED lamps are regulated.

Chapter 5: Conclusions and Key Findings – this chapter provides a summary of the salient findings and key outcomes from the report.

2. Data Availability, Quality, and Limitations

To conduct this analysis, data sets have been obtained from a wide variety of both publically available and confidential sources. Overall, approximately one million individual data points have been amassed which record the performance of over 10,000 LED and CFL products currently or previously available in the following economies:

- Australia
- Cambodia
- The European Union (EU) with specific data sets drawn from various member economies
- Indonesia
- Lao PDR
- The Philippines
- Thailand
- USA
- Vietnam

In assembling this data, acknowledgements are made for the assistance given and data provided by:

- The Australian Government's Department of Industry;
- The Australian Consumers' Association (CHOICE);
- The Global Efficient Lighting Centre (GELC);
- The United Nations Environment Programme-Global Environment Facility (UNEP-GEF) en.lighten Initiative and the Governments of some of their South East Asian Partner Economies (Indonesia, Lao PDR, the Philippines, Thailand, and Vietnam); and
- The United States Agency for International Development's Eco-Asia program.

The remaining sources of data have requested their Identities not be disclosed, or the data has been obtained from publically available sources.

2.1 Data analyzed and presented

Table 1 presents a summary of all the data sets available to the analysis. The data sets cover the performance of CFL and/or LED lamps available in the years 2006-2014 (more detailed descriptions of each data set are given in *Appendix 1: Overview of data sets analyzed*).

Figure 1 provides an indication of the quantity of information available for analysis within the data sets by showing the performance of CFLs and LEDs from the various economies for just the 2014 year. The figure plots the light output of lamps relative to their efficiency (efficacy) and illustrates, for any quantity of light emitted by a lamp, the significant spread of product efficiencies within products types, across product types, and within and between economies. This information allows policymakers to identify where the performances of products in their market sit relative to similar products elsewhere, and to identify the potential for improvement in product performance that is already possible.

Table 1: Summary of source, size and age and content of data sets referenced

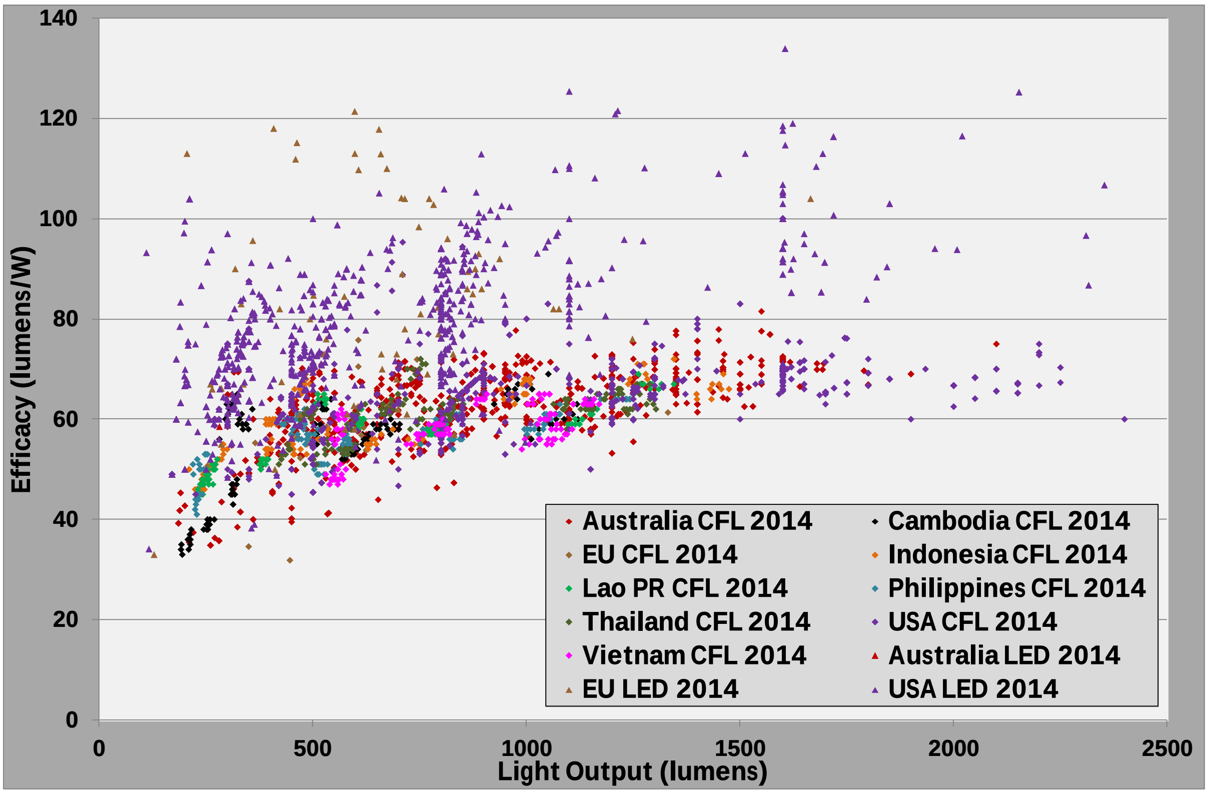
Data set [1]	Data set reference[2]	Economies included in data set	Lamp type	Data confidence score	Dates of sampling	Models/ Samples in data set
Australia CFL benchmarking and check testing[3]	B*	Australia	CFL	1A	2008, 2010, 2013	307
Australian Government registration	F	Australia	CFL/LED	2A	2014	1300
CHOICE Australia	L*	Australia	CFL/LED	3B	2013	58
Australia LED testing	G	Australia	LED	3B	2009 - 2013	85
LED Benchmark	P Q	Australia USA	LED	3B	2014 (assumed)	317
UNEP-GEF en.lighten initiative	C* J* W* X* Y* Z*	Cambodia Indonesia Lao PDR Philippines Thailand Vietnam	CFL/LED	1B	2014	100
Olina	R	EU	LED	3B	2014 (assumed)	70
Premium Lights	O	EU(Austria/ France/ Sweden)	LED	3B	2014 (assumed)	66
CLASP Clear LED Research	D	EU Countries	LED	1B	2014	18
Anonymous EU	E	EU Country	CFL	1B	2014	19
EcoAsia CFL Benchmarking	S* T* U* V*	Indonesia Philippines Thailand Vietnam	CFL	1B	2008	160
California Energy Commission	N	USA	CFL/LED	1A	2014	2250
CALiPER	K	USA	LED	1B	2006-2014	60
Energy Star CFL Testing	A*	USA	CFL	1B	2007	41
Energy Star	H	USA	CFL/LED	2B	2014	4000
Lighting Facts	I	USA	LED	1B	2009-14	1400

[1] The U.S Department of Energy's Compliance Certification has been excluded from the analysis as limited product performance parameters are available from the source and sufficient alternative sources were available to provide a detailed picture of the market in the USA.
Limited historic data from 2008 was also available for India and China, but due to the lack of any data on recently available products, India and China have been excluded from the analysis.

[2] An asterisk (*) next to the data set reference indicates those data sets where model averages are presented rather than individual sample values.

[3] The *Australia CFL benchmarking and check testing* data set is a combined data set from different testing activities undertaken over a number of years. However, given the similarities in objective, sampling, test methodology and testing facilities used, the individual data sets have been combined to simplify presentation.

Figure 1: Lumen output and efficacy of CFLs and LEDs demonstrating data sets available for the year 2014



Due to the wealth of data, an enormous amount of analysis is possible, but the material presented is limited to that which is relevant to answering the questions presented in the report introduction. Further, in answering these questions, material presented is primarily related to the analysis of performance parameters generally deemed to be of critical importance to the policymaker and to the consumer experience, i.e. lamp power (watts, W), light output (luminous flux, lm), efficacy (lm/W), color rendering index (CRI, unit less numerical value), lumen maintenance (luminous flux as percentage of initial light output at given time period) and lifetime (hours).[4]

However, as detailed in Table 2, the availability of performance parameters varies with each data set referenced and analyzed. Besides what is declared by manufacturers, there is limited original data on lumen maintenance and lifetime and therefore analysis of these parameters is limited.

[4] Data and some analysis of CFLs is further subdivided by whether the products have a second envelope (referred to in the report as covered or uncovered/bare), and by the correlated color temperature (CCT, K).

Table 2: Availability of primary performance parameters in each referenced data set

			Initial values					Lifetime	
Data set	**Data set reference**	**Economies included in data set**	**Power**	**Light Output[5]**	**Efficacy**	**CCT**	**CRI**	**Lumen maintenance**	**Life**
Australia CFL Benchmarking and check testing	B	Australia	X	X	X	X	X	X	X
Australian Government Registration Data	F	Australia	X	X	X	X	X	X	X
CHOICE Australia	L	Australia	X	X	X	X		X	
Australia LED testing	G	Australia	X	X	X	X	X		X
LED Benchmark	P	Australia	X	X	X	X	X		
	Q	USA				X	X		
UNEP-GEF en.lighten initiative	C	Cambodia	X	X	X	X	X		
	J	Indonesia	X	X	X	X	X		
	W	Lao PDR	X	X	X	X	X		
	X	Philippines	X	X	X	X	X		
	Y	Thailand	X	X	X	X	X		
	Z	Vietnam	X	X	X	X	X		
Olina	R	EU	X	X	X	X	X		
Premium Lights	O	EU (Data from Austria/France/ Sweden)	X	X	X	X	X		X
CLASP Clear LED Research	D	EU Countries	X	X	X	X	X		X
Anonymous EU	E	EU Country	X	X	X	X	X	X	
EcoAsia CFL Benchmarking	S	Indonesia	X	X	X	X	X	X	
	T	Philippines	X	X	X	X	X	X	
	U	Thailand	X	X	X	X	X	X	
	V	Vietnam	X	X	X	X	X	X	
Energy Star CFL Testing	A	USA	X	X	X	X	X	X	
Energy Star	H	USA	X	X	X	X	X		
Lighting Facts	I	USA	X	X	X	X	X		
CALiPER	K	USA	X	X	X	X			
California Energy Commission	N	USA	X	X	X	X	X		X

2.2 Summary of the data quality and limitations

The data sets analyzed have been sourced from a wide variety of organizations all of which have unique approaches to product sampling, testing, and data recording. Together these differing approach impact on the comparability of the data and the resulting quality of the analysis.

There is an argument for excluding data sets from the analysis that are not wholly comparable, do not fully reflect markets, or are deemed to have low levels of confidence for some other reason. However, doing so would limit presentation of product performance information from economies where full monitoring, verification and compliance regimes have been in place for extended periods. In particular, analysis would be limited to those economies which have independent product testing and registration, and/or commission extensive independent market surveillance testing, and which make much of the resulting data public. For the data sets available, such strict criteria would limit the

[5] Normally at 2,000 hours, but other times also reported (e.g. 40% of rated life, etc.).

performance information presented to products available in Australia and the USA only, and it would remove a number of smaller data sets, particularly from Asia. However, on condition that there is transparency in the limitations of these smaller and/or less representative data sets, and suitable cautions on inappropriate interpretation are provided (refer to Section 2.3), these relatively small data sets still offer policymakers useful international performance comparisons of products within their markets, even if those comparisons are not comprehensive.

Further, discounting data sets that are not fully representative would exclude high-quality data sets that provide useful insights into specific aspects of the market. For example, the U.S. ENERGY STAR data represent only “premium performing products” in the U.S. market, yet presentation of this data gives the opportunity to view some of the best performing products, which could form a benchmark to which policymakers elsewhere may wish to aim.

Thus, in order to present the widest possible comparison of historical and currently available products, from the broadest number of economies, analysis has been conducted on all data sets made available to the study. However, to provide readers with transparency regarding the degree of ‘reliability and comparability’ that can be attributed to the specific data and analysis presented, a *Data Confidence Score* has been assigned to each data set.

Details of the methodology for allocating the confidence scores to individual data sets is provided in *Appendix 2* but, in summary, the score is in two parts to reflect:

1. **Data confidence:** Combines data reliability and data source to give a score from 1 to 5. One signifies a high level of confidence in the reliability of data and the source. Five signifies low confidence in one or both. (Note a low data confidence score should **NOT** be interpreted as a poor quality data source but as a source where the original objectives of data capture and ultimate data provision are not fully aligned with the analytical needs of this study.)
2. **Market representativeness:** A score of A is given to data sets that are deemed to be representative of the whole of the relevant market, and B to those that are deemed not to be fully representative.[6]

So, for example, a data set that is has been assigned a data confidence score of 1A is deemed to be from a market representative data set with high levels of confidence in the data/source. Conversely, a data set assigned a data confidence score of 5B is deemed not to be representative of the whole market and has low levels of confidence in the data/source.

Table 3 shows the data confidence scores assigned to each data set.

[6] It should be noted that even where a data set is not considered representative of the whole market (e.g. a data set drawn from a premium labeling registration system such as the USA’s ENERGY STAR), it may still be comparable with other data sets drawn from similar market segments or for understanding specific segments of that market.

Table 3: Data confidence score assigned to each data set

Data set	Data set reference[7]	Data confidence score
Australia CFL benchmarking and check testing[8]	B*	1A
Australian Government registration	F	2A
CHOICE Australia	L*	3B
Australia LED testing	G	3B
LED Benchmark	P, Q	3B
UNEP-GEF en.lighten initiative	C*, J*, W*, X*, Y*, Z*	1B
Olina	R	3B
Premium Lights	O	3B
CLASP Clear LED Research	D	1B
Anonymous EU	E	1B
EcoAsia CFL Benchmarking	S*, T*, U*, V*	1B
California Energy Commission	N	1A
CALiPER	K	1B
Energy Star CFL Testing	A*	1B
Energy Star	H	2B
Lighting Facts	I	1B

2.3 Clarifications and cautions in interpreting data

When interpreting the degree of confidence attributable to any particular data set and resulting analysis/outcomes, reference should always be made to the data confidence score. However, to facilitate the comparison of data across national boundaries, a number of additional compromises have been made that lead to the following cautions when interpreting the information presented:

- **Data sets are of significantly different sizes:** In a number of graphics it may *appear* that individual economies have significantly more models displaying certain performance characteristics in comparison with elsewhere. This *may* not be the case in the actual market and may simply be differences in the size of the original data set (refer to Table 1) or the filters that have subsequently been applied in analysis. Thus, it is important to review the size of individual data sources to gauge likely skew that may have been caused by differing data set sizes.
- **Single samples and model averages are not differentiated:** Other than in the data confidence score[9], there has been no differentiation in the presentation/analysis between data sets that contain results for only a single sample of each model, in which multiple samples of each

[7] Data set letters that have an asterisk (*) next to the data set letter are those data sets where model averages are presented rather than individual sample values.
[8] The *Australia CFL Benchmarking and check testing* data set is combined data sets from different testing activities undertaken over a number of years. However, given the similarities in objective, sampling, test methodology and testing facilities used, the individual data sets have been combined to simplify presentation.
[9] As described in Appendix 2, a score for data quality is designated based on the number of samples of a particular model tested. Single samples will therefore be given a lower data confidence score. However, there are certain situations when a number of samples of the same model have been tested where the average of those samples is the more robust basis for the analysis, and others where analysis of the individual samples is more informative. Hence, on balance, these are assigned the same score, i.e., the data confidence score assigned to a model average from, for example, six samples is the same as the data confidence score assigned to each of those six samples if they are reported individually.

model have been reported individually, and in which the results of multiple samples have been aggregated.[10]

- **Comparison of lamps with differing color temperatures:** A number of the performance parameters of certain lamp types are significantly affected by the color temperature of those lamps, thus comparison of lamps of different color temperature can be misleading. However, while it is possible to conduct the analysis of wholly comparable lamps based on small color temperature ranges, in practice this generally leads to *very* small data sets from which little can be learned. Thus, the analysis has separated lamps in "low" and "high" color temperatures, i.e. lamps with color temperatures <4500K (designated as CCT1) and lamps where the color temperature is ≥4500K (CCT2). This color temperature delineation is broadly in line with regulations in the majority of the world, although the specific Kelvin thresholds vary slightly.[11]

- **Test and Declared Performance Parameters:** The data sets contain a mix of performance parameters declared by manufacturers (e.g. on product registration databases), and those acquired through tested by third parties, and in some cases both.[12] Where both manufacturer-claimed and third-party tested data is available, only the tested data is used in the analysis.

- **Differences in test methodologies and supply voltages:** There are differences in the test methodologies and voltages used to establish the performance parameters in the different data sets. However, the analysis focuses on electrical and photometric tests of omnidirectional lamps with integral ballasts, thus differences in supply voltage will not have a significant impact on lamp performance as the ballasts are optimized for their design voltage. Further, the vast majority of tests methods used around the world (for the key parameters compared) are derived from the same underlying international standards, e.g., from the CIE and IEC.[13] Consequently, in most instances the data from the various sources is considered to be comparable. The exceptions are reported values for lumen maintenance and lifetime due to substantive differences in aging time and switching cycles used for lumen maintenance and lifetime tests. Unless otherwise stated, differences in switching cycles are ignored and data analyzed/presented for lumen maintenance is for values at 2,000 hours and lifetime is detailed in the text where used.

  Associated tolerances within the test methodologies/laboratory/regulatory declaration requirements have been ignored as, in most cases they are unknown, even though in some cases they *may* be significant (potentially up to 10% variation from reported values).

- **Differences in performance parameters available in data sets:** As noted in the preceding sub-section, data sets vary considerably in the number of lamp performance parameters available, and particularly those parameters related to lumen maintenance and lifetime. Consequently the data analyzed for a particular parameter at a particular point in lamp lifetime is somewhat self-selecting based on the availability of data related to that parameter in an individual data set.

[10] The high volume, low cost nature of lamp manufacturing can result in variations in performance within a product model. This is recognized in international test standards by requiring a sample test population (often of ten lamps) to be tested, with their means and medians, and performance ranges used instead of individual results. This is the case for the majority of data sets used in this report.

[11] For specific national CCT thresholds refer to Appendix 3.

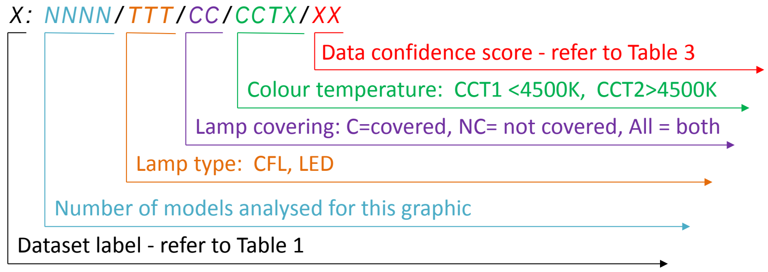
[12] Note that additional data on declaration on packaging is also available in some data sets but has not be analyzed or presented either directly in any graphics.

[13] Note that some CIE test procedures use "relative photometry". However, for lamps, this is always converted by the laboratory into "absolute photometry" which is the absolute luminous flux of the lamp.

2.4 Understanding data quality displayed on graphics

To provide transparency for the data displayed in a graphic, the limitations of that data, and the degree of comparability of that data to other data displayed, a coding system has been developed and is displayed in the legend of each graphic. An explanation of the code system is given in Figure 2.

Figure 2: Coding system identifying contents and confidence level of data sets displayed in graphics



3. Summary Mapping and Benchmarking of CFL and LED Policy Frameworks

When analyzing product performance data from individual economies, it is obviously important to have an understanding of the policy frameworks influencing that product performance. Table 4 (for CFLs) and Table 5 (for LEDs) provide summaries of the policy frameworks in place in the economies/regions where data is analyzed.

