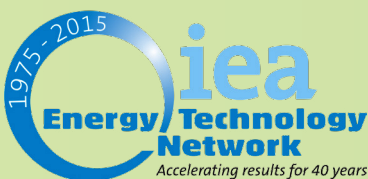**4E**

Energy Efficient End-use Equipment
International Energy Agency

Achievements of appliance energy efficiency standards and labelling programs

A GLOBAL ASSESSMENT

1975 - 2015
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Accelerating results for 40 years

SEAD

The IEA Implementing Agreement on Energy Efficient End-Use Equipment (4E) is an International Energy Agency (IEA) Implementing Agreement established in 2008 to support governments to formulate effective policies that increase production and trade in efficient end-use equipment. Twelve countries have joined together to form 4E as a forum to co-operate on a mixture of technical and policy issues focused on increasing the efficiency of appliances and equipment. However 4E is more than a forum for sharing information – it initiates projects designed to meet the policy needs of participating governments. Participants find that pooling of resources is not only an efficient use of available funds, but results in outcomes which are far more comprehensive and authoritative.

Current members of 4E are: Australia, Austria, Canada, Denmark, France, Japan, Korea, Netherlands, Switzerland, Sweden, UK and USA.

Further information on the 4E Implementing Agreement is available from: **www.iea-4e.org**

Acknowledgements

DISCLAIMER

4E

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Executive Summary

National energy efficiency standards and labelling (EESL) programs have been in existence since the 1970s and now operate in more than 80 countries around the world, covering more than 50 different types of appliances and equipment in the commercial, industrial and residential sectors. While the design and coverage of EESL programs vary according to national circumstances, they provide the cornerstone of most national energy efficiency and climate change mitigation programs.

As governments consider how best to take advantage of further energy efficiency resources to meet future demands for cleaner energy, this report identifies the achievements of EESL programs, which have been among the most broadly adopted and longest running energy efficiency policies.

Based on evidence from a wide cross-section of countries with EESL programs, the energy efficiency of major appliances in these countries have increased at more than three times the underlying rate of technology improvement.

One-off improvements of more than 30% have been observed when new EESL programs have been first introduced to a market where few energy efficiency programs had existed previously.

These substantial efficiency improvements for individual appliances and equipment have translated to national energy savings and reductions in CO_2 emissions. The most mature national EESL programs covering a broad range of products are estimated to save between 10% and 25% of national or relevant sectoral energy consumption.

In all of the EESL programs reviewed, the national benefits outweighed the additional costs by a ratio of at least 3 to 1, i.e. EESL programs deliver energy and CO_2 reductions while also reducing total costs. This compares extremely favourably with the cost of other clean energy options and supports the conclusion from the International Energy Agency that end-use efficiency measures offer the least cost pathway to energy and CO_2 emission reductions.

Appliances and equipment covered by EESL programs have not only dramatically improved in efficiency over the past 20 years, but are also cheaper to purchase. While EESL programs may have caused small changes in prices close to the implementation of new energy efficiency measures, they appear to have had little long-term impact on appliance price trends.

> **The energy efficiency of major appliances in these countries have increased at more than three times the underlying rate of technology improvement**

This is mainly due to the ability of appliance manufacturers to find new and cheaper ways to improve efficiency and to volume-related cost reductions. EESL programs have been very successful in fostering innovation, expanding existing markets and opening up new market opportunities. This has led to enhanced employment outcomes, with 800,000 direct jobs created by EESL programs in the EU and 340,000 jobs in the US.

A range of other benefits, including improvements in air-quality and the reduction of public expenditure on health, have been found to flow from EESL programs, and provide additional justification for investment in these types of programs. In jurisdictions where these types of policy objectives are of high national importance, the contribution made by such co-benefits can be sufficiently large in their own right to justify EESL programs.

In some very specific cases, the reduced energy costs resulting from EESL programs may be used by householders and companies to purchase additional energy services (the rebound effect). In developed countries, this is likely to be limited to the use of heating, cooling, water heating and to a lesser extent lighting, mainly in low-income households. In many cases, these increased comfort levels may be an intended outcome of EESL programs, for example when targeted at low-income households. Even when a rebound effect has been found to occur, EESL programs have still demonstrated a net energy saving, and overall cost-effectiveness.

1 Introduction

This report summarises the recorded achievements of government energy efficiency standards and labelling (EESL) programs, which are amongst the longest running and most widely adopted type of national energy efficiency program.

National EESL programs have been in existence since the 1970s and have grown since this date, so that now EESL programs operate in more than 80 countries around the world and apply to more than 50 different types of appliances and equipment in the commercial, industrial and residential sectors [1]. While the design and coverage of EESL programs vary according to national circumstances, they provide the cornerstone of most national energy and climate change mitigation programs.

Typically, EESL programs use one or more of the following complementary tools to improve the energy efficiency performance of appliances and equipment[1]:

- ▶ Energy labels enable consumers to make an informed choice at the point of purchase, either by showing the comparative performance of all appliances (rating labels) or by identifying the best-in-class products (endorsement labels).
- ▶ Minimum energy performance standards (MEPS) provide a level playing field in competitive markets by removing the worst performing products without diminishing consumer choice [2].

Analysis by the International Energy Agency (IEA) shows that the contribution currently made by energy efficiency to meet national demands for energy services is very substantial. Energy efficiency is in fact the "first" fuel since the quantity of energy avoided by on-going energy efficiency activities in IEA member countries during 2011 was larger than the actual demand met by any other single supply-side resource, including oil, gas, coal and electricity [3].

As governments consider how best to take advantage of further energy efficiency resources to meet future demands for cleaner energy, this report provides a catalogue of the achievements to date of one of the largest and longest running energy efficiency programs.

This record is drawn from over 100 publications that detail the evidence of the impacts of EESL programs in 20 countries, and covers more than 25 different product types (see Attachment A for more information on the methodology).

The recorded impacts from EESL programs summarised in this report include:

- ▶ Increases in the energy efficiency of appliances, equipment and lighting technologies, over and above autonomous rates of change.
- ▶ Reductions in national energy consumption and associated greenhouse gas emissions savings.
- ▶ Changes in the consumer purchase price of appliances and equipment.
- ▶ Delivery of co-benefits, such as employment, health and energy security.
- ▶ The effects on manufacturing innovation and market transformation.
- ▶ The additional energy services purchased by beneficiaries of energy efficiency fuel bill reductions – the 'rebound' effect.

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[1] Both types of programs are underpinned by test procedures and compliance strategies.

2 Impact on rates of energy efficiency improvement

The evidence from a wide cross-section of countries with EESL programs indicates that the energy efficiency of major appliances has improved at an average rate around 3% to 4% per annum over a long period (see Attachment B). This compares favourably to the underlying rate of technology improvement of between 0.5%-1% per annum.

For example, in the years prior to efficiency regulations in 2004, the average efficiency of Australian air conditioning units improved at approximately 0.5% per annum. This grew to around 3% per annum after 2004 and to around 4% per annum after updated requirements in 2006/07 [4]. In Korea, a 59% increase in energy efficiency across all products covered by its EESL program was observed between 1996 to 2010 [5], equivalent to an annual improvement of 3.4% per annum.

> **For the larger EESL programs in the USA, China and Europe total savings are estimated to range between 10-20% of national or sectoral energy consumption**

Larger improvements have been observed, for example when new EESL programs have been first introduced to market where few energy efficiency programs had existed previously. A 32% efficiency improvement was achieved in one year (1994-1995) when Mexico first implemented MEPS [6]. A 7% improvement in the efficiency of refrigerators in the EU was recorded in the first year following the introduction of mandatory energy labelling in 1995 [7], [8], [9].

The rate of improvement in the efficiency of televisions and some other consumer electronics products has also been above average since the introduction of EESL programs by several economies from 2008. In most of these cases, the underlying rate of technology change has also exceeded 1% per annum [10] [11].

Where lower long-term rates of efficiency improvements have been observed, this appears to be the result of a failure to review and upgrade performance requirements to keep pace with the rate of improvement in new products entering a market. There is strong evidence to show that significant and sustained improvements in energy efficiency occur where policies are subject to on-going revision and updating.

For example, Figure 1 illustrates the impact of successive policy measures on the performance of refrigerators in Australia, leading to an annual 3.6% decline in the average energy consumption between 1986 and 2010. The USA has also seen a 4% per annum improvement in the energy efficiency of its refrigerators over the period 1989 to 2010, driven by continued updating of policy measures in 1990, 1993, 2001 and 2014 [12].

