

Global Assessment of Appliance Energy Efficiency Standards and Labelling Programs Achievements, 2021

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ABSTRACT

Energy efficiency standards and labelling programs have been cornerstones of many countries' energy efficiency policy for several decades. Over 120 countries have implemented or are developing mandatory standards and labels for a range of appliances and equipment. This retrospective study draws on a global review of nearly 400 published reports, studies and papers covering more than 100 products – representing one of the most comprehensive datasets assembled on the topic to date. It confirms that improvements to the energy efficiency of appliances and equipment are some of the lowest-cost options available today for reducing energy consumption and associated emissions, with typical society benefit/cost ratios of 4:1. Programs that have been operating the longest, such as those in the United States and the European Union, are estimated to deliver annual reductions of around 15% of total current electricity consumption. These programs provide net financial benefits to individuals and the community. Other benefits, including employment, product innovation, water savings, improvements in air quality and the reduction of public expenditure on health, add to the case for stronger, more ambitious, standards and labels.

Introduction

Energy efficiency will play a significant role in helping the world achieve Paris climate targets and realize the United Nation's Sustainable Development Goals. Within that, energy efficiency standards and labelling (EES&L) programs will be key to deliver improved efficiency.

National EES&L programs have been in existence since the 1970s and have since proliferated. As of 2021, EES&L programs operate in more than 120 countries around the world and apply to more than 100 types of appliances and equipment in the commercial, industrial and residential sectors (U4E 2021). While the design and coverage of EES&L programs vary according to national circumstances, they provide the cornerstone of most national energy and climate change mitigation programs.

Typically, EES&L programs use one or both of the following complementary tools as the basis to improve the energy efficiency performance of appliances and equipment:

- Minimum energy performance standards (MEPS), which are employed to overcome barriers to improved efficiency and provide a level playing field in competitive markets by prohibiting the least efficient products
- Energy labels, which are used to address information barriers and enable consumers to make more informed choices at the point of purchase, either by showing the comparative performance of all appliances (known as rating labels) or by identifying the best-in-class products (endorsement labels e.g. ENERGY STAR) (CLASP 2013).

These two measures may be complemented by other policy measures, such as subsidies and rebates to help transform markets.

While EES&L programs can make up a substantial proportion of nationally determined contributions (NDCs), the current focus for many countries is on Covid-19 recovery policies and energy security. In this context, EES&L programs also provide a mechanism to kick-start economic recovery while at the same time reaping a range of wider benefits, as catalogued in this study.

In all countries, the demand side of energy systems is becoming increasingly important as a greater share of variable renewables are connected to grids. Efficient end-use technologies lower overall system size requirements and hence grid investment needs and technologies that reduce energy use offer the possibility of improving both end-use and system efficiency.

As governments consider how best to take advantage of untapped energy efficiency resources to meet increasing demand for cleaner energy, in 2021 the International Energy Agency (IEA) Technology Collaboration Program on Energy Efficient End-Use Equipment (4E) and the IEA commissioned research on the impacts of national EES&L programs.

This global assessment drew on a review of nearly 400 reports and papers covering more than 100 product types, which evaluated the impact of energy efficiency programs. (4E TCP 2021). The majority of the reports and studies examined were either produced by governments, commissioned by governments or prepared with the co-operation of governments. Wherever possible, multiple sources were identified to corroborate the findings. Of these sources, 81 were found to contain substantive quantitative data relevant to this study. This process drew on similar less extensive exercises to collect retrospective evidence undertaken in 2015 and 2016.

The following sections provide a summary of the key findings from the 2021 research. It is followed by a discussion of the lessons learnt about the evaluation of EES&L program and the reporting of evaluation results. It concludes by suggesting some actions that may help to encourage future program evaluations to be conducted and reported in a manner that will increase robustness and transparency and facilitate future international impact assessments.

Overall Energy System and CO₂ Impacts

The longest-running EES&L programs with the largest product coverage have saved approximately 15% of their country's total electricity consumption. Around two-thirds of these savings are seen in the residential sector, while savings in the services and industrial sectors each account for around one-sixth of the total on average.

The nine economies shown in Figure 1 together saved at least 1 580 TWh in 2018. This is a similar order of magnitude to the total electricity generation of wind and solar energy in those countries, which was 1 626 TWh in the same year. This suggests that global savings of around 3 500 TWh could have been realized in 2020 if all countries adopted similar measures, roughly equivalent to halving the total electricity consumption of China (Meyers et al. 2016; deLaski and Mauer 2017; METI 2015; CNIS 2015; SPR 2019; BEE 2019; Khanna et al. 2016, Wierda and Kemna 2020).

Under these programs, new, more efficient products are continually entering the market and replacing older, less efficient ones, compounding the energy savings year after year as the overall stock of appliances becomes more efficient. For example, the savings achieved by the current EES&L programs in the European Union (EU) are forecast to increase from 14.9% of total EU electricity consumption in 2020 to 24.1% by 2030 (Wierda and Kemna 2020).

This means that longer-running programs show greater levels of savings, partly because sufficient time has elapsed for regulated products to represent a larger share of the overall appliance stock in use. These more mature programs also tend to cover a wider variety of products and have increased their levels of stringency over time, which increases the energy savings they deliver. In the case of the United States (US), the EES&L program has achieved a reduction of 15.5% of total electricity consumption savings; newer and less extensive programs in other countries have not yet reached this level (Meyers et al. 2016).