On one level, these summary policy frameworks are very superficial. For example, due to difficulties in obtaining historical information on some policy actions, the tables only provide ranges for the dates of when each policy element was initiated, i.e., within the last 5 years, 5-10 years, and greater than 10 years. So, for example, they show that USA's ENERGY STAR premium product label has been in place for an extended period (over 10 years) while the Vietnamese MEPS/Registration program was only introduced two years ago. However, they do not detail the robust compliance mechanisms and extensive promotion and subsidy activities supporting ENERY STAR, nor explain that policies supporting the Vietnamese program are still very much in the embryonic stage. However, even at this superficial level, the tables do enable us to deduce two important facts given in the boxes below.

Contrary to widely held perceptions, the developing countries represented typically have relatively comprehensive policy frameworks for CFLs and, in some cases, appear to be developing such frameworks for LEDs in advance of a number of their more developed counterparts.

In comparison with CFLs, the policy frameworks for LEDs are much less developed across most countries. However, as highlighted in Sections 4.1 and 4.2, LEDs are undergoing very rapid development and there is an expectation among many stakeholders of high levels of consumer adoption of LEDs in the near future. Thus there is an urgent need to develop appropriate policy frameworks to ensure product quality is maintained and the LED market continues to expand. In particular, management of initial and maintained color, lumen maintenance and lifetime are important to ensuring consumer satisfaction and avoiding the consumer backlash against CFLs that resulted from dissatisfaction with quality during early consumer adoption.

Table 4: Summary Mapping of Policy Frameworks for CFLs in Economies Studied[14][15]

	MEPS	HEPS	Comparative labeling	Endorsement labeling/ certification	Import registry	Domestic product registry	Mandatory testing	Market surveillance program	Registry of non-compliant products	Fines or penalties
Australia	Yes (5-10 years)		Yes (5-10 years)		Yes (5-10 years)	Yes (5-10 years)	Yes (5-10 years)	Yes (5-10 years)		Yes
Cambodia[16]	Yes (<5 years)		Yes (<5 years)	Yes (<5 years)	Yes (<5 years)	Yes (<5 years)	Yes (<5 years)			Yes
European Union	Yes (5-10 years)		Yes (5-10 years)	Some Countries (>10 years)			Indirectly (CE requirement)	Some Countries (>10 years)	Limited	Variable by Country
Indonesia	(Being implemented)		(Being implemented)		Yes (<5 years)	Yes (<5 years)	Yes (<5 years)	Yes (<5 years)		Yes
Lao PDR[16]					Yes	Yes				
Philippines			Mandatory (5-10 years)							
Thailand	Voluntary (>10 years)	Voluntary (>10 years)	Voluntary (>10 years)				Yes (>10 years)	Yes (5-10 years)		Yes
USA	Yes (limited >10 years)			Yes (>10 years)	Yes (>10 years)	Yes (>10 years)		Yes (5-10 years)		
Vietnam	Yes (<5 years)	Voluntary (<5 years)	Yes (<5 years)	Voluntary (<5 years)	Yes (<5 years)	Yes (<5 years)	Yes (<5 years)	Yes (<5 years)		Yes

[14] Source: Lites Asia Regional Position Paper, 2013 *lites.asia*, updated to include EU and USA requirements.
[15] Time periods in brackets denote the approximate age of the specific policy measure.
[16] Cambodia and Lao PDR are both reported as having CFL and LED regulations in some form, but detailed performance requirements have been not been identified.

Table 5: Summary Mapping of Economy Policy Framework for LEDs[17]

	MEPS	HEPS	Comparative labeling	Endorsement labeling/ certification	Import registry	Domestic product registry	Mandatory testing	Market surveillance program	Registry of non-compliant products	Fines or penalties
Australia	Under consideration		Under consideration	Voluntary[18] (>5 years)	Under consideration	Under consideration	Under consideration	Under consideration		Under consideration
Cambodia[16]	Yes (<5 years)		Yes (<5 years)	Yes (<5 years)	Yes (<5 years)	Yes (<5 years)	Yes (<5 years)			Yes
European Union	Yes[19]		Yes	Some Countries (>10 years)			Indirectly (CE requirement)	Some Countries (>10 years)	Limited	Variable by Country
Indonesia	Being prepared	To be considered	To be considered	To be considered						
Lao PDR[16]					Yes (<5 years)	Yes (<5 years)				
Philippines										
Thailand			Voluntary (5-10 years)							
USA	Yes (>10 years)			Yes (>10 years)				Yes		
Vietnam										

[17] Source: Lites Asia Regional Position Paper, 2013 *lites.asia*, updated to include EU and USA requirements.
[18] The Australian LED certification and labeling programme is an industry operated system.
[19] EU regulations for omnidirectional LEDs currently primarily address consumer satisfaction criteria and not lamp efficacy.

To enable comparisons between economies, Appendix 3 details the key performance parameters specified within each of the CFL and LED initiatives outlined above, with Table 6 and Table 7 providing a summary mapping of the performance parameters specified within each initiative. Knowledge of these individual national/regional performance requirements is necessary for evaluating current levels of compliance investigated in Section 4.2. However, there are some valuable lessons simply by looking at the regulations themselves.

The performance parameters mapped in Table 6 and Table 7 show minor difference in the parameters on which regulators are placing requirements. For example there are fewer requirements related to color in Asian economies than elsewhere simply because color is generally considered of less importance by consumers in this region. However, the tables illustrate that policymakers around the world have recognized the importance of placing requirements upon a broad spectrum of lamp performance parameters. This recognizes the interdependent nature of these parameters where, for example, improving one aspect (e.g. a higher CRI) can result in a reduction in another (e.g. lower efficacy).

In many jurisdictions stakeholders are seeking to reduce regulatory requirements across a broad range of products. However, for lighting products in particular, it is important for policymakers/regulators to maintain the application of requirements across a broad spectrum of performance parameters to ensure energy, environmental and/or consumer programmatic goals are not directly or indirectly compromised.

Table 6: Summary mapping of CFL performance parameters included in MEPS and voluntary programs for CFLs in economies analyzed[20]

Economy	Program Type / Performance Parameter	Efficacy	Life time	CRI	CCT	Lumen maintenance	Switch withstand	Start time	Run-up time	Color consistency	Harmonic distortion	Power factor	Mercury content	Premature failure
Australia[21]	MEPS	X	X	X	X	X	X	X	X	X	X	X	X	X
EU	MEPS	X	X	X	X	X	X	X	X	X		X	X	X
Indonesia	MEPS	X	X		X	X								
Philippines	MEPS	X	X		X	X								
Thailand	Voluntary	X										X		
USA	Voluntary Premium (ENERGY STAR)	X	X	X	X	X	X	X	X			X	X	
US	MEPS	X	X		X	X	X							
Vietnam	MEPS	X			X	X								

[20] As note previously, Cambodia and Lao PDR are both reported as having CFL and LED regulations in some form, but detailed performance requirements have been not been identified.

[21] Note that Australia and New Zealand have the same requirements for CFLs as part of their cooperative Equipment Energy Efficiency Program (E3).

Table 7: Summary mapping of LED performance parameters included in MEPS and voluntary programs for LEDs in economies analyzed

Economy	Program Type / Performance Parameter	Efficacy	Life time	CRI	CCT	Lumen maintenance	Switch withstand	Start time	Run-up time	Color consistency	Harmonic distortion	Power factor	Premature failure
EU	MEPS		X	X	X	X	X	X	X	X		X	X
USA	Voluntary Premium (ENERGY STAR)	X	X	X	X	X	X	X				X	

Figure 3 and Figure 4 show the variations in approach to regulating lamp efficiency relative to the light output of the product (i.e. stepped and continuous curve), and the differences in actual efficacy requirements at any individual light output and color temperature. In many cases the differences in efficacy requirements between economies are marginal.[22] Further, as Appendix 3 shows, while a small number of other lamp performance parameters are broadly internationally aligned (for example, where regulated, a CRI requirement of 80 is typical in most regulations), such alignment is the exception rather than the rule.

These issues are discussed in some detail elsewhere[23], but it is worth reiterating the potential for harmonization of product requirements is great, with few technical barriers limiting this opportunity.[24]

Given CFLs and LEDs are amongst the most globally traded products, and are technically relatively similar in all geographic markets, there appears little need for the large number of marginal differences in performance requirements at the national and regional levels. Closer alignment/harmonization of these performance requirements has the potential to reduce international barriers to trade and increase competition, with the associated reductions in market price and accelerated product development, Further, such alignment increases the opportunities for cross border enforcement actions reducing costs to individual program operators/regulators, while simultaneously reducing the risk of poor quality products undermining growing markets.

As noted earlier, there are marked differences in the number of current regulations for efficacy between CFLs and LEDs. This is visually highlighted in Figure 3 and Figure 4.

In comparison with CFLs, the markedly lower number of current regulations for LEDs reinforces the earlier observation on the current lack of regulatory oversight of the developing LED markets, and the urgent need for policymaker intervention to ensure ongoing consumer satisfaction to maintain the market growth.

[22] International alignment of these requirements is rarely undertaken, even with marginal differences, although there have been proposals made to IEC's TC34 to do so.
[23] Recently in the IEA 4E benchmarking of the efficiency of lighting markets (refer mappingandbenchmarking.iea-4e.org/shared_files/676/download).
[24] It is worth noting efforts have been made in this direction including the recent announcement by ASEAN to harmonize performance requirements across their member countries. Further, there are instances where differences in performance requirements are introduced for good reason. For example, Indonesia is currently *downgrading* performance requirements for CFLs in order to assist the development of local industry.

Figure 3: Benchmarking of MEPS and voluntary labeling efficacy requirements for bare CFL (CCT<4,500) in economies analysis[25]

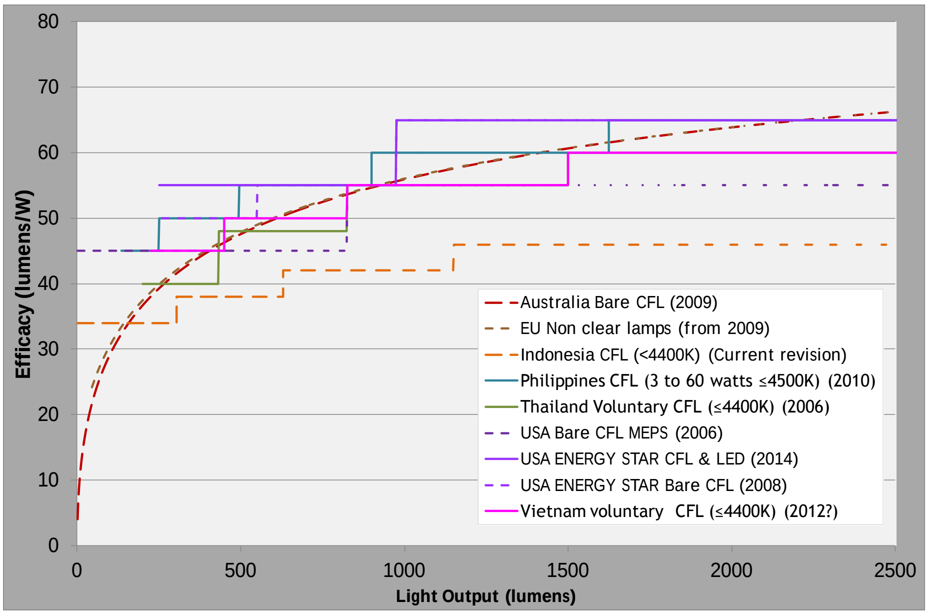
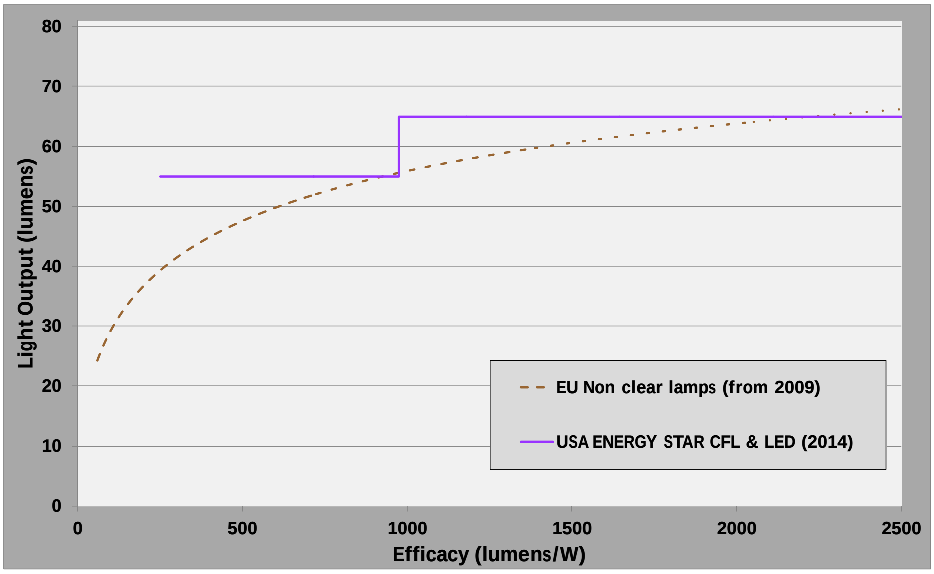


Figure 4: Benchmarking of MEPS and voluntary labeling efficacy requirements for LEDs[26,27]



[25] The graphic shows CFL efficacy requirements for lamps with color temperatures of *approximately* <4500K, with the specific national/regional color temperature thresholds noted in the legend where they are not exactly 4500K. Such minor variations in color temperature thresholds serve to reinforce the minor differences between many regulations and the relatively easy with which alignment would be possible,

[26] At the time of report preparation Australia has no performance requirements for LEDs but a consultation process is currently underway which may result in MEPS and/or Labeling for LEDs. However, the Australian industry association (Lighting Council of Australia) voluntary SSL quality scheme in place, refer to http://www.lightingcouncil.com.au/site/ssl/overview.php.

[27] The EU non-clear lamp requirement is actually technology neutral and so was not developed for LEDs specifically. Further, at the time of report preparation, the EU is undertaking a study aimed to bring together all lighting regulations and will most likely result in increasing the efficacy (and other) performance requirements for LEDs.

4. Product Availability, Quality and Trends

4.1 What incandescent replacement products are available, and how is this changing?

The aim of this sub-section is to examine the availability of CFL and LED products with appropriate levels of light output to be suitable replacements for A-shaped incandescent GSL lamps and how this availability has changed over time. Note that the issue of lamp quality (as opposed to light output) is discussed separately in Section 4.2.

In order to comprehensively answer the question of "availability", significant global market based data would be required. For example:

- Numbers of models of CFL/LED available in retail outlets to replace GSL lamps in each lumen range across the primary consumer base.
- Detailed sales data to show in what quantities lamps are being sold and hence the speed of actual market adoption and ongoing consumer satisfaction.

Unfortunately such comprehensive global market data was not available to this study, so the question of product availability is addressed indirectly from the data available.

4.1.1 Light output necessary for equivalence to incandescent GSL products

In order to investigate the availability of equivalent replacement lamps for given wattages, it is first necessary to ascertain how much light is emitted from standard A-shaped incandescent GSL product at the various "standard" lamp wattage thresholds. This is somewhat complicated by the range of lamp outputs on the various markets, and the fact that light output of filament lamps is directly affected by the voltage under which it is tested.[28] However, Table 8 shows the approximate light output for GSLs at both 115V and 230V (drawn from European and North American manufacturer catalogue claims).

Table 8: Approximate light output for GSL lamps in 110V and 230V markets

	European Catalogues				North American Catalogues			
GSL Power (tungsten incandescent)	Philips *(lumens)*	GE *(lumens)*	OSRAM *(lumens)*	**Average *(lumens)***	Philips *(lumens)*	GE *(lumens)*	OSRAM *(lumens)*	**Average *(lumens)***
25W		230	220	**225**	220		190	**205**
40W	410	410	415	**412**	500	505		**503**
60W	700	700	710	**703**	880	865	880	**875**
75W		930	935	**933**	1195	1190	1200	**1,195**
100W	1330	1330	1330	**1,333**	1590	1710	1720	**1,673**

As the light output from CFLs and LEDs often depreciates considerably more than incandescent lamps over their lifetime, consumers might desire CFLs and LEDs to (initially) emit approximately 10% more

[28] There are a large number of "equivalence" tables used in regulation and other policy measures actions around the world. For example, in the EU, Table 6 of Commission Regulation 244/2009; Section 9.2 of version 1.0 of the U.S. ENERGY STAR product specification for lamps; and from government issued data in Australia available at http://www.energyrating.gov.au/products/lighting/phaseout. There is little alignment between these various equivalence tables partially due to voltage difference, but also local cultural expectations and traditional product availability. Hence, a transparently derived, globally appropriate alternative is proposed.

light than "equivalent" CFL and LEDs.[29] Thus, to determine the availability of CFLs and LED replacements lamps it is necessary to establish the market availability of products with light output allowing for this marginal 10% lumen depreciation relative to the incandescent lamps as shown in Table 9. The remainder of the analysis will assume appropriate thresholds for GSL replacements as the midpoint values of the ranges shown in the final column of Table 9.

Table 9: Required initial lumen output of CFL and LED lamps to be deemed equivalent replacements for GSL incandescent lamps at a range of standard voltages

GSL Power (tungsten incandescent)	Lumen output range for replacement LEDs and CFLs to be deemed equivalent assuming a net 10% lumen depreciation allowance	Mid-point of replacement range used as equivalence threshold in the remainder of the analysis
25W	225-250 lumens	240 lumens
40W	450-550 lumens	500 lumens
60W	775-960 lumens	850 lumens
75w	1,025-1,315 lumens	1,160 lumens
100W	1,465-1,840 lumens	1,650 lumens

4.1.2 Availability of CFL replacements for incandescent GSL lighting

CFLs were developed by GE in 1975, but first introduced in developed economies by Philips in 1980, with other manufacturers following soon after.[30] As Section 3 illustrated, in many economies CFL have subsequently been a major policy focus (regulation, labeling, subsidy support, etc.) resulting in extensive product development by manufacturers. Further, in the majority of developed economies, the intention to phase out inefficient lighting has been signaled since 2010, at the latest, giving manufacturers the opportunity to expand their range of products to service the various market niches. Consequently, it is not a surprise to see that a large number of CFLs are available in Australia (Figure 5) and the USA (Figure 6)[31] in each of the lumen ranges suitable for replacing 25-100W incandescent GSLs. Further, the broad stability in the number and range of CFLs available over the 2010-2014 period (Figure 7) demonstrates the relative maturity of CFLs in these markets, at least in terms of light output.

[29] Various studies indicate incandescent lamps depreciate by 3-15% over their life, and CFLs by around 5-25% over several thousand hours. For LEDs, end-of-life is often defined as the point where the lamp has lost 30% of its initial light output. Thus it has been assumed that CFLs and LEDs should ideally (when new) emit at least 10% more light than incandescent lamps in order to compensate for their more significant lumen depreciation over time.

[30] https://en.wikipedia.org/wiki/Compact_fluorescent_lamp

[31] Insufficient data was available for the EU, but there is broad expert consensus that CFLs in the EU are similar to those of Australia and the USA (noting the difference in supply voltage has little impact on the performance of CFLs that are optimized for local conditions).