Figure 1: Change in efficiency of Australian refrigerators [13]
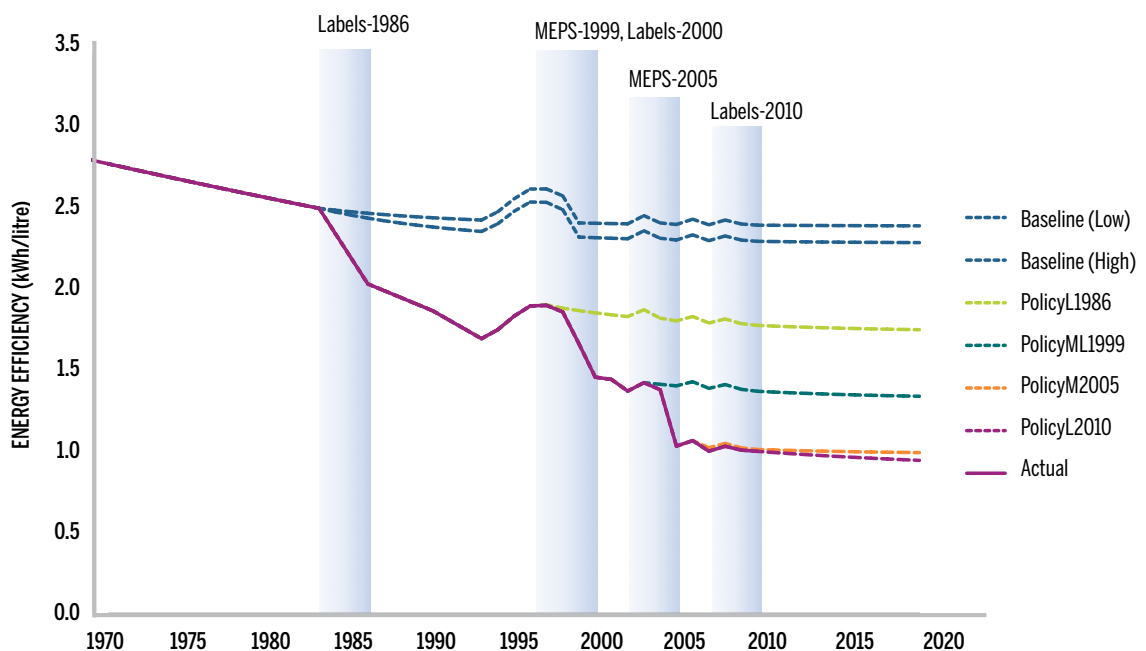
3 The cost-benefit of energy efficiency

The costs of efficiency improvements include the EESL program administrative and compliance/enforcement costs, together with the incremental cost to consumers of more efficient technologies. However, the net cost of efficiency improvement must also account for the reduced operating costs experienced by users of more efficient equipment.

As shown in Figure 2 for the US, the net financial benefits to consumers from EESL programs already implemented are considerable.

Figure 2: Annual undiscounted net consumer benefit for all MEPS by sector, USA [14]
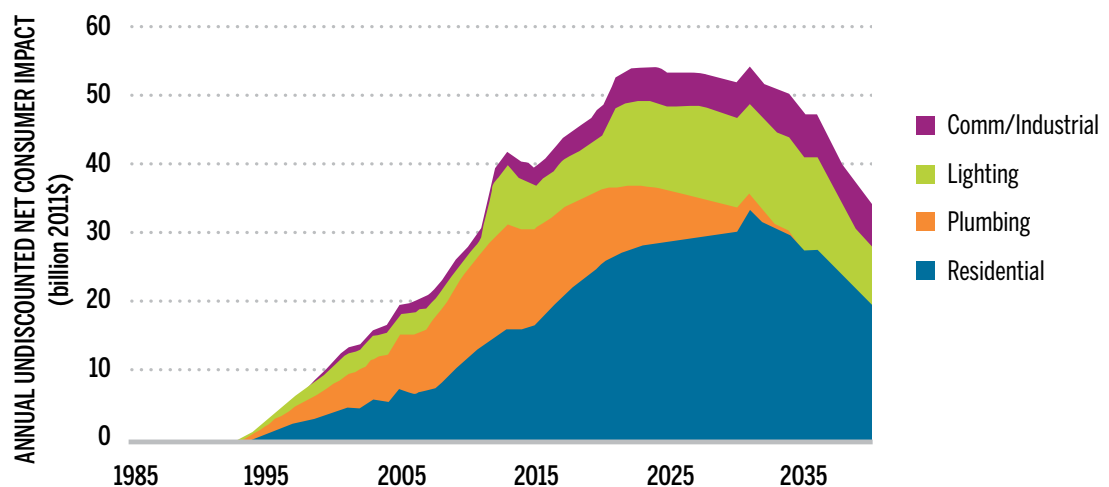
In all of the EESL programs reviewed the national benefits outweighed the additional costs by at least 3 to 1[2], i.e. the net cost of energy savings was negative from a societal viewpoint.

> **For every metric tonne of greenhouse gas emissions reduced through ENERGY STAR, Americans saved more than $125 on their energy bills**

For example, in the United States, MEPS for all products has had an estimated average benefit to cost (B/C) ratio of about 3:1 [15]. In the UK, product policy (mainly European EESL legislation) in 2012 had a B/C ratio of 3.8:1 [16]. Similarly, the EESL program for refrigerators and freezers in Fiji showed a B/C ratio of 3.5:1 [17].

Voluntary programs can also deliver cost-effective outcomes, with the extensive US based "ENERGY STAR" program reporting that for every incremental dollar Americans invested in energy efficiency through ENERGY STAR, they saved, on average, $4.50 [18].

These finding supports the conclusion from the International Energy Agency that end-use efficiency measures offer the least cost pathway to CO_2 emissions reductions (see Figure 3) [19].

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[2] As part of the regulation process in many jurisdictions, ex-ante impact assessments are undertaken of any proposed program measures; and measures are usually only pursued if the there is a Benefit/Cost ratio (B/C) that exceeds 1.0 and/or if the sum of Net Present Value of costs and benefits from the measure is greater than zero.

Figure 3: Marginal emission reduction costs for the global energy system, 2050 (IEA) [19]
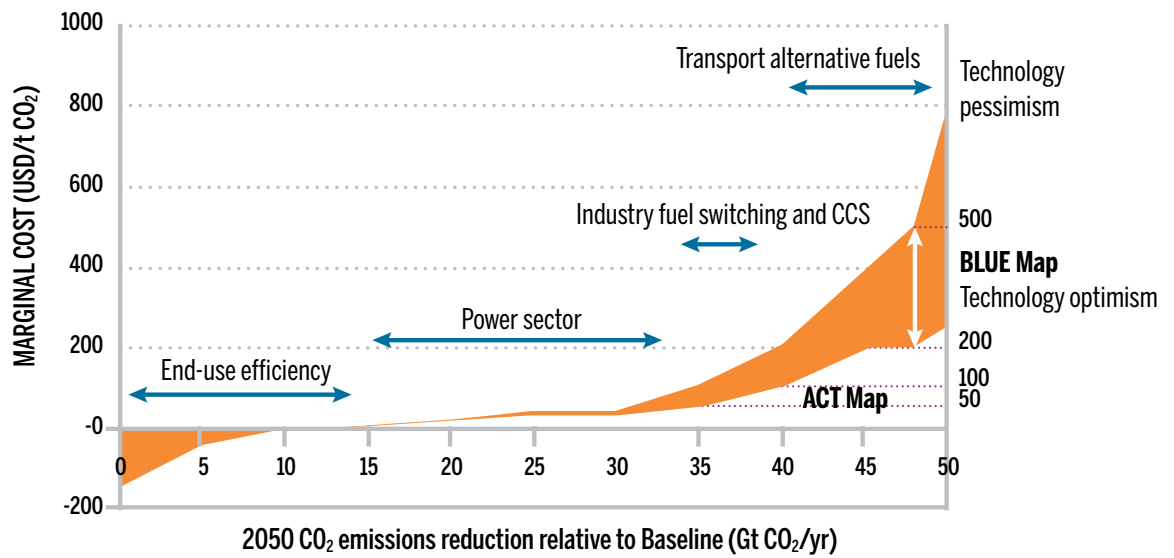
It should be noted that cost-effectiveness of EESL measures are usually ensured by setting performance requirements at a level where the life cycle costs are minimised[3].

Since a large proportion of the costs associated with EESL programs relate to the expected changes in product purchase price, understanding the incremental cost of energy efficiency improvement is key to accurately predicting the benefit to cost ratio. This is discussed further in the following section.

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[3] This is typically a core part of the standard setting methodology, e.g. in the USA and the EU.

4 Impact on appliance and equipment purchase prices

While it is commonly assumed that raising energy efficiency levels will push up purchase prices for equipment, the reviewed evidence shows that long-term appliance purchase prices are generally declining in real terms while products are also becoming more efficient.