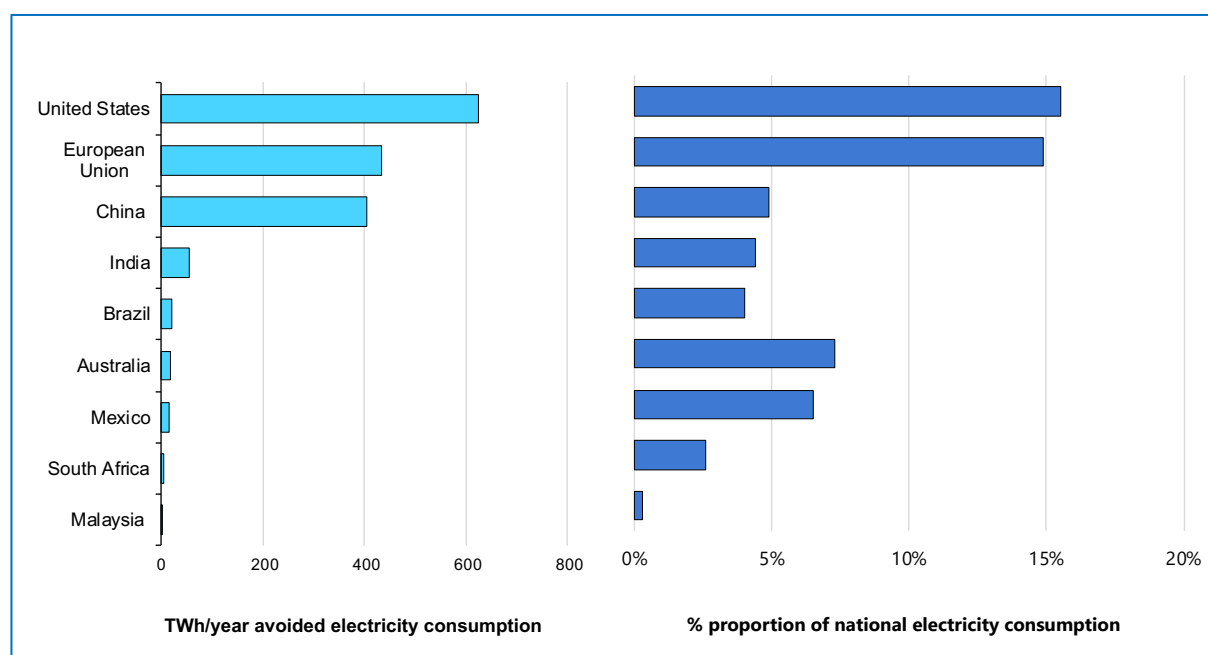


Figure 1: EES&L program-related annual electricity savings, 2018

EES&L programs also can extend beyond electricity to cover oil- and gas- powered space and water heating. In Europe, for example, including these end uses raises the total energy savings from EES&L programs to 1 777 TWh or 15.3% of total primary energy consumption in 2020 (Wierda and Kemna 2020).

Because fossil fuels still dominate the energy mix, energy savings through EES&L programs also lead to substantial CO₂ reductions (Figure 2), making the recorded greenhouse gas emission impacts attributable to EES&L programs equally impressive. In the United States, MEPS avoided 343 Mt CO₂ in 2020, equivalent to 7.1% of all national energy-related emissions for 2019 (Meyers et al. 2016; deLaski and Mauer 2017).

The EU EES&L program – Ecodesign and mandatory labelling – has had a similar impact, cutting emissions by 311 Mt CO₂, or 10.7% of the European Union’s total energy-related emissions for 2019. This is 7% of total EU CO₂ equivalent emissions from all sources in 2018. By 2030 the impact of current policy measures will accumulate to 498 Mt CO₂ or 12% of the EU 2018 total from all sources (Wierda and Kemna 2020).

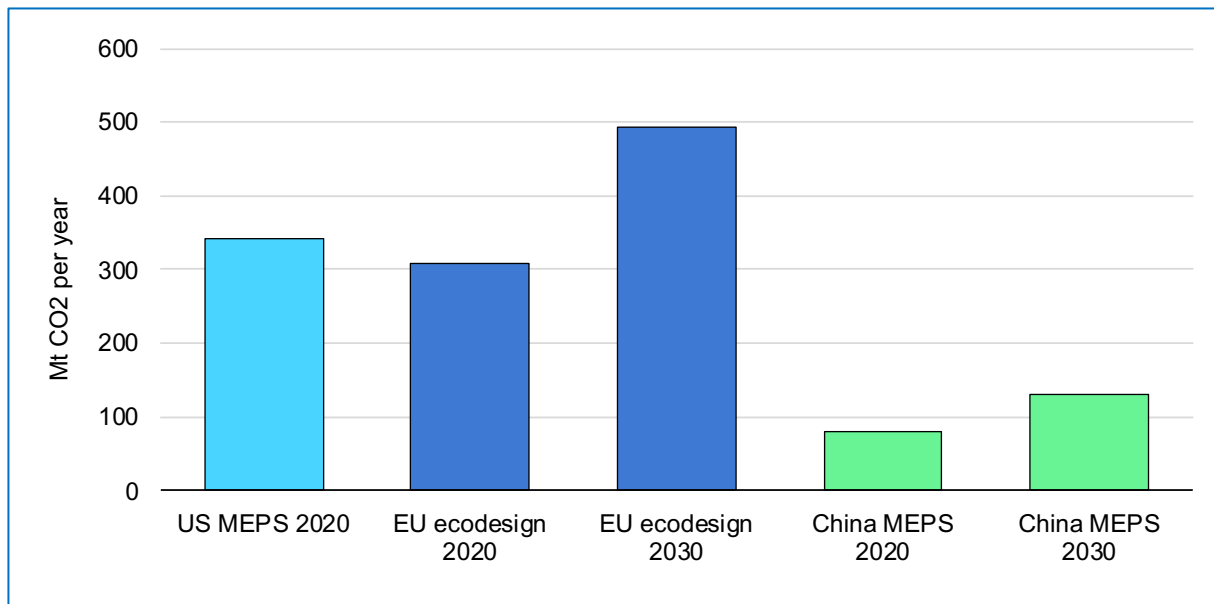


Figure 2: Annual CO2 emissions reductions from standards and labelling programs

Impact of EES&L Programs on Costs, Employment and Household Incomes

EES&L programs are highly cost-effective, with energy cost savings often many times larger than any incremental increases in the cost of purchasing products or administering the program. This is demonstrated in Figure 3, which shows the overall net benefit-to-cost ratios for EES&L programs in several major economies (E3 2014; NRC 2018; Meyers et al. 2016, Wierda and Kemna 2020).