Figure 5: Incandescent GSL equivalent light output (and efficacy) of registered CFLs for potential sale in Australia in 2010, 2013 and 2014

(Data: Australian CFL Testing (B: 2010-13) and Registration Database (F: 2014))

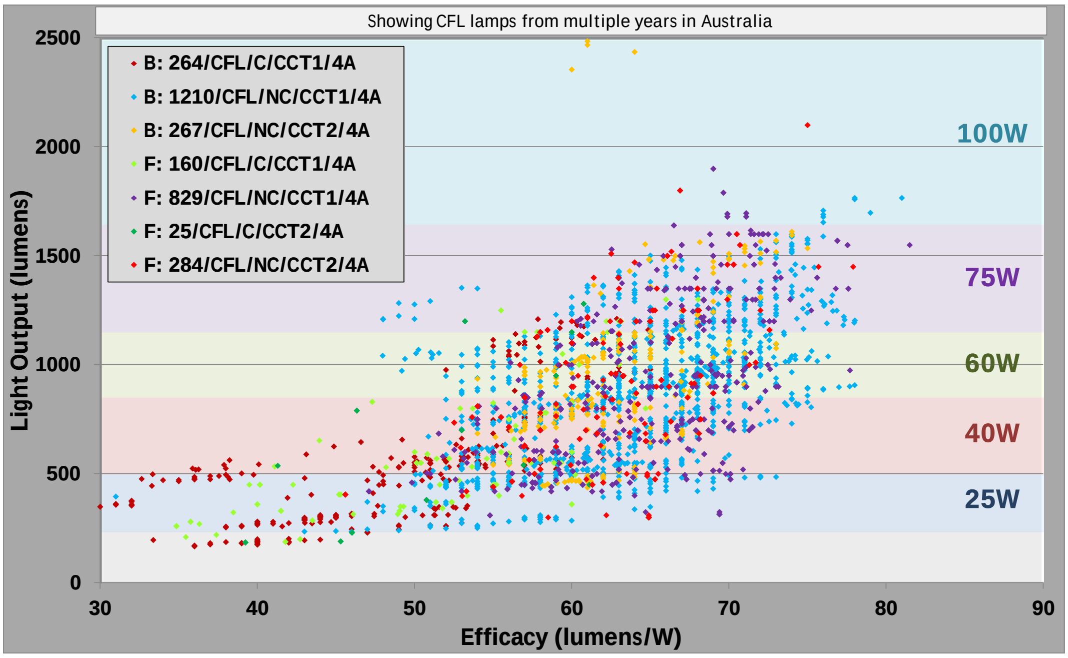


Figure 6: Incandescent GSL equivalent light output (and efficacy) for registered CFLs for potential sale in USA in 2010, 2013 and 2014

(Data: California Energy Commission (N: 2010-14))

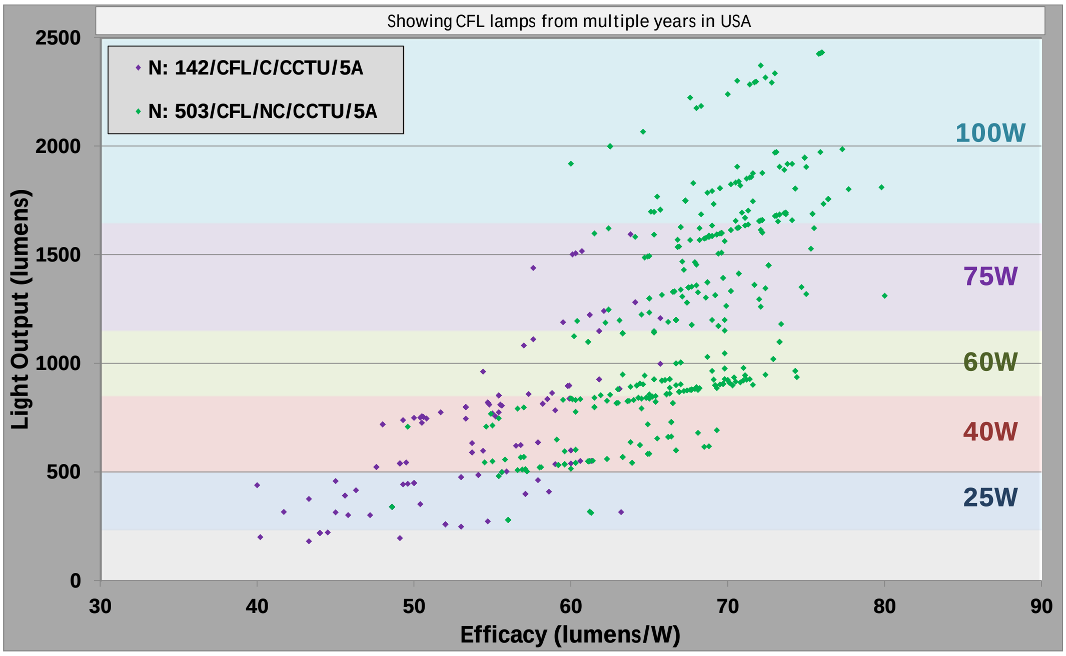
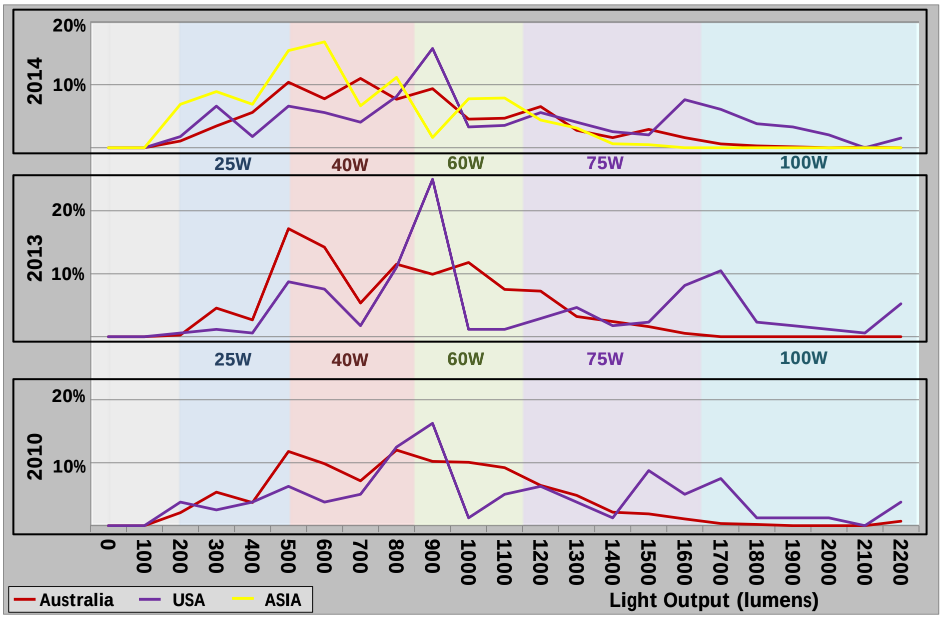


Figure 7: Comparative distribution of the light output of CFLs in the Australian, Asian, and USA datasets in 2010, 2013 and 2014

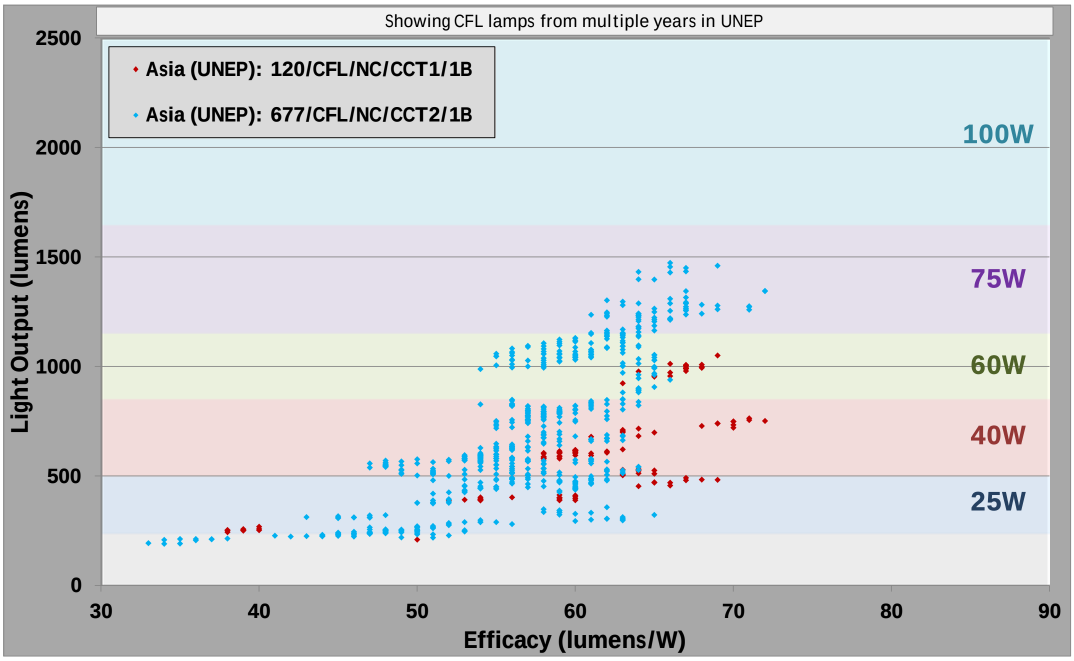
(Data Australian CFL Testing (B: 2010-13) and Registration Database (F: 2014); California Energy Commission (N: 2010-2014); and UNEP-GEF en.lighten (combined 2014) for Cambodia (C), Indonesia (J), Lao (W), Philippines (X), Thailand (Y) and Vietnam (Z))



For individual economies in Asia, a definitive demonstration of the availability of replacement CFLs across all lumen ranges in not possible due to the small data sets available. However, by drawing together the 2014 results for all six of the economies participating in the UNEP-GEF en.lighten tests, it is possible to see a broad picture of CFL availability across Asia (Figure 8).

Figure 8: Incandescent GSL equivalent light output (and efficacy) for a selection of CFLs available in the Asian market in 2014

(Data: UNEP-GEF en.lighten for Cambodia (c), Indonesia (J), Lao PDR (W), Philippines (X), Thailand (Y) and Vietnam (Z))



Even from this somewhat limited combined data set, it appears reasonable to conclude CFLs are available in the Asian economies studied in lumen ranges to replace GSL incandescent lamps up to, and including, 75W. From this limited test data it is difficult to conclude if genuine replacements for larger wattage lamps are available. To some extent this is not surprising, as the original sampling used in the UNEP data set focused specifically on the most typical/popular products in each market and, in the majority of Asian markets, 25-60W incandescent lamps (and their replacements) dominate household demand. However, a brief review of online lamp retailers in some of these economies[32] has shown that CFL replacements are also available at equivalent light output levels to 100W incandescent lamps, although the total number of products available in these markets is unknown.

Conclusion:

In all economies studied, CFLs are currently available with light output suitable to replace incandescent GSLs up to and including 75W. Within the developed countries (Australia, the USA and very likely the EU) there is also demonstrable availability of 100W equivalent CFLs. Demand for larger 100W replacement lamps is limited in Asian countries and so, unsurprisingly, there is less direct evidence for the availability of such lamps in these markets. However, there is sufficient indirect evidence to suggest 100W equivalent lamps are being supplied, although the validity of claims is unknown.

In developed countries, the typical number of CFLs available, and the range of light outputs of those CFLs, has been relatively static in recent years. This indicates a mature market where consumer expectations regarding light output and quality requirements are being fully realized. Although there is insufficient evidence to confirm a similar situation in Asia, given the globally traded nature of the CFLs, there is no reason to suggest the situation is different.

4.1.3 Availability of LED replacements for incandescent GSL lighting

LEDs became available in a GSL replacement format starting around 2006, with probably the most obvious recognition of the availability of a true replacement product occurring in 2009 with Philips' L-Prize entry.[33] Since that time there have been further advances in LED design and manufacturing technology, with many additional products entering the market at various price/quality ranges.

The expansion in the range of products offered is amply demonstrated by Figure 9, Figure 10, and Figure 11 which show a selection of LED plug in GSL replacement products available in 2010, 2013, and 2014 in Australia, the EU and the USA respectively[34] (Figure 12 provides direct comparison of the evolution of the three markets). As illustrated, replacement products are now available for all incandescent GSL standard wattages up to and including 75W, and in the USA up to and including 100W, although the exact degree of penetration of such products in any of these markets is not known due to the limited market representation of any of the data sets.

The relatively recent entry of the higher flux, 100W replacement lamps into the US market reflects the speed of product development and, thus, the entry of similar products into the Australian and the EU markets can be expected in the very near future if they have not already done so.

[32] For example: Udeman Lighting in the Philippines (http://www.udeman.asia/lamps-energy-saving-lamps/jumbo-t5.html) and Megaman supplying into Indonesia (http://megaman-indonesia.com/products/list1/3/1/33/SPIRAX-series).

[33] Refer to http://www.webcitation.org/60jS9wT6Q for the U.S. Department of Energy announcement of the success of the Philips lamp in meeting all the all the stringent criteria laid down to be deemed a true replacement for a 60W GSL incandescent lamp. 2013 measurement of the original samples used in the tests showed lumen maintenance levels in excess of 100% at 25,000 hours (refer to http://www.lightingprize.org/pdfs/lprize_60w-lumen-maint-testing.pdf)

[34] Although these graphics by no way represent the entire product availability in these markets as evidenced by over 800 products being registered for the premium U.S. ENERGY STAR label in 2014 alone. Note that the wide range of LED efficacy present an unregulated market, as shown by efficacy results that would not comply with CFL MEPS. This presents a good case for MEPSs for LEDs, as consumers appear to generally assume that LEDs are always efficient.

Unfortunately the research team was not able to obtain any data on LED lamps from the Asian economies. Therefore, although likely, equivalent conclusions cannot be drawn for Asia.

Figure 9: Incandescent GSL equivalent light output (and efficacy) of a selection of LEDs available in Australia in 2013 and 2014

(Data: Australian LED Testing (G), Choice Data (L) and LED Benchmarking (P))

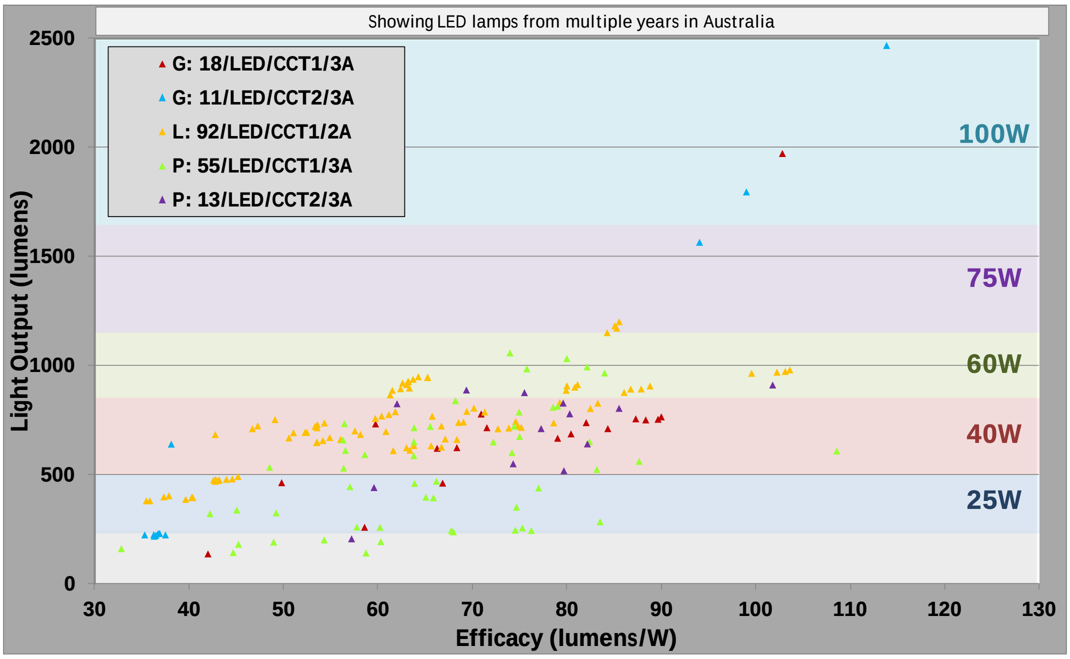


Figure 10: Incandescent GSL equivalent light output (and efficacy) of a selection of LEDs available in the EU in 2010, 2013 and 2014

(Data: EU Clear (D), Premium Lights (O) and Olina (R))

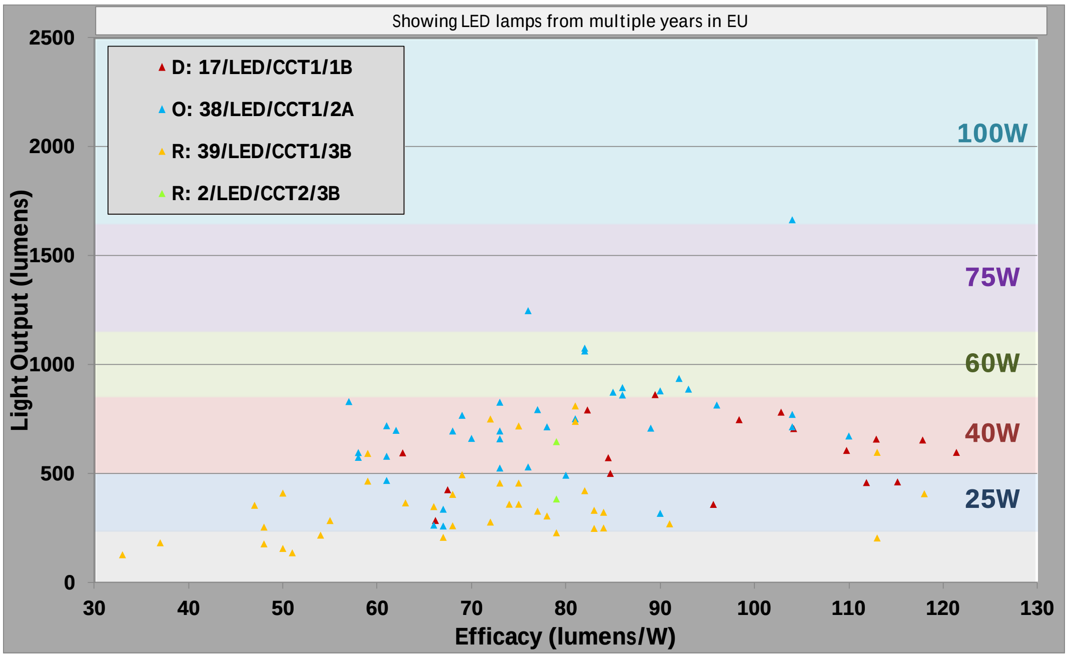


Figure 11: Incandescent GSL equivalent light output (and efficacy) of a selection of LEDs available in the U.S. in 2010, 2013 and 2014

(Data: Lighting Facts (I)