Australian refrigerator prices declined by between 2.5%-5%[4] per annum in real terms between 1993 to 2008, and this trend did not change around the introduction of MEPS in 2005, which resulted in a 25%-35% reduction in energy consumption [13].

A recent study in Sweden also shows an upward trend in efficiency whilst product prices were falling [20]. Similar long-term declines in real product prices have been observed in reliable studies from the UK, Australia [21] and the EU [12].

In this context of falling appliance prices, a comparison of expected purchase price increases with the actual price changes observed two years after the MEPS implementation in the US found that the marginal price increase had been overestimated on average by a factor of 10 (see Table 1) [22][5].

Long-term appliance purchase prices are generally declining in real terms while products are also becoming more efficient

Table 1: Comparison of predicted and actual price increases from US MEPS [22]

PRODUCT	DOE ESTIMATE OF INCREMENTAL PRICE OF STANDARD (NOMINAL $)	DOE ESTIMATE (2011$)	COST FROM CENSUS (2011%)	DIFFERENCE (2011$)
Refrigerators	32	56	37	-18
Clothes Washers	34	54	-35	-89
Clothes Washers	126	199	10	-188
Electric Water Heaters	67	108	28	-80
Non-Electric Water Heaters	75	121	34	-88
Central AC – 3 tons	167	267	207	-59
Room AC	7.50	13	-162	-175
Commercial AC – 15 tons	334	512	-224	-736
Ballasts	4.27	6.73	-1.74	-8.47
Average		148	-12	-158
Median		108	10	-88

In Europe, product prices were anticipated to rise on average by 14% following the introduction of EU Ecodesign regulations. However, evidence suggests that these increases did not happen or were smaller than anticipated [23].

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[4] The range in the declining rate of prices and energy consumption reflect different categories of refrigerators

[5] Excluding AC, since their price fell dramatically. The late 1990s saw a dramatic increase in the production of air conditioners in China, together with dramatically increased world trade, and this had major impacts on the price of these appliances in most countries.

More detailed analysis indicates that there may be a small change in the decreasing price trend close to the implementation of significant new energy efficiency measures but the downward trend re-appears soon after. This is illustrated by the example of clothes washer in the USA in Figure 4 and in Attachment D.

Figure 4: Price and energy trends for clothes washers in the USA [22]
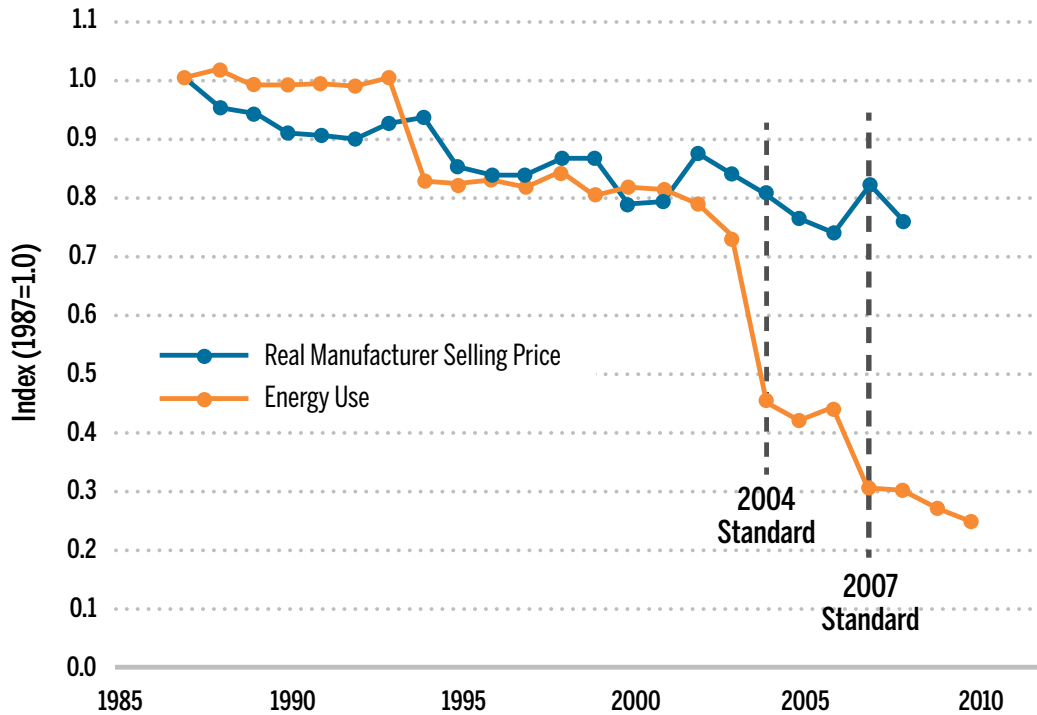
The reason why energy efficiency regulations have had little long-term impact on purchase prices appears mainly due to changes in retail mark-ups, economies of scale in production and innovation by manufacturers [24], [43], [25].

These findings indicate that it will be cost-effective for EESL programs to be more ambitious than under the previously assumed static or increasing price assumptions, by using the concept of "learning rates" to predict future appliance price trends (as proposed for the US) [26]. Reducing appliance purchase costs and increasing energy costs push the cost effectiveness threshold for energy efficiency to higher levels.

5 Innovation, industry leveraging and employment benefits

EESL programs foster innovative solutions within competitive markets where the manufacturing sector strives to deliver improved product performance at least cost. As noted in the previous section, the ability of appliance manufacturers to find new and cheaper ways to improve efficiency in part explains how products prices have not increased despite dramatic increases in efficiency.

> **EESL programs are estimated to have created 800,000 *direct* jobs in Europe and 340,000 jobs in the US**

Successful innovation in response to EESL programs typically leads to the expansion of existing markets and/or new markets for those local industries that take up the innovation challenge, leading to enhanced employment outcomes. In the EU it has been estimated that by 2014, 0.8 million direct jobs had been created by EESL programs together with a further 3 to 5 times as many indirect jobs [23]. It is estimated that MEPS in the USA were responsible for the creation of 340,000 full-time equivalent jobs by 2010 [27].

On-going innovation appears strongest in the deployment, commercialisation and diffusion of innovative energy efficiency technologies [28], which is shown clearly by the market entry of more efficient products following announcements of new EESL regulatory requirements, but in advance of the due dates [21], [13], [4].

Similarly, in the case of comparative labelling schemes, industry has been found to respond to the program by striving for higher and higher ratings to differentiate their products from competitors, particularly for products that use a significant amount of energy[6].

For example, in Australia it is evident that manufacturers of refrigerators strive to achieve the 'next' highest half star on the energy rating label, as shown in Figure 5. Analysis of European data for refrigerators has also shown a prevalence of models just reaching the labelling efficiency thresholds [29].

Figure 5: Distribution of Australia refrigerators according to star rating [30]

Australian Refrigerator and Freezer Registrations - 2012 to 2015 (2010 star rating equation)

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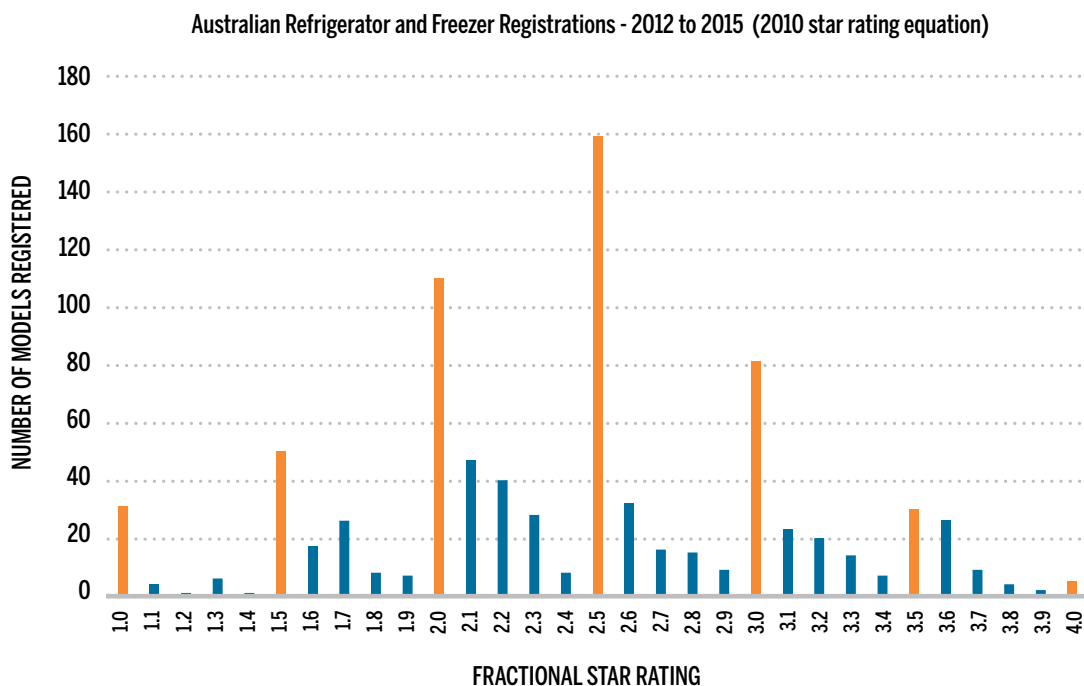
[6] E.g. refrigerators and ACs

Further examples of innovative responses to energy efficiency policies are numerous. The Korean lighting market has been transformed through a program designed to replace 40 W fluorescent lamps with higher efficiency 32 W fluorescent lamps that increased their market share to around 70% by 2004 (see Figure 6) [5].