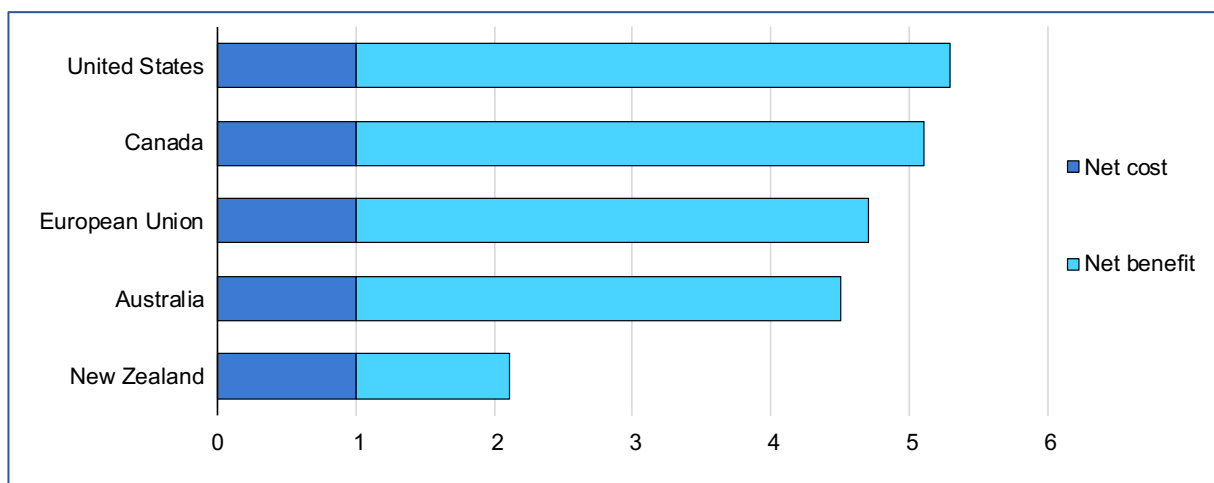


Figure 3: Benefit/cost ratio for MEPS and labelling programs

This is no coincidence, as most governments demand that new regulatory measures pass strict net-benefit or benefit/cost ratio tests before they can be adopted. However, in many cases regulators have overestimated the costs of meeting efficiency requirements, since retrospective analysis consistently shows that innovation and “learning by doing” reduces the impact on product manufacturing costs, which may be reflected in prices (Figure 4) (Weiss et al. 2010; US Department of Energy 2011; Desroches 2012 and 2013). In fact, most products in countries with EES&L programs have become both more efficient and cheaper over the

duration of these programs. Falling consumer purchase prices suggest that more stringent policy settings still deliver net consumer benefits.

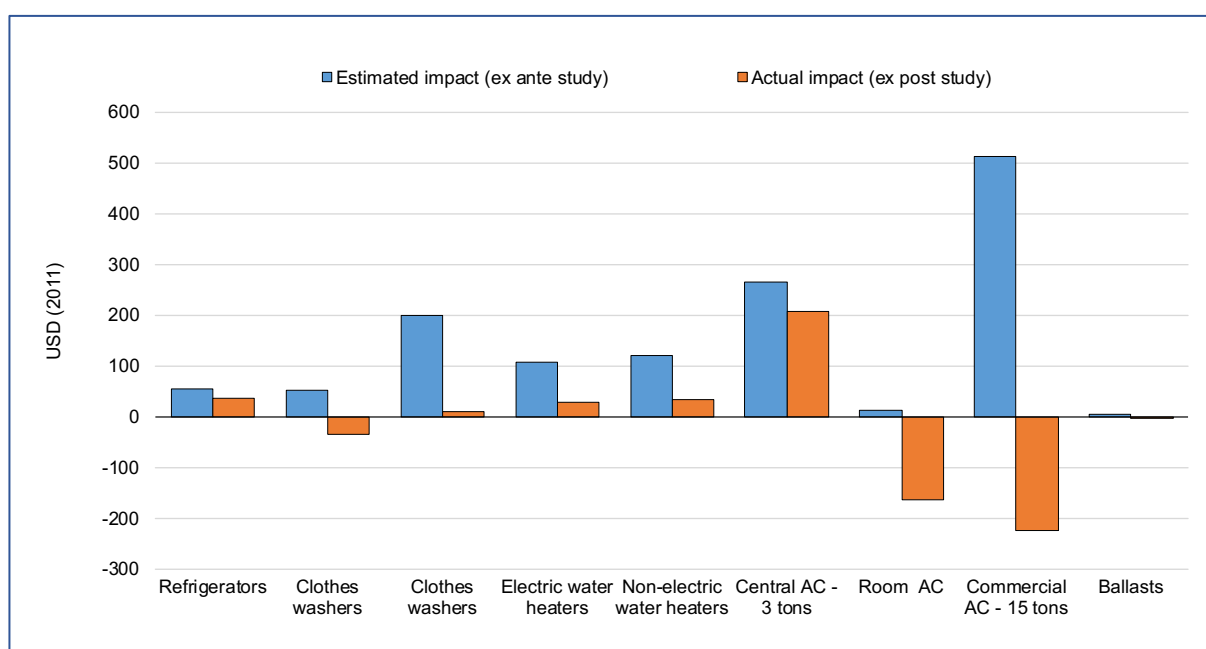


Figure 4: Comparison of predicted and actual price increases from US MEPS (Nadel, S. and deLaski 2013).

Not only are EES&L programs highly cost-effective overall, but they deliver very large savings for households and businesses. In the United States, EES&L programs delivered annual fuel cost savings of USD 40 billion in 2020, resulting in an annual reduction in the average US household energy bill of around USD 320 (Meyers et al. 2016).

This survey of available evidence confirms that EES&L programs are one of the lowest-cost policies available to reduce CO₂ emissions. Since EES&L programs generate net benefits to individuals and to society, they deliver CO₂ savings at “negative cost” in most representations of CO₂ marginal abatement cost curves.

EES&L programs also directly create jobs in manufacturing, wholesale, retail and maintenance, and indirectly through the spending of fuel cost savings in the local economy. Although challenging to estimate this impact, figures have been estimated for some economies. For example, the EU EES&L program was estimated to have directly created 906,000 jobs in 2020, a figure expected to rise to over 1.2 million annually by 2030 (Wierda and Kemna 2020). While direct job creation is significant, the creation of indirect jobs can be three to five times larger, as evidenced in the European Union.