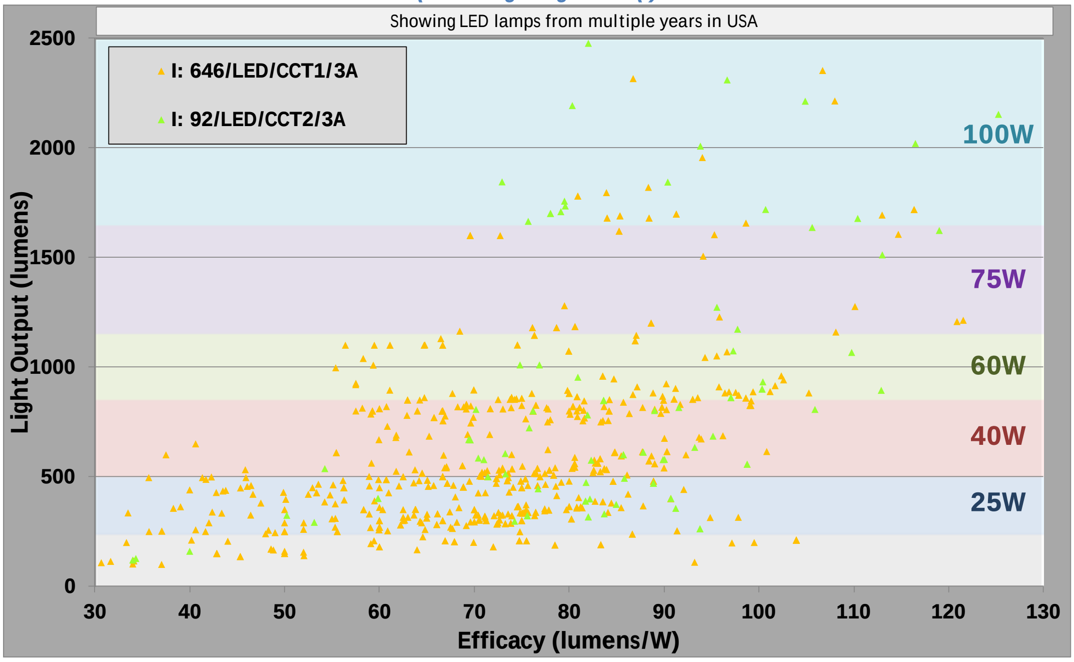
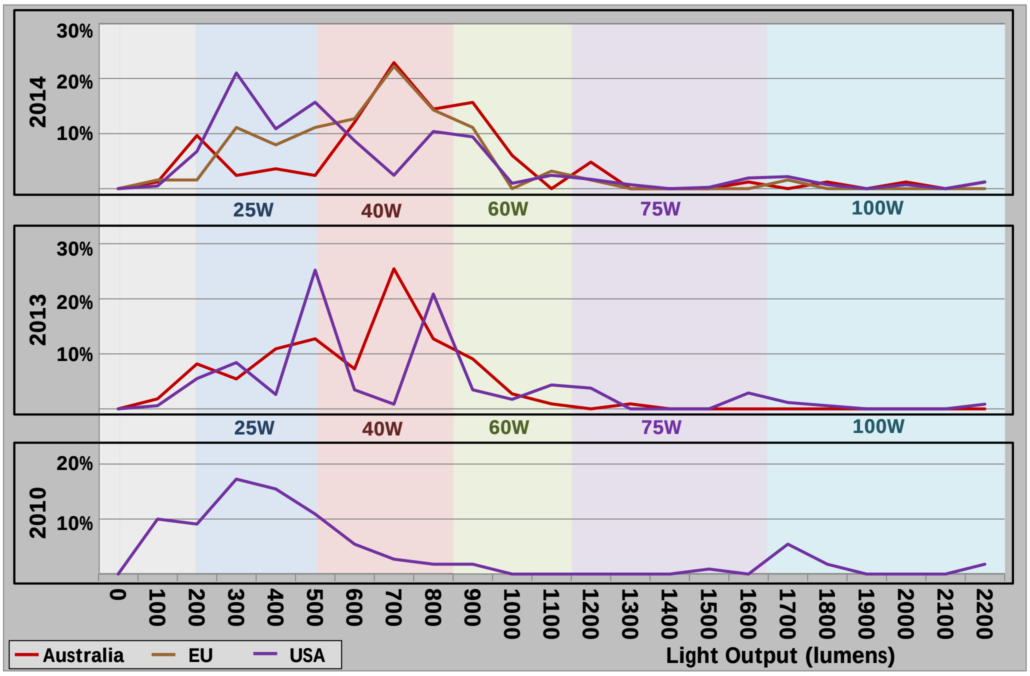


Figure 12: Comparative distribution of the light output of LEDs in the Australian, EU and USA datasets in 2010, 2013 and 2014

(Data: Australian (Combined 2013-14) LED Testing (G), Choice Data (I) and LED Benchmarking (P); EU (combined 14 only) EU Clear (D), Premium Lights (O) and Olina (R); and USA Lighting Facts (I: 2010-14))



Conclusion:

For Australia, the EU and the USA, LEDs with sufficient light output to replace all incandescent GSL lamps up to and including 75W are now available. However, significant numbers of LED replacements for the higher lumen output 100W GSL incandescent have only recently appeared in the US market and there is yet to be significant evidence of these products in Australia and the EU in 2014. However, given the obvious speed of product development, it seems probable 100W replacement products will enter the Australian and EU markets in the near future if they have not already done so.

Insufficient data were available to support any conclusions for the Asian countries.

4.2 What is the current quality of CFLs and LEDs and how is this evolving?

This section examines the quality of CFL and LED lamps, how they evolved over time, and any observable correlations with the regulations of the economies studied. The lamp quality parameters critically important to the consumer in most economies, and for which significant quantities of data are available, are efficacy and CRI and hence these are used as the basis for the analysis.[35] Lumen maintenance and lifetime are clearly also of importance to consumers (and regulators more so), but as noted in Section 2.1, limited contemporary data is available on lumen maintenance, and no datasets contain lifetime except that claimed by manufacturers. Hence, only limited analysis of lumen maintenance is possible with no analysis of product lifetime undertaken.

4.2.1 A framework for comparative evaluation product quality

While mapping of the national requirement for lamp performance allows analysis of compliance of products *within* any particular national market (illustrated in Figure 3 and Figure 4 for efficacy but applicable to other performance criteria), it does not provide an adequate absolute framework against which product quality can be benchmarked *across* international markets because:

- While almost all national regulations (MEPS or premium product identification) incorporate efficacy, CRI and lumen maintenance within their requirements,[36] typically the requirements provide a single threshold for each parameter. Hence comparing products against such thresholds would provide a single "better than/worse that" comparison and make it difficult to form a picture of the *range* of quality of products within markets;[37]
- Selection of any individual national performance requirement against which international products are compared is likely to provide a distorted picture of "quality" as the specific regulation will have been developed within the national legislative and cultural context, and obviously, products sold within that market are more likely to precisely align with the local requirements.

Fortunately, there are internationally developed performance criteria that are suitable for application in such cross market analysis for both LEDs and CFLs: namely the IEA 4E SSL Annex's Product

[35] There are a number of other parameters that are important for light quality that should be considered by regulators, such as accuracy of colour temperature, start up time (CFL), mercury (CFL) and hazardous materials content, switching withstand, premature failure. Power factor is also seen as very important by some countries.
[36] Refer to Section 3 Table 6 and Table 7 and Appendix 3.
[37] A number of markets in Asia have comparative labeling *within* a product group type (e.g. CFLs), but the performance requirements for these labels *typically* only related to efficacy and so fail to provide a broad spectrum framework for the evaluation of overall performance.

Performance Tiers[38] and the proposed IEC performance limits for self-ballasted CFLs, supported by Australia and a number of Asian countries.[39] Use of these internationally agreed tiers is useful as:

- In each case they provide 3 bands[40] of increasing levels of product performance;
- They are based on international agreement among a range of stakeholders and are not directly aligned with the requirements in any one economy.

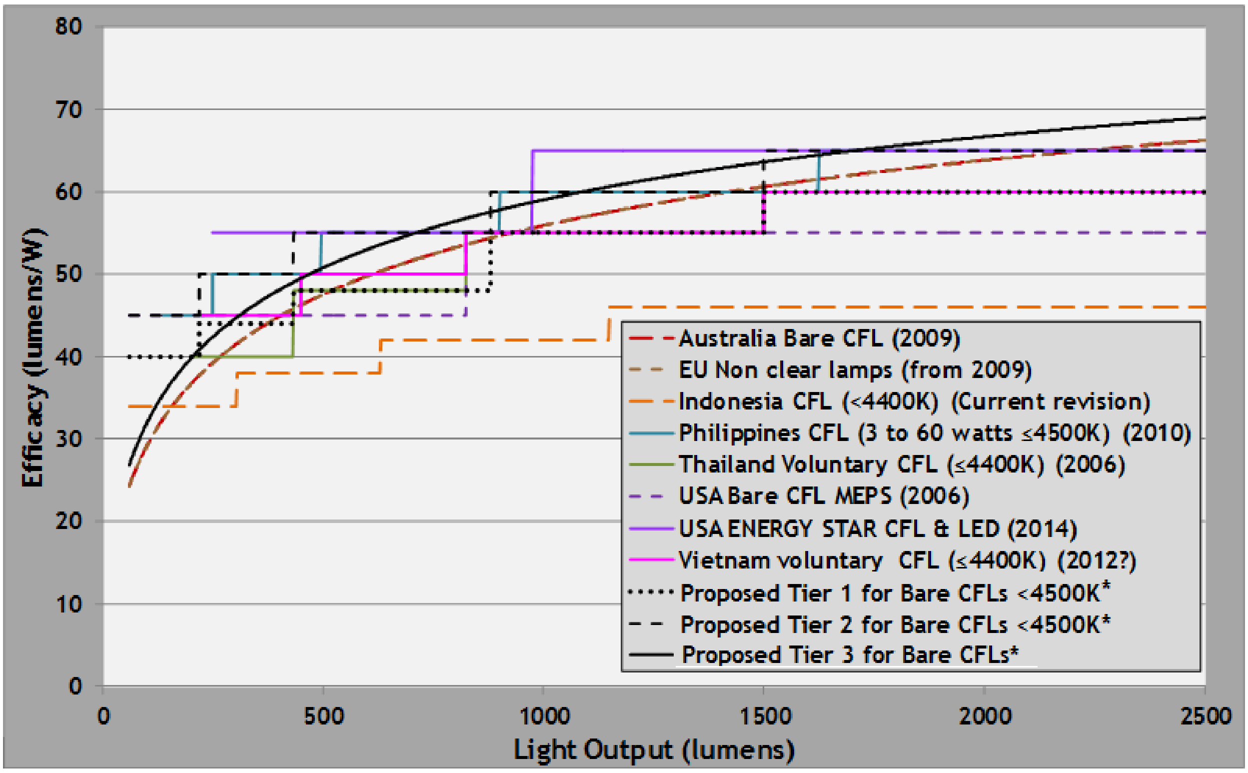
Therefore, where international comparison of lamp quality is required as part of the following analysis, the 4E SSL LED and proposed CFL performance tiers will be used as the basis for these comparisons. **However, it should be noted this is *only* for comparative measure of quality and lamps of lower performance tiers should not necessarily be assumed to be inferior as they may well be both**

[38] Refer to http://ssl.iea-4e.org/product-performance. These are currently under review for update.
[39] Note that these CFL performance tiers were proposed as a work item for the IEC (reference 3 4A/1754/NP PNW *34A-1754: Self-ballasted compact fluorescent lamps for general lighting services - Performance limits*). The proposal to adopt the work item was rejected by TC34. Nevertheless, the performance tiers proposed provide a suitable framework for the purposes of this analysis. However, the term “proposed” is used as a preface to each reference to the performance tiers to emphasize the tiers were not adopted by the IEC.
[40] Technically there are three IEA 4E SSL performance tiers, although the highest tier differs only from the tier below by requiring an LED CRI of 90 rather than 80.

compliant with regulations in the market from which they were sampled, and appropriate to local needs in those markets.

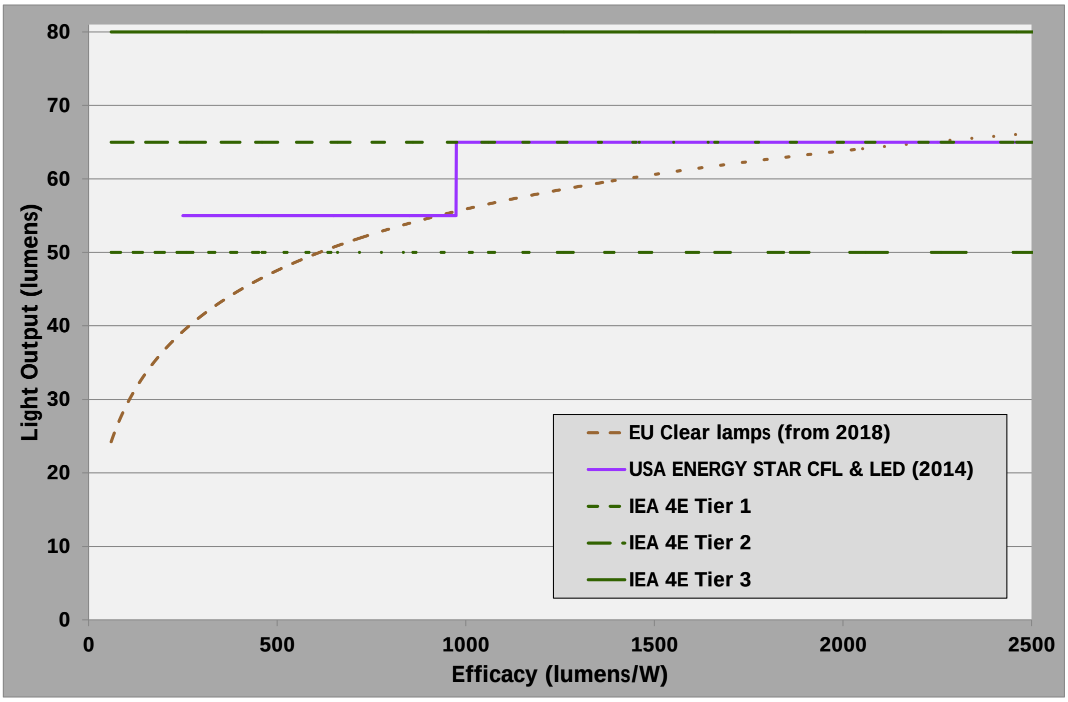
Figure 13 and Figure 14 respectively reproduce Figure 3 and Figure 4 overlaid with the proposed CFL and 4E SSL performance tiers to illustrate comparisons between the international performance tiers and the national thresholds for efficacy.

Figure 13: Proposed CFL Performance Tiers in comparison to National MEPS and voluntary labeling efficacy requirements for bare CFLs (CCT<4,500)



* Proposed to the IEC with the support of Australia and a number of Asian countries.

Figure 14: 4E SSL Performance Tiers in comparison to National MEPS and voluntary labeling efficacy requirements for LEDs



4.2.2 International comparison of CFL quality: Efficacy

Figure 15 shows the measured efficacy of CFLs in 2013 or 2014 from all economies analyzed compared to the requirements of the proposed CFL tiers and relevant national requirements where they exist.[41]

As can be seen from these graphics, for **all** economies analyzed there are a very high proportion of lamps that meet the highest (Tier 3) efficacy requirement.[42] Further, with the exception of data drawn from the Australian registration system, none of the data sets displayed is fully market representative and therefore there are likely to be additional products that exceed the Tier 3 requirements.[43] Thus, there is clear evidence of the availability of high efficiency CFLs in all markets.

Unfortunately, in a number of the markets there are also a notable proportion of lamps tested that fail to meet the lowest proposed CFL Tier 1 requirement (notably 11% of both the Cambodian and EU data sets), and in a few case, national mandatory requirements. Lower efficacy levels were particular evident at the lower lumen levels (25 and 40W incandescent GSL equivalents), i.e., the lamp sizes used in large numbers in a number of the Asian markets analyzed.

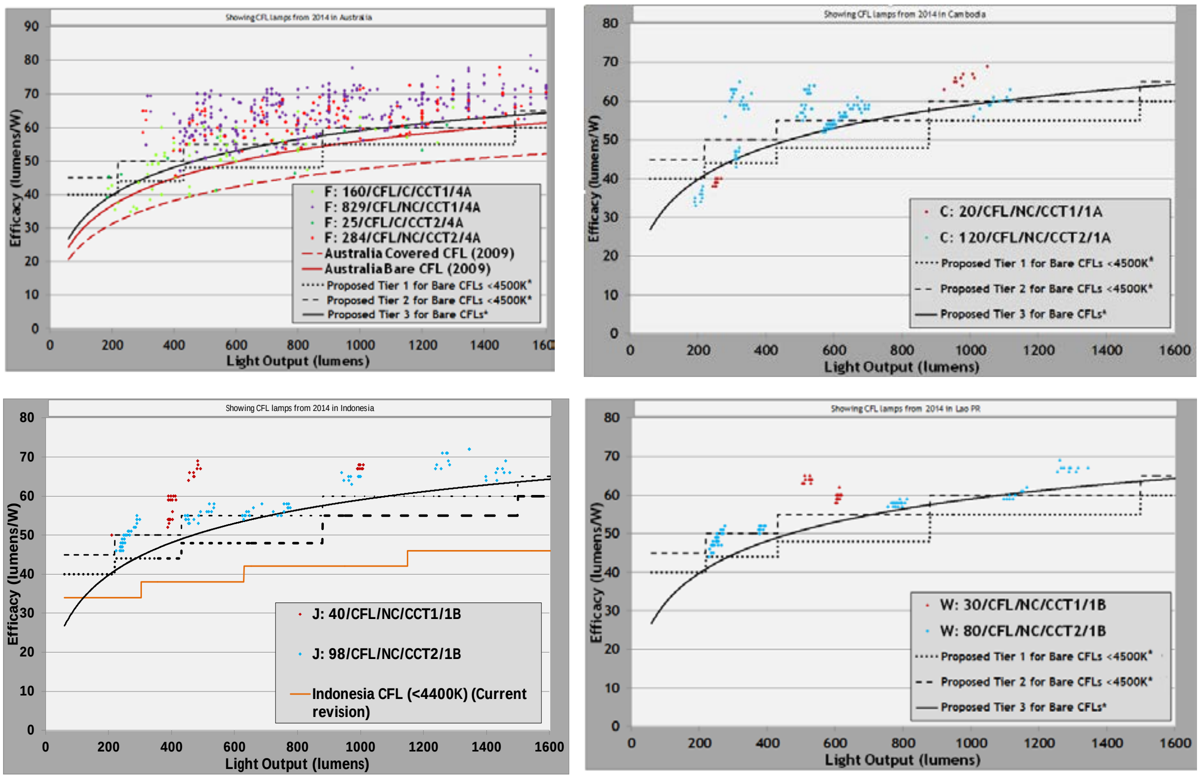
Unsurprisingly, the data sets with the smallest *proportion* of lower efficacy products are drawn from registration systems with high performance requirements *and* stringent monitoring, verification and enforcement (MV&E) regimes, i.e. the Australian national product register and the U.S. ENERGY STAR program. While again noting that most data sets are not comprehensive and are potentially subject to sampling bias, this does seem to indicate stringent performance requirements coupled with effective MV&E regimes (and supported by other appropriate policy measures) do bring high efficacy products to market and protect against product of lower quality.

[41] These are the CFL performance tiers proposed by Australia and a number of Asian countries.
[42] For uncovered lamps, the proportion of products in the data set attaining proposed IEC Tier 3 requirements was Australia 89%, Cambodia 78%, Indonesia 98%, Lao 94%, Philippines 76%, Thailand 98% and Vietnam 67%; EU 84%; USA Energy Star 96%.
[43] It is unknown whether these high efficiency lamps in the different markets are very similar models with different packaging and/or branding produced by a small number of global suppliers, or whether there is a genuine range of products across all markets.