In Vietnam the introduction of a voluntary labelling scheme prompted one major lamp importer to stop importing low efficiency lamps and ballasts, and influenced the largest local lighting manufacturer to develop more efficient compact fluorescent lamps and ballasts in advance of the introduction of MEPS. The same local manufacturer also established an LED programme in anticipation of more demanding future regulations [31].

Figure 6: Replacement of 40W fluorescent lamps with 32W fluorescent lamps in Korea, 1999-2010 [5]
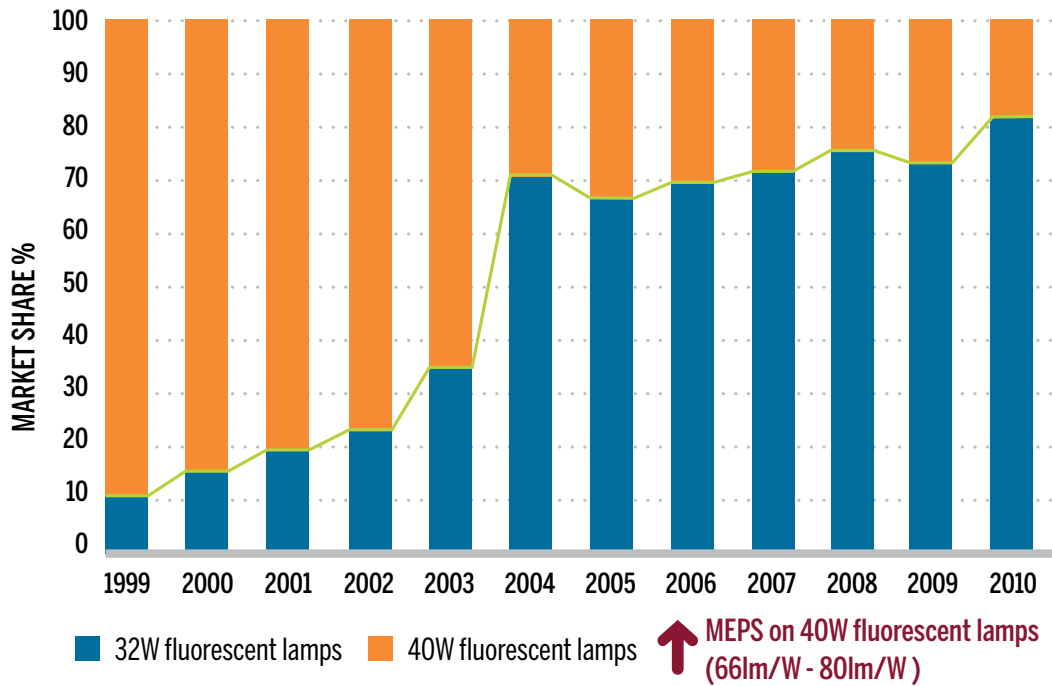
6 Multiple benefits

A range of benefits, in addition to efficiency improvements and energy savings, have been found to flow from EESL programs and often provide further justification for investment in these types of programs. These are referred to as multiple or co-benefits.

In the EU, 336 million m³ of drinking water (equivalent to 1.2% of the EU residential total) will be saved by 2020 as a result of the EESL program for washing machines and dishwashers [23].

In China the EESL program will remove the need for 28 gigawatts of generating capacity by 2020, improving air quality by annually avoiding 6.8 million tonnes of sulphur dioxide emissions, 4.8 million tonnes of NO_X and 29 million tonnes of particulates [32].

The IEA has noted that a broad spectrum of significant co-benefits are routinely associated with the introduction of EESL programs (see Figure 7) [33].

For example, improved indoor temperatures associated with space heating energy efficiency improvements in New Zealand were found to generate savings in health costs that were around 10 times the energy related savings [34].

In general, these co-benefits will improve the cost-benefit case for EESL programs. In jurisdictions where policy objectives such as improving air-quality or reducing public expenditure on health are of great national importance, the contribution made by increased energy efficiency in these areas may be sufficiently large in their own right to justify EESL programs.

> *"Policy-makers may well consider other co-benefits (alone) to be satisfactory outcomes of these investments in light of broader national priorities ..... particularly for emerging economies looking to improve the quality of life of its citizenry"* [33].

In China the EESL program will remove the need for 28 gigawatts of generating capacity by 2020

Figure 7: Range of co-benefits associated with EES&L programs [33]

Individual level Co-benefits
(individuals, households, enterprises)
▶ Health and well-being impacts;
▶ Poverty alleviation: Energy affordability and access;
▶ Increased disposable income.

Sectoral level Co-benefits
(industrial, transport, residential, commercial)
▶ Industrial productivity and competitiveness;
▶ Energy provider and infrastructure benefits;
▶ Increased asset values.

National level Co-benefits
▶ Job creation;
▶ Reduced energy-related public expenditures;
▶ Energy security;
▶ Macroeconomic effects.

International level Co-benefits
▶ Moderating energy prices;
▶ Natural resource management;
▶ Achievement of Development goals.
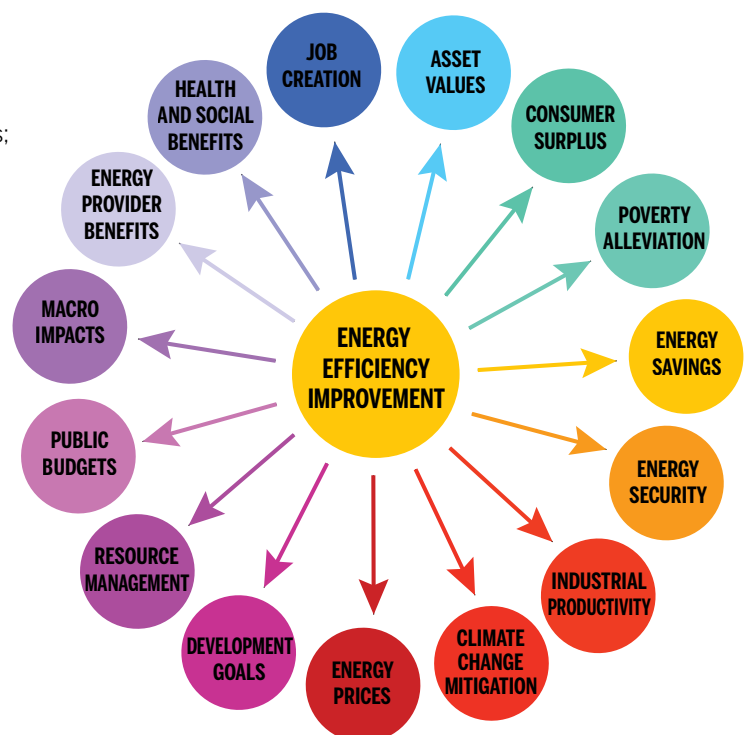
7 Rebound effect

A key impact of increased energy efficiency is that the delivery of energy services, such as heating, cooling or lighting, is made cheaper for consumers. Where consumers choose to use some of this cost saving to pay for increased use of energy services, thereby reducing the projected energy savings, this is commonly known as the rebound, substitution or take-back effect [35][7].

In recent years there has been concern expressed that the scale of the rebound effect may significantly reduce the impacts of energy efficiency programs in terms of energy and cost savings to households and companies [37-39] [40, 41]. While there is not a large body of empirical evidence, it is possible to provide clarification on the likely impact of the rebound effect in relation to EESL programs.

Firstly, it should be noted that the rebound effect can be an intended consequence of the EESL program. In programs targeted at low income households in the northern hemisphere, factoring-in a 30% increase in heating is typical [42]. Similarly, in the New Zealand example in section 6 a key objective from the policy to improve heater efficiency was to enable householders to heat their dwellings to a higher standard.