Different national contexts regarding local manufacturing, industrial structure, the cost of labor and the degree to which expenditure in the economy at large will generate indirect jobs mean it can be difficult to transfer results from one country to another. This may explain why a study of the US EES&L program estimates are lower but still significant, with the creation of 299,000 direct and indirect jobs in 2016, rising to 553,000 in 2030 (Stickles et al. 2018).

In Australia, an estimated 59,000 to 236,000 people work in roles related to the energy efficiency of residential and commercial buildings. This is significantly more people than are employed in coal mining and electricity networks. It is estimated that new appliances and equipment upgrades in Australia could create an additional 40,000 jobs per year (EEC 2019).

In all countries, the potential to replace jobs in fossil fuel sectors, such as coal, with energy efficiency jobs offers an important pathway in ensuring a just, more people-centered energy transition. Various additional policy and program approaches will be required, such as support for reskilling, to stimulate this transition.

Impact of EES&L Programs on the Energy Consumption of Key Appliances

EES&L programs typically reduce the average energy consumption of most new products around two to three times faster than similar products not covered by such programs (where only the autonomous rate of efficiency improvement is present). The average rate of improvement varies for different products, as shown in Figure 5¹. For products such as refrigerators, and especially televisions, the increasing popularity of larger models has reduced the observed rate of improvement.

Average annual improvement rates for new appliances' energy consumption are primarily determined by the stringency of policy settings within EES&L programs and the frequency at which they are updated. These vary over time and between economies, which explains the ranges shown in Figure 5. The countries with the longest-running programs and the most stringent standards, such as the United States, the European Union and Japan, are at the top of these ranges. The countries with more recent assessment periods and programs, or where standards are not as strict, are towards the lower end of the ranges.

For example, the energy consumption from average new residential refrigerators and freezers fell by around 2.3% per year across all countries. The best-performing countries with the most advanced programs recorded improvement rates of up to 8% per year. The improvement rate represents the average energy reduction each year of that appliance type based on the specific impact of EES&L programs. Other changes, such as autonomous rates of improvement, are excluded.

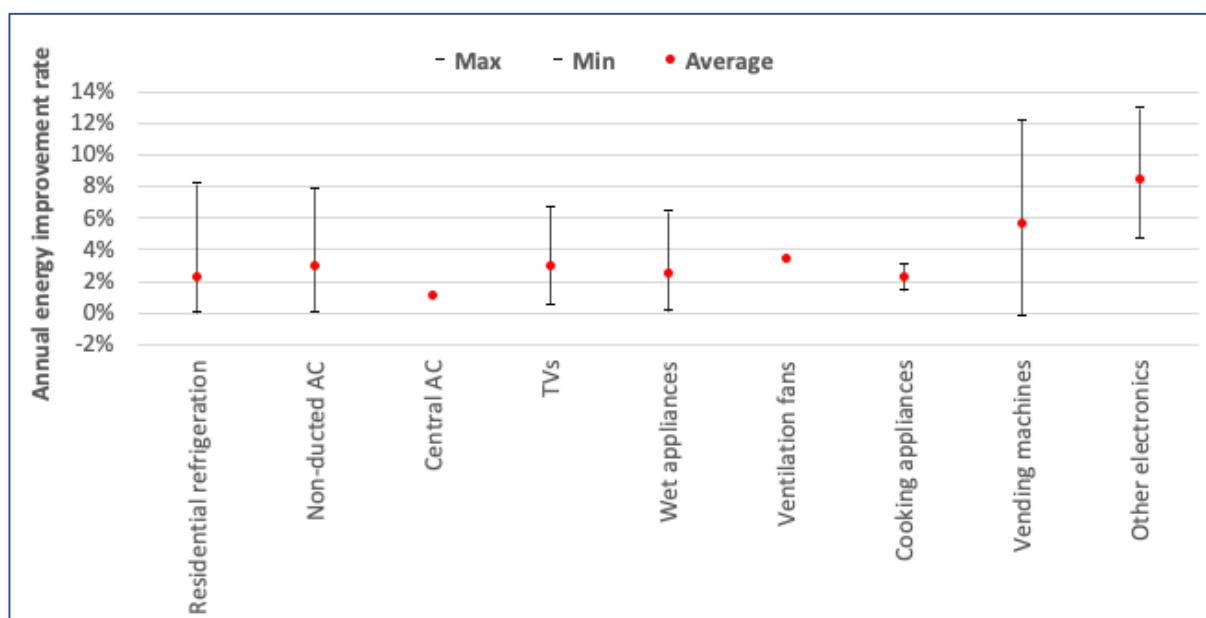


Figure 5: Annual reduction in average new-product energy consumption from EES&L programs

¹ For full list of references see (4E TCP 2021).

EES&L programs set the bar for new products entering the market, raising the average efficiency of all products in use over time. The impact of EES&L programs on the annual rate of improvement by type of product is shown in Figure 6. Since it takes time to replace old, inefficient units with new, more efficient ones, the annual rate of improvement across the entire stock always lags behind the improvement rate of new appliances.