Further, as the vast majority of smaller lumen output lamps within both the Australian and ENERGY STAR data sets achieve the challenging national and the proposed IEC Tier 3 requirements,[44] it suggests that the low lumen, lower efficacy products elsewhere are the result of either less challenging national performance requirements and/or less stringent MV&E regimes rather than any technical barrier. Such a conclusion is supported by the very wide spread of efficacies for products across the entire lumen output range; most clearly illustrated in Figure 5 and Figure 6 in Section 4.1.2 above. Note these same two graphics also highlight the potential for the more developed economies to raise the minimum and premium performance requirements of CFLs (or, align more with LEDs parameters and performance levels if they exist) in their national programs to maximize the consumer and national energy saving available without jeopardizing product availability across all lumen ranges.[45]

Figure 15: Light output and efficacy of CFLs in 2014 data sets from Australia, Cambodia, Indonesia, Lao PDR, Thailand, the USA and Vietnam compared with proposed CFL Tiers and national regulations[46]

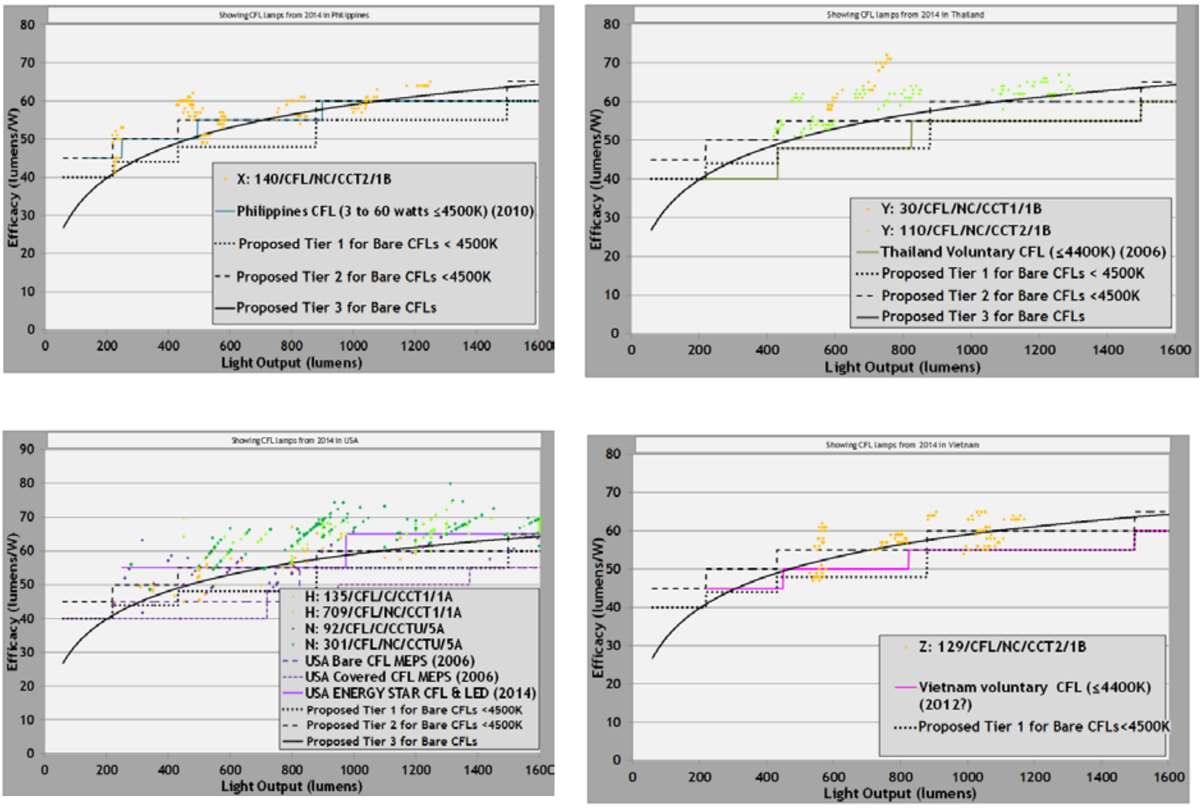
(Data: Australia registration (F); Cambodia (C), Indonesia (J), Lao PDR (W), Philippines (X), Thailand (Y) and Vietnam (Z) all UNEP-GEF en.lighten; EU anonymous (E); USA: Energy Star (H) and CEC (N))



[44] Note this is to be expected as the Tier 3 requirements closely align with the minimum requirements of both Australian MEPS and Energy Star.

[45] Economies with good CFL MEPS in place and without LED MEPS may consider directing both regulator and industry resources to LEDs in preparation for further price and performance evolution.

[46] For clarity and simplicity of presentation, proposed IEC Tiers are only shown for bare lamps with CCT<4,500K). Tiers 1 and Tier 2 efficacy requirements for lamps with CCT>4,500K lamps are slightly more stringent than the Tier 1 and Tier 2 values shown. Efficacy requirements for all covered lamps are less stringent than the values shown.



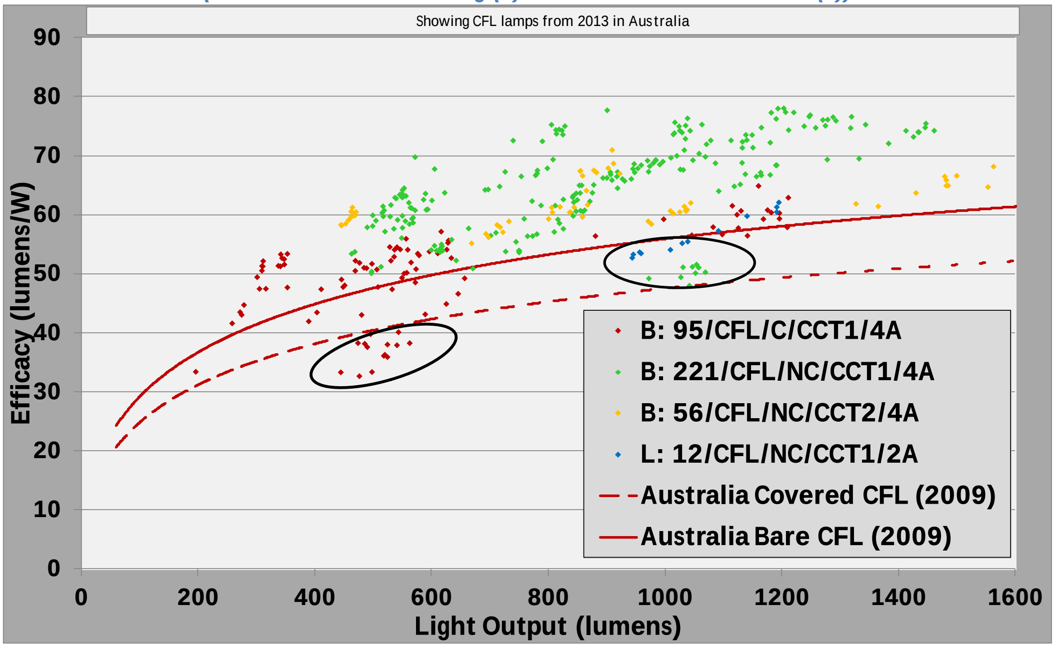
* Proposed to the IEC with the support of Australia and a number of Asian countries.

Even where MV&E systems are relatively robust, the need to maintain market integrity through ongoing market surveillance and subsequent enforcement action against non-compliant products is vital. This is plainly evidenced by the identification of potentially non-compliant[47] products during testing of lamps purchased in the Australian market in 2013 on behalf of the Australian Government and the Choice consumer organization (Figure 16).

[47] It is important to note that at least some products below the efficacy threshold are within the laboratory tolerance allowed by the regulations and may thus be compliant with Australian regulation (or are part of a group of samples where the average of the group is compliant) and/or may be exempt from the threshold requirement for other reasons. However, the graphic is still useful to show the need for surveillance activities to identify these products and verify the reason for not attaining the threshold and to pursue enforcement actions where there is no justification for failing to do so.

Figure 16: Identification of potentially non-compliance CFLs available for sale in the Australian market through Australian Government and CHOICE market surveillance activities (2013)

(Data: Australia CFL testing (B) and Australian CHOICE data (L))



Conclusion:

In all countries analyzed, a high proportion of lamps meet the most stringent (Tier 3) efficacy requirement of the proposed IEC Performance Tiers. This provides clear evidence of the availability of high efficiency CFLs in all markets. However, in a number of the markets there are also a notable proportion of lamps tested that fail to meet the lowest proposed IEC Tier 1 requirement (and in a few cases the minimum national requirements). This is particularly true at the lower lumen levels typical of lamps demanded in the Asian markets analyzed. Nevertheless, evidence suggests there is no technical reason why all markets should not be able to access the higher efficiency CFLs at *all* lumen levels for 25-100W incandescent GSL equivalent lamps. Indeed there is potential to raise the minimum and premium performance requirements of CFLs in national programs beyond the current proposed IEC Tier 3 requirements to maximize the consumer and national energy saving without jeopardizing product availability.

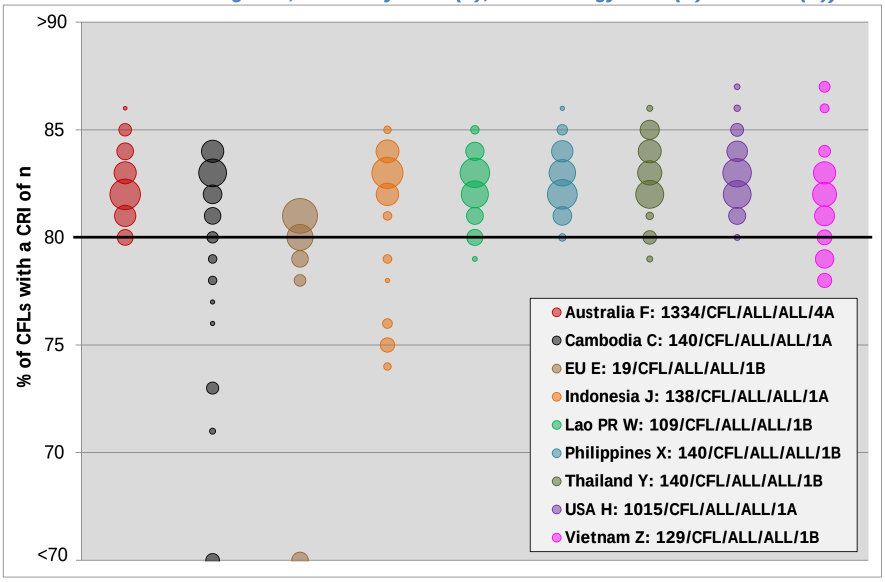
Further, evidence suggests stringent performance requirements coupled with effective MV&E regimes (and supported by other appropriate policy measures) are an extremely effective route to bringing these higher efficiency CFLs to market. Nevertheless, even where MV&E systems are relatively robust, there is still a demonstrable need to maintain market integrity through ongoing market surveillance and subsequent enforcement action against non-compliant products to protect against infiltration of lower quality.

4.2.3 International comparison of CFL quality: Color Rendering Index (CRI)

Somewhat surprisingly CRI is not universally regulated for CFLs, although this may be a function of lamp color being considered less important to the consumer in many Asian economies. Among the economies studied only Australia, the EU, Indonesia, and the USA (within ENERGY STAR) set thresholds for CRI, with these thresholds universally set at 80, the equivalent of the proposed IEC Tier 3.[48] Figure 17 shows the distribution of CFL CRI values around this CRI=80 threshold for all economies studied.[49]

The most important observation is the very high proportion of CFLs that reach the CRI=80 threshold, with or without regulation or program drivers.[50] Further, while it appears CFLs from some economies are performing better than others (e.g. 100% attainment of the threshold in Australia, Philippines and the USA[51]), lamps within almost all economies perform above CRI=78 which is generally within the test/laboratory tolerance range. However, a few poor results from Indonesia and, again, Cambodia and the EU (both with some tested lamps below CRI=70), suggests ongoing vigilance of markets is still necessary to counter the entrance of products failing to meet consumer expectations in markets where color is important.

Figure 17: Distribution of CRI values of CFLs in 2014 data sets from Australia, Cambodia, Indonesia, Lao PDR, Thailand, the USA and Vietnam compared with proposed IEC Tiers and national regulations.
Size of circles denotes proportion of lamps in the data set achieving specific CRI values
(Data: Australia registration (F); Cambodia (C), Indonesia (J), Lao PDR (W), Philippines (X), Thailand (Y) and Vietnam (Z) all UNEP-GEF en.lighten; EU anonymous (E); USA: Energy Star (H) and CEC (N))



Conclusion:

CFLs that attain CRI values of all least 80 represent the vast majority of products in all markets. Achievement of this consumer satisfying threshold appears not be of issue in any market irrespective of policy approach. However, vigilance is again required to ensure the market is not soured by a small number of lamps failing to meet this consumer satisfaction threshold in countries where color is a key consumer issue.

[48] There are marginal differences in the specific regulations. For example, the proposed IEC Tiers themselves specify a CRI of 80, but this is the average of samples tested for a model, with no sample to fall below CRI=72.
[49] The universal use of a CRI of 80 as acceptable by consumers is evidenced by the proposed IEC performance requirements using a CRI threshold of 80 for all three proposed Tiers.
[50] This may support the hypothesis that a small number of manufacturers supply products to many markets and do not find it economic to reduce lamp specifications where regulations are less challenging.
[51] Again this is partially a function of the data sets selected, in particular the Australian and U.S. ENERGY STAR datasets are drawn from registration systems that require CRI=80 over an average of samples for entrance. However, drawing from the Australian 2013 check testing (data set B), 92% of lamps achieved of exceed the CRI=80 threshold, and significant number of the remaining lamps were within test/laboratory uncertainty ranges of the CRI=80 value.

4.2.4 International comparison of CFL quality: Lumen Maintenance

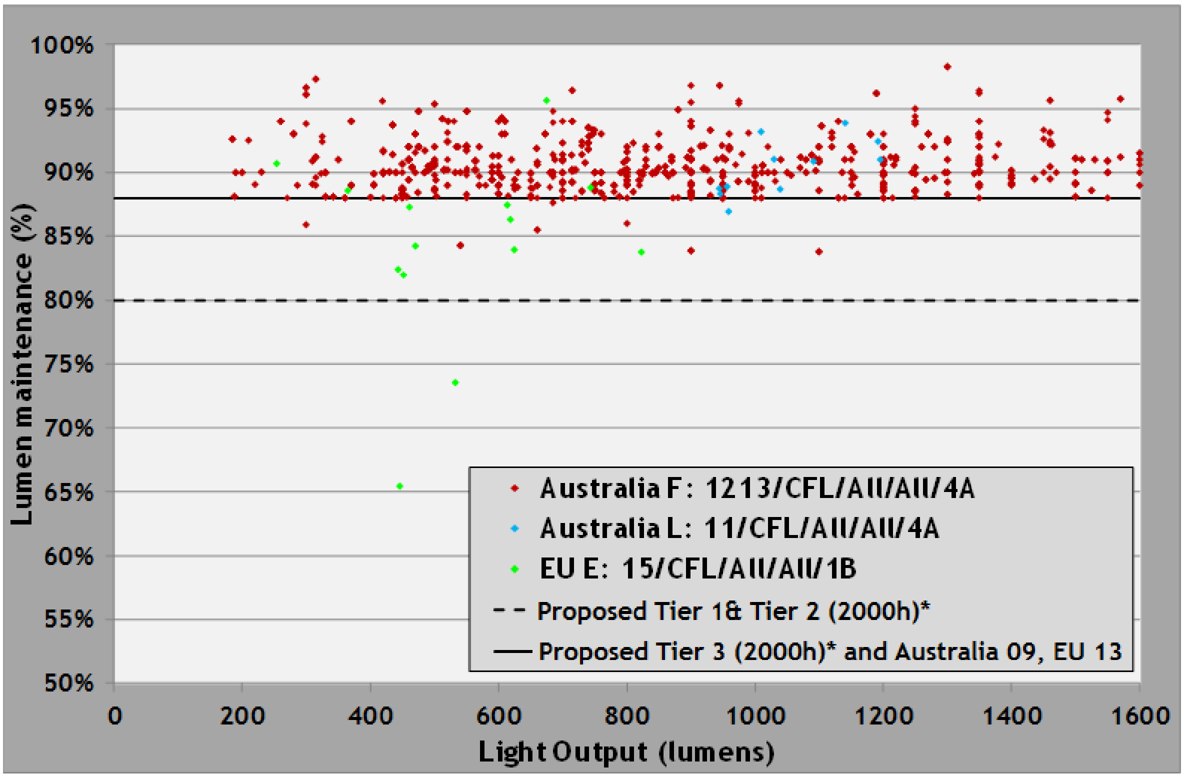
It is vitally important to consumer acceptance for a CFL lamp to continue delivering sufficient light over the course of its operational life (i.e., lumen maintenance). Otherwise the lamp will not remain installed for extended periods and the consumer will not reap the economic and energy savings projected. This is clearly recognized by regulators and program operators in most economies analyzed. (Only Cambodia and Thailand lack mandatory or voluntary performance requirements.)

Unfortunately, contemporary CFL data (2012 onward) on lumen maintenance is very limited. The only data available is from the Australian registration system (2014), Australian Government and Choice test data (2013) and the very small EU data set, plus minimum achieved values for ENERGY STAR qualified products.[52] This in itself is of concern as it is clear some regulators and program operators are failing to undertake market monitoring of this critical element of consumer acceptance, or at least not making the data public where this is undertaken (as is the case in much of the EU and for U.S. Energy Star).

Further, as note in Section 2.3, attempting to compare lumen maintenance across economies is somewhat challenging given the range of switching cycles, the period at which lumen maintenance is measured and the threshold values set. However, given available data is limited to that from Australia and the EU where switching cycles are identical, and 2000 hour lumen maintenance requirements align with each other *and* the proposed IEC Tier requirements[53], the available data is presented in Figure 18.

Figure 18: 2000 hour lumen maintenance of CFLs in 2013 and 2014 data sets from Australia and the EU compared with proposed IEC Tiers and national regulations

(Data: Australia CHOICE data (L-2013), registration data (F-2014); and EU anonymous (E-2014))



* Proposed to the IEC with the support of Australia and a number of Asian countries.

[52] U.S. ENERGY STAR products must have met at least the minimum program requirements of lumen maintenance >90% at 1000 hrs; >80 at 40% of rated life where life is ≥ 10,000 hours). However, this data is displayed as the actual product performance is unknown.

[53] Noting that additional lumen maintenance tests are required in each case, i.e. Australia ≥ 80 % at 5,000 hours, the EU ≥ 70 % at 6,000 hours and the proposed IEC Tier 3 ≥ 78 % at 6,000 hours *and* ≥ 70 % at 10,000 hours.

Not surprisingly, all the Australian registered products meet the national and IEC Tier 3 lumen requirement to maintain at least 88% of their initial light output following 2,000 hours of operation. Further, of the 11 models check tested in Australia in 2013, only one of these lamps failed to meet the 88% lumen maintenance requirement, and then only by a marginal amount. However, from the EU 2014 check test results, 10 of the 15 models tested failed to meet the 88% requirement, and two even failed to meet the 80% lumen maintenance Tier 1 requirement that is considered a minimum even in many developing markets. There is little doubt that there was a difference in sampling methodology between Australia and the EU data sets, with the later deliberately seeking to maximize value from check-testing activities by targeting products where there was a suspicion of non-compliance. However, even in such circumstances, the 66% non-compliance rate highlights the need for regulators and program managers to focus on this critical performance criteria.