> **While the direct rebound effect may be significant, it is likely to be limited to some very specific cases, where increased comfort levels may be a desirable outcome of the EESL programs**

Secondly, the main rebound effect in households will occur when users of appliances and equipment constrain their usage due to excessive running costs prior to the energy efficiency improvement. I.e. they limit their use of individual appliances to what they can afford to spend on energy bills[8]. This suggests that the rebound effect will mainly apply where the demand for energy services is not satiated and this will predominantly apply to low-income consumers. It also suggests that it will be most evident for those types of appliances with the greatest potential for significant savings in running costs, as understood by consumers and where they feel they have some discretion in usage.

In developed countries, the numbers of households where the rebound effect is relevant will be limited. Just over 10% of households are classified as fuel poor[9] in England, and this proportion is likely to be equivalent or less in most other developed countries[10] [43]. The proportion of relevant households in developing countries is likely to be greater, although this will depend upon national circumstances, including demographics and climate.

Thirdly, the rebound effect is also limited to appliances that individually consume considerable quantities of energy and that are under the control of the householder. This explains why there is little evidence for any significant rebound effect in refrigeration, clothes or dishwashing, home entertainment and other uses of consumer electronics . The effect in lighting may be in the region of a 5-12% reduction in energy savings. Any rebound effect may be most apparent in space heating, cooling and in water heating. Estimates, largely from the US, indicate a direct rebound effect for heating, cooling and water heating of 10-30%, 0-50% and 10-40%, respectively (see Attachment E) [44, 45]. These large variations are largely due to the extent that the demand for energy services is satiated in households targeted by the EESL program.

Within the commercial and industrial sector, the reduction of input energy costs should be reflected in cheaper products and services, and stimulate increased demand for outputs. Since energy is typically a small component of input costs (<10%), a doubling of energy productivity might be expected to increase fuel use by not more than 2.5% [45].

Finally it should be noted that, while the direct rebound effect may be significant, it is likely to be limited to some very specific cases, where increased comfort levels may be a desirable outcome of the EESL programs. Any such effect should be accounted for within the cost-benefit analysis conducted by EESL programs. Where this has been done, programs have still demonstrated a net benefit.

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[7] Indirect rebound effects can also occur but these are difficult to identify within an economy where various behaviours by consumers and producers may offset each other. These include the use of savings to purchase other goods and services that also require energy to provide, and where new technology creates new production possibilities and increases economic growth [36].

[8] A similar effect to rebound can also occur where there are physical (not cost) constraints on energy service supply, For example where energy supplies are limited or where appliance capacity is inadequate (heating or hot water system unable to meet the desired user demand (e.g. in rental properties). In these cases, a switch to a more efficiency appliances effectively provides the consumer with increased capacity, which may be used to access a greater level of energy services.

[9] Fuel poor households are those that spend more than 10% of their income on heating bills.

[10] Note that data on fuel poverty in England has been collected over many years and understanding of this issue is highly advanced.

8 Conclusions

This thorough review of the achievements of EESL programs provides overwhelming evidence that these programs have made a very significant contribution to the reduction of energy use and CO_2 emissions, and at a very much lower cost than could have been achieved by other clean energy supply options.

This conclusion takes into account any likely rebound effect if end-users purchase more energy services with the savings generated by increased efficiency. Furthermore, the additional flow-on benefits from EESL programs in terms of improved health from higher thermal comfort and/or avoided air pollution; job creation and energy security provide added justification for these programs.

Governments should take account of these findings when they consider their investment options and priorities for meeting energy demand, noting that all EESL programs have the potential to expand in scope and ambition to deliver more energy and CO_2 savings, as well as beneficial additional policy outcomes.

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Abbreviations

4E	Energy Efficient End-use Equipment, IEA Implementing Agreement
AC	Air-conditioner
B/C	Benefit to Cost ratio
CLASP	Collaborative Labelling and Appliance Standards Program
COP	Coefficient of Performance (output energy / input energy)
EE	Energy efficiency
EESL	Energy Efficiency Standards and Labelling programs
EU	European Union
Ex-ante	Before an event; term used in policy appraisals to indicate that savings estimates are undertaken before the measure has been implemented
Ex-post	After an event; term used in retrospective policy evaluation to indicate that savings estimates were done after the measure has been implemented
TWh	Terawatt hour
IEA	International Energy Agency
kWh	kilowatt hour
MEPS	Minimum Energy Performance Standards
MtCO$_{2e}$	Mega-tonnes of carbon dioxide equivalent
US	United States of America
USD	US dollars, currency

Attachment A: Methodology outline

The project methodology involved an extensive international review of the published reports and conference papers, including over 100 reports and papers from more than 20 countries covering more than 25 product types, which deal with the impact evaluation of energy efficiency programs. Many leading energy efficiency experts from around the world were consulted (see acknowledgements) regarding suitable studies that could be utilised as part of the evidence base for this study. Wherever possible, multiple sources have been identified to support and corroborate the findings and to confirm the wide spread benefits of energy efficiency programs.

In selecting published data to include, comprehensive ex-post studies were given the highest weighting, as these tend to provide the most reliable evidence base of savings achieved in practice. This is particularly true where such studies effectively address key aspects that may have had an impact on savings (capacity changes, ownership trends, sales, actual efficiency, etc.) using a decomposition approach in the analysis. However, formal ex-post evaluation studies, where energy savings are estimated from a review of historical data after program implementation, are not common in the published literature.

MEPS impacts are generally easier to estimate, and many ex-ante estimates of energy savings have been found to be accurate through ex-post evaluation studies. This is because MEPS defines an efficiency benchmark that all products must reach, providing some certainty regarding the likely future program impact. In contrast, it can be more challenging to estimate the likely future impact of labelling programs before they are introduced, particularly voluntary labelling programs, as the savings achieved rely on consumer and manufacturer market responses, which in turn are dependent upon communication, marketing and stakeholder understanding. In the case of labelling impacts, ex-post studies were generally considered more robust and accurate in terms of estimating energy savings achieved.

A final aspect of note is that few reports examined document in any detail the issue of attribution of claimed energy savings. Attribution[13] can be quite important where there are several programs that overlap and/or where there is rapid technology change that is driven by issues that may not be directly related to energy efficiency.

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[13] Attribution of saving requires the development of a credible counter-factual scenario of what may have happened if the program was not implemented in the past. Savings are then calculated as the difference between the counter-factual and what actually happened. This can be relatively simple for a single program measure where there is good data. Counter-factual cases where programs have been in place for many years (e.g. a no labelling counter-factual for a country that has had energy labelling for over 30 years) is potentially very uncertain. Attribution requires good data, knowledge and understanding and to some extent is subjective. The methodologies deployed in the development of counter-factual scenarios are often poorly documented. Estimating future scenarios of program impacts and savings requires the same approach in terms of attribution.

Attachment B: Efficiency Improvements

Through the use of MEPS and labels, governments have measured an increase in the rate of efficiency improvement of new appliances and equipment being sold in their markets. Typically, annual rates of improvement across many major jurisdictions were found to be in the range of 3% to 4% per annum for large whitegoods over a long period, compared to an underlying autonomous rate of improvement of around 1% per annum[14].

For example, in China between 1999 and 2007 the average rate of efficiency improvement for labelled mid-sized refrigerators was 3.8% per annum under their EES&L program and for air-conditioners between 2005 and 2009 the average annual rate of efficiency improvement was estimated to exceed 5% per annum based on a combination of ex-ante and ex-post estimates [32].

Similar annual improvement rates have been found by IEA 4E Mapping and Benchmarking studies on refrigerators, washing machines, dishwashers and air conditioners across a range of countries, all of which have policy measures in place over at least part of the period where data is available [46-49][15]. A summary of the annual 'efficiency' improvements in the IEA 4E benchmarking studies are shown in Table 2 below. It should be noted that some of the data used to estimate these averages are model-weighted (rather than sales weighted, which tends to be more accurate). In addition, the time series available varies by country and these do not always fully span EES&L policies of interest. As such, they are likely to be underestimates of the impact of EES&L policy measures.

Table 2: Average annual efficiency improvements from 4E benchmarking studies (% per annum) [46-49].