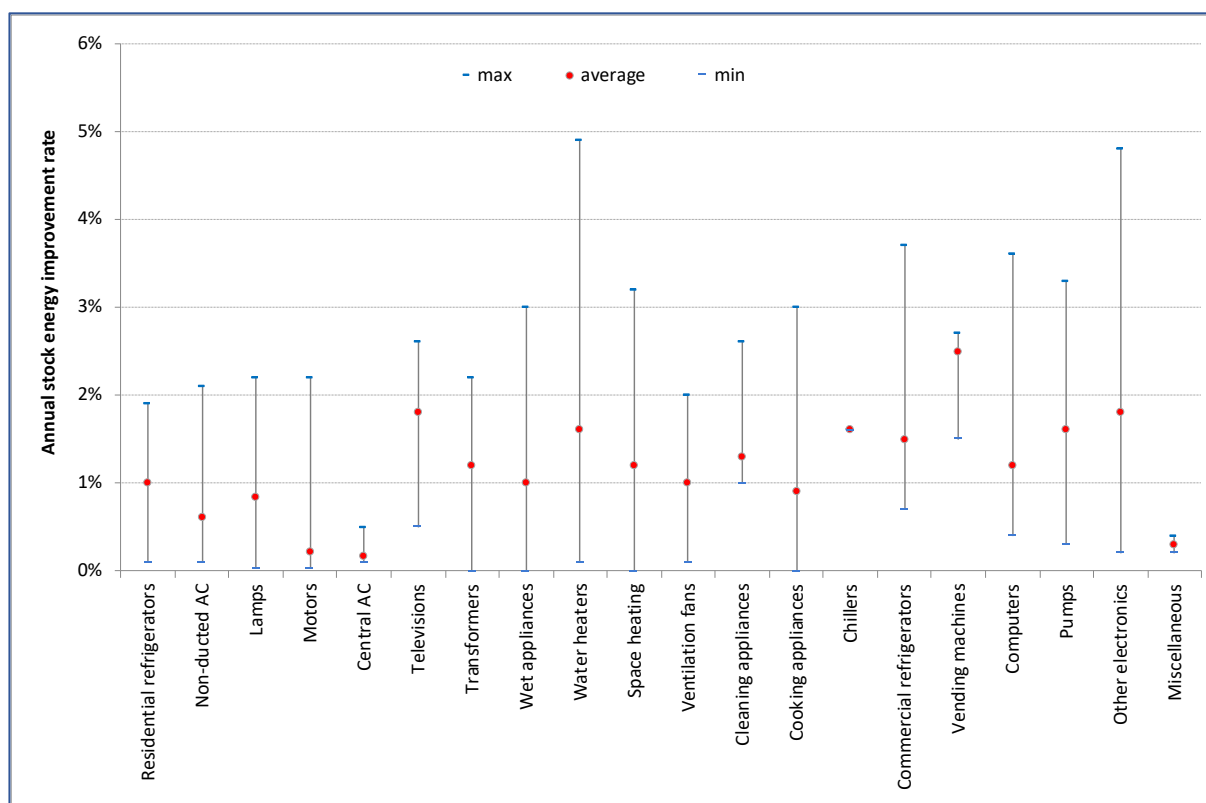


Figure 6: Annual reduction in stock average energy consumption from EES&L programs

Figure 7 shows the overall energy reductions achieved by EES&L programs over the life of the entire program. This shows that average energy reductions between 10% and 30% have been achieved over moderate time frames for the stock of most regulated products. The savings are determined using a baseline without the EES&L programs. For example, the average reduction in the energy consumption of the stock of domestic cold appliances was around 22% and ranged up to 64% for the more mature programs. These energy performance improvements have enabled the number and size of refrigerators to grow without significantly increasing overall national energy consumption, and in some cases, helped decrease overall energy consumption.

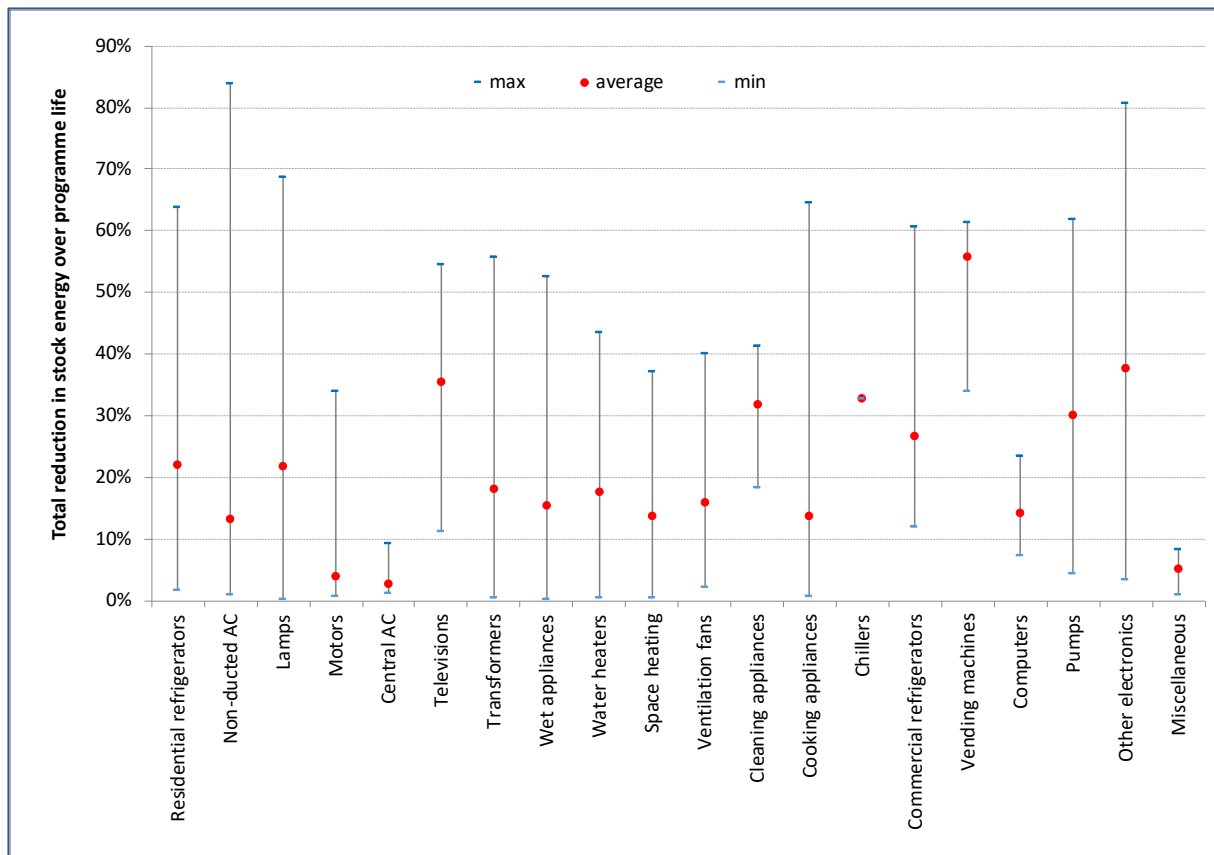


Figure 7: Appliance energy savings from EES&L programs over the life of programs

These results highlight not only the effectiveness of EES&L programs in lowering the average energy consumption of appliances and equipment, but also the significant disparities between countries with advanced programs, as opposed to countries with relatively new EES&L programs where the impacts are still accruing.