Conclusion:

Lamp lumen maintenance is vitally important to consumer acceptance. However, it is clear few regulators or program managers are currently focusing on this critical performance parameter during check-testing of products. However, the experience in the EU, where 66% of products check tested failed to meet lumen maintenance requirements illustrates that the allocation of sufficient time and financial resources to test for lumen maintenance is essential to protect the quality products in the market, and ensure lamps remain installed for extended periods to reap the economic and energy savings projected.

4.2.5 International comparison of LED quality: Efficacy

As previously noted, there are relatively few data sets for LEDs, so measurement of market quality is challenging, particularly given the rapid market evolution illustrated in Section 4.1.3. However, contemporary data sets are available for Australia, the EU and the USA and these are presented for lamp efficacy in Figure 19 in comparison with the 4E SSL Tier requirements, and EU MEPS and the U.S. Energy Star regulations.[54]

Again it is not surprising to see the Energy Star registered product compliance at 100% given the data set is drawn from the registration system. Similarly, there is little surprise to see EU products are also compliant with the EU regulations given some of the data sets target premium products. Further, the EU performance requirement for non-clear lamps was set in 2009 and LED products have progressed significantly over that period.[55] However, there are poor performing products with efficacies below the basic SSL Tier 1 requirement of 50 lm/W shown in other U.S. data sources and in Australia, neither of which have MEPS for LEDs.

Within this context, the very broad spread of efficacies for any given light output within each economy is significant. Lamp efficacies for any given lumen range are widely spread across the entire SSL Tier 1-3 range, with some lamps recording efficacies of over 100m/W, far in excess of the highest SSL Tier 3 requirement.[56] Thus, while Tier 1 products still provide a basic "quality lamp" to the consumer

[54] At the time of report preparation Australia has no performance requirements for LEDs but a consultation process is currently underway which may result in MEPS and/or Labeling for LEDs. However, the Australian industry association (Lighting Council of Australia) voluntary SSL quality scheme in place, refer to http://www.lightingcouncil.com.au/site/ssl/overview.php.

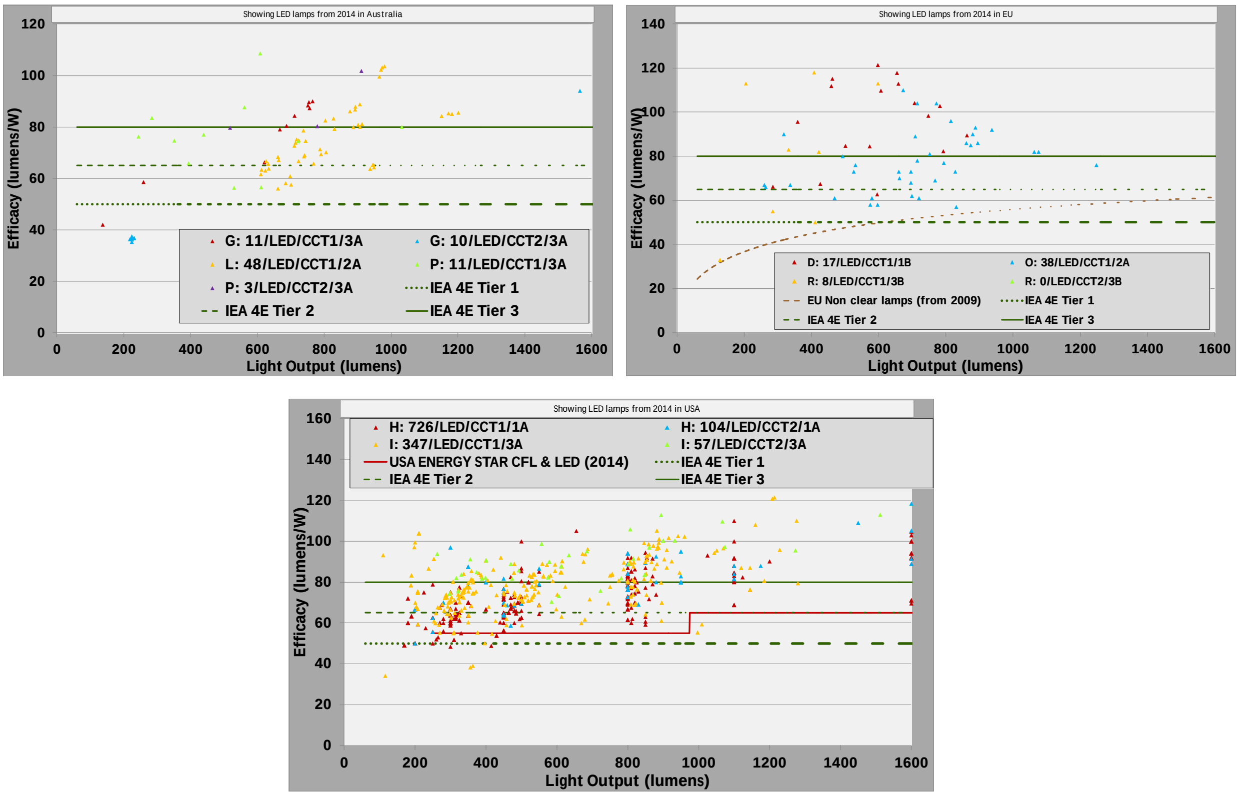
[55] As noted previously, the EU non-clear lamp requirement is actually technology neutral and so was not developed for LEDs specifically. Further, at the time of report preparation, the EU is undertaking a study aimed to bring together all lighting regulations and will most likely increase the efficacy (and other) performance requirements for LEDs.

[56] It is interesting to note that the 4E SSL tiers are all flat lines, i.e. there is an underlying assumption that efficacy is not a function of lumen output for LEDs. However, within the largest contemporary LED data set (amalgamated for all data sets available for LEDS available in the USA in 2014), there is a strong positive relationship between lumen output and efficacy, i.e. as lumen output rises, so does efficacy. However, when broken into smaller lumen ranges, this relationship is much weaker for lamps with 0-500 lumens, and is actually negative for products in the 1,500-2,500 lumen range. Unfortunately, from the data available it is unclear whether this is a reflection of the typically lower efficiency of smaller products resulting from the proportionately greater impact of control electronics, the challenges of dissipating heat from larger lumen lamps designed for standard fittings, and/or other factors.

(50lm/W is a *relatively* high efficacy compared with the GSL alternatives) there is significant potential for the EU and Energy Star to raise the minimum and premium performance requirements for LEDs to maximize the consumer and national energy saving, again without jeopardizing product availability across all lumen ranges. Obviously, in those economies where no current MEPS exist, the introduction of any similar regulation and/or other policy support has the potential to rapidly yield high energy savings to the consumer and the nation by limiting the penetration of the lower efficacy products in the market.

Figure 19: Light output and efficacy of LEDs in 2014 data sets from Australia, the EU and the USA compared with 4E SSL Tiers and national regulations

(Data: Australian (combined) LED Testing (G), Choice Data (I) and LED Benchmarking (P); EU (combined) EU Clear (D), Premium Lights (O) and Olina (R); and USA combined Lighting Facts (I) and Energy Star (H))



Conclusion:

For the limited number of countries where data is available (Australia, the EU and the USA), only the EU has MEPS for LED efficacy and is the only country where all incandescent GSL replacement LEDs could be considered "of at least minimum quality" with respect to efficacy (i.e. performing above 50lm/W). However, in all three countries, lamp efficacies for any given lumen range are widely spread with some LEDs reaching efficacies in excess of 100lm/W. Thus, there is significant potential for the EU and Energy Star to raise the minimum and premium performance requirements for LEDs to maximize the consumer and national energy saving without jeopardizing product availability across all lumen ranges. Obviously, in those countries where no current MEPS exist, the introduction any similar regulation and/or other policy support has the potential to rapidly yield high energy savings to the consumer and the nation by limiting the penetration of the lower efficacy products that are currently (or are likely to become) available in the market.

4.2.6 International comparison of LED quality: Color Rendering Index (CRI)

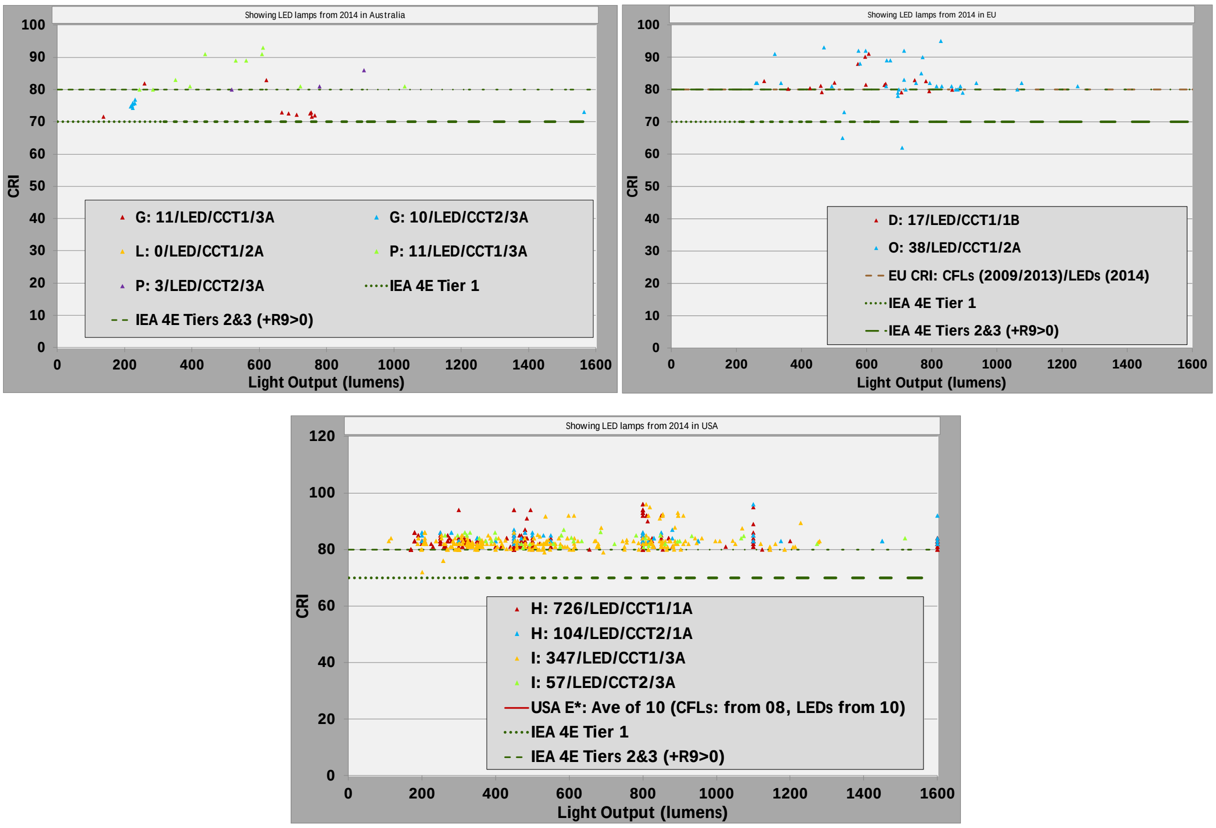
Again, data sets for CRI of LEDs[57] are limited to Australia, the EU, and the USA, and these are presented in Figure 20 in comparison with the 4E SSL Tier requirements for CRI, EU MEPS, and the U.S. Energy Star requirements.[58]

Almost all lamps in the USA meet the minimum IEA SSL Tier 3 and Energy Star requirement of CRI>80. This is not the case for a significant proportion of EU lamps where the MEPS threshold is also CRI>80, nor in Australia where there is currently no regulation.

However, again there is a wide range of CRI values in each market, with some lamps exceeding CRI=90. This suggests a CRI>80 is not significantly challenging and may be suitable for serving as an absolute baseline for regulation in all economies to protect the consumer until alternative color measurement approaches are possible. Nevertheless, once regulations are in place, again the EU data set demonstrates the need for ongoing surveillance activities to protect the market from lower performing products.

Figure 20: CRI of LEDs in 2014 data sets from Australia, the EU and the USA compared with 4E SSL Tiers and national regulations

(Data: Australian (combined) LED Testing (G), Choice Data (I) and LED Benchmarking (P); EU (combined) EU Clear (D), Premium Lights (O) and Olina (R); and USA combined Lighting Facts (I) and Energy Star (H))



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[57] As extensively discussed elsewhere, the use of CRI as a metric for measuring the color performance of LEDs is limited (a clear explanation is provided by U.S. Department of the Environment at http://cool.conservation-us.org/byorg/us-doe/color_rendering_index.pdf). However, extensive efforts are underway to find alternatives, at present CRI remains the typical international measure of color quality of LEDs, a fact reflected in the data available and so is used in this analysis.

[58] At the time of report preparation Australia has no performance requirements for LEDs. However, a consultation process is currently underway which may result in MEPS and/or Labeling for LEDs.

Conclusion:

While it is recognized that CRI is not a perfect metric as a measurement of LED color properties, evidence suggests a CRI>80 is not significantly challenging and may be suitable for serving as an absolute baseline for regulation in all countries until alternative color measurement approaches are possible.

However, all markets have lamps currently available below this CRI>80 baseline, with Australia and the EU having lamps below the IEA SSL's Tier 1 threshold of CR>70. This suggests poor quality lamps are still available and regulation of most markets may be necessary for consumer protection. In the case of the EU such regulations are already in place, which once more emphasizes the need for ongoing market surveillance.

4.2.7 International comparison of LED quality: Lumen Maintenance

As noted earlier for CFLs, it is vitally important to consumer acceptance for an LED lamp to continue delivering sufficient light over the course of its operational life (i.e., lumen maintenance). Otherwise the lamp will not remain installed for extended periods, and the consumer will not reap the economic and energy savings projected. However, the lumen maintenance measurement is problematic for LEDs due to their (typically) extremely long lifetimes. Hence, where regulations exist, the approaches adopted for measuring lumen maintenance vary considerably (in addition to the differing switching cycles used internationally). In the EU, there is a mandated minimum lumen maintenance level at a specific time (i.e. 80% of initial light output at 6,000. The U.S. Energy Star requirement varies both the test length and the required lumen maintenance level according to the lifetime of the lamp. The 4E SSL tiers use performance requirements at 15,000 hours (Tier 1) and 25,000 hours (Tiers 2 and 3), although based on a shorter test time and a predicted lumen decline using internationally recognized algorithms.[59]

The only available contemporary data for LED lumen maintenance comes from Australian Choice test data (2013)[60] and is shown in Figure 21.[61] This is not particularly useful as there is no regulation in Australia for LED lumen maintenance. The 2,000 hour test period and switching cycle used by Choice does not align with other regulations elsewhere and so no comparative baseline exists. However, in itself the data is interesting as it demonstrates that in this currently unregulated Australian market there are extreme variations in the lumen maintenance levels. While most lamps are in the 95-105%[62] range, a significant number fall below this, with some achieving little more that 70% lumen maintenance at 2,000 hours, significantly lower than the equivalent requirements for CFLs in most economies (Australia included), and far below lumen maintenance requirements for LEDs, where they exist elsewhere. Poor performance has the potential to sour consumer perceptions of LEDs and slow their market penetration in the same way that early poor-performing CFLs led to a bad reputation for the technology and ultimately slowed overall market adoption. This finding only reinforces the urgent need for regulation of LEDs in all markets—ideally in some internationally harmonized manner rather than the current divergent approaches—and the subsequent enforcement of those regulations.[63]

[59] It should be noted that most regulations/voluntary initiatives also have other elements to ensure consumer satisfaction with the ongoing performance of lamps over their lifetime, e.g. a lifetime requirement itself, supplemented by minimum lamp survival levels at specific times, maximum premature failure rates, etc. Refer to Appendix 3 for examples.

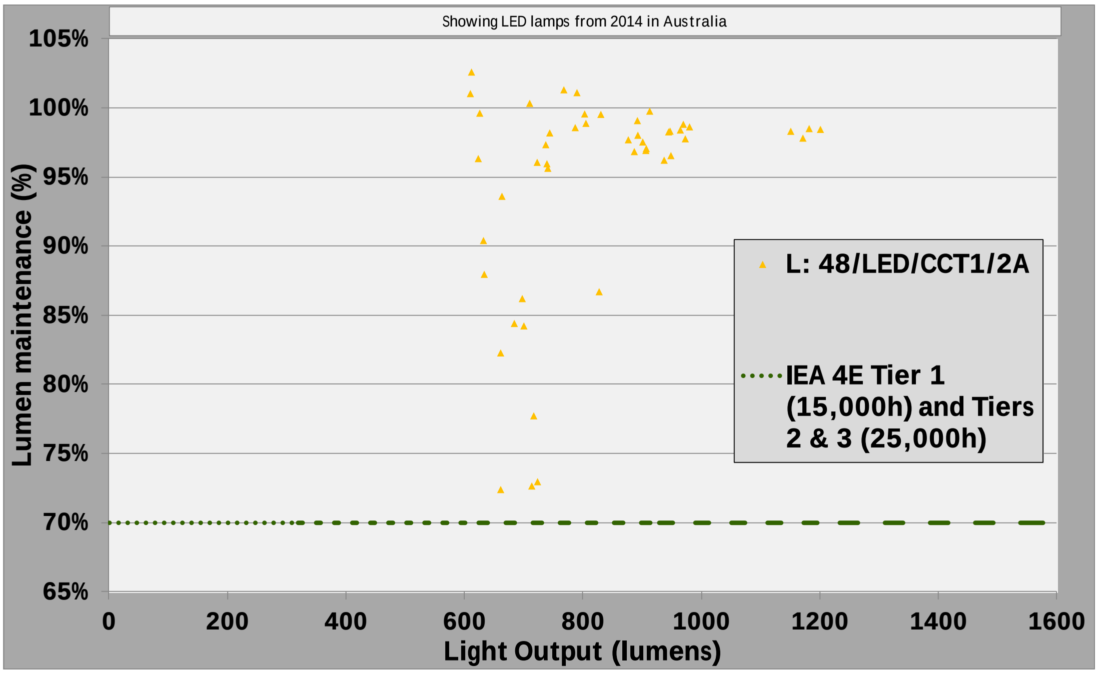
[60] Products achieving ENERGY STAR accreditation must have achieved the required lumen maintenance specification, but data on actual values reported are not available.

[61] Note that other data may have recently become available after the finalization of this report

[62] Note that values in excess of 100% are not unusual for LEDs. Depending on the particular design used, the lamps often increase in brightness in the early period of operation, sometimes for many thousands of hours, before (typically) tailing of later in the lifecycle.

[63] Note that lifetime and lumen maintenance testing are two significant challenges regulatory challenges due to the facts that testing require significant amounts of time, and there is yet to be international agreement on an accelerated lifetime test.

Figure 21: Lumen Maintenance of LEDs in 2014 data set from Australia
(Data: Australian Choice Data (I))



Conclusion:

While data on LED lumen maintenance is limited to a relatively small dataset drawn from the (currently) unregulated Australian market, it does demonstrate extreme variations in the lumen maintenance levels, with some LEDs achieving little more that 70% of their initial lumen output at 2,000 hours. This is significantly lower than the equivalent requirements for CFLs in most countries, and far below lumen maintenance requirements for LEDs, where they exist elsewhere.

Given that lamp longevity, and the consequential economic benefits to the consumer, are two of the main selling points deployed by policymakers to promote adoption of high efficiency lamps,, the existence of LEDs in the market where lumen maintenance is so poor ultimately risks the slowing of overall market adoption of LEDs. Hence, in order to protect the consumer, and to align with the typical policy goals to transition markets to more efficient lighting, there is an urgent need for regulation of LEDs in all markets, and the subsequent enforcement of those regulations.