PRODUCT ->	REFRIGERATOR	DISHWASHER	WASHING MACHINES FRONT LOADERS	AC-UNITARY	AC-SPLIT
Underlying units ->	(Normalised kWh/Litre) [1]	(Normalised EEI) [1]	(Normalised EEI) [1]	(EER)	(EER)
Australia	-3.6%	-2.3%	-1.4%	3.1%	5.3%
Austria	-4.0%	-4.8%	-3.7%	-	-
Canada	-2.3%	-2.1% *	-10.4% *	0.2% *	-
Denmark	-2.6%	-1.9%	-	-	-
Korea	-	-2.3%	0.0% [2]	0.5%	1.5%
Switzerland	-	-0.9%	-	-	-
UK	-3.9%	-2.8%	-2.3%	-	-
USA	-11.9%	-2.1% *	-	-	-
EU	-3.0%	-1.3%	-3.0%	-	5.1%
Average (including EU overlap)	**-3.2%**	**-2.3%**	**-2.1%**	**1.8%**	**3.0%**

Note 1: the underlying units for the first three products are 'energy intensity', so a negative figure implies an increase in energy efficiency.
Note 2: The underlying data are varying in quality and extent, so some of these figures should be treated with caution, for example, front loader washing machine values for Korea are based on just 3 years of data, whilst reference [24] reports a 14% decrease in energy intensity from 2006 to 2010, equivalent to a decrease of -2.1% per annum.

'*' indicates where the values are model-weighted, rather than sales-weighted.

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[14] See IEA publications: Tracking Clean Energy Progress 2015, Energy Technology Perspectives. Also Manne and Richels 1992, Global 2100 model which estimates the rate of autonomous energy efficiency improvement at 0.23% to 1.2 % p.a.

[15] The 4E Mapping and Benchmarking studies provide a useful basis for comparing data across different countries, which was the primary purpose of this work. For almost all products examined, data show that energy efficiency rates have improved significantly, often over very long periods. However, these comparisons have some limitations in that some of the data sets provided by individual countries do not have sales data attached to individual model data and the time periods where data are available is not always comparable. For example, the refrigerator data included in Table 2 cover a period of 16 years for Denmark and Canada, 15 years for Japan, 12 years for the UK, 10 years for Australia, 8 years for the EU and 7 years for Austria. Also, the start and end years vary and the timing of different policy measures varied in each country.

A major international review of major appliance energy and price trends was published in the journal Energy Policy in 2010 [24]. That paper documents a large number of studies that cover many countries and appliance types around the world. That paper also assesses the long-term historical reductions in energy consumption and price for refrigerators, freezers, washing machines, clothes dryers and dishwashers. The rate of energy efficiency improvement ranged from 1% per annum to as much as 6% per annum in some cases. The data also showed long term reductions in appliance purchase prices. The key results are summarised in Table 3.

Table 3: Yearly changes in price and specific energy consumption of large appliance [24]

APPLIANCE	SOURCE	COUNTRY	TIME PERIOD	YEARLY CHANGE IN %	
				PRICE	SEC[A]
Washing machines	Weiss et al. (2010)	NL	1965-2008	-2.4	-2.5
	Bertoldi and Atanasiu (2007)	EU-15	1996-2004	-	-3.3
	CECED (2003)[b]	EU	1994-2002	-	-4.5
	Dale et al. (2002)	USA	1983-2001	-2.4	-0.9
	EES (2006)	AUS	1993-2005	-2.6	-1.3
	Laitner et al. (2004)	USA	1980-1998	-3.4	-
	Waide (2001)[c]	EU-15	1996-1998	-	-2.5
Laundry dryers	Weiss et al. (2010)	NL	1969-2003	-2.1	-1.5
	Bass (1980)[d]	USA	1950-1961	-2.3	-
	Bass (1980)[d]	USA	1950-1974	-2.2	-
	EES (2006)	AUS	1993-2005	-1.1	-0.7
	Laitner et al. (2004)[d]	USA	1980-1998	-3.2	-
	Laitner et al. (2004)[e]	USA	1980-1998	-2.9	-
Dishwashers	Weiss et al. (2010)	NL	1968-2007	-3.8	-2.3
	Bass (1980)	USA	1947-1968	-2.0	-
	Bass (1980)	USA	1947-1974	-2.0	-
	Ennen (2006)[b,f]	EU	1998-2994	-	-5.1
	Ennen (2006)[b,g]	EU	1998-2004	-	-6.0
Refrigerators	Weiss et al. (2010)	NL	1964-2008	-1.2	-2.4
	Bass (1980)	USA	1922-1940	-2.6	-
	Bertoldi and Atanasiu (2007)[f]	EU-15	1993-2005	-	-4.3
	Bertoldi and Atanasiu (2007)[b]	EU	1993-2004	-	-4.5
	CECED (2004)[b,h]	EU	1999-2003	-	-3.5
	Dahlman (2007)	AUS	1993-2005	-	-3.9
	Dale et al. (2002)	USA	1980-2001	-2.5	-4.6
	EES (2006)	AUS	1993-2005	-1.7	-4.6
	ECCJ (2006)	JPN	2001-2005	-15.1	-5.1
	Laitner et al. (2004)	USA	1980-1998	-3.2	-
	Schiellerup (2002)	UK	1992-1999	-6.3	-3.9
	Schiellerup (2002)[i]	UK	1992-2000	-	-3.4
	Waide (2001) [c,j]	EU-15	1994-1998	-	-2.3
Freezers	Weiss et al. (2010)[k]	NL	1970-2003	-1.5	-1.9
	Weiss et al. (2010)[l]	NL	1970-2003	-1.1	-
	EES (2006)	AUS	1993-2005	-2.5	-3.3
	Laitner et al. (2004)	USA	1980-1998	-5.3	-
	Schiellerup (2002)[k]	UK	1992-1999	-5.1	-3.1
	Schiellerup (2002)[l]	UK	1992-1999	-5.0	-5.6

(See notes overleaf…)

Table reproduced from Weiss et al. in Energy Policy 38(2) 2010 [24].
Abbreviations: AUS-Australia, EU-Europe, EU-15-15 member countries of the European Union; JPN-Japan; NL-The Netherlands; UK-United Kingdom; USA-United States of America.
a SEC-specific energy consumption.
b Including member countries of CECED (European Committee for Domestic Equipment Manufacturers).
c Sales weighted averages.
d Electric laundry dryers.
e Gas laundry dryers.
f Referring to dishwashers with a capacity of 12 standard place settings.
g Referring to dishwashers with a capacity of 9 standard place settings.
h Total of cold appliances.
i Refrigerator-freezer combinations.
j Covering the total of cold appliances.
k Upright freezers.
l Chest freezers.

Table 4 below provides an update of the values shown in Table 3 for selected countries, based on more recent data. Australia's data are for the period 1993 to 2014 inclusive, whilst Korea's data for refrigerators are for 1996 to 2010. Korea data for clothes washers for top loaders are from 2005 to 2010 [50], [21], [51].

Table 4: Updated rates of annual efficiency improvement for selected appliance in Australia and Korea

COUNTRY	REFRIGERATORS	FREEZERS	DISHWASHERS	CLOTHES
Australia	-3.3%	-2.3%	-2.7%	-2.5%
Korea	-5.8%			-3.4%

Note: Values quotes are rates of change in specific energy consumption, which can be taken as the inverse of energy efficiency. All Australian data are 1993 to 2014 inclusive, Korean refrigerators are 1996 to 2010 and Korean clothes washers are 2005 to 2010.

In Japan, the Top Runner Program has delivered consistent efficiency improvements of between 0.3-9% per annum since the late 1990s across a broad range of product types [50] (see Table 5).

Table 5: Average annual product efficiency improvements – Japan Top Runner Program 1998 – 2008 [50]

PRODUCT TYPES	AVERAGE EFFICIENCY IMPROVEMENT PER ANNUM
Air Conditioners - Room	7.6%
Refrigerators	7.6%
Freezers	4.4%
Lighting	4.1%
Computers	9.0%
Copiers	6.3%
Water heaters	0.9%
Heaters - Space	0.3%
Televisions - Flat	6.7%
VCRs or DVD	9.0%
Microwaves	2.5%

Note: Efficiency improvements are sales-weighted values. The figures in this table may be different from other studies due to different time periods and the type of data processing undertaken (e.g. models or sales weighted averages)

The Top Runner approach used in Japan is different from MEPS used in other countries in that sales weighted average efficiency of shipments for each supplier is required to meet the Top Runner target (compared to traditional MEPS where all products from all suppliers must exceed the minimum efficiency level specified). However, it has been argued that the policy objectives and impacts are very similar [52].

Attachment C: Energy & CO$_2$ Savings

Information on total programmatic energy, greenhouse gas and financial savings are taken from both ex-ante studies that provide national impact assessments, as well as a number of ex-post studies. Savings reported in a selection of studies are summarised in Table 6. It should be noted that the scale of these savings depend upon the scope and maturity of national EESL programs.