Countries that have relatively new EES&L programs have the potential to leapfrog to the most efficient technologies. In many countries, the falling costs of efficient lighting, such as LEDs, make them competitive with less efficient technologies. Likewise, more efficient inverter air conditioners are, in many cases, cheaper than less efficient units. EES&L programs have the opportunity to encourage their uptake, driving down costs still further.

The Japanese Top Runner Program is one good example of an EES&L program where the actual achievements consistently exceed original expectations. The average expected improvement rate across all products was 24%, while the average improvement rate actually achieved was 33% over moderate time frames of five to eight years (METI 2016). The annual actual improvement rates for selected individual products are shown in Figure 8.

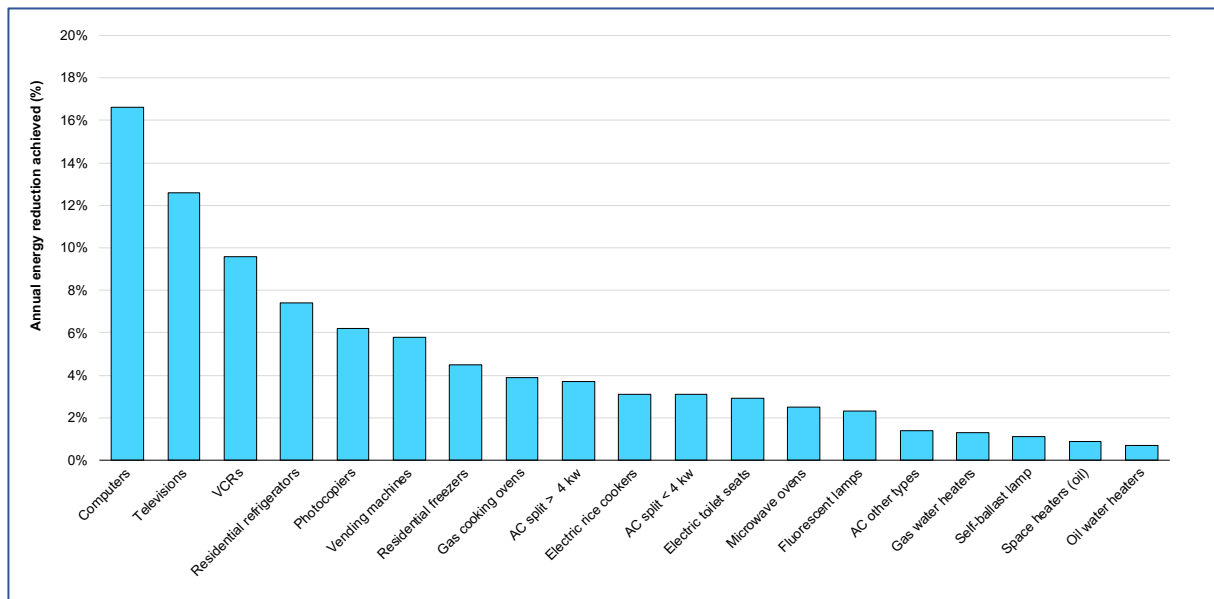


Figure 8: Annual energy improvement delivered by the Japanese Top Runner Program

Impact of EES&Ls on Innovation and Appliance Prices

EES&L programs have been an important driver of innovation in appliances and equipment since the 1970s. The need to meet performance requirements has demanded new technologies, manufacturing techniques and control systems that would not otherwise have been invented or widely adopted (Stewart 2010). The fact that manufacturers have improved the efficiency of regulated products while continuing to reduce appliance purchase prices is clear evidence of their innovation (Figure 9).

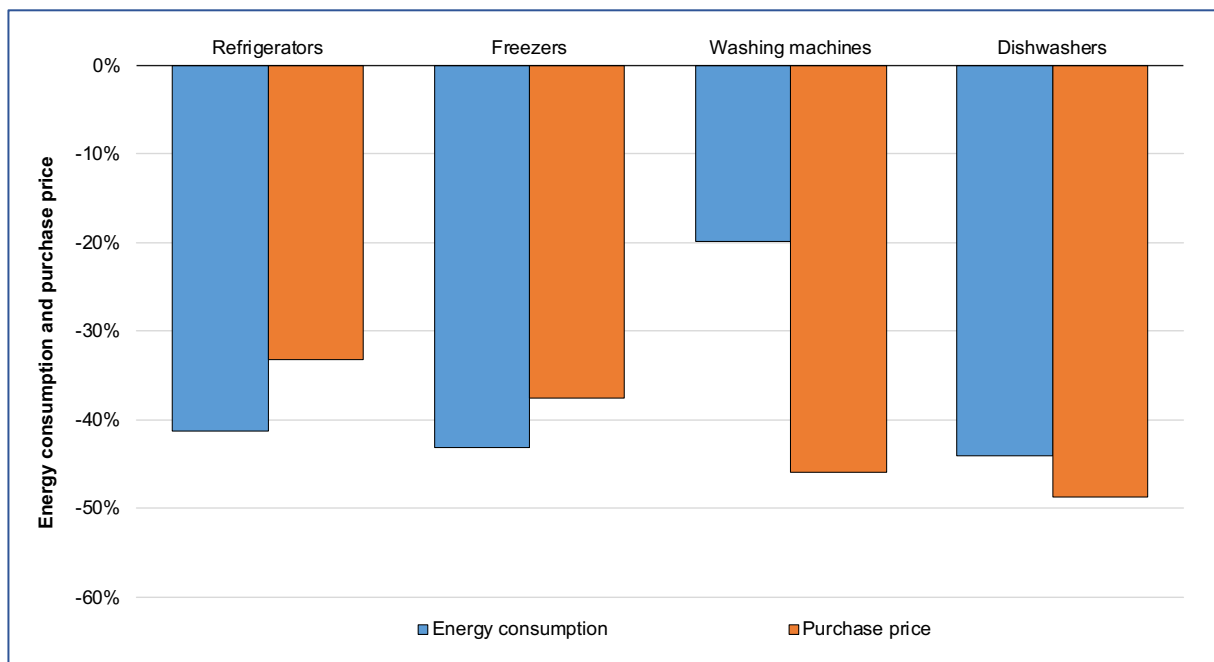


Figure 9: Real appliance prices and energy performance in Australia, 1993-2014, % change (EES 2016)