4.2.8 Interrelationship of performance parameters and associated regulatory requirement

As originally noted in Section 3, there is interdependence between performance parameters for both CFLs and LEDs, i.e. improving one aspect of a lamp's performance can result in a reduction in another. That is the reason to analyze products across a variety of consumer acceptance parameters through the use of the 4E SSL and proposed IEC CFL Tiers. Unfortunately, due to data limitations (particularly related to the lumen maintenance of both CFLs and LEDs), it has not been possible to analyze the degree of "product quality" for all parameters simultaneously (the exception being CFLs registered in Australia, 90% of which meet the very challenging proposed IEC Tier 3 requirements across all criteria, hence demonstrating premium CFL products are definitely available, at least in this market).

However, an extensive analysis was conducted investigating correlations between each of the key consumer acceptance parameters available in any data set, i.e., lumen output, efficacy, CRI, CCT and lumen maintenance.[64] Interestingly, the analysis found almost no correlation between any pair of parameters, with the exception of lumen output and efficiency. Even the correlation with efficacy was weak—across a broad range of lumen outputs—with an r^2 value of around 0.4 for both CFLs and LEDs.[65] It appears that while the performance parameters are linked for any given lamp design, a similar change to a lamp employing a different design approach may yield very different results. Consequently, no individual parameter can be considered a proxy by which overall lamp performance can be measured or regulated.

This finding reemphasizes the need for regulators and program managers to ensure a wide range of performance parameters are considered when seeking to deliver consumer satisfaction. They should also undertake adequate and ongoing market monitoring/check testing to confirm products are indeed delivering declared levels of performance and satisfying consumers. To accomplish this goal, market monitoring programs need to be extended beyond initial lamp performance and include performance over time (at the very least to the point of lumen maintenance requirements and ideally full life). Failure would risk dissatisfied consumers, and failure to reap full economic and energy benefits from the transition to higher efficiency lighting products.

Conclusion:

While there is interdependence between key performance parameters for both CFLs and LEDs, the relationship is specific to individual approach to lamp design. Consequently no individual parameter that can be considered a proxy by which overall lamp performance can be measured or regulated.

This outcome reemphasizes the need for regulators and program managers to ensure a wide range of performance parameters are considered when seeking to deliver consumer satisfaction. It also emphasizes the need to undertake adequate and ongoing market monitoring/check testing to confirm products are indeed delivering declared levels of performance and satisfying consumers. Market monitoring should include initial lamp performance and lumen maintenance.

Failure to regulate across performance parameters, and to ensure those parameters are being met in the market, risks dissatisfied consumers and resulting failure to deliver full economic and energy benefits from the transition to higher efficiency lighting products.

[64] Ideally lamp lifetime would be included in the list of consumer acceptance parameters. Unfortunately no independently test lifetime data was available.

[65] This relationship is shown in the graphics in Sections 4.1.2 and 4.1.3 where efficacy generally increases with lumen output, but there are very wide ranges of efficacies for any given lumen output

5. Conclusions and Key Findings

This study sought to establish the availability of high quality CFLs and LEDs suitable for replacing omnidirectional incandescent general service lamps in both developed and developing economies. To achieve this, 25 historical and contemporary data sets of CFL and LED products drawn from Australia, Cambodia, the EU, Lao PDR, Indonesia, the Philippines, Thailand, the USA and Vietnam were analyzed. The policy frameworks influencing the penetration of lamps into each market were also analyzed. Key findings and conclusions from the analysis are given below.

In all economies studied, CFLs are currently available with light output suitable for replacing incandescent GSL lamps up to and including 75W. Within the developed economies there is also demonstrable availability of 100W GSL equivalent CFLs. Despite limited demand for 100W replacement lamps in Asian economies, there is sufficient indirect evidence to suggest 100W equivalent lamps are also available in these economies. Further, evidence suggests that a high proportion of these GSL replacement CFLs achieve high levels of efficacy, have good color performance (defined by CRI) and, from the limited data available, exhibit satisfactory levels of lumen maintenance.

Thus, based on the evidence, CFLs that fully meet key performance parameters are available for all GSL-equivalent wattages from 25W to 100W in Australia, the EU, the USA, and in *most* Asian markets, with the possible exception of Cambodia. In fact, in almost all economies, there is scope to raise current performance requirements for CFLs to further enhance the consumer experience and/or maximize energy savings without significantly limiting the number and range of products available.

This outcome is not surprising, as evidence suggests CFLs are now a fully mature technology. Further, CFL markets are being widely protected through MEPS in 5 of the economies examined: Australia, Cambodia, the EU, the USA, and Vietnam. Several other economies examined have not implemented MEPS: Indonesia is currently implementing a new MEPS program, Thailand has a voluntary minimum standard, and the Philippines has mandatory comparative labeling. Additionally, almost all economies have extra policy support measures for CFL adoption. Thus, contrary to widely held perceptions, the developing economies represented typically have relatively comprehensive policy frameworks for CFLs, albeit not necessarily as well developed as elsewhere.

Nevertheless, in all markets analyzed, CFLs were available that failed to meet national requirements and/or internationally recognized norms of consumer acceptability, in some cases by substantial distances. Poor performance on efficacy was more evident among the lower-lumen-output lamps that are in demand in many Asian economies. However, the evidence demonstrates that technically there is no longer a need to accept these lower performing products, and in some markets, for example Australia, they are uncommon. The scarcity of poor quality products appears directly related to the presence of a strong policy support framework (in place in most economies, as noted above), coupled with ongoing and visible market surveillance/check-testing activities. In the majority of economies there is a need to strengthen market surveillance, particularly related to the lumen maintenance of products. It is critical to ensure lamps provide extended consumer-satisfying service, and hence remain installed, to yield the appropriate levels of economic and energy benefits.

Unfortunately, due to only slight differences in performance requirements between the economies, it is difficult to share market surveillance across borders. As a result, each economy bears the full cost of their surveillance programs, so they are often limited. International alignment of similar national CFL performance requirements offer the opportunity to share information on poor performing products. The inherent benefit is the shared market surveillance costs and resulting higher product quality at the national level. Such an alignment of performance requirements is relatively simple and has been attempted previously, as illustrated by the proposed CFL performance tiers used in this report. It is currently being pursued in some areas, for example among ASEAN members. However, efforts to internationally align performance requirements should be accelerated and widened. They could increase product quality and lower surveillance costs, and participating economies would benefit from the resulting increased trade and market competition, which should lower the prices of high-quality, efficient alternatives to incandescent lamps.

The situation for LEDs is more fluid, with very rapidly evolving products. In Australia, the EU, and the USA (very limited data on LED performance was available for Asian economies), products with sufficient light output to replace all omnidirectional incandescent GSL lamps up to and including 75W have been available for several years. However, significant numbers of LED replacements for the higher lumen output 100W GSL incandescent have only recently appeared in the U.S. market. In 2014, there was little evidence that these products had entered the Australia and EU markets. This lack of evidence is at least partly related to limitations on available data and, given the speed of product development, it seems likely 100W replacement products will now have entered most markets.

Of these three developed economies, the EU is the only one considered all LED performance parameters with its MEPS. It is also the only economy where there is direct evidence that all available incandescent GSL replacement LEDs could be considered "of at least minimum quality" with respect to efficacy, i.e., performing above 50lm/W. However, in all three economies, lamp efficacies for any given lumen range are widely spread, with some LEDs now reaching efficacies in excess of 100lm/W. Thus, there is significant potential for the EU and the USA's premium Energy Star program to raise the efficacy requirements for LEDs across all lumen ranges to maximize the consumer and national energy saving without jeopardizing product availability. Obviously, in those economies where no current MEPS exist, the introduction of similar regulation or other policy support has the potential to rapidly yield high energy savings to the consumer and the overall economy by limiting the penetration of the lower efficacy products that are currently (or are likely to become) available in the market.

Further, across all three developed economies, there is evidence to suggest there are significant quality issues for color, with some LEDs showing CRI values below 70, and lumen maintenance, with some products achieving little more that 70% of their initial lumen output at 2,000 hours. The latter is significantly lower than the lumen maintenance requirements for CFLs in most economies and far below requirements for LEDs, where regulations exist. This is troubling, given that long lifetimes and the resulting economic benefits to consumers are key selling points used by policymakers to promote the adoption of high-efficiency lamps. Thus, the presence in the market of LEDs with poor lumen maintenance ultimately risks the slowing of overall market adoption of LEDs.

The existence of an extensive range of Energy Star qualified products demonstrates that LEDs are available that meet consumer expectations of quality across some key performance parameters. There is a strong expectation among the majority of policymakers worldwide that LEDs will soon penetrate all markets in significant quantities. They view LEDs as one of the primary products facilitating the transition to lower lighting energy consumption. It is critical to expand availability of high-quality products and protect markets from low-quality products. Thus, there is an urgent need in almost all economies to develop strong policy frameworks similar to those in place for CFLs (test methods, MEPS, premium product labeling, product registries, etc.) and to rigorously enforce compliance with those frameworks. However, the rapid evolution of LEDs makes the development of performance requirements on which such frameworks are based challenging (and expensive) to undertake at the national level, as is maintaining effective market supervision of the rapidly changing product landscape. Therefore the potential for international cooperation and alignment of performance requirements highlighted above is particularly important, e.g., through widespread adoption of the 4E SSL performance tiers. Further, given the relatively embryonic nature of most LED policy frameworks, such alignment should be easier than amending the embedded CFL frameworks.

Appendix 1: Overview of data sets analyzed

The data sets used in this analysis are shown below. For details of how Data Confidence Scores are assigned and how they should be interpreted, refer to Appendix 2. Note, in some cases test data is available on the sample level, in others as a single value representing the model average of all samples tested. Data set letters that have an asterisk (*) next to the data set label are those data sets where model averages are presented rather than individual sample values.

Table 10: Overview of the ENERGY STAR data set.

Data set overview			
Source	Energy Star	Economy	USA
Product	CFL/LED (Covered and Uncovered)	Data set label	H
Objective of testing	Certification of premium products		
Website	http://www.energystar.gov/productfinder/product/certified-light-bulbs/		
Assigned data confidence score: 2B			
Data type	0	Data source	2
Market representativeness		B	
Testing details			
Test lab(s)	Certified	Dates of sampling	2014
Test method	IES		
Models tested	4000	Samples per model	20+ per model
Description			
ENERGY STAR register of certified "premium performance" lamps. Approximately 10% of lamp models are also subject to verification testing annually. This data set includes lamps introduced to the market between 2008 and 2014, only those that meet the new 2014 ENERGY STAR standard and so all are listed as 2014 lamps.			

Table 11: Overview of the CALiPER data set.

Data set overview			
Source	CALiPER	Economy	USA
Product	LED (Various)	Data set label	K
Objective of testing	Market surveillance		
Website	http://www1.eere.energy.gov/buildings/ssl/caliper/default.aspx		
Assigned data confidence score: 1B			
Data type	0	Data source	1
Market representativeness		B	
Testing details			
Test lab(s)	Certified	Dates of sampling	2006-2014
Test method	IES		
Models tested	60	Samples per model	6
Description			

The CALiPER (Commercially Available LED Product Evaluation and Reporting) program began in 2006 to support testing of a representative array of solid-state lighting products for general illumination, using industry-approved test procedures carried out by qualified test labs.

Table 12: Overview of the Lighting Facts data set.

Data set overview			
Source	Lighting Facts	Economy	USA
Product	LED (Various)	Data set label	I
Objective of testing	Product certification		
Website	http://www.lightingfacts.com/Products		
Assigned data confidence score: 1B			
Data type	0	Data source	1
Market representativeness		B	
Testing details			
Test lab(s)	Certified	Dates of sampling	2009-14
Test method	IES		
Models tested	1400	Samples per model	0
Description			
U.S. Department of Energy's LED Lighting Facts program aims to assure decision makers that the performance of solid-state lighting (SSL) products is represented accurately as products reach the market.			

Table 13: Overview of the Energy Star CFL Testing data set.

Data set overview			
Source	Energy Star CFL Testing	Economy	USA
Product	CFL (Bare, Reflector and Covered)	Data set label	A*
Objective of testing	Benchmark/Capacity building		
Website	http://www.energyrating.gov.au/blog/resources/events-calendar/200808-2/		
Assigned data confidence score: 1B			
Data type	0	Data source	1
Market representativeness		B	
Testing details			
Test lab(s)	Independent/Certified	Dates of sampling	2007
Test method	Energy Star V3.0		
Models tested	41	Samples per model	10
Description			
Australian Government funded testing to investigate market compliance levels and range of product performance within high profile, large volume, overseas CFL programmes prior to national policy development. Investigations sought to identify overall levels of compliance to be expected; the speed at which suppliers can be expected to migrate products to new specifications (in this case from Energy Star (CFL) version 3 to 4); and gain experience in check testing.			

Table 14: Overview of the Australia CFL Benchmarking data set.

Data set overview			
Source	Australia CFL Benchmarking 2008, 2010 and 2013	Economy	Australia
Product	CFL (Bare, Reflector and Covered)	Data set label	B*
Objective of testing	2008 and 2010: Market Characterization/ Benchmarking testing prior to MEPS introduction. 2013: MEPS compliance.		
Website	http://www.energyrating.gov.au/blog/resources/events-calendar/200808-2/		
Assigned data confidence score: 1A			
Data type	0	Data source	1
Market representativeness		A	
Testing details			
Test lab(s)	Independent/Certified	Dates of sampling	2008, 2010, 2013
Test method	AS/NZS 4847.1		
Models tested	307	Samples per model	10
Description			
2008 testing as part of an Asia Pacific Partnership (APP) project on CFL Harmonization investigating the performance and mercury content of CFLs on the Australia, India, Indonesia, Philippines, Thailand and Vietnam markets. Australia data also used in formulating MEPS levels for CFLs. 2010 testing was a follow-up to testing undertaken in 2008 on CFLs (pre-MEPS). The 2010 testing was conducted following the introduction of MEPS with the objective of assessing the compliance levels and assessing any improvement in the quality of CFLs since MEPS was introduced. 2013 testing with the primary objective of assessing compliance against MEPS.			

Table 15: Overview of the Australia LED testing data set.

Data set overview			
Source	Australia LED testing	Economy	Australia, USA, UK
Product	LED (Directional and Non-directional)	Data set label	G
Objective of testing	Market surveillance		
Website	Unavailable		
Assigned data confidence score: 3B			
Data type	2	Data source	1
Market representativeness		B	
Testing details			
Test lab(s)	Independent/Certified	Dates of sampling	2009 - 2013
Test method	0		
Models tested	85	Samples per model	1
Description			
Research testing for the Australian Government for the purpose of developing a potential MEPS for LEDs with lamps sampled both from Australia, the UK and the USA.			

Table 16: Overview of the CHOICE Australia data set.

Data set overview			
Source	CHOICE Australia CFL testing	Economy	Australia
Product	CFL (Directional and Non-directional)	Data set label	L*
Objective of testing	Identification of market leading products		
Website	https://www.choice.com.au/home-improvement/energy-saving/light-bulbs		
Assigned data confidence score: 3B			
Data type	2	Data source	1
Market representativeness		B	
Testing details			
Test lab(s)	Independent/Certified	Dates of sampling	2013
Test method	0		
Models tested	58	Samples per model	Unknown
Description			
Testing was conducted by CHOICE (Australian Consumer) Magazine for publication in the regular magazine.			

Table 17: Overview of the Australian Government Registration Data set.

Data set overview			
Source	Australian Government Registration Data	Economy	Australia
Product	CFL/LED (Bare, Reflector and Covered/Directional and Non-directional)	Data set label	F
Objective of testing	National product register		
Website	http://www.energyrating.gov.au/		
Assigned data confidence score: 2A			
Data type	0	Data source	2
Market representativeness		A	
Testing details			
Test lab(s)	Certified	Dates of sampling	2014
Test method	IEC or other international standards		
Models tested	1300	Samples per model	10+
Description			
Australian Government's mandatory registration database.			

Table 18: Overview of the EcoAsia CFL Benchmarking Data set.

Data set overview			
Source	EcoAsia CFL Benchmarking	Economy	Indonesia, Philippines, Thailand, Vietnam
Product	CFL (Bare CFLs)	Data set label	S* (Ind), T* (Tha), U* (Phi), V* (Vie)
Objective of testing	Regional comparison of CFL quality to assess potential for harmonization		
Website	http://www.lites.asia/document/55/testing-for-quality-benchmarking-energy-saving-lamps-in-asia		
Assigned data confidence score: 1B			
Data type	0	Data source	1
Market representativeness		B	
Testing details			
Test lab(s)	Independent/Certified	Dates of sampling	2008
Test method	IEC 60969 (draft)		
Models tested	60	Samples per model	10+
Description			
Australian Government and ECO-Asia Clean Development and Climate Program (ECO-Asia) funded testing under the APP to assess the overall quality of CFLs sold various Asian markets to assess the viability of alignment of test and performance standards. • To assess the opportunities for harmonization of CFL standards based on test results. • To gain insight into the possibility of implementing a regional product testing program and its complexity. • To make a first-order examination of lamp mercury content.			

Table 19: Overview of the CLASP Clear LED Research Data set.

Data set overview			
Source	CLASP Clear LED Research	Economy	EU Countries
Product	LED (Omnidirectional)	Data set label	D
Objective of testing	Establishing performance of "Clear LEDs" available within the EU		
Website	http://clasp.ngo/en/Resources/Resources/PublicationLibrary/2015/European-Testing-Study-finds-LED-Performance-Out-paces-Expectations.aspx		
Assigned data confidence score: 1B			
Data type	0	Data source	1
Market representativeness		B	
Testing details			
Test lab(s)	Independent/Certified	Dates of sampling	2014
Test method	CIE 15/2004, EN50285/1999,		
Models tested	18	Samples per model	10
Description			
Testing undertaken for CLASP as to establish performance of LEDs appropriate as replacements for GSL in Europe			

Table 20: Overview of the Premium Lights data set.

Data set overview			
Source	Premium Lights	Economy	EU (Data from Austria/France/ Sweden)
Product	LED (Omnidirectional)	Data set label	O
Objective of testing	Product certification		
Website	Unavailable		
Assigned data confidence score: 3B			
Data type	2	Data source	1
Market representativeness		B	
Testing details			
Test lab(s)	Independent/Certified	Dates of sampling	2014 (assumed)
Test method	??		
Models tested	66	Samples per model	Unknown
Description			
Testing funded by a consortium of 12 pan-European organizations led by the Austrian Energy Agency. Testing seeks to identify performance leading products.			

Table 21: Overview of the Olina data set.

Data set overview			
Source	Olina	Economy	EU
Product	LED (Omnidirectional)	Data set label	R
Objective of testing	Product certification		
Website	Unavailable		
Assigned data confidence score: 3B			
Data type	2	Data source	1
Market representativeness		B	
Testing details			
Test lab(s)	Independent	Dates of sampling	2014 (assumed)
Test method	Not specified		
Models tested	70	Samples per model	Unknown
Description			
Low cost independent testing to certify lamp performance under unspecified typical conditions			

Table 22: Overview of the LED Benchmark data set.