The two studies from Australia are notable, as these were very detailed long-term ex-post studies that estimated the energy impacts actually realised from a range of previous programs [4, 13]. These studies were found to validate the pre-regulatory ex-ante impact estimates. In fact, both of these studies showed that the actual savings were higher than predicted by the impact assessment undertaken prior to implementation of the last major program measure. This type of outcome has been found to be true in many cases[16], as the ex-ante estimates are often based on conservative estimates, which underplay the potential savings from the program measure and over-estimate likely program and product costs (see section 4).

Table 6: Examples of savings within different jurisdictions

JURISDICTION	PRODUCT TYPES	SAVINGS ACCRUAL PERIOD	SAVINGS (TWH)	SAVINGS (USD)	SAVINGS (MTCO$_{2-E}$)
European Union [23]	Ecodesign / Labelling directives	1990-2010	213	N/A	N/A
European Union [23]	Ecodesign / Labelling directives	2010-2020	1719 [1]	120bn [2]	320 [3]
USA [14]	Federal energy and water conservation standards [4]	1987 - 2013	10,753	N/A	2,113
USA [14]	Federal energy and water conservation standards [4]	In 2013	1,187 [5]	56bn [6]	218 [7]
USA [18]	Energy Star – Voluntary Program	1992 - 2013	2,700	295bn	2,198
USA [18]	Energy Star – Voluntary Program	In 2013	380	32bn [8]	294
China [32]	All programs	To 2020	1,143 [9]	N/A	N/A
Australia [4] 10	Air-conditioner program	2003-2020	6.5	0.8bn	N/A
Australia [13]	Refrigerators/Freezers	1986 - 2009	5.9 [11]	N/A	6
Fiji [17]	Refrigerators and Freezers	2012 - 2014	0.005	0.85m	0.002
India [53]	All programs	2012 - 2030	70	N/A	N/A

Notes:
1. On average the energy saving is 19% for the products included in the accounting.
2. This represents the net benefit from a €170 bn. gross saving on running costs (87% energy) compared with €60 bn. in extra acquisition costs associated with the more efficient products.
3. This is 18% of the included products and 6.7% of the EU total (4721 MtCO$_{2e}$).
4. Includes the impacts of energy and water conservation standards that have been adopted from 1987 through 2013 covering a total of 43 product categories.
5. This is equivalent to 4% of total US energy consumption and 4% of national CO$_{2e}$ emissions. The implied carbon/cost conversion factors for the "USA - All Federal programs" is significantly different to that reported for the "USA Energy Star Program" because Federal Programs report primary energy savings whereas the Energy Star program reports delivered energy savings. There will also be some other differences relating to aspects such as coverage, fuels, time periods and evaluation methodologies.
6. This represents an average household saving of US $361 in operating costs in 2013.
7. This is equivalent to 4% of national CO$_{2e}$ emissions.
8. In addition to direct reductions in energy costs the study estimates that more than $11billion in benefits to society due to reducing damage from climate change were also realised in 2013.
9. By 2020, annual savings are expected to be equivalent to 11% of residential electricity use.
10. This analysis included an accurate ex-post analysis of data between 2003 and 2008.
11. Most of the savings (around 4.1 TWh/year) is attributed to energy labels introduced from 1986, thus policies from the late 1990s onwards will have realised an estimated energy savings of around 1.8 TWh/year per annum by 2009.

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16 One exception was in the case of some of the EU preparatory measures. A study by the Wuppertal Institute made corrections for some factors: accounting for rebound/take back and double counting of some aggregate savings (e.g. refrigerator and motors) [44].

Information presented in the main report also includes the following:

▶ In the US, it is estimated that in 2014, standards and labelling programs saved 12% of electricity consumption and 4% of US end-use natural gas demand [56]. In addition, the voluntary Energy Star program saved a further 5% of electricity consumption in 2014. Together these programs are estimated to have saved 17% of total electricity and 4% gas consumption in US.

▶ The Australian and New Zealand Equipment Energy Efficiency committee [57] has estimated that in 2012, standards and labelling programs saved 6.2 TWh within the residential sector. This equates to 10% of the residential sector electrical energy consumption in that year (ABARE).

▶ The EU Eco-design program is estimated to deliver an annual saving in primary energy of 19% by 2020 and savings in the residential sector amounting to 25% of residential energy consumption [23].

▶ Also by 2020, annual savings from residential energy efficiency programs in China are expected to be equivalent to 11% of residential electricity use [32].

Attachment D: Impact on appliance and equipment purchase prices

Most countries that conduct ex-ante assessments of the future impact of MEPS regulations assume that the average purchase price of equipment is static and will rise after program implementation due to increased costs of energy efficiency. However, the reviewed evidence showed that appliance purchase prices are generally declining in real terms and have been for many years.

For example, across all the EU Ecodesign regulations, the average product price rise was anticipated to be 14% [23]. However, much of the ex-post evidence suggests that these increases in purchase prices tend not to happen or are much smaller than anticipated. This is partly due to the long term decline in product prices (as observed in reliable longitudinal sales data based studies from the UK, Australia [21] the US and the EU [12]), so any relative increase is usually small and not necessarily seen by the consumer as a price rise in the context on ongoing price reductions.

This phenomenon has been identified by various studies, for example, an international study by Ellis et al. suggests that more efficient appliances do not necessarily cost more to buy [54]. Similarly, a recent study in Sweden shows efficiency improving whilst product prices were falling [20]. While regulatory interventions may still have an impact on the price trends (i.e. to reduce the rate of real price decline), the ongoing trend towards lower capital costs of appliances and equipment means that greater levels of efficiency can be justified within a total life cycle analysis.

Recently, a few detailed long term studies in the EU and the US have been undertaken to explain these falling purchase prices, both as a function of time and total cumulative production [24], [25]. The outcome of such research is sufficient for analysts to now recommend that these so called "learning rates" on appliance price trends be taken into account in ex-ante studies, thereby allowing the setting of MEPS requirement levels at slightly more stringent levels (e.g. as proposed for the US) [26].

Despite these longitudinal analyses, there are few current studies that compare the ex-ante estimates of expected price increases against the ex-post evidence. An analysis of Australian refrigerator prices changes for each major type for each year from 1993 to 2008 using actual prices paid by consumers (corrected for inflation) show that real prices for most types have declined rapidly in real terms over the 15 year period (2.5% to 5% per annum depending on the type) [13]. Importantly, that study found that MEPS in 2005 resulted in a 25% to 35% reduction in energy consumption (which varied by type) over three years with no discernible change in the long-term real price trend before and after implementation.

A US study took the ex-ante DOE estimates of expected purchase price increases and compared them to the actual price changes two years after the MEPS were implemented as set out in Table 7. This study concluded that the ex-ante study, on average, overestimated the marginal increase in purchase price by a factor of 10 [22][17]. However, it should be noted that the early DOE studies tended to assume purchase prices were flat whereas there is sufficient evidence to strongly suggest that they were in fact falling, so this US study's findings in relation to the degree of overestimate in purchase price should be somewhat tempered[18].

An earlier LBNL paper reached a similar conclusion on overestimating the expected rise in purchase price from MEPS [55]. This paper listed four conclusions about appliance trends and retail price setting:

1. For the past several decades, the retail price of appliances has been steadily falling while efficiency has been increasing.

2. Past retail price predictions made by DOE analyses of efficiency standards, assuming constant prices over time have tended to overestimate retail prices.

3. The average incremental price to increase appliance efficiency has declined over time. DOE technical support documents have typically overestimated this incremental price and retail prices.

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[17] Excluding AC, since their price fell dramatically. The late 1990s saw a dramatic increase in the production of air conditioners in China, together with dramatically increased world trade, and this had major impacts on the price of these appliances in most countries.

[18] The DOE estimated purchase price increases may be reasonable when superimposed on the underlying price trend, but not the implied absolute purchase price.

4. Changes in retail mark-ups and economies of scale in production of more efficient appliances may have contributed to declines in prices of efficient appliances.

Table 7: Comparison of predicted and actual price increases from US MEPS [22]

JURISDICTION	STANDARD EFFECTIVE DATE	DOE ESTIMATE OF INCREMENTAL PRICE OF STANDARD (NOMINAL $)	PRIMARY CASE (CUSTOM 2-YEAR PERIOD)				
			BEFORE	AFTER	DOE ESTIMATE (2011$)	COST FROM CENSUS (2011%)	DIFFERENCE (2011$)
Refrigerators	7/1/2001	32	2000	2002	56	37	-18
Clothes Washers	1/1/2004	34	2002	2004	54	-35	-89
Clothes Washers	1/1/2007	126	2006	2008	199	10	-188
Electric Water Heaters	1/20/2004	67	2003	2005	108	28	-80
Non-Electric Water Heaters	1/20/2004	75	2003	2005	121	34	-88
Central AC – 3 tons	1/23/2006	167	2005	2007	267	207	-59
Room AC	10/1/2000	7.50	1998	2000	13	-162	-175
Commercial AC – 15 tons	1/1/2010	334	2009	2010	512	-224	-736
Ballasts	1/1/2005	4.27		2006	6.73	-1.74	-8.47
Average					148	-12	-158
Median					108	10	-88

A deeper, more recent, analysis of several federal MEPS regulations by the USA over time explored whether purchase prices continue to fall, and whether further efficiency opportunities exist following the introduction of MEPS. This US analysis clearly shows that the decline in both the purchase price and the LCC continues after the implementation of successive measures, and in most cases at a higher rate of decrease (Figure 8) [12]. This data suggests that MEPS has little impact on purchase price, while cumulative shipments are a far more important determinant in the estimate of long-term price trends.