These findings hold for a wide range of appliances across many countries. For example, air conditioning prices have fallen by approximately 2% per year, and lamp ballast prices by 3% per year, while continuing to reduce energy consumption. In the case of residential refrigeration, washing machines and dishwasher products, average appliance prices have fallen around 2% per year, ranging from 1% to 5% for refrigerator/freezers and up to 4% for wet appliances.

Setting performance-based requirements across technologies is one specific way that EES&L programs create space for innovation. This has enabled niche products and materials that offer very large efficiency improvements to gain sufficient market share and benefit from economies of scale. Notable examples include inverter-driven compressors, vacuum insulation for refrigeration systems and heat pump clothes dryers (Wold et al. 2015).

As an example, industry-led innovation offered dramatic efficiency increases in circulation pumps through the use of high-efficiency motors coupled with integrated variable speed drives. EU ecodesign regulations, supported by industry, have helped to underpin the transformation of the market, with recent rounds of ecodesign requiring all pumps sold to reach high-efficiency performance levels (Bidstrup et al. 2001; Thomas and Bartlett 2008). Some EES&L programs also foster innovation through advanced signaling of future efficiency requirements. In Korea, this is achieved by adopting the previously highest energy label grade as the new minimum performance level approximately every five years (Seongin and Jinyoung 2017). In Japan, the Top Runner Program sets the efficiency target level some four to ten years in advance based on the best available technology. The sales-weighted average of all products shipped by each supplier is then required to meet this target (MRI 2020).

EES&L programs worldwide have also supported the wide-scale adoption of inverter technology in the air-conditioner industry, a significant change that provides a range of consumer benefits, especially lower energy bills. By developing new air-conditioner test methods and metrics that are more representative of consumer behavior, EES&L programs have helped demonstrate the real-life advantages to consumers of inverter technologies over conventional equipment.

Televisions and LED lighting have seen a technology revolution in recent years. The transformations that have occurred within these product categories have been rapid and profound and have been influenced by factors beyond energy efficiency (Gerke et al. 2014). EES&Ls have played an important role in highlighting energy performance in consumer purchasing decisions and hence in the thinking of industrial product designers without any apparent detrimental effect on innovation.

These are just some of the many examples of how EES&L programs have helped to stimulate innovation in appliance and equipment design globally through the creation of new markets for energy-efficient products

Other Benefits from EES&L Programs

Other “co-benefits” from EES&L programs include improvements to people’s comfort, health and finances, leading to stronger, more resilient regional economies (Ryan and Campbell 2012). Accounting for these important benefits is often complex and has been less studied, but some countries are already factoring these into their cost/benefit analyses of EES&L programs. Going forward, stronger quantitative evidence set around these benefits will provide additional impetus for the development of EES&L programs.

Reduced Water Consumption

Devices that are both energy- and water-efficient, such as low-flow showerheads, dishwashers and washing machines, can considerably reduce water consumption and sewage output. All economies that have regulated the energy performance of water-using products have reported reductions in both their energy use and their water consumption, with corresponding reductions in consumer energy and water bills. The most effective means of improving the energy efficiency of such products is to reduce the amount of water that must be heated required for them to fulfil their function.

For example, in the European Union, Australia and Canada, water consumption rates for regulated dishwashers and clothes washers have fallen by 3% to 4% annually over the last 20 years (EES 2016; NRC 2020). By 2020, EES&L measures in the European Union reduced water consumption by over 1,800 billion liters, cutting water bills by more than EUR 8 billion. This is in addition to the EUR 5 billion consumers have saved on fuel costs (Wierda and Kemna 2020). The longer-running US program saved almost four times as much water in 2020.

Improved Health Outcomes

The health benefits of EES&L programs are not often assessed, but there is emerging evidence that these benefits could be substantial and could become a key factor in the overall value proposition of these policy measures.

The main health benefit of energy-efficient equipment is reduced air pollution, thanks to reduced direct emissions from the combustion of gas, oil, coal and biomass for cooking and space and water heating, as well as reduced indirect emissions from the burning of fossil fuels to produce electricity.

The projected avoided direct air emissions attributable to the EU EES&L program for the year 2030 include reductions of 22% in particulate matter, 20% in carbon monoxide and 11% in organic gaseous carbon compared with 2010 emissions levels (Wierda and Kemna 2020).

Health benefits are already a major part of the value proposition of EES&L programs in some countries. In New Zealand, more energy-efficient space heating has created health cost savings around ten times the value of energy-related cost savings (Preval et al. 2010).

As new light is shed on the health impacts of fossil fuel pollutants, it seems likely that the role played by EES&L programs will become increasingly valuable for policy makers.

Lessons Learnt from the Global Assessment

To encourage greater coverage and ambition, this research has provided an important expansion of the evidence set on the real benefits of existing EES&L programs so that they can be more accurately assessed and deployed.

However, given their importance in meeting net zero targets and UN Sustainable Development Goals, it is critical that the evidence of the full range of benefits that EES&L programs can deliver is expanded and the quality improved. It is in this context that the following general observations relating to program evaluations, based on the 2021 study and previous similar exercises in 2015 and 2016, are provided.