Data set overview			
Source	LED Benchmark	Economy	Australia/USA
Product	LED (All types)	Data set label	P (Aus), Q (USA)
Objective of testing	Consumer Information		
Website	Unavailable		
Assigned data confidence score: 3B			
Data type	2	Data source	1
Market representativeness		B	
Testing details			
Test lab(s)	Independent	Dates of sampling	2014 (assumed)
Test method	Not specified		
Models tested	317	Samples per model	Unknown
Description			
Independent testing aiming to "to measure the characteristics of residential LED lighting and make the details available to the public. With a focus on LED lights that could be used to replace traditional incandescent and halogen lights."			

Table 23: Overview of an Anonymous EU data set.

Data set overview			
Source	Anonymous EU	Economy	EU Economy
Product	CFL (Omnidirectional)	Data set label	E
Objective of testing	Market surveillance		
Website	Unavailable		
Assigned data confidence score: 1B			
Data type	0	Data source	1
Market representativeness		B	
Testing details			
Test lab(s)	Independent/Certified	Dates of sampling	2014
Test method	EN60969		
Models tested	19	Samples per model	190
Description			
Compliance testing with EU MEPS and Labeling requirements. Sampling deliberately targets likely failures and hence the data set targets the bottom of the market.			

Table 24: Overview of the CEC data set.

Data set overview			
Source	California Energy Commission	Economy	USA
Product	CFL/LED	Data set label	N
Objective of testing	Product certification		
Website	Unavailable		
Assigned data confidence score: 1A			
Data type	0	Data source	1
Market representativeness		A	
Testing details			
Test lab(s)	Independent/Certified	Dates of sampling	2014
Test method	IES		
Models tested	2250	Samples per model	21
Description			
Compliance testing for lamps sold in California. For CFLs the reference the DOE methods and requirements. For LEDs, which do not yet have Federal Standards, they reference IES test procedures.			

Appendix 2: Methodology for allocating individual data confidence scores

Considerable efforts have been made to ensure the integrity of the data and resulting analysis presented in the report. However, by their very nature, the data sets differ as they are secondary sourced from a wide variety of organizations. Hence, the original objectives and resulting approach to product sampling, testing, and data recording vary, and these variations affect the comparability of the data sources and quality of the analysis possible in the context of this report.

What characteristics affect confidence in the reliability and comparability of data sets?

There are many issues that can affect the confidence in data, data comparability, and resulting analysis, but the three main issues are:

- The sampling methodology used and how representative the resulting data captured is of the market from which it was gathered;
- The sample size, testing procedure used, and competence and independence of the laboratory undertaking the testing;
- The source of the data.

Market representativeness

The *test results* for a group of products will be directly comparable if they are tested for the same performance parameters, using the same testing methodology and in the same location. However, this does not necessarily make the data set as a whole comparable. For example, if one data set is drawn from a premium product registration system (e.g. the U.S. ENERGY STAR); a second is drawn from testing following a structured random sampling of the market across the USA; and a third from a data set created by enforcement testing specifically targeting those where non-compliance is anticipated, there will inevitably be a degree of non-comparability in the overall data sets. Hence, when comparing results it is important to consider the sampling methodology used, and how that impacts on the overall market representativeness of the resulting data set, *particularly* when considering products purchased in different economies[66].

Data reliability: Sample size, test procedure used and the reliability of the laboratory

Clearly how many product samples are used to represent an individual model performance, the test procedure used and the competence and independence of the laboratory undertaking the test all impact on the level of "reliability" that can be attributed to a particular data set. Fortunately, the vast *majority* of data analyzed within the report uses parameters where the local test methodologies draw directly from underlying CIE testing methodologies and are thus (generally) comparable. However, the sample sizes used to define the performance of a model within in each data set vary significantly from individual lamps to over twenty, and hence there is variability in the likelihood that the specific results represents typical performance for a particular model. Similarly, while the majority of data sets comprise results drawn from tests in accredited laboratories, the specific levels of accreditation, and degree of independence of the laboratories vary significantly.

Data source

Data sets used within the report draw original data from a variety of sources: directly from manufacturers/suppliers; government/third party registration schemes (where data may still be manufacturer declared, sometimes with some level of independent verification, or it may have been independently tested), government enforcement testing and/or government/third-party research testing. Obviously, more confidence may be attributed to data originally drawn from sources where independent third party testing is undertaken.

[66] It is important to note that "non-comparable" and/or "unrepresentative" data sources are still extremely valuable, particularly in identifying products with premium or poor performance characteristics.

Assessing confidence in the reliability and comparability of data presented in this analysis

In order to provide transparency regarding the degree of 'reliability and comparability' that can be attributed to specific data and resulting analysis presented in this report, a *Data Confidence Score* has been assigned to each data set. The score is in two parts to reflect:

1. Data confidence: Which combines data reliability and data source to give a score from 1-5, with 1 signifying a high level of confidence in the data source (in the context of this report), and 5 signifying low confidence.
2. Market representativeness: a simple 2 level score of A for data sets that are deemed to be representative of the whole of the local market and B for those that are not[67].

So, for example, a data set that is labelled 1A is deemed to be from a market representative data set with high levels of confidence in the data, while a result labelled 5B is not whole market representative and has very low levels of confidence in the data.

The methodology for assigning these scores is shown in the table below:

Table 25: Confidence in the Accuracy of the Data

Field	Possibilities	Score Assigned to Possibility
(i) Data Type	A) Rated performance	3
	B) Test result - single sample (or unknown)	2
	C) Test result - mean of 2-5 samples	1
	D) Test result - mean of 6+ samples	0
(ii) Data Source	A) Manufacturer	2
	B) Government / independent party	1
Score (/5)		**(i) + (ii)**

Table 26: Confidence that the Data Represent the Market

Field	Possibilities	Score Assigned to Possibility
(iii) Market representativeness	A) Considered broadly representative	A
	B) Considered not representative (e.g. skewed, not enough models tested, etc.)	B
FINAL SCORE		**(i) + (ii) & (iii)**

The specific values attributed to each data set have been assigned by the experts preparing this report.

[67] It is worth noting that even where a data set is not considered representative of the whole market (e.g. a data set drawn from a premium labeling registration system such as the USA's ENERGY STAR), it may still be comparable with other data sets drawn from similar premium product market segments.

Appendix 3: Performance thresholds for voluntary and mandatory programs in economies analyzed

	Australia	Australia	EU	EU	Indonesia	Indonesia
	MEPS	MEPS	MEPS	MEPS	MEPS	MEPS
Date	Nov-09	Nov-09	Staged: 1) 2013 2) 2014 3) 2016 *(Performance requirements from stage 1 with exceptions)*	Staged: 1) 2009 2) 2010 3) 2011 4) 2012 5)2013 6) 2016 (pending review)	2003	Under revision
Description	AS/NZS 4847.2	AS/NZS 4847.2	Regulation (EC) No 1194/2012	Regulation (EC) No 244/2009	MEPS operated in conjunction with comparative label. MEPS set at label one star level. SNI 04-6958-2003, *Household and similar electrical appliances - Energy rating labels*, sets out the requirements	MEPS and labels currently being revised
Scope (lamp type)	CFLi	CFLi	Directional and non-directional LEDs	non-directional lighting (with the exception of non-directional LEDs)	CFL	CFL
Scope (other)	Bare non-directional	Covered non-directional		1)>950lm (~80W GSL), <950lm (Energy Class F&G) 2)>725lm (~65W GSL) 3)>450lm (~45W GSL) 4)>60lm (~7W GSL) 5)increased requirements 6)>60lm	6500K lamps	2700K up to < 4400K ≥ 4400K up to 6500K

	Australia	Australia	EU	EU	Indonesia		Indonesia	
Efficacy	Efficacy >= 1 / (0.24/sqrt(F) + 0.0103) where F=initial flux in lm	Efficacy >= 0.85 / (0.24/sqrt(F) + 0.0103) where F=initial flux in lm	Maximum (EEI) Stage 1 0.50 Stage 2 0.50 Stage 3 0.20	Maximum rated power (Pmax) for a given rated luminous flux (Φ) (W) Clear lamps Stage 1)-5) 0,8 * ($0,88\sqrt{\Phi}+0,049\Phi$) Stage 6) 0,6 * ($0,88\sqrt{\Phi}+0,049\Phi$) Maximum rated power (Pmax) for a given rated luminous flux (Φ) (W) Non-Clear lamps Stage 1-5) $0,24\sqrt{\Phi}+0,0103\Phi$ Stage 6) $0,24\sqrt{\Phi}+0,0103\Phi$	Power (W) 5 – 9 10 – 15 16 – 25 ≥ 26	lumens/w 45 – 49 46 – 51 47 – 53 48 – 55	Power (W) **< 4400K:** ≤ 8 > 8 - 15 > 15 - 25 > 25 – 60 **≥ 4400K to 6500K:** ≤ 8 > 8 - 15 > 15 - 25 > 25 – 60	lumens/w < 34 < 38 < 42 < 46 < 33 < 37 < 41 < 45
Lumen maintenance	At 2000 h: ≥ 88 % At 5000 h: ≥ 80 %	At 2000 h: ≥ 88 % At 5000 h: ≥ 80 %	Lumen Maintenance at 6 000 h From 1 March 2014: ≥0,80	Lumen maintenance Stage 1: At 2 000 h: ≥ 85 % (≥ 80 % for lamps with second lamp envelope) Stage 5: At 2 000 h: ≥ 88 % (≥ 83 % for lamps with second lamp envelope) At 6 000 h: ≥ 70 %	After 2,000 hours (including ageing period), the lumen value should be not less than 80% of its claim			
Life time	≥ 6000 hrs	≥ 6000 hrs	Lamp survival factor at 6 000 h From 1 March 2014: ≥0,90	Lamp survival factor at 6 000 h Stage 1: ≥ 0,50 Stage 5: ≥ 0,70	Minimum lifetime 6,000 hours (2,000 hours test)		• Minimum life time 6.000 hours (producer's claim)à 2.000 hours test	
CRI	≥ 80	≥ 80	Color rendering (Ra) ≥80 ≥65 if the lamp is intended for outdoor or industrial applications according to point 3.1.3(1) of this Annex	Color rendering (Ra) Stage 1: ≥ 80 Stage 5: ≥ 80				

	Australia	Australia	EU	EU	Indonesia	Indonesia
Rated CCT (K) and/or description					6500K	2700K up to < 4400K ≥ 4400K up to 6500K
Power factor	≥ 0.55	≥ 0.55	Lamp power factor for lamps with integrated control gear P ≤ 2 W: no requirement 2 W < P ≤ 5 W: PF > 0,4 5 W < P ≤ 25 W: PF > 0,5 P > 25 W: PF > 0,9	Lamp power factor Stage 1: ≥ 0,50 if P < 25 W ≥ 0,90 if P ≥ 25 W Stage 5: ≥ 0,55 if P < 25 W ≥ 0,90 if P ≥ 25 W		
Switch withstand	≥ 3000 cycles	≥ 3000 cycles	Number of switching cycles before failure ≥15 000 if rated lamp life is ≥ 30 000 h otherwise: ≥ half the rated lamp life expressed in hours	Number of switching cycles before failure Stage 1: ≥ half the lamp lifetime expressed in hours ≥ 10 000 if lamp starting time > 0,3 s Stage 5: ≥ lamp lifetime expressed in hours ≥ 30 000 if lamp starting time > 0,3 s		
Rated mercury content (mg)	≤ 5mg	≤ 5mg				
Start Time	≤ 2 s	≤ 2 s	Starting time 0,5 s	Starting time Stage 1: < 2,0 s Stage 5: < 1,5 s if P < 10 W < 1,0 s if P ≥ 10 W		
Run-up Time	≤ 60 s	≤ 60 s	Lamp warm up time to 95% φ <2s	Lamp warm-up time to 60 % Φ Stage 1: < 60 s or < 120 s for lamps containing mercury in amalgam form Stage 5: < 40 s or < 100 s for lamps containing mercury in amalgam form		

	Australia	Australia	EU	EU	Indonesia	Indonesia
Maximum Total Harmonic Distortion	Comply IEC 61000-3-2	Comply IEC 61000-3-2				
Color coordinates (x/y)			Color consistency Stage 1 except where indicated otherwise (and Stage 3): Variation of chromaticity coordinates within a six-step MacAdam ellipse or less.			
SDCM	≤ 5	≤ 5				
Other			Premature failure rate ≤ 5,0 % at 1 000 h If the lamp cap is a standardized type also used with filament lamps, then as from stage 2, the lamp shall comply with state-of-the-art requirements for compatibility with equipment designed for installation between the mains and filament lamps.	Premature failure rate Stage 1: ≤ 2,0 % at 200 h UVA + UVB radiation ≤ 2,0 mW/klm UVC radiation ≤ 0,01 mW/klm Stage 5 :≤ 2,0 % at 400 h ≤ 2,0 mW/klm ≤ 0,01 mW/klm		

	Philippines	Thailand	USA	USA	USA	USA	Vietnam
	MEPS	MEPS	MEPS	Voluntary (ENERGY STAR)	Voluntary (ENERGY STAR)	Voluntary (ENERGY STAR)	MEPS
Date	2010	Voluntary (2006)	2006	2008	2010	2014	Unclear
Description	MEPS specified in PNS 2050-2:2007, Lamps and related equipment – Energy efficiency and labeling requirements Part 2:Self-ballasted lamps for general lighting service.	Performance standard: TIS 2310-2549 (2006), Self-Ballasted Lamps for General Lighting Services: Energy Efficiency Requirements	DOE CFL MEPS (Mandatory)	ENERGY STAR CFLs 4.0 (Voluntary)	ENERGY STAR Integrated LED Lamps 1.0 (Voluntary)	ENERGY STAR Lamps 1.0 (Voluntary)	Performance standard: TCVN 7896:2008, *Compact fluorescent light bulb - Energy performance*
Scope (lamp type) Scope (other)	CFLs Self-ballasted lamps for domestic and similar general lighting service, with 3 to 60 watts power input, having a rated voltage up to 230 volts, 60Hz, with Edison screw base E14 & E27. LED and power supply unit regulating (PSR) lamps are specifically exempted.	CFLs Reference standard for TIS 2310-2549 (2006): *National Appliance and Equipment Energy Efficiency Committee (Australia) Report no.: 2005/12 Minimum Energy Performance Standards – Compact Fluorescent lamps* Test method standard based on IEC 60969	Self-ballasted CFLs with medium base. Bare and covered. Does NOT include reflector types	Self-ballasted CFLs including medium base and candelabra base CFLs. Bare, covered, and reflector types	Integrated LED Lamps	CFLs and Integrated LED Lamps	CFL Lamps with power from 5W to 60W with electronic ballasts

	Philippines		Thailand		USA		USA		USA		USA		Vietnam	
Efficacy	Power (W) **≤ 4000K** ≥ 3 to < 5 ≥ 5 to < 9 ≥ 9 to < 15 ≥ 15 to < 25 ≥ 25 **> 4000K** ≥ 3 to < 5 ≥ 5 to < 9 ≥ 9 to < 15 ≥ 15 to < 25 ≥ 25	lumens /w 45 50 55 60 65 41 46 52 57 62	Power (W) voluntary >4400K: 5 - 8 9 -14 15 - 24 25 – 60 4400K: 5 - 8 9 -14 15 - 24 25 – 60	lumens /w 36 44 51 57 40 48 55 60	Bare lamp, <15W 15+W	45 60	Bare lamp, fixed output, <10 W 10-14 W 15+ W	50 55 65	<10 W >10+W	50 55	<15W 15+W		Power (W) **<4400 K** from 5 to 8 9 to 14 15 to 24 25 to 60 **≥ 4400 K** from 5 to 8 9 to 14 15 to 24 25 to 60	Lumens/W 45 (55) 50 (60) 55 (65) 60 (70) 40 (50) 45 (55) 50(60) 55(65)
	(Covered Lamps not be less than 85% of these requirements)													

	Philippines	Thailand	USA	USA	USA	USA	Vietnam
Lumen maintenance	After 2000 hours of operation the lumen maintenance of the lamp shall not be less than 80%		At 1000 hrs: Average lumen output measurement of the 5 lamps tested must be greater than 90% of initial (100-hour) At 40% of Rated Life: Average lumen output measurement of the 5 samples tested must be greater than 80% of initial (100-hour)	At 1000 hrs: Average lumen output (10 lamps) must be greater than 90% of initial (100-hour) average lumen output measurement. No more than 3 individual samples can have a lumen output measurement less than 85%. At 40% of Rated Life: Average lumen (10 lamps) must be greater than 80% of initial. No more than 3 individual samples can have a lumen output less than 75%.	At 6,000 hrs: 91.8% lumen maint At 25,000 hrs: > 70% lumen maint (L70 at 25,000 hrs).	CFL: >90% at 1000 hrs; >80 at 40% of rated life LED: Depends on life claim but essentially 91.8% for claimed life of 25,000 hrs	CFL luminous flux after 2000 h operation must not be less than 80% of the initial luminous flux.
Life time	The average life time (the length of time during which 50% of the lamps reach the end of their individual life) shall not be less than 6,000 hours		> 6000 hours Life test @ 80% of rated life, "statistical methods may be used to confirm lifetime claims based on sampling performance."	> 6000 hours Life test @ 40% of rated life: 1 of 10 sample failure, acceptable; 2 of 10 sample failures, requires submission of a product failure report from the manufacturer that describes in detail the specific reasons for the sample product failures. 3 of 10 sample failures, does not qualify	None	CFL rated life 10,000+ @ 40% of rated life, 90% samples operational 50+% sample operational at rated life All other lamps = rated life of 25,000+ @ 6000 hrs, 90% samples operational	Not less than 6000h (it is permitted to use rapid test methods (Cycle turn on - turn off) to assess life expectancy)

	Philippines	Thailand	USA	USA	USA	USA	Vietnam
CRI			none	Average of the 10 samples tested must be greater than 80, and no more than 3 individual samples can have a CRI less than 77.	CRI 80, R9>0	All lamps: CRI 80, LEDs also must have R9>0	
Rated CCT (K) and/or description		> 4400K and ≤ 4400K	none	Must be one of the following: 2700 3000 3500 4100 5000 6500	Must be one of the following: 2700 3000 3500 4000	Must be one of the following: 2700 3000 3500 4000/4100 5000 6500	< 4400K and ≥4400K
Power factor			none	0.5	<5W no requirement >5W 0.7	CFL .5 LED .7	
Switch withstand			Cycle times must be 5 minutes on, 5 minutes off. Lamp will be cycled once for every two hours of rated lamp life. At least 5 out of the 6 sample lamps must meet or exceed the minimum number of cycles.	Cycle times must be 5 minutes on, 5 minutes off. Lamp will be cycled once for every two hours of rated lamp life. At least 5 out of the 6 sample lamps must meet or exceed the minimum number of cycles.	Cycle times must be 2 minutes on, 2 minutes off. Lamp will be cycled once for every two hours of required L70 life. 9 of 10 samples must pass	CFLs: Cycle times 5 minutes on, 5 minutes off. Lamp will be cycled once for every two hours of rated lamp life. At least 5 out of the 6 sample survival. LEDs: Same as above except can use 2 min cycles instead if desired; must last the lessor of 1 cycle per hour of rated life or 15,000	

	Philippines	Thailand	USA	USA	USA	USA	Vietnam
Rated mercury content (mg)			none	<25 Watts 5mg 25+ Watts6mg	n/a	<23 Watts 2,5mg 23+ Watts 3mg	
Start Time			none	1 sec	none	1 sec	
Run-up Time			none	3 min	none	CFL (covered) 80% in <120 sec; CFL (all other) 80% in < 60 sec; LED no requirements.	
Maximum Total Harmonic Distortion			none	none	none	none	
Color coordinates (x/y)							
SDCM							