This is more clearly illustrated in a long-term analysis of clothes washer energy and price in the USA. Figure 9 shows that clothes washer prices have been declining for more than two decades. Small increases (or pauses) in the decreasing price trend are evident close to each MEPS level, suggesting that some small price impacts may have occurred[19] but the downwards trend re-appears soon after.

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[19] Note: Care is required in the ainterpretation of this type of data, as the mix and capacity of products may change slightly from year to year, as well as the features that may impact on price but not efficiency. It is therefore important to disaggregate the data and take account of features and services at a model level. An example is the recent popularity of stainless steel refrigerators – these are considerably more expensive but the outer material has no impact on energy efficiency. If an analysis of price trends did not take the prevalence of this non-energy feature into account from year to year, it could be wrongly interpreted that price increases are due to energy related factors if shifts in the share of such features happen to coincide with the implementation of energy program measures. The analysis presented in Figure 8 and Figure 9 use a "quality adjusted price" to account for changes in

Figure 8: Purchase price (red) and LCC (blue) trends for appliances pre-standards and post-US Federal MEPS [12]
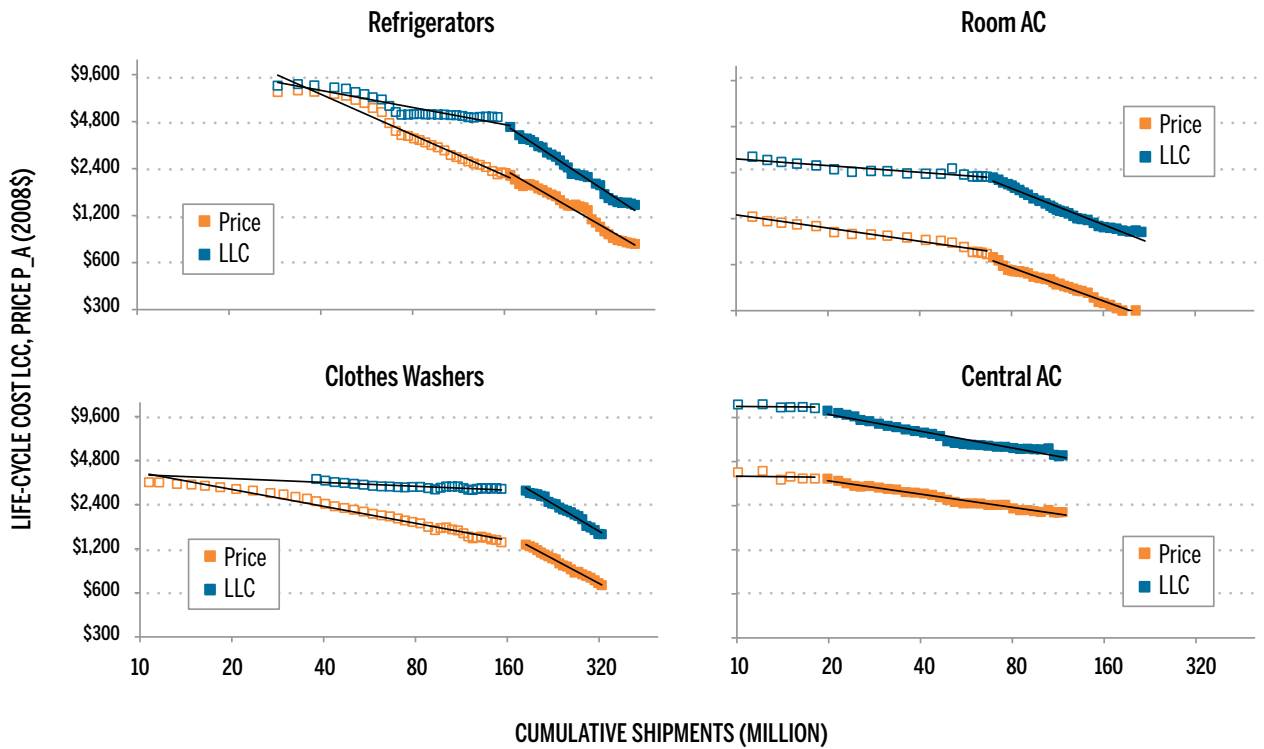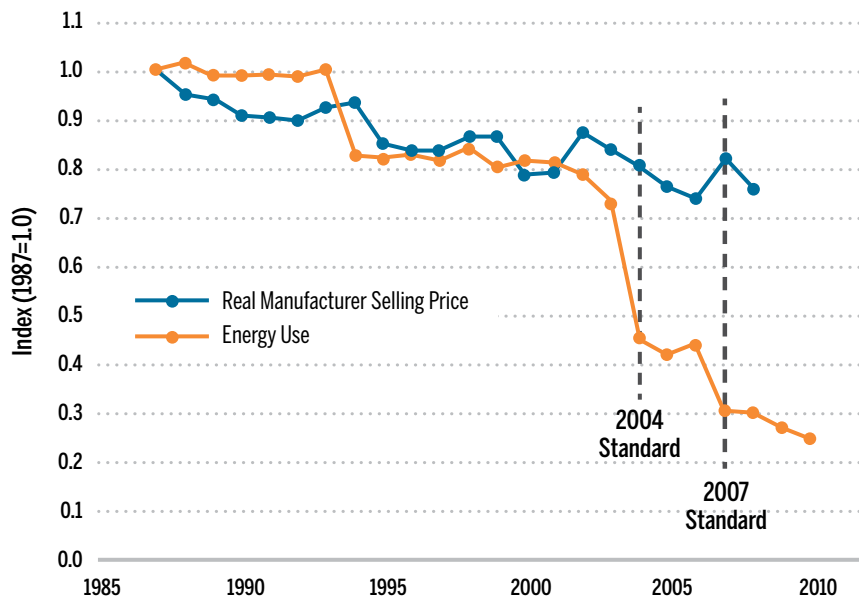

Figure 9: Price and energy trends for clothes washers in the USA [22]

Attachment E: Estimates of the rebound effect

From the available literature, it appears that for many residential appliances the direct rebound is relatively small, and could be close to zero for whitegoods because their use is rarely constrained by energy cost issues alone. In a 2010 review of the impact of EU Ecodesign, Irrek et al found from the available evidence that the range of estimates for direct rebound effect for lighting were relatively low (5%-12%), while the reported values for heating and air conditioners may be higher (10%-30% and 0-50% respectively) [44]. The overall estimate of direct rebound was however relatively low, at approximately 10%. Much of the evidence cited is from a meta-analysis published in 2000 and summarised in Table 8 [45].

In most studies cited in this report any rebound (in the form of changes in the level of energy service provided) is taken into account when estimating the overall energy and program benefits. Furthermore, where direct rebound does occur, it should not necessarily be considered a negative outcome.

Where consumers choose to take some of the potential energy savings from an energy efficiency program in the form of increased service levels, this means that the consumer is valuing the increased energy service more than the potential energy cost reductions that they might have otherwise realised if the energy service level had remained the same. In some cases, such as programmes for low income households, this so called 'take back', in the form of higher standards of heating or cooling, is in fact an intentional policy outcome which may have other benefits such as improved health and well-being (e.g. 30% increase in heating was intended in one low-income programme [42]). Such potential "co-benefits" associated with this type of rebound are discussed further in Section 6.

Finally, it should also be noted that with energy service saturation, and increasing income effects, the direct rebound is expected to be lower in the future.

Table 8: Estimates of direct rebound by application [44, 45]

SECTOR	APPLICATION	DIRECT REBOUND EFFECT	AVERAGE
Private households	Space Heating	10-30%	20%
Private households	Space Cooling	0-50%	25%
Private households	Hot water	<10-40%	25%
Private households	Lighting	5-12%	8.5%
Private households	White goods	0%	0%
Industry and commerce	Lighting	0-2%	1%
Industry and commerce	Process technology	0-20%	10%