The studies reviewed all required the gathering of at least the following information from evaluation documents, either directly or by calculation based on the reported methodologies and data, in order to quantify and compare their results:

- Annual rates for change in average new products delivered to the market: typically, these would be changes in energy consumption, energy efficiency, product attributes. The first two of these can be converted to a generic percentage rates to allow comparison across products and regions.
- Changes in stock energy consumption in a specific year as a result of the S&L program measures: typically, these are reported as savings (from a Business as Usual, BAU, case). Again, to allow a generic comparative measure to be generated, both the savings generated and the BAU (prior to savings) are generally required to generate a change in stock energy per annum as a result of the EES&L program.
- Cumulative energy savings and emissions over a specified period. Again, to allow a generic comparative measure to be generated, both the cumulative savings for each parameter and the cumulative BAU (prior to savings) are generally required to generate a cumulative change in percentage stock average energy per annum as a result of the EES&L program.
- Costs and benefits were commonly reported in many ex-ante studies (typically to satisfy regulatory requirements) and these were generally reported as an overall Benefit Cost Ratio (BCR) ratio. Time periods for analysis and parameters such as discount rates varied by jurisdiction, so it was generally only possible to report the stated values, noting that for the most part these were official government documents used to fulfil their local regulatory requirements, so were generally credible and relatively conservative.

We would encourage all future evaluations to report these impacts. In addition to these core parameters, and depending on the objectives of the program, evaluations might also have collected and reported information on other potential benefits, such as economic, innovation, employment and health impacts.

Increasing the Transparency and Cross Comparability of Savings Estimates

A key focus of this study is to examine and quantify savings that are attributable to EES&L programs. The term savings means “a reduction or lessening of expenditure” (or other parameter such as energy) and naturally implies that there is a base case (which is referred to as BAU) and an alternative case where savings are made against the base case. This alternative case is often called a counterfactual (meaning “a case that could happen”).

When assessing future impacts of a potential program, typically the BAU case is what is expected to occur under the current trends without any change in policy settings. The ‘with measures’ case is what is estimated to occur if policy settings were to change. When assessing future impacts, both the BAU and the “with measures” are necessarily counterfactual cases and will be based on a range of data. The savings are then expressed as a ratio of the BAU case to get a generic comparative impact parameter (% change or savings).

For most of the studies examined for this report, savings were reported in absolute units of various types (energy, emissions, water etc.). However, in many instances the study did not report either the expected parameter for the BAU or “with measures” case (or even the parameter after savings - “with measures” case). This made it difficult to put the savings in context and use the data reported for regional comparisons.

For example, if a country reported savings of 500 GWh in year 2015, this could be seen to be of some interest. But if the BAU is not reported, there is no way to know whether this is a little or a lot of energy relative to the country size and its overall energy consumption and trends for the specific product.

The methodology reported in many of the documents analyzed failed to identify whether a BAU case had been developed. Even when it is clear that the evaluation included the development of a BAU case, this is not always quantified in published reports.

A further important issue is the attribution of impacts, which can be quite challenging where there are several programs that overlap and/or where there is rapid technology change that is driven by factors that may not be directly related to energy efficiency.

As noted above, the BAU case compared to the “with measures” case allows the calculation of the impact of the specific measure being investigated. In this case the differences between the two scenarios are attributed to the particular program measure. This may appear to be simple; however, there are often cases where the BAU already has the impact of previous EES&L program measures built into it and new program measures are introduced at regular intervals. This makes the separation of impacts for overlapping program attributes more complex and to some extent reliant on judgement. Many jurisdictions do not even attempt to separate the impacts of individual program measures over time – they are all just lumped into a “standards and label” program bucket, so these effects tend to be mixed together. Preparation of accurate and realistic counterfactual scenarios and base cases can be quite complex and requires a great deal of skill and understanding.

Conclusions

This report shows that EES&L programs deliver large energy and cost savings, enabling the transition to a cleaner energy future. Evidence shows that EES&L programs can deliver annual electricity demand savings on a par with the current annual production of renewable energy. Reflecting the increasing recognition of such benefits, EES&L programs have continued to grow in quantity to a greater number of countries and in scope to include a wider range of appliances and equipment.

As products currently covered by these programs replace the existing stock, the size of EES&L savings will grow naturally. By this process, even a 2% annual improvement in stock energy efficiency will result in almost a 50% reduction in energy consumed over a 30-year period.

For this to occur, policy makers must regularly update EES&L policies to keep them in step with technological improvements and test methods need to keep improving measurement approaches. This demands adequate resources to ensure due diligence, including industry consultation. As indicated by the benefit/cost ratios, governments can expect multiplicative returns on their investments in program planning and delivery.

There is substantial evidence that with sustained support from governments, EES&L programs could deliver even more by expanding the scope of programs to cover more products and by increasing the levels of ambition in policy settings.

Analysis of historic changes in product prices reviewed in this study indicates that mainstream products have continued to become much more energy-efficient while becoming less expensive. In addition, most programs have overestimated the costs of meeting product regulations. This suggests that more accurate, updated estimates of the impact on future product costs would make more stringent policy settings more cost-effective than previously considered.

The above conclusions regarding the impacts of EES&L programs are based on an examination of several hundreds of detailed program evaluations across many countries. It is clear that further EES&L impact assessments that involve ‘normalizing’ the results across different countries and program types would be greatly improved if future program evaluations were more uniform in both methodology and standardized in reporting.

In particular, we found that:

- The number of high-quality ex-post² evaluations identified was rather limited, and these tended to be from those programs that are longer running with good ongoing data collection strategies and a clear policy of undertaking ex-post evaluations.
- Many reports that appeared relevant could not be used for the more in-depth analysis because quantitative data was not reported at all or was only reported in a way that could not be converted into a form suitable for international benchmarking and comparisons.
- Few reports examined in any detail the issue of attribution of claimed energy savings. Attribution can be quite important where there are several programs that overlap and/or where there is rapid technology change driven by factors unrelated to energy efficiency.

In order to address some of the issues raised about inconsistencies in programmatic evaluations, 4E is currently producing an ‘Evaluation Guidebook’. This is aimed at assisting those commissioning the future evaluation of EES&L programs to encourage the consistent use of best practice and more transparency in the reporting of results.

It should be noted that this will not address the overarching need for more evaluation to be undertaken on EES&L programs!

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² Ex-post is the re-evaluation of historical data in the light of what actually occurred.